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Paul R. KLEINDORFER

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By

Paul R. Kleindorfer*

Paper prepared for the project on "The Known, the Unknown and the Unknowable" at the Wharton Financial Institutions Center. I am grateful for discussions on the ideas of this paper with George B. Kleindorfer, Howard Kunreuther and Jerry Wind, who continue to inspire my journey into KuU territory. Comments on a previous draft by Enrico Diecidue are gratefully acknowledged

* Paul Dubrule Professor of Sustainable Development at INSEAD, Boulevard de Constance 77305 France.Ph: +33 (0) 1 60 72 91 28 Email : paul.kleindorfer@insead.edu

Reflections on Decision Making under Uncertainty[1]

Paul R. Kleindorfer
Anheuser-Busch Professor of Management Science (Emeritus)
The Wharton School of the University of Pennsylvania
Paul Dubrule Professor of Sustainable Development, INSEAD

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"Chance favors the prepared Mind!" Louis Pasteur (1822-1895)

This conference has brought together some fascinating strands of research on an issue that has interested me since I first read Frank Knight's pioneering doctoral thesis some 40 years ago. Knight (1885-1972) completed his thesis at Cornell in 1916, at a time when great geo-political uncertainties were unfolding in horrific ways in World War I. A minor revision of his thesis later became the essence of his celebrated book (Knight (1921)), which remained the center piece of his economic contributions at the University of Chicago, where Knight joined other great economists in creating the intellectual fabric of risk, uncertainty and profit that has become the foundation of modern finance and business strategy.

The essence of Knight's contribution was arguably his recognition that the modern firm was not just a means of solving the contracting problems that Ronald Coase eventually put to rest, but was also a mutualization institution that absorbed shocks and allowed capital recovery for investments, and that implemented and rewarded entrepreneurial initiative. In the process, Knight also made the key distinctions between management and decision making under conditions of certainty, risk and uncertainty, which we are revisiting in this conference.

For Knight, the essential distinction between risk and uncertainty was that <u>risk</u> was characterized by known probability distributions with observable outcomes, and such outcomes could therefore be completely contracted on in the market (e.g., in insurance contracts for negative outcomes). <u>Uncertainty</u>, on the other hand, was characterized by a decision making context in which probability distributions on outcomes were not or could not be known with assurance at the time of choice. Knight argued that it was precisely a willingness to take action under uncertainty that allowed entrepreneurs and firms to make profits, even under perfect competition. Refinements in these concepts have taken place since Knight's original treatise, and we will revisit a few of these refinements below. However, I continue to appreciate the essential groundwork that was initially laid by Knight for understanding decision making as taking place along a continuum of the Known, unknown and Unknowable (the KuU metaphor of this Conference), representing an increasing lack of codified and accepted knowledge underlying the outcomes associated with choice.

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Interestingly, World War I also saw another of the 20th century's great economists, John Maynard Keynes (1883-1946), begin his voyage of discovery in the area of KuU choice. Keynes was among the economic experts supporting the British delegation at the deliberations leading to the Treaty of Versailles in 1919. As he considered the likely economic consequences of punitive actions against Germany, he also continued work on his treatise on subjective probability theory, inspired no doubt by the imponderables that were all too evident to him in the negotiations amongst the Versailles parties. His life and interests as an economist were affected permanently by these deliberations, and his work on macro-economics and monetary policy were imbued as a result with a sense of the limits of control of governments and central bankers and the consequent need for flexibility in response to the often unpredicted and unknowable consequences of economic activity.[2] *The Treatise on Probability* (Keynes (1920)) argued that probabilities, or degrees of belief as he called them, were an important element of everyday life and the conduct of choice, and that these could not be isolated from the evidence underlying statements of likelihood, which involved mental models of causation and prediction and other cognitive activities that were by their very nature personal or subjective to the decision maker.

The important role of subjectivism emphasized by Keynes is one central element of the KuU metaphor.[3] Echoing the editors' introduction to this volume, the other central element is the set of models or theories used by individuals and groups to interpret and connect observable data to outcomes. While mental models and causal reasoning in economics were largely ignored in the early formalizations of finance and economics, these issues are now clearly center stage in both econometrics (e.g., the work of Granger noted in this volume), decision sciences (e.g., Kleindorfer et al. 1993) and business strategy (e.g., Wind and Crook, 2005). Suffice it to say that, since the Carnegie School of decision making and behavioral choice was launched by Herbert Simon and Allen Newell in the 1950s, economics and decision sciences have been grounded in the foundational notion that to the extent that human action is purposeful it is based on predictions of consequences of competing choices, using mental

[2] The overview in the present volume by Donald Kohn of the contemporary guise of these problems in the Federal Reserve System would, I think, find a resonant nod of appreciation by Lord Keynes.

[3] Of course, subjectivism had long been an active area of inquiry in Philosophy, beginning with Plato and Aristotle, with its possibilities and limitations brilliantly noted in Immanuel Kant's celebrated *Critique of Pure Reason* (1781). The particular reason for the rebirth of subjectivism in the 20th century is no doubt due in good measure to what might be called the "brilliant failure" of logical positivism, which attempted to resuscitate empiricism and objectivism in science through a solid grounding of it in mathematical logic. Positivism achieved great visibility and vigor through the work of Bertrand Russell and Alfred North Whitehead in their pioneering work on the foundations of mathematics and logic, the *Principia Mathematica* (1913) and the ensuing contributions of Russell's student Ludwig Wittgenstein in his use of this theory as the foundation for his research on what would now be called mathematical linguistics. The positivist's program of finding a unique correspondence between logical propositions and "facts in the world" was dealt two heavy blows by the Heisenberg Uncertainty Principle in physics (published in 1927) and Kurt Gödel's celebrated Incompleteness Theorems (published in 1931). Together these results showed mathematically that neither would it be possible to establish the asserted correspondence nor, even it were established, to propose a parsing algorithm that would determine the truth or falsity of well-formed propositions based on these "facts". Some things, in the end, are simply unknowable and others cannot be communicated in purely logical and objective terms from one party to another! In this sense, the rebirth of subjectivism and KuU theory were an essential part of the philosophy of the 20th century, as well as an important accompaniment to the development of modern economics and finance. For an interesting account of the history and contributions of positivism, see Weinberg (1960).

models to predict these consequences. Whether these models are well formed theories, based on science, merely heuristic rules of thumb or perhaps even wildly erroneous notions of how the world functions, the simple fact is that mental models are the basis of purposeful action and choice. We will note below some of the implications of our model-dependent reasoning in the recent discussions for KuU problems relating to "model uncertainty", "epistemic risk" and other concepts that are currently used to capture the intersection of KuU with the choice of supporting models and theories.

The issue of subjectivity of beliefs, as formulated by Keynes, was taken up further in the pioneering work of Frank Ramsey (1903-1930). Ramsey, who died all too young at 26, made seminal contributions to the theory of taxation and public finance. He was also a gifted mathematician and logician. While he appreciated the subjectivity of probability and its anchoring in the human experience that Keynes had introduced, he pointed out several unsatisfactory features of the Keynes treatment, including in particular his treatment of induction (the idea of drawing general conclusions from limited samples). Going beyond his critique of Keynes, Ramsey (1926) developed the fundamental insight that was eventually to result in the first fully satisfactory treatment of choice under uncertainty in the brilliant treatise of Leonard Savage (1917-1971). The Savage work, *The Foundations of Statistics*, was published in 1954, a decade after the Von Neumann-Morgenstern (1944) resolution of choice under Knightian risk.[4] The Ramsey insight underlying the Savage approach was that, in decision making, beliefs (e.g., about likelihoods of events) and values (e.g., about the consequences of decisions) cannot easily be disentangled. He therefore proposed a revealed preference theory that integrated the interaction in choice of beliefs and values.[5] The Savage theory and its precursors in Keynes, Ramsey, and von Neumann-Morgenstern provided a parsimonious and usable theoretical construct, subjective expected utility theory (SEUT), which presented a model of rational choice that encompassed differences in beliefs and values among individuals. Elaborations of this framework in a general equilibrium context of SEUT-rational actors trading in a market economy was soon to follow, inspired by the work of Arrow and Debreu.[6] Therewith, SEUT provided the platform on which portfolio theory,

[4] The Keynes-Ramsey debate on subjective probability theory was further explored by several prominent authors in the quarter of a century that elapsed between the publication of Ramsey's work in 1931 and the eventual publication of Savage's solution to the problem in 1954. In this regard, one should note the work of de Finetti (1931, 1937) on probability theory, the philosophical work of Ludwig Wittgenstein, Rudolf Carnap and the Vienna School (see Carnap, 1950), and the work of John von Neumann and Oskar Morgenstern on game theory and the foundations of choice under risk, published in 1944. These precursors, together with the growing sense of the importance of having a formal theory of decision making under uncertainty in economics, were important in the huge leap forward made in the early 1950s in formalizing the micro foundations of finance and economics. Given the contributions involved in these precursors, the "Savage framework" could well be called the "Ramsey-Von Neumann-Morgenstern-Savage framework".

[5] The paradigmatic version of the Ramsey-de Finetti insight is this: Suppose a person is given a choice between two gambles X and Y, which have monetary outcomes x and 0, and y and 0 respectively, in which $x > y$. Suppose the outcome x in X is predicated on the truth of proposition P and the outcome y in Y is predicated on the truth of proposition Q. Then if the person chooses Y over X, it must be the case that the probability of Q (being true) is judged by the person to be greater than the probability of P (being true). This sort of "rational" integration of beliefs, values and choice became an essential foundation for the Savage axioms of Subjective Expected Utility Theory.

[6] Now commonly referred to as Arrow-Debreu-McKenzie equilibrium theory, following the work of Lionel McKenzie in the 1980s. See Debreu (1959) and Arrow and Hahn (1971) for the two major monographs on the foundations of general equilibrium theory; see the survey paper McKenzie (1999) for McKenzie's contributions..

financial trading, rational expectations, and so much else of the superstructure of modern finance could be constructed.

To complete the circle of early KuU heroes in economics, it is important to note the contributions of Friedrich Hayek (1899-1992) and Ludwig von Mises (1885-1973) and the Austrian School.[7] For the Austrian School, subjectivity and associated uncertainty were crucial elements of economics. For one thing, its lucid elaboration by von Mises vitiated whatever intellectual life was left in Marxism as an economic theory by noting the superiority of subjective value theory for emerging market-based theories of economics relative to the clumsiness of the Marxian ("objective") labor theory of value. For another, the emphasis on personal responsibility and entrepreneurial purpose was crucial in explaining the motive force behind economic development and profit, and the process through which human action led to market outcomes. The Austrian School held that uncertainty and subjectivism were not just of philosophical interest, but they are quintessential to the functioning of the economy and to the nature of innovation and entrepreneurship. In this sense, they echoed and reinforced the KuU metaphor of Frank Knight and his successors in the Anglo-American School of subjectivity in economics.

The above precursors of our knowledge about management and finance in KuU environments argue for the necessity of uncertainty in human affairs, and the fact that the nature of this uncertainty is inherently subjective. However, these precursors do not suggest any prescriptive or normative approaches to management under conditions of "unknown probabilities" (the "u" world) or unknowable probabilities and outcomes (the "U" world), other than, perhaps, "life is an uncertain affair; do the best you can". Indeed, my personal observation after watching students and executives wrestle with their respective worlds for over 40 years is that the human species seems to be addicted to "certainty", denying both the "u" and the "U" of the "KuU" metaphor and adhering tenaciously rather to the notion that only Knightian risk is worthy of discussion or contemplation. For various reasons, many of them reflected in the papers in this book, this view is changing.

In the sections that follow I review some of the tools, concepts and approaches that have emerged to cope with the far side of "KuU" thinking, and some of the research challenges that still await us. For ease of exposition, I will consider the differentiating features of KuU choice, separately, for individual decision making (which has been the focus of most research on the subject of KuU) and for the organizational or management level. As the world of risk (the "K" world) is well understood, I will focus on the "uU" worlds of KuU theory, using the world of Known conditions (Knightian certainty or risk) only as a contrasting baseline.

[7] A survey of von Mises contributions to KuU theory is von Mises (1973), which is a translation of his work from the early 1930s. The book has an excellent introduction by Guido Hulsmann on the Austrian School. Chapter 5 of this book contains von Mises' summary of the fundamental problems and approaches of the "subjective theory of value".

2. Individual Decision Making under Knightian Uncertainty

For a single decision maker, capturing the essential ingredients of uncertainty and ignorance in the KuU metaphor requires expanding the standard framework of decision sciences to encompass explicit formation of belief intensity and the models or theories used to predict choices with consequences. In doing so, I will follow the decision sciences literature in using the term "ambiguity" to refer to a decision situation between Knightian risk and uncertainty, whereby something may be known about the probabilities of unknown states or parameters affecting the decision context, but perhaps not with the complete precision associated with Knightian risk.

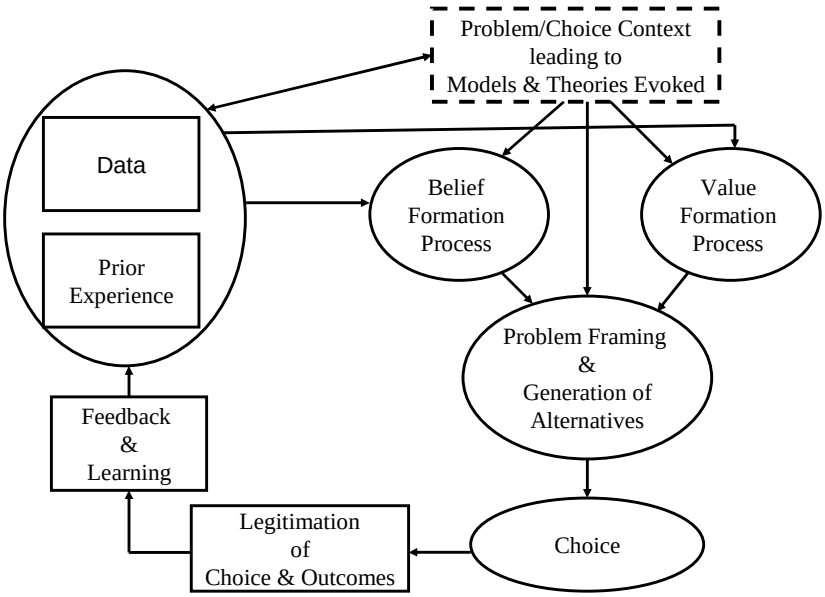

Figure 1: Mental Models, Beliefs, Values and Choice

Figure 1 shows the ingredients of choice under ambiguity or uncertainty, following Kleindorfer et al. (1993). A few points should be noted. First, in contrast to the choice under risk, ambiguity and uncertainty require attention be paid to the belief formation process, including the choice of appropriate models/theories that can be used as guides to action. Little attention has been given in economics and finance to the belief and mental modeling process, focusing rather on certainty and Knightian risk.[8] Exceptions include research on the rules of evidence (Shafer, 1976), on various forms of "belief calculus" on how to combine beliefs from multiple sources in consistent ways (Schocken and Kleindorfer, 1989), and the study of modeling errors (the fact that different models may provide different results for the same data, Dempster, 1968). The standard modeling error problem can be stated simply

[8] On this point, see Taleb (2001) for a detailed assessment of all the short-cuts financial decision makers use to avoid confronting uncertainty. A recent paper making the point that decision theorists and economists have paid precious little attention to the belief formation process is Gilboa et al. (2007), who also review the formal literature on the subject. Kleindorfer et al. (1993) review calibration and other literatures related to biases in belief formation processes, for which there is an extensive literature in psychology.

enough: One model or source of data yields one choice as being "optimal" (relative to that model), while other models and potential data yield other choices as "optimal". In this situation, the choice problem requires not just that one choose optimally in the face of an accepted causal model, but one must also weigh the plausibility of alternative models/data in some manner. Intuitively, concepts of adaptive control, robustness and worst case error analysis arise naturally in this setting. I will not review the extensive statistical and econometric literature on these subjects here. The central point I wish to underline is that the key problem for choice in repetitive situations with good data is computational, whereas the key problem in the "uU" world shifts to the evaluation of multiple competing models and data sources.

The standard approach to multiple competing models of reality has been robustness or sensitivity analysis (to the extent that the competing models can be characterized by parametric variations of some meta-model). The original theory (e.g., Dempster, 1968)) for addressing this problem as a choice problem was "second-order probability theory" in which (in the spirit of Savage) each possible model was viewed as a competing state of the world. By assigning subjective likelihoods that each of these models was the true model, one could generate a two-stage problem, with the first stage reflecting the probability of each model being the true model and the second stage reflecting the consequences of various choices given each particular model. The resulting generalized choice problem would then be a trade off between the decision maker's knowledge about the validity of various models and the consequences (both upside and downside) of choices under various models.

Later writings on model-based uncertainty analysis recognize two basic types of risk associated with KuU worlds: epistemic and aleatory risk. Epistemic risk (from the Greek word "episteme" meaning knowledge) arises from our lack of knowledge about the appropriate model or theory that might be valid or relevant for a particular phenomena, and aleatory risk (from the Latin root "aleator" for dice player) arises from randomness inherent in a phenomena (though this randomness itself may be defined or qualified by the underlying epistemic assumptions made).[9] While there is a gray area between what is epistemic and aleatory risk, the key difference is that epistemic risk can be reduced through exploration and knowledge acquisition, whereas aleatory risk cannot be reduced by such informational activities. This fundamental difference has given rise to a number of related approaches to decision making under uncertainty, based on the value of information (e.g., the work of Raiffa (1968) on decision analysis and the more recent research on information gap theory by Ben-Haim (2006)). These differences are also essential elements of modern treatments of operational risk in banking and insurance in extreme value theory (e.g., Cummins et al., 2006).

[9] For example, as described in the Kunreuther and Pauly paper in this volume, in predicting the consequences of, say, earthquakes, recurrence rates for seismic activity, for propagation of seismic energy and for geological conditions, and the contents and fragility of buildings all represent epistemic assumptions that are necessary for modeling insurance losses from seismic activity in a particular region. In addition to these sources of epistemic uncertainty, there is a natural randomness associated with the effects of such earthquakes. Such randomness would remain unresolved even if one knew for a fact when and where earthquakes would occur, the complete geology of a particular region and all relevant details of affected buildings.

Perhaps the most general model advanced to frame the problem of integrating epistemic and aleatory risk (the problem of prediction and explanation under KuU conditions) is that of the British philosopher Stephen Toulmin (1958). His "theory of argument" is a general framework, firmly grounded in subjectivism, which encompasses the data underlying belief formation, specific and general models supporting beliefs, and rebuttal models that qualify beliefs. The overall process can be thought of as weighing pros and cons amongst competing models in deriving a "plausibility" or degree of confidence in a given belief. With an eye on Figure 1, Toulmin's theory of argument is grounded on prior experience and available data, specific to the person, to the problem context and possibly to broader fields of science in support of theories that might be used for predictive purposes in a particular problem context.[10]

A further important element of Figure 1 is legitimation.[11] This refers to the process by which choices are explained ex post, making sense of these both to the decision maker as well as to other stakeholders. The anticipation of an open legitimation process ex post can be expected to have a significant effect on choice itself, as well as on the espoused theories used for belief and value formation. Often it is legitimation that leads us to use "accepted models" or particular data that are in common use. In that way, if a negative outcome occurs, one can take shelter in the company of fellow travelers. I will revisit this issue below, but it should be clear that in the uncharted terrain of "uU" worlds, legitimation is of a different character than for established problems with well defined and accepted public data and models/approaches that have been validated by both research and practice.

Let us now consider formal theories and experimental evidence on KuU theory at the level of individual choice. I begin with Savage, and his intellectual heirs. I then consider a few of the experimental and empirical results raised by KuU theory.

Formal Theories of Choice under Uncertainty

Imagine a single decision maker facing a choice over various alternatives f, g and h, as represented in Table 1 below (which follows Savage (1954)). In this Table, the (mutually exclusive and collectively exhaustive) states of the world are labeled $S = \{s_1, \ldots, s_n\}$and the

[10] Using the Toulmin framework in support of decisions under uncertainty is elaborated in Kleindorfer et al. (1993), Chapter 3. As an example of its general structure for prediction theory, consider the following example. If a wheel is set free at the top of a hill, an observer might make a plausible prediction with considerable confidence that the wheel will roll down the hill. In the Toulmin Theory of Argument, the observer would "back up" the plausibility of this prediction with both personal experiences as well as Newtonian Theory (if that were known to the observer) and all the interlocking corroborative data of that more general theory. Rebuttals to the prediction would be in the form of making sure that there were no unseen impediments or barriers to the wheel beginning its anticipated descent. The power of this theory becomes apparent in more general problem settings, where analysis of "Underlying Data", "Theories of specific warrant", "General Theories of further support", "Rebuttal conditions and theories" are integrated under Toulmin's prescription of attaining a balance among all of these elements in the process of prediction and belief formation.

[11] The most famous modern writer on the subject of legitimation is the German philosopher Jürgen Habermas. A summary of the legitimation theory of Habermas in the context of decision theory under KuU conditions is chapter 5 of Kleindorfer et al. (1993). A very short summary of this theory could be stated as follows: a credible anticipation of being held accountable not just for outcomes but for the logic that led to them will have predictable effects on the nature of the choice process itself.

entries $U_i(x)$ represent the utility that the decision maker derives from choosing x = f, g, h. Following Anscombe and Aumann (1963), these utilities themselves may derive from random variables, but of the traditional risk sort, so that (we assume here) there is no difficulty computing the decision maker's choice once both the alternative (f, g or h) and the state of the world are known (s_1, s_2 , … or s_n). As explained by Wakker (2006), the states of the world may be best thought of in a world of Knightian uncertainty as corresponding to certain observable events (e.g., market or political events) (E_1, …, E_n), where state of the world s_i is said to occur if event E_i occurs.

Table 1: Illustrating Subjective Uncertainty

	s_1	s_2	…	s_n
f	$U_1(f)$	$U_2(f)$	…	$U_n(f)$
g	$U_1(g)$	$U_2(g)$	…	$U_n(g)$
h	$U_1(h)$	$U_2(h)$	…	$U_n(h)$

The Savage theory assumes that the decision maker has sufficient knowledge to assign subjective relative likelihoods p_1, …, p_n to the states of the world s_1, …, s_n (or equivalently to the events E_1, …, E_n) in a consistent fashion (i.e., the p_i's are to be thought of as the subjective probability that state s_i will occur, so that they are non-negative and sum to one). The Savage Axioms assure that the decision maker's preferences among alternatives such as f, g, h can be computed using the standard expectation operator across the states of the world, with the final utility of alternative x computed as:

$$V(x) = \sum_{i=1}^{n} p_i U_i(x), \quad x = f, g, h \tag{1}$$

and where the choice among the alternatives f, g, h would then be the alternative with the greatest expected utility: V(f), V(g) or V(h).

Consider a simple example, where an investor faces mutually exclusive opportunities f, g and h (one of them being a default investment) and where the payoffs from these opportunities depend on the state of the economy and perhaps other unknown factors that will influence returns. These unknown states are represented by S = {s_1, …, s_n}, where $U_i(x)$ represents expected returns from alternative x if the state of the world is s_i. Savage Theory provides an axiomatic foundation for concluding that that the investor would use the rule summarized in (1), choosing the opportunity f, g or h by trading off the subjective likelihood that the economy will find itself in each of the respective states of the world against the profitability of each investment in these states.

Suppose, however, that all that can be reasonably assured for our investor is that some states of the world are "highly unlikely" for the relevant future, and indeed that only two states of the world, say s_1 and s_2 are assumed to be relevant, but even for these two states of the world, the probabilities p_1 and p_2 are not known with confidence. Two issues immediately occur: <u>first</u> what does the term "highly unlikely" mean, and <u>second</u> how should one deal with the now ambiguous state of knowledge of the probabilities of s_1 and s_2 in this new problem. Various approaches to these two problems have been proposed in the axiomatic choice

literature, perhaps the best known due to Gilboa and Schmeidler (1989) and Schmeidler (1989).[12]

The first of these provides an axiomatic approach that yields as an outcome a choice rule that associates the least favorable conditions with any elements of a choice situation that are not known with certainty (this is famous Max Min rule due originally to Abraham Wald (1950) for the case where several prior distributions could reasonably be advanced in a particular decision context). One might think of this as a "safety first" rule that assumes a malevolent nature choosing the worst possible state of the world for any choice one is about to make. Knowing this, the decision maker would choose that alternative which maximized his expected utility over alternatives, given a least favorable outcome in terms of states of the world would occur after the choice is made. Note that in this case, the decision maker might have evidence to suggest that only certain belief structures/probabilities could be reasonably associated with states of the world. This might suggest constraints of the form, e.g. $p_1 \leq p_2$, $p_3 \geq p_4 + p_5$, $p_1 = 0.1$, $p_5 = 0.4$ and $p_1 = 2p_4$ (the last meaning that s_1 is twice as likely as s_4). Taken together, these beliefs would spell out some likelihoods precisely, while others would remain imprecise. If the resulting set of feasible state probability vectors is specified as Δ, then the rule implied by the Gilboa-Schmeidler theory is the Wald MaxMin Rule, namely, choose the alternative x which maximizes:

$$V(x) = \text{Min}\left\{ \sum_{i=1}^{n} p_i U_i(x) \middle| \; p \in \Delta \right\} \tag{2}$$

The second approach, due to Schmeidler, provides a rather general solution to the question of incompleteness of likelihood specifications over the state space. It is based on the idea of non-additive measures of likelihood to capture ambiguity, and follows earlier work by Dempster (1968) and Shafer (1976) on this same theme. To illustrate this very powerful idea in its simplest form, consider the above investment example, and assign a further measure to the completeness of the decision maker's information, say some number $c \leq 1$ (where $c < 1$ is taken to mean that the decision maker has less than complete confidence in her assessment of the underlying state probabilities). Assume that the investor begins with a standard probability distribution $p_1, \ldots, p_n$ on some relevant states of the world (so that, in particular, $p_1 + \ldots + p_n = 1$). Define a new probability distribution $\mu(p, c)$ as follows: For any subset of states $A \subseteq S$, define the likelihood of A as

$$\mu(A) = \sum_{i \in A} c p_i, \; A \neq S; \quad \mu(S) = 1 \tag{3}$$

The reason that $\mu(p, c)$ is referred to as a non-additive measure of likelihood is that for any $A \subseteq S, A \neq S,$ (3) implies that $\mu(A) + \mu(S \setminus A) = c$, so that if $c < 1$, the sum of the likelihoods

[12] A summary of recent theoretical advances is provided in Klibanoff et al. (2005) and Nau (2006), both of which extend the Gilboa and Schmeidler work to articulate differences in preferences and beliefs in situations that involve both ambiguous and non-ambiguous probabilities (the latter being the standard Knightian risk context).

of a set A and its complement S \ A do not sum to one.[13] One can think of the parameter "c" as connoting the surety that the states s_1 and s_2 do, indeed, provide a complete description of the states of the world that could occur. In this particular case, the Schmeidler Theory results in the following valuation of a given alternative x:

$$V(x) = c\left(\sum_{i=1}^{n} p_i U_i(x)\right) + (1-c)\left(\mathrm{Min}\left\{U_i(x) \,\middle|\, i = 1,\ldots,n\right\}\right) \qquad (4)$$

which is a weighted sum of the usual Savage measure of expected utility (1) and the worst case outcome (for alternative x), with the weight specified by the incompleteness parameter "1-c". Of course, this is only one simple example of the Schmeidler Theory, which encompasses considerable flexibility to reflect ambiguity in belief structures and its interaction with normal (expected utility) value structures. One aspect of this generality to be noted is the non-linearity of the mathematical process integrating values (in this case the $U_i(x)$ terms) with beliefs (in the above example, the p-vector and the completeness parameter c). This non-linearity has made it difficult to generalize the standard problems of finance (e.g., portfolio theory, investment theory, and valuation of financial contracts/instruments) to the more complex world of incomplete belief structures.[14]

Experimental Evidence on Individual Choice under Uncertainty

Let me now note some experimental results related to KuU theory. The first paper in economics to clearly substantiate the fact that human decision makers act differently under conditions of unknown states (the "u" world) than under Knightian risk was Daniel Ellsberg (1961). In his famous challenge to SEUT theory, now known as the Ellsberg Paradox, the following choice situation was presented to subjects in an experiment.[15]

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[13] For example, if S = {1, 2} and $p_1 = .4$, $p_2 = .6$, and c = .9, then the measure $\mu(p, c)$ would be given by: $\mu(\emptyset) = 0$, $\mu(s_1) = 0.36 = .9*.4$; $\mu(s_2) = .54 = .9*.6$, $\mu(s_1 \text{ or } s_2) = \mu(S) = 1$. Note that this is a non-additive measure since $\mu(s_1) + \mu(s_2) < 1 = \mu(s_1 \text{ or } s_2)$.

[14] See the paper of Dow and Werlang (1992) for the simplest example of incorporating non-additive likelihood measures in the portfolio context. See also the advances and applications of the Schmeidler theory surveyed in Gilboa (2004). Several problems must be overcome to apply this theory in practice. First is the elicitation problem (quantifying both beliefs and values, including uncertainty elements, in a form usable by the theory). Second is the computational problem (to apply the theory to a particular decision setting); this is less of a problem these days, but it can still be important if the set of options is large. Third is the deeper analysis of optimal choices as a function of the elicited beliefs and values. This is difficult in most applications. Contrast, for example, the Markowitz-Sharpe-Lindner portfolio problem using market data to characterize returns and to compute the efficient frontier, and Sharpe ratios to explore the investor's risk appetite. The results of this process are relatively intuitive and can be executed within a time frame that could support decision making. Not so with any of the uncertainty formulations that have been advanced thus far. There are evidently a lot more degrees of freedom in expressing what one knows and doesn't know than there are in determining optimal choices under the standard belief/probability structure which assumes, in essence, that probabilities are fixed for a given problem context. Research continues, of course, but whenever subjectivity and personally weighted evidence enter the problem, the key barrier is no longer computation but rather elicitation from the decision maker of his/her beliefs and values. Finding shortcuts around this elicitation problem while faithfully capturing key elements of the decision maker's actual beliefs remains an unachieved goal of research to date.

[15] This experiment has remained a gold standard for research on KuU problems. A recent experimental analysis and revisiting of the Ellsberg results is provided by Halevy (2007).

An urn contains 30 red balls and 60 black balls or yellow balls (with the proportion of these last two colors unknown). Subjects are told that the number of black or yellow balls was determined by a random process prior to the experiment, but the details are not revealed. Subjects are asked to choose between choices A and B in situation I and C and D in situation II.

Situation I

Choice A	Win $100 if a red ball is pulled
	Win $0 if a black or yellow ball is pulled
Choice B	Win $100 if a black ball is pulled
	Win $0 if a red or yellow ball is pulled

Situation II

Choice C	Win $100 if a red or yellow ball is pulled
	Win $0 if a black ball is pulled
Choice D	Win $100 if a black or yellow ball is pulled
	Win $0 if a red ball is pulled

By a wide margin, the most popular choice for subjects was to prefer A to B in situation I and D to C in situation II. Yet a little reflection shows that these preferences are inconsistent with the Savage SEUT Theory (or any theory linear in probabilities). Letting p_1 = probability of a red ball, p_2 = probability of a black ball, and p_3 = probability of a yellow ball, and using (1) we would find according to SEUT theory that "A preferred to B" and "D preferred to C" imply the following two inequalities:

$$p_1U(100) + (p_2 + p_3)U(0) > p_2U(100) + (p_1 + p_2)U(0) \qquad (5)$$

$$(p_2 + p_3)U(100) + p_1U(0) > (p_1 + p_3)U(100) + p_2U(0) \qquad (6)$$

It is easy to see (canceling $p_2U(0)$ in (5) and $p_3U(100)$ in (6)) that these two equations are contradictory. What this means is that there can be no viable SEUT set of beliefs and preferences (the former represented by p_1, p_2, p_3 and the latter by the utility function U) that could possibly represent the modal preferences of subjects in this experiment. Quite apparently, the modal choices of A and D over B and C reflect a preference for non-ambiguous lotteries. This preference was further underlined in accompanying verbal protocols for the experiment. Subjects were clearly averse to the ambiguity about the probabilities in this very simple setting.

The Ellsberg experiments remained a paradox for received theory for some time. The non-additive theory of Schmeidler or the multiple priors (MaxMin) theory of Gilboa and Schmeidler finally provided a consistent theory for the modal choices here. The reason is that these theories have the power to capture what is, in effect, the ambiguity aversion evident in the subjects' choices in Ellsberg's experiments (e.g., in the Gilboa-Schmeidler theory, ambiguous probabilities or outcomes are evaluated in worst-case terms, leading effectively to ambiguity aversion). The Schmeidler theory received additional support as a vehicle for

explaining choice in uncertain environments through the work of Tversky and Kahneman (1992). In their path breaking work on Cumulative Prospect Theory (extending their earlier work on Prospect Theory), they advanced a theory of descriptive choice that, as it turns out, has the same formal representation as the Schmeidler normative theory introduced above.[16] In so doing, they provided a key link between normative theory and the important work they and others had done in the course of the 1980s on behavioral anomalies of choice under uncertainty. I will not review the details of the connection between these two theories (both formal representations of choice, but one normative and the other based on experimental evidence). Suffice it to say that the story did not end with noting the (near) formal equivalence of these two theories.

Two other matters are of interest in the experimental history of KuU choice. The first of these is termed the "source of the uncertainty" and the second falls under the heading of legitimation. On the first point, Tversky and Fox (1995) noted important and systematic differences in the nature of choice when the source of uncertainty underlying the outcomes was held to be "objective" and "mechanistic" (think of this as chance determined by a roulette wheel) versus chance outcomes determined subjectively (think of this as determined by the outcome of an event, like a sporting or market event, the likelihood of which requires judgment to estimate). Thus, in describing the preferences and beliefs of a decision maker under Tversky and Kahneman's Cumulative Prospect Theory (and variants thereof), the nature of the non-additive belief function underlying these choices depends not just on the decision maker but on the source of randomness itself. This is not very encouraging for those looking for a simple unifying theory of choice that they could use to underpin, say, portfolio theory. What this says is that alternative data sets may give rise not just to alternative beliefs, but also to alternative weightings of these beliefs in decision making, at least if the current non-additive models of choice are to be used as the foundation for choice.

A sec ond interesting set of experimental results has to do with legitimation. This matter was first examined by Curley, Yates and Abrams (1986). They used the Ellsberg Paradox setting described above, but they added the following wrinkle. Subjects assigned monetary values to the various choices in the Ellsberg Paradox setup (where a higher monetary value for one choice versus another was interpreted as preferring that choice). After they made a number of such monetary value assignments, some of these were selected at random and "played", where "played" meant that they were given their declared monetary value or they actually played the corresponding Ellsberg lottery and were rewarded according to the outcome. They would therefore see the results of their choice in Situation I and II of Ellsberg for some of the lotteries they chose. In addition, for some experimental treatments, subjects were told that they would be shown (after their choice was made) the actual number of black and yellow balls (the ambiguous state of the world in the Ellsberg setup). In other cases they would not know the number, but would just be shown the actual outcome of drawing a ball from the urn.

[16] I pass over here the important fact that the Tversky-Kahneman theory has an additional piece of apparatus, the reference point or status quo, which is quite important to explaining a host of experimental findings about differences in choice behavior in the domain of gains versus losses. The point I am making about formal equivalence here concerns the role of the weighting function, first introduced by Quiggin (1982) in his Rank Dependent Expected Utility Theory. The interested reader can follow the outlines of this fascinating interplay between descriptive theory and normative theory development in Tversky and Wakker (1995) and in the survey by Wakker (2006).

Finally, in some instances the actual draw of the urn (and their choice of bets) would be done in front of their group of fellow subjects, while in others the outcomes would only be done with each individual privately. The Group was never informed of the actual number of black and yellow balls, even when the individual was. The experimental setup is shown in Table 1 below.

Curley et al. recorded the differences that subjects were prepared to pay to avoid ambiguity (this ambiguity premium" was just the difference between what they were prepared to pay for the non-ambiguous choices under the Ellsberg setup relative to the ambiguous choices). The results of the experiment were that there was no significant difference between the high and low individual knowledge states (i.e., no significant differences if the subject were informed of the number of black and yellow balls after choices had been made). However, there were significant differences in the ambiguity premium between the conditions of group observability. When the Group could observe the playing of the ambiguous lottery, and this was known in advance, subjects were prepared to pay significantly more to avoid the ambiguous outcome. One explanation for this, based on legitimation theory, is that when subjects anticipate the need to be able to explain (or even expose) to others the amount of money they had been willing to pay for these lotteries, ambiguity becomes even more undesirable than it is in isolated personal choice settings.

Table 1: Curley, Yates and Abrams (1986): Legitimation

	Observability to Group	
Ex Post Ambiguity	**Outcome Observable to Group**	**Outcome Not Observable to Group**
High	(H, O) Known to subject, played in front of the Group	(H, N) Known to subject, played after Group has left
Low	(L, O) Not known to subject, played in front of the Group	(L, N) Known to no one, played after Group has left

In a related paper, Heath and Tversky (1991) examined differences in choice between risks that were based on "objective probabilities" and those based on subjective events, such as the outcome of sporting events or elections. What they found is that those who thought of themselves as experts in a field preferred to bet on their judgments rather than on equivalent chance events (i.e., chance events that had the same probability of a positive outcome as what the expert predicted for the judgment event in question), while the opposite was true of those subjects who viewed themselves as lacking expertise in a particular area. One explanation for this phenomenon is that those who thought of themselves as "experts" understood that they would be able to justify their choices better, both when the outcomes of these choices were positive as well as negative. The point of these and other experiments is that the nature of anticipated legitimation, even in experimental settings, can have significant effects on the outcomes of choice under uncertainty.

The psychological and behavior decision making literature on choices under ambiguity and uncertainty has considered several other important issues that I will just note briefly here.[17] First, individuals tend generally to be overconfident and myopic (the General Custer effect, "I haven't lost a battle yet!") and, as the Heath and Tversky study above suggests, this is, if anything, exacerbated when expertise and judgment are required. Second, there is considerable inertia in mental models (one explanation for which being the cognitive energy it takes to re-integrate a new mental model with existing beliefs). The result is that, rather than adopting a posture of balancing supporting and rebuttal evidence on the validity of their current model, there is rather a search for confirmatory evidence that one's current model is the right way to go. As Mandelbrot and Taleb point out in their paper in the current volume, this results in far too many hundred year events occurring every 5 years, giving rise to cries of "oops" and "duh", but rarely to an adjustment of our mental models (in their case the model of Gaussian theory). Third, there are herd dynamics and contagion effects evident in the use of models. Some of these are understandable in terms of minimizing coordination costs of social coordination (a point underscored by Schelling (1978) and Beck (1992)). Finally, there appears to be a mix of the rational and irrational when it comes to dealing with the unknown. Part of this arises undoubtedly from our biological heritage in seeking meaning and order in life so that we can continue to function without undue neurosis. And certainly, the mere thought of making choices of consequence under conditions of ambiguity and ignorance calls out for company.[18]

In general, the golden ideal embodied in Figure 1 of rational analysis in the face of uncertainty and ignorance seems not to be the first impulse of human decision makers. Rather, our impulse seems to be to use models and data that have worked passably well in the past, and that seem to be supported by many fellow travelers. If the models we use for navigating KuU worlds have been crowned with some formal dignity by academic or professional credentials or practices, so much the better. The dangers of this approach may be evident to the reader, and the cure (namely, unrelenting skepticism and continued challenging of our knowledge base) obvious. However, like healthy eating and daily exercise, I suspect the costs of this very rational approach are also obvious.

3. Organizational Decision Making and Strategy for KuU Environments[19]

Let us now turn to organizational decision making in KuU environments. My point of departure is that globalization, together with its technological underpinnings in new communication technologies, has fundamentally changed the level of interdependency of financial and market activities, with many more actors involved in these activities directly or indirectly, and in real time. The increased interdependency and speed of responses means that organizational decision making and action confront a considerably expanded set of states of

[17] The literature on these matters is discussed in detail in Kleindorfer et al. (1993) and Schoemaker (2002).
[18] The increased need for traveling companions in uncertain times may be understood as the result of the existential need for reinforcement and endorsement of our worth as individuals, where this comes primarily through our interaction with others, per the trenchant writings of Soren Kierkegaard and Martin Buber.
[19] Many of the ideas of this section were recorded earlier in Kleindorfer and Wind (2006). The ideas here on network-based strategies and competencies for the core of an on-going research project at Wharton's SEI Center for Advanced Studies in Management.

the world conditioning outcomes. The resulting increase in complexity currently exceeds organizational abilities to incorporate these increased states into decisions at the time they are made. The result implies something like the intuitive import of the KuU spectrum underlying our discussion. What can be done about this from a management perspective is suggested by the anthropomorphic metaphor of an explorer entering uncharted terrain. That individual would do well to prepare mentally for surprises, to be agile and unencumbered by heavy baggage, to have increased acuity and perhaps communication capabilities to home base, and in general to have developed the ability to react to unforeseen and unforeseeable exigencies as they arise. This anthropomorphic metaphor of the prepared, agile explorer is helpful in describing some of the research on these questions and the initiatives being implemented in various organizational contexts to cope with the far side of the KuU world that is unfolding before us.

The last two decades have seen immense changes in the forces and institutions that govern economic activity. They encompass the on-going changes associated with the European Union, and the changes in liberalization and governance initiated by the World Trade Organization.[20] New markets and new forms of contracting are supporting outsourcing, unbundling, contract manufacturing and a variety of other forms of extended value constellations. The Internet has empowered consumers and given rise to peer-to- peer networks. In the process, it has transformed whole industries – the impact of Skype on the telecommunications industry, search engines (Google) and e-Retailing, and the growth of e-Bay, to mention a few of the more evident signs of change. In tandem, revolutionary developments in transportation and logistics (the rise of FedEx, UPS and DHL) are providing new global fulfillment architectures for B2B and B2C. These mega-trends are summarized in Figure 2.

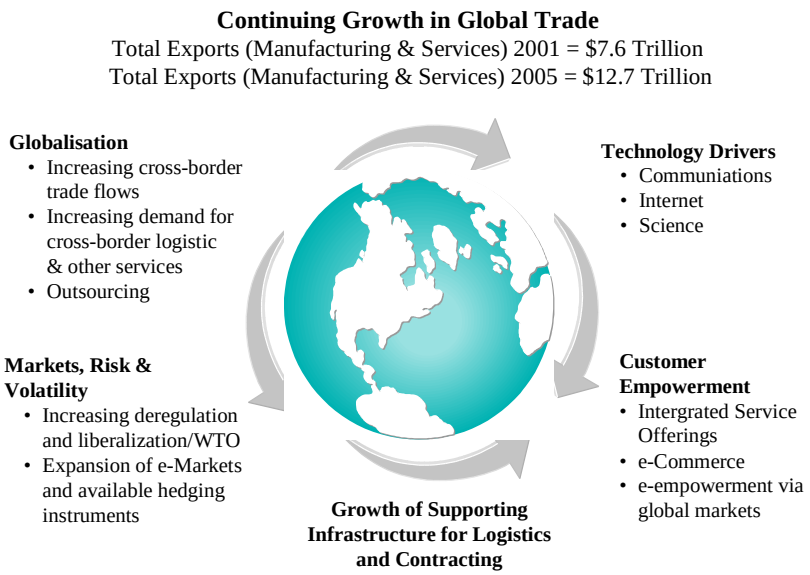

Figure 2: Key Trends Driving Profitability and Uncertainty for Management

[20] For a readable account of these changes and their implications for management and governance, see Friedman (2005).

Consider the area of logistics as an example of the interdependent trends exhibited in Figure 2. A mere twenty years ago, logistics (maritime, air and land-based) was considered a mature industry, operated by "real men", which meant lots of inefficiencies and empty backhauls, huge cycles of overcapacity and undercapacity, and head-butting competition. The communications and information revolution gradually gave way to improved routing and scheduling, and eventually to improved utilization through regional coordination of capacity. But it was clearly the mega-trends of Figure 2 that took logistics to an entirely new level, driven by outsourcing and huge increases in intra-regional and international trade. Expansion of physical capabilities at air hubs and ports began in the 1990s and has continued unabated, with Hong Kong and Dubai the most evident examples, but with increases in capacity in nearly every established port and air hub. This was accompanied by increased sophistication and intermediation activities of brokers and forwarders, followed by the development of financial overlays and trading instruments for air cargo and shipping capacity.[21] The logistics industry is an interesting example on how physical markets have dovetailed with financial and information markets in supporting and profiting from globalization and outsourcing as shown in Figure 2.

Logistics is a typical scenario, with similar changes occurring in a host of markets from energy to insurance and banking. In every case, we see the power of the market being used to provide better information, better coordination, with the instruments of finance, hedging and arbitrage playing essential roles in promoting improved discovery of scarcity values and prices. Arguably these mega trends represent the most important element of the present economic environment for management to respond to unknown and unknowable environments. By relying on the aggregation and discovery power of markets, and the valuation signals available through financial instruments overlaying the goods and services provided in these markets, a great deal of otherwise opaque uncertainty can be understood, mitigated and managed.[22]

However, the changes described above have also introduced new and poorly understood risks. Just to focus on financial services, Buehler and Pritsch (2003) trace the tide of bankruptcies and other forms of financial distress that continue to plague the financial services industry, noting that in the period of 1998-2002 for their sample of 90 financial institutions, some 150 instances of financial distress took place (see their paper for the definition of financial distress). Even given the volatility of the period in question, this rather astonishing level of 1.67 instances of financial distress per institution over a five-year period suggests something is amiss. What was amiss, according to Buehler and Pritsch, was a lack of appreciation of the magnitude of the changes that had occurred in global markets and the level of new risk and uncertainties these represented, coupled with a lack of appropriate management systems for understanding enterprise vulnerabilities and correlations across different lines of business, and for responding to discontinuities in the environment before they became full-blown crises. Research in the area of interdependency and risk has picked up on these ideas and pointed to

[21] Kavussanos and Visvikis (2006) describe the growth in options trading on shipping capacity. Kaminski (2004) describes related hedging options on aviation fuel and bunker oil.

[22] See Kleindorfer and Wu (2003) for a description of new contracting and hedging strategies being followed in manufacturing industries as a result of these changes. See Kunreuther and Pauly in the present volume for a discussion of similar changes in the global (re-)insurance industry.

contagion and other network effects as central to the new uncertainties of the financial services industry.[23]

The risk in financial institutions noted above is also evident in manufacturing. On the positive side, technologies such as web-based tools have helped improve coordination and remove information distortions. A classic example is the collaboration between Wal-Mart and P&G leading to the now widespread practice of Vendor-Managed Inventory. The basic vision driving supply chain design and plant management in manufacturing has clearly been the anthropomorphic metaphor of "leanness". However, while the resulting "leaner" supply chains reduce inventory costs, companies have started to experience some of the negative consequences of leanness in uncertain environments.[24] In addition to the risks of mismatch in supply and demand, disruption has now become a major source of risk in global supply chains. Disruption risks include: operational risks (equipment malfunctions, unforeseen discontinuities in supply, human-centered issues from strikes to fraud), and risks arising from natural hazards, terrorism, and political instability. Disruption risk has increased significantly because of the longer and more complex global supply chains now enabled through globalization.[25] The Taiwan earthquake of September 1999, which sent shock waves through the global semiconductor market, the terrorist attack on the World Trade Center on September 11, 2001, and the August 14, 2003 blackout in the Northeastern US are but a few reminders of the potential for significant disruptions to supply chains. Given these events, and the increasing reliance on cross-country supply chains, it is not surprising that Enterprise Risk Management has become a high priority topic for senior management and shareholders in manufacturing.

Beyond the traditional notion of risk, involving capital reserves and response capabilities for unforeseen contingencies, a fundamental driver of the need for a new vision of coping with the evident move to the far side of the KuU metaphor derives from the increased complexity of the systemic interactions that are the core of network-based models of firms and their interactions with their customers, trading partners and the markets in which they operate. In particular, complexity theory and systems theoretic notions deriving from general networks and artificial intelligence are beginning to provide new insights on risk and resilience of firms in the new economy. Some well-known examples may serve to illustrate:

> Power laws and scale free networks dramatically shift increase risks. There may be significantly increased long-tail impacts on net-centric businesses resulting from the fact that there will be both the usual high-frequency local disturbances (with controllable and lower losses) as well as very low-frequency but potentially catastrophic events for interconnected sub-networks of the overall value

[23] Allen and Gale (2000) provide the foundation for this analysis. For a recent discussion of the theory of networks in finance, see Babus (2007).

[24] See Sheffi (2005) for a call to retreat form mere "leanness" to "resilient supply chains", with clear echoes of our explorer heading into uncharted terrain.

[25] Hendricks and Singhal (2005) analyze announced shipping delays and other supply chain disruptions reported in the *Wall Street Journal* during the 1990s and show, based on matched sample comparisons, that companies experiencing such disruptions under-perform their peers significantly in stock performance as well as in operating performance as reflected in costs, sales and profits.

constellation.[26] The anthropomorphic desiderata of adaptation, resilience and process/organizational time to maturity become more important than optimization under conditions of high uncertainty and complexity.

Peer-to-peer interactions also conform to scale-free networks and the "empowered customer" may be dramatically shaped in their behavior by network interactions even though they often do not know it. "Fractal marketing" and "fractal finance" will play a key role in the future in understanding and predicting behavior in markets for both goods and capital.[27]

These challenges suggest that increased complexity and network-based interdependence arising from globalization are the roots of the increased emphasis on management in KuU environments. Recent work in organization science and business strategy on this problem can only be sketched here, but it follows the basic anthropomorphic metaphor of our explorer going into uncharted territory. Some of the key areas can be briefly noted.

Establishing Purpose through Strategy and Leadership

Russell Ackoff is perhaps the best known proponent of the view that a company navigating rough terrain must have a well charted course that reflects its purpose and strategic intent, i.e., it needs to design its own future. Ackoff proposes the "idealized design approach" (Ackoff et al., 2006) as a disciplined way of crafting such a design. Amit and Zott (2001) and Chan and Mauborgne (2005) (the authors of the Blue Ocean strategy) argue similarly that crafting new business models to accommodate the dictates of the network economy require a strong commitment and a decisive direction for company strategy. Michael Useem (1998) and many others have emphasized the importance of leadership in times of great uncertainty.

Creating an Organization with Unique Competencies

Core competency theory (Hamel and Prahalad, 1994) has focused on making a company unassailable through the development of competencies, both technology-based and organizational, which serve to define the value proposition for the products and services produced by the company and are not easily imitable by competitors. The resulting confluence of the core competency movement with the paradigm of process management augured many of the changes that have occurred in the past decade, including unbundling of value chains and outsourcing (while maintaining core competencies firmly in control of the "Mother Company"), and the contracting and supply chain innovations that have occurred in parallel with these. Size and core capabilities are a reasonable defense against many uncertainties.

[26] See the Mandelbrot and Taleb paper in this volume for a discussion. For network effects, see Babus (2007). For the evolving work on artificial intelligence, see the GECCO website and publications (Genetic and Evolutionary Computation Conference): http://www.sigevo.org/gecco-2007/.

[27] See Mandelbrot and Hudson (2004) on financial implications of these changes and Wind and Mahajan (2001) on the marketing implications.

Creating a Resilient and Responsive Organization

Jay Galbraith (1977) was a pioneer in studying the appropriate fit between an organization and its environment. He noted that successful organizations tended to decentralize when facing more turbulent environments, and also engaged in other organization innovations to increase the information processing capabilities of the organization when faced with environmental complexity. These thoughts were elaborated in a slightly different tone by Williamson in his celebrated analysis of the boundaries of the firm (e.g., Williamson, 1996) and, more recently, by Santos and Eisenhardt (2005) in studying organizational design in the internet age. Beyond these general contributions to organization design, the topic of crisis management and business continuity assurance have surfaced as essential elements of responsive and resilient organizations (e.g., Sheffi, 2005), following the World Trade Center attacks on 9/11/01 and the growing awareness of the costs of supply chain and operational disruptions experienced in the past decade.

Creating Leanness, Opportunism and Flexible Response

The "lean organization" paradigm has been recognized in two ways in responding KuU conditions. First is the time-based leaning of supply chains noted in the discussion above and exemplified by the Dell Computer story (see e.g., Sheffi (2005)). Second, is the outsourcing and divesting of non-core processes epitomized by the Lou Gerstner years at IBM, in which huge chunks of the business were divested in order to get back to a capital base and competencies that represented a lean organization with all the necessary core assets to control its destiny. Flexibility and opportunism have been emphasized in the "real options" approach to corporate strategy and project execution. As explained by Bowman and Moskowitz (2001) and Loch et al. (2006), the essential idea is to approach strategy and multi-stage projects, be they new technologies, new facilities or new markets, as part of a portfolio of prepared options, with selective execution of individual projects as opportunities present themselves (i.e., if and only if these projects turn out to "in the money").

Improving Organizational Acuity and Long-term Vision

Beginning with Royal Dutch Shell's use in the late 1960s, scenario planning has become a key approach to environmental uncertainty. As explained cogently by Paul Schoemaker (2002), scenario planning helps to map the environment 10 to 15 years out (beyond the limits for which normal market and pricing signals would be useful), and identify key stakeholders and uncertainties that could be sources of profit or vulnerability for a company in the future. If trends and uncertainties are anticipated, a company can prepare a "play-book" of contingent response strategies that allow it to switch among strategies with some degree of grace and, perhaps, ahead of its competitors. Scenario planning and related scanning mechanisms (see Day and Schoemaker, 2005) have seen a surge in recent use because of perceived increases in long-term uncertainties such as the course of climate change and political reactions to it, ideological conflicts, and the speed and success of key technological innovations (such as the hydrogen powered automobile).

Legitimation Different under KuU

The problems of legitimation and governance at the organizational level are compounded with those we already saw at the individual level. The tendencies noted above towards lean organizations and decentralization must face controls on levels of financial commitment and risk to which an organization can be exposed based on actions of individual employees. The lessons of Barings Bank and Enron have shown the limits of unchecked action, whether on the trading floor or in the Board Room. Many innovations and regulatory changes have occurred recently in an attempt to provide some discipline to the problems associated with playing with the house money, from Basel II in Banking to Sarbanes-Oxley in general governance. The search continues for workable solutions to responsible controls that do not extinguish entrepreneurship and innovation.

Hedging and Diversification

Of course, the long-hallowed strategy, and the core of the international reinsurance market, is diversification. By taking thin slices of risks in separate markets, correlated risks can be shared among a larger number of competing capital providers. Similarly, hedging strategies have become the center piece of protecting against undue volatility in individual company cash flows, whether these are caused by commodity price fluctuations or the weather. The pioneering work of Karl Borch (1919-1986) and advances since then in the science of risk bearing and diversification are summarized in Doherty (2000). Interesting new work in this area is focusing on understanding and hedging correlated risk patterns due to network and contagion effects, as noted in Babus (2007).

The above admittedly selective list of current initiatives and research activities shows, I think, that the effects of increased complexity and uncertainty in today's business environment have led to a clear recognition that the economy has moved to the far side of KuU territory. In short, the above list highlights the creation of new management systems for Enterprise Risk Management and crisis management, new strategic initiatives in scenario planning and scanning, and a general deepening of diversification and hedging strategies. These themes underscore the anthropomorphic metaphor of an explorer in KuU territory I have used to structure my discussion. In one sense, these organizational innovations reflect a Darwinian evolution of survival benefits for companies that have adopted the right niche strategies relative to the new environment. At another level, in the spirit of Lamarckian evolution, this is evolution that can be influenced by the foresight of the well prepared explorer, who brings the right options along on the voyage, who is able to move quickly to exploit these when opportunities present themselves and who has improved his long-range vision so as to see these opportunities in time to respond.

4. Concluding Comment

The reader will hopefully take from these reflections a sense of the incompleteness of research on KuU problems, but at the same time the very necessity of this incompleteness. Since the dawn of intellectual history, the subject of epistemology (what can know of our

external environment) has been a fundamental field in philosophy. In philosophy, we have seen wave after wave of objectivism and subjectivism, with the current upper hand being in the hand of the subjectivists. Given the unsettled state of this long debate, it is not surprising that the keen force of logic alone has not settled the issue of how best to navigate the maze of belief, value and choice under KuU conditions of interest in this Conference. To be sure, examination of this question by psychologists, economists and decision scientists in the last 100 years has brought some progress in mapping the territory through axiomatic theory and experimental testing. But arguably these approaches, while dressed up in formal attire, leave one not a whole lot better off than we were 100 years ago when it comes to coping with the far side of KuU problems.[28] Certainly, we have increased computer power to explore the "unknown" and to undertake robustness studies, scenario planning and other activities that improve our ability to avoid cliffs and to pre-plan contingent responses to exigencies so as to be better prepared to react to them. Moreover, chastened by evidence of increased complexity of the global economic environment and the visible and painful failures of a number of companies, many organizations are improving their ability to detect and respond to environmental uncertainties. However, we remain very much a product of our own very human limited abilities. This will continue to make the journey into the far side of KuU territory both more perilous and more interesting.

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[28] On this point, it is worth recalling the tone of Taleb (2004) in his discussion of KuU problems, who suggests that the approach to KuU problems should not be principally driven by the premature codification of our enduring state of incomplete knowledge, but rather by a continuing cultivation of humility and skepticism in addressing the (in-)adequacy of our theories and data in the light of human needs.

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Europe Campus
Boulevard de Constance
77305 Fontainebleau Cedex, France
Tel: +33 (0)1 60 72 40 00
Fax: +33 (0)1 60 74 55 00/01

Asia Campus
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Fax: +65 67 99 53 99

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