UNCERTAINTY: ON THE DIFFERENCE BETWEEN IMAGINARY TALE AND REAL SIGNIFICANCE

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ABSTRACT. The objective of this study is to analyze and clarify misunderstandings concerning the concept of uncertainty. We look upon Heisenberg's uncertainty principle in physics and Knightian uncertainty that connotes the complexity of predicting future events. The first one applies to elementary particles only and refers to the impossibility of the simultaneous measurement of the position and the velocity of a particle at present. Many disciplines borrow this concept with no scientific justification. Knightian uncertainty, mainly the unstructured one (practical impossibility of precise construction of probability model) cannot quantify and predict outcomes. This set sights on more reasonable approach in mathematical finance or climate change issues, among others.

KEY WORDS. Uncertainty principle, Knightian uncertainty, decision making, climate change, scientific context.

> I like relativity and quantum theories
> Because I don't understand them
> and they make me feel as if space shifted about like a
> swan that can't settle,
> Refusing to sit still and be measured;
> And as if the atom were an impulsive thing
> Always changing its mind.
>
> D. H. Lawrence

> Every word or concept, clear as it may seem to be, has only a limited range of applicability.
>
> Heisenberg, *Physics and Philosophy*

We have thought about the concept of *uncertainty* at great length and would like to take this opportunity to express a number of concerns about the subject, which seems to escape obvious, logical and sensible formulations when it is transcribed into the language of disciplines outside mathematics. It can be said that the notion of *uncertainty* is one of these subtle and abstract concepts that defy a transparent picture. This is an opportu-

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nity to explore the concept carefully, in an attempt to distinguish the original mathematical *uncertainty principle* from the garden of its philosophical, sociological, and educational uses, where it functions as a "borrowed" concept. It looks as if no scientific idea from the last century has been more wrongly used and misunderstood—by laypeople and academics alike—than Heisenberg's uncertainty principle.

HEISENBERG'S VISION

In 1927, Werner Heisenberg, the German theoretical physicist, opened the gate *to an entirely new field of quantum mechanics*, one that applied to atomic and subatomic particles. In elaborating the *uncertainty principle* he wrote:

> The question therefore arises whether, through a more precise analysis of these kinematic and mechanical concepts, it might be possible to clear up the contradictions evident up to now in the physical interpretations of quantum mechanics and to arrive at the physical understanding of the quantum mechanical formulas. (...) The more precisely the position is determined, the less precisely the momentum is known in this instant, and vice versa [1].

The principle held that certain pairs of quantities such as the momentum and the position of a particle cannot be known simultaneously with absolute precision: the more precise the measurement of one, the more imprecise that of the other. Heisenberg concluded that these uncertainties or inaccuracies in the measurements were not the fault of the scientist, but inherent mathematical properties of operators in quantum mechanics.

To begin with, we look into the connotation of the concept within physical science, where it was born and where it strictly belongs. The *uncertainty principle* can be delineated as following:

> It is impossible to design any apparatus whatsoever to determine through which hole the electron passes that will not at the same time disturb the electron enough to destroy the interference pattern. I cannot predict through which hole an electron will go. I only know that each time I look it will be one hole or the other; there is no way to predict ahead of time which hole it will be. The future is unpredictable. (...) the characteristics of nature are not to be determined by pompous preconditions; they are determined always by the material with which we work, by nature herself. (...) It is not our ignorance of the internal gears, of the internal complications, that makes nature appear to have probability in it. It seems somehow intrinsic [2].

The uncertainty principle is one of the most famous and important aspects of quantum mechanics. It has often been regarded as the essentially unique feature in which quantum mechanics differs from classical theories of the physical world. Generally speaking, the uncertainty principle states that one cannot assign precise simultaneous values to the position and momentum of a physical system. Rather, these quantities can only be determined with some characteristic 'uncertainties'. (In his original work, Heisenberg only speaks of "uncertainty relations.") So what is the exact meaning of this principle, and indeed, is it really a principle of quantum mechanics? Quantum theory contains some apparent conceptual paradoxes that remain unresolved. An electron appears to be both a wave and a particle. So does light. Moreover, the theory gives only statistical predictions of subatomic behavior. Our ability to do any better than that is limited precisely by the *uncertainty principle*, which tells us that we cannot measure a particle's position and momentum at the same time. Moreover, this interpretation that broke free from the old time determinism and realism has raised havoc within philosophy of science. Physicists have traditionally expected that science should give us an accurate image of the world 'out there,' as it would be in our absence. Physics was supposed to be more than a set of formulas that predict what we will observe in an experiment; it should give a picture of what reality *is*. Quantum theory does not fit within this posture. It can be described as a new sort of language to be used in a dialogue between us and the systems we study. It says nothing about what the world would be like on its own. In quantum theory, each variable is subject to the *uncertainty principle* that maintains the intrinsic impossibility of the exact simultaneous measurement of certain physical quantities in quantum physics. We can say that the measurement error of velocity multiplied by the measurement error of position is larger than some constant. With a particular choice of units it becomes exactly the Planck's constant. One implication is that the more precisely you try to measure a variable, the more it swings wildly. Further, a contemporary physicist points out, an infinite number of variables fluctuating uncontrollably can easily get out of hand. When we ask the theory questions, we have to be very careful not to get endless and inconsistent answers [3]. Indeed, any attempt to translate this principle into the observable world is completely nebulous.

In addition, George Gamow's account of alpha decay via tunneling, upheld the principle of quantum mechanics and highlighted the notion of uncertainty. (Gamow was a Russian born theoretical physicist and cosmologist of the last century, and creator of the popular *Mr. Tompkins* series.) To ask for a specific prediction of when or where something will happen is to ask for more than quantum mechanics can give. Even though Einstein insisted that chance and uncertainty arose from physicists' inadequate understanding of the world they were trying to portray theoretically, the new rule of probability overthrew the old order of determinism. "Classical physics gave rise to the quantum theory, which brought forth quantum mechanics, which spawned uncertainty [4]." The metaphorical appeal of Heisenberg's uncertainty principle is well known; for that reason we have to lay strong emphasis on the fact that *to all intents and purposes Heisenberg's* uncertainty principle *refers to present observations, while Knight's uncertainty (and other connotations) stem from the impossibility of predicting the future events.*

THE TRICKY NOTION

Nonetheless, there was a time when some believed that it was German civil discontent and the disorder of the Weimar period—with its brief and crazy art movement of nightclub brawls and cabarets, of Bertold Brecht and Fritz Lang, and of socialist realism—that dispensed with causality in physics. Uncertainty allegedly arose in opposition to the old ways of life, in some sort of awakening of romantic feelings, of embracing Nature over the Machine, passion over reason, chance over logic. Heading for absurdity, sociology of science professed that uncertainty came to light as a "political response to the conditions of Weimar Germany and had next to no connection with any tedious problems of physics itself [5]." All the same, no scientists would ever admit that the new physical theory had emerged in order to conform to some passing cultural trend. Uncertainty had many roots and antecedents, from kinetic theory to radioactivity and the spectra of glowing bodies. Yet it is hard to see any influence of art, social problems or politics there. Unquestionably, uncertainty is a ubiquitous phenomenon in everyday life, but it is also a topic of fundamental significance to many scientific disciplines. The concept taken in a broad sense has many facets—among them probability and vagueness, as well as possibility, confidence, fuzziness, etc. These are captured by different theories that often seem to be conceptually and technically incompatible. Generally speaking, there is no universally accepted theory covering all those areas and there are many reasons why we shall neither expect nor want to have one. Then again, using *uncertainty* to refer indiscriminately to both the hard science and the unfamiliar or unknown events of daily life is to confuse the concept even more. As Einstein once observed, when the laws of mathematics refer to reality, they are not certain, and as far as they are certain, they do not refer to reality. On one occasion he remarked that Heisenberg's uncertainty was a sign of our lack of ability to comprehend the physical world, not an indication of something strange and inaccessible about the world itself [6]. By the same token he expressed the hope that a more satisfactory physical theory than quantum mechanics would restore the traditional objectivity and certainty lost to the mere constellation of possibilities. Perhaps he was right. Richard Feynman (1918-1988), a renowned scientist who helped to build the fundamentals of the New Physics, one of the most brilliant and original individuality of his generation noted: "The laws are guessed laws, extrapolations, not something that the observations insist upon. They are just good guesses (...) All scientific knowledge is uncertain [7]."

The notion of 'uncertainty' appears with several different meanings in the physical literature concerning the macro world. It may refer to a lack of knowledge of a quantity by an observer, or to the experimental inaccuracy with which a quantity is measured, or to some ambiguity in the definition of a quantity, or to a statistical spread in an ensemble of similarly prepared systems. Also, a number of different names are used for such uncertainties: inaccuracy, spread, imprecision, indefiniteness, indeterminateness, indeterminacy, latitude, etc. Both Heisenberg and Bohr could not settle on a single terminology for quantum mechanic's uncertainties.

Numerous physicists who have been working on various aspects of quantum physics were much too busy with the vast range of practical problems opening up to them to waste time over philosophical concerns. The analysis of the early interpretational problems of the uncertainty relation ultimately suggests that most of the disputes over its meaning probably originated from the fact that physicists, mislead by the many conceptual difficulties associated with quantum physics, have often placed different physical relations under the banner of the indeterminacy principle. Then again, quantum mechanics is a specialized and mathematical subject, which only few philosophers choose to study in detail. As Richard Feynman observes:

> A philosopher once said 'It is necessary for the very existence of science that the same conditions always produce the same results'. Well, they do not. (...) Yet science goes on in spite of it—although the same conditions do not always produce the same results. That makes us unhappy, that we cannot predict exactly what will happen. Incidentally, you could think up a circumstance in which it is very dangerous and serious, and men must know, and still you cannot predict [8].

Several us authors in different humanistic fields and social sciences invoke, often metaphorically, scientific concepts that they, and their readers, understand only vaguely. Fancy scientific jargon, full of symbols and formulas, has been popular in trying to promote some weak and inadequate social theory. This hollow extrapolation of scientific concepts beyond their domain of validity, and the indiscriminate use of scientific language that often conceals plenty of well-sounding nonsense, have been pointed out many times over. "Armed with home supercomputers and chained processors, and helped by complexity and 'chaos' theories [9]," the semi-scientists, and pseudo-scientists start using scientific buzzwords, like 'uncertainty principle', 'Gödel's theorem', 'parallel universe', or 'relativity', either out of context or, as often, in exact opposition to their scientific meaning. Postmodern theorists invoke the uncertainty principle as proof of the unstable hermeneutics of subject-object relations, arguing that it undermines science's claim to objectivity. The famous Sokal's hoax is the best example of such a practice [10]. Alan Sokal, a professor of physics, wrote a seemingly erudite essay, using exceedingly elaborate language and composition that was nothing more than nonsense cloaked in pseudo-scientific jargon. The piece was published in an acknowledged sociological journal. The principal point here is that hortatory prattle and wishful rhetoric might not be of much relevance in social sciences *per se*; nevertheless, when applied by policy makers it can conceal errors with results hard to foresee.

At the present time most physicists are indifferent to the humanistic discourse on the subject of Heisenberg's concept. In contrast, philosophers, literary theorists, anthropologists and many others from the social sciences have enthusiastically appropriated the attractive and slippery expression of *uncertainty*, only to confuse its real meaning with whatever sort of arranged fictitious connotation they found fitting. Science, they assumed, no different than the arts and humanities, offers us models, images, and metaphors of the world, and there is no reason why the layman should not make use of these models in his or her dealings with the world, without having to become a nuclear physicist to do so. In a majority of cases, this kind of elucidation is, generally speaking, meaningless from the scientific point of view. While there is understanding of probabilities and uncertainty in the hard sciences, particularly in mathematics or physics, there is little understanding of such concepts in the social sciences in spite of the appearance of 'experts'.

Then again, many researchers also misread statistics, and one of the most surprising examples of another logical flaw can be found in the global warming debate. Time and again, when a large natural event takes place (like hurricanes, tornados, temperature changes, etc.) we hear that oft-repeated "it has never happened before" phrase, as if indeed its absence from past history is enough for it now to be a surprise. If we were dealing with a deterministic world, the universe stripped of randomness, the pattern of the series would reveal predictive information. But we live in a world that is not well charted. The judgments derived from past features, sometimes relevant, may be meaningless on other occasions. As history reveals, the things that never happened before do happen—in other words, time gone by teaches us to avoid the brand of naïve empiricism that consists in learning from casual historical facts. The sad truth is that quite often in soft sciences people confuse science and scientists, who are biased as we all are. Even now, practitioners of what Taleb calls "disgusted charlatanism under the weight of equations" measure risks, using the tools of past history as an indication of the future [11].

What's more, recently, an entire industry of "risk measurers" has emerged, specializing in the application of probability methods to assess risks in social sciences. Certainly, the odds in games where the rules are clearly and explicitly defined are calculable, and the risks accordingly measured. But not in the real world, since Mother Nature did not endow us with a clear set of laws. Benoit Mandelbrot once said that there is a 'wild' type of randomness of which we will never know much, due to its unstable properties, even with a deterministic mechanism behind it. On the large-scale that we conform to in our daily life, uncertainty arises mostly because of the technical impossibility of precise measurements. Reality is too complex to be modeled deterministically or even by well-defined probability models. This fact paved the way for Knightian uncertainty. In his seminal work that deals explicitly with decision making under conditions of uncertainty, *Risk, Uncertainty, and Profit*, economist Frank Knight wrote:

> Uncertainty must be taken in a sense radically distinct from the familiar notion of Risk, from which it has never been properly separated. (...) The essential fact is that 'risk' means in some cases a quantity susceptible of measurement, while at other times it is something distinctly not of this character; and there are far-reaching and crucial differences in the bearings of the phenomena depending on which of the two is really present and operating It will appear that a *measurable* uncertainty, or 'risk' proper... is so far different from an *unmeasurable* one that it is not in effect an uncertainty at all [12].

Much has been made of this famous distinction between "risk" and "uncertainty". In his interpretation, "risk" refers to situations where the decision-maker can assign mathematical probabilities to the randomness which he is faced with. In contrast, "uncertainty" refers to situations when this randomness cannot be expressed in terms of specific mathematical probabilities. (Knight's uncertainty rises from the difficulty of predicting the future.) He and Keynes deeply distrusted classical theories based on the laws of mathematical probability or assumptions of certainty as guides to decision-making. As John Maynard Keynes was to express it later:

> By 'uncertain' knowledge (...) I do not mean merely to distinguish what is known for certain from what is only probable. The game of roulette is not subject, in this sense, to uncertainty The sense in which I am using the term is that in which the prospect of a European war is uncertain or the price of copper and the rate of interest twenty years hence... About these matters, there is no scientific basis on which to form any calculable probability whatever. We simply do not know [13].

Knight's distinction between uncertainty and risk is quite well preserved in classical decision theory [14]. A decision is made under risk when the probability of each end result is known, and under uncertainty if the outcomes of the alternatives are known, but the probabilities of these outcomes are "completely unknown or are not even meaningful [15]." Nowadays, modern decision theory frequently aims toward more robust approaches particularly in modern finance, where one specific model is replaced by a plurality derived from different scenarios. Many economists argue that Knightian risk and uncertainty is one and the same thing. In particular, the distinction is challenged by Bayesian decision theory. Central in this theory is the idea that a unique, numerical subjective probability, or degree of belief, can be assigned to any state of affairs. Others assume that there are actually no probabilities out there to be "known," since probabilities are just individual expressions of our beliefs and have no connection to the blurry randomness of the "real world." The world of pure probability does not exist except on paper or perhaps as a partial description of nature. Our decision matters. Whether that turns out to be for better or for worse is up to us. The spin of roulette has nothing to do with it [16].

The idea of certainty emerging through organization is deeply embedded in the culture of modern biology, and it is one of the reasons that life sciences are so eager to assert that microscopic uncertainty does not matter, as organization creates certainty on the higher level. Socrates once said that the notions of probability held by the people are founded on a likeness to truth [17]. Jacob Bernoulli, author of the theorem for calculating probabilities known as the Law of Large Numbers, insisted that moral certainty (as a practical matter) is less than absolute certainty: "Probability—he proclaims—is degree of certainty, and differs from absolute certainty as part differs from the whole [18]." It denoted the degree of certainty he thought a reasonable person would require in order to make a rational decision. It is only a small section of natural phenomena that one gets from direct experience. Our imagination is spun out to the utmost, not to imagine things which are not really there, but just to comprehend those things which are there [19]. The recognition of risk management as a practical art rests on a simple cliché with the most profound consequences: when our world was created, nobody remembered to include certainty. Much of the information we have is either incorrect or incomplete. Therefore, under conditions of uncertainty, our choice is not between rejecting a hypothesis and accepting it, but between reject and not-reject.

DRAWING ON UNCERTAINTY

> It is the mark of an educated mind to rest satisfied with the degree of precision which the nature of the subject admits and not to seek exactness where only an approximation is possible.
> Aristotle [*Nicomachean Ethics*]

Policy analysis, risk assessment, and engineering are the fields where the notion of uncertainty has been discussed at length. Philosophers appear to have been only sparsely interested in this idea, identifying it mostly with *incomplete* knowledge. Then again, the concept of uncertainty has arisen repeatedly in varied contexts, from postmodern deconstruction to ethical theorizing in face of the unpredictable, unforeseen, and unanticipated nature of complex social events and technology development. Equally, we come across economic and personal uncertainty that has played different roles in different modes of production, and was closely linked to the processes and social foundations of exploitation. Uncertainty and its distribution were assumed to be shaped by social structures and institutions [20].

Composer John Cage, a visual artist, placed it in opposition to the philosophy of the Enlightenment, which believed that "the mind would soon make sense of most things." Cage's art suggests, so it is said, that we shall never really know what is going on in the universe, much less control it. It asks the ear to bend to uncertainty, to negotiate with chance, not defiantly but with wit, grace and invention [21]. Jac Saorsa, a modern painter, develops the idea of the indeterminacy of understanding through a fragmentation of the text that is the exhibition of Drawing on Uncertainty itself [22]. The painting exploits the concept of uncertainty that, according to one critic, is derived from a discontinuous dialogue between the artist and viewer and the work. Others search for the uncertainty in general ethics and ethics of technology in particular, where they distinguish between epistemic and ontological uncertainty [23] (i.e., if is inherent to a specific framework and/or reality). Derrida in his work inscribes a profoundly ethical uncertainty, a radical openness to the other, in a style of "incomprehensible philosophy [24] (that is, incomprehensible to anyone outside of their ranks)". "Uncertainty is any departure from the unachievable ideal of completely deterministic knowledge of the relevant system", considers W. E. Walker. For his part, D. P. Thunnisen agrees that uncertainty is a condition of not knowing, and defines it as the difference between an anticipated or predicted value and a future actual value. Then again, he adds another kind of uncertainty—*aleatory.* While the *epistemic* depicts the lack of knowledge or information in any phase or activity of the modeling process, the *aleatory* uncertainty is described as an "inherent variation associated with a physical system or environment under consideration [25]." However, one very important technical point is to be made here. The concept of *aleatory* derives from the Latin word *alea* meaning "pertaining to luck," the rolling of dice, and translates into English as random, indeterminate, or chance occurrences.

Few authors assessed the scientific definition of uncertainty in multidisciplinary literatures as narrowly probabilistic, and intended, through refined conceptualization, to make this complex concept more complete. Uncertainty was considered "a dynamic state in which there is a perception of being unable to assign probabilities for outcomes [26]." Shoveling through volumes of writings we have also come across 'outcome uncertainty' and 'evidential uncertainty [27].' Evidential uncertainty may be reduced by more information; outcome uncertainty may be lessened by waiting and seeing. And again, some defined uncertainty as a capacity to entertain many rival hypotheses that all refer to the same event [28]. Moreover, this definition carries on the idea that being uncertain means to entertain several, mutually exclusive, epistemic possibilities. Considerations of practical uncertainty have led some to adopt a "personal view of randomness." "You see a quantity as random if you do not know of any pattern or model that can account for its variation. (...) A quantity may legitimately be random to one person, but deterministic to another who knows its underlying generating process [29]." It is also quite shocking to find out that some presuppose the existence of different theories of probability. That is apparently how things are with the Bayesian and *Frequentist* approaches. "While *Frequentists* derive judgments of probability from recording statistical frequencies, Bayesians take into account how human beings actually make judgments on the basis of limited evidence [30]."

We have to emphasize that there is only one probability theory, and that is Bayesian [31]. *Frequentist* approaches only lead to a different specification of the probability model. Bayesian method means that subjective specification of the model changes according to the observations made: *Frequentists* depart from the observations in order to construct an objective model. Uncertainty relates to questions of how to deal with the *unprecedented, and whether the world will behave tomorrow the way it behaved in the past.* This way of reasoning by looking at past events is the way classical statistic works. Bayesians use the past in order to change your previously established beliefs.

FINAL NOTES

We can go on forever trying to list all the possible descriptions and definitions of a concept, that is able to encompass all kinds of linguistic generality when we talk about vagueness, ambiguity, indeterminacy and so on. Several other meanings arise in natural and scientific languages. Even physicists show considerable uncertainty about what *uncertainty* really means. Dozens of different interpretations have been proposed over the years. Some locate uncertainty in some inherent clumsiness in the act of measurement itself. Seemingly, uncertainty instigates uneasiness, since it does not fit within the metaphorical yet most wanted category, where science is pictured as the method of finding things out and the architect of reliable knowledge. Scores of investigators call for more objective research that should aim at "reducing uncertainties" in the attempt to solve a puzzle. This view can be found in the first scientific assessment of climate change by the IPCC: "*We are confident that the uncertainties can be reduced by further research* [32]." The borders between facts and values, knowledge and ignorance, science and policy are hard to define with precision, and trying to understand the way nature works is full of "fascinating byways and confusing cul-de-sacs [33]."

Evidence from the life sciences strengthens the belief that most natural processes are constantly changing, making the predictions or scenarios of possible future events more difficult. Even greater uncertainties are associated with possible climate change. Scenarios of likely events accommodate many types of forecasts based on history and estimates based on models. Yet, there are countless questions to be answered on natural climatic variations, changes in the sun's energy, land-use changes, the warming or cooling effects of pollutant aerosols, and the impacts of changing humidity and cloud cover. We neither know how much warming will occur, how fast it will occur, nor how the warming will affect the rest of the climate system including precipitation patterns and storms [34]. The increasing complexity of global models inevitably decreases the precision of their results making it the case that "*full predictability of the earth system is almost certainly unattainable.*"

Striving for certainty is not a relic of a long-gone era promoted by outdated physicists; it is like old time religion—occasionally annoying and tiresome but never irrelevant. All of us use the especially reliable things that nature wishes to reveal as beacons to navigate through an otherwise uncertain world. Yet, one of the worst things we can do is to confuse a falsehood with a truth. Were the world a happy place containing only unfailing laws, it would indeed be true that mathematics will be always predictive, and that mastering nature would always come down to acquiring sufficiently large and powerful computers. Protection would heal all errors. But in the world we actually inhabit dark laws abound, and they destroy predictive power by exacerbating errors and making measured quantities wildly sensitive to unruly external factors [35]. In a dynamic world, there is no single answer under conditions of uncertainty. The mathematician A. F. M. Smith has summed it up well: "Any approach to scientific inference that seeks to legitimize an answer in response to complex uncertainty is, for me, a totalitarian parody of a would-be rational learning process [36]."

NOTES

1 W. Heisenberg, "On the physical content of quantum-theoretical kinematics and mechanics," in *Quantum Theory and Measurement*, ed. John Archibald Wheeler and Wojciech Hubert Zurek, Princeton University Press, 1985: 62-84, p. 62.

2 Richard P. Feynman, *The Character of Physical Law,* Penguin Books, England, Clays Ltd. St. Ives, 1992, 143, 146.

3 Lee Smolin, *The Trouble with Physics. The Rise of String Theory, The Fall of a Science, and What Comes Next,* A Mariner Book, Houghton Mifflin Company, Boston, New York, 2006: 55.

4 David Lindley, *Uncertainty. Einstein, Heisenberg, Bohr, and the Struggle for the Soul of Science,* Anchor Books, a Division of Random House, Inc., New York, 2008: 178.

5 *Ibidem*, 206.

6 *Ibidem*, 6

7 R. P. Feynman, *The Meaning of it All. Thoughts of a Citizen-Scientist,* Basic Books, a Member of the Perseus Books Group, New York, 1998: 24, 26.

8 Feynman, *The Character of Physical Law,* op. cit, 147.

9 Nassim Nicholas Taleb, *Fooled by Randomness. The Hidden Role of Chance in Life and in the Markets*, Clays Ltd, St Ives, England, Penguin Books, 2007: xiii

10 Alan Sokal and Jean Bricmont, *Fashionable Nonsense. Postmodern Intellectuals' Abuse of Science,* Picador USA, New York, 1998.

11 Taleb, *op.cit*, 115.

12 Frank H. Knight, *Risk, Uncertainty and Profit*. Boston, MA: Hart, Schaffner & Marx; Houghton Mifflin Company, 1921: 20.

13 John Maynard Keynes, "The General Theory", *Quarterly Journal of Economics.* Vol. LI, Feb. 1937: 209-233.

14 Luce, R.D. and Raiffa, H. (1957): *Games and Decisions. Introduction and Critical Survey*, New York: Dover Publications, 1989.

15 *Ibidem*, p. 13.

16 Peter L. Bernstein, *Against the Gods. The Remarkable Story of Risk*, John Wiley & Sons, Inc. New York, Chichester, Brisbane, Toronto, Singapore, 1996, p. 230.

17 Plato, *Phaedrus*, 273d, "the probable for the many has happened to come to be through a likeness of the truth."

18 *Against the Gods.*

19 Richard P. Feynman, *The Character of Physical Law*, 127-149.

20 Engelbert Stockhammer, Paul Ramskogler, "Uncertainty and exploitation in history," Institut für Geld- und Finanzpolitik, Vienna University of Economics and Business Administration, Augasse 2-6, A-1090 Vienna, Austria, Working Paper No. 104, April 2007.

21 Bernard Holland, "Critic's notebook; John Cage's music: Room for nearly anything", *The New York Times,* August 27, 1992.

22 "Drawing on Uncertainty": Works by Jac Saorsa.

23 Paul Sollie, "Ethics, technology development and uncertainty: an outline for any future ethics of technology", Ethics Institute, Utrecht University, Utrecht, The Netherlands, *Philosophy Pathways*, http://www.philosophypathways.com/newsletter/Issue number 129, 14th September, 2007.

24 Taleb, *op.cit,* 7.

25 Walker, W.E., et al., "Defining uncertainty. A conceptual basis for uncertainty management in model-based decision support", *Journal of Integrated Assess-*

ment, 4 (1) 2003: 5-17. Thunnisen, D.P., *Propagating and Mitigating Uncertainty in the Design of Complex Multidisciplinary Systems* (PhD Thesis), California Institute of Technology Pasadena, California, 2005: 36-39.

26 Penrod, J. "Refinement of the concept of uncertainty," *Journal of Advanced Nursing 3*4 (2) 2001: 238-245.

27 Horwich, P, *Asymmetries in Time: Problems in the Philosophy of Science,* Cambridge, Mass., MIT Press, 1987: 7.

28 Shackle, G.L.S. *Epistemics and Economics. A Critique of Economic Doctrines*, Cambridge: Cambridge University Press, 1972: 19.

29 Millett G. Morgan and Max Henrion, *Uncertainty. A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis,* Cambridge: Cambridge University Press, 1990: 63.

30 Ibidem.

31 Thomas Bayes, 18th century British mathematician. His theory allows for data to be constantly added to calculate probabilities.

32 Houghton, et al., 1990.

33 Dembo, R.S, A.Freeman, 1998, *Seeing Tomorrow. Weighing Financial Risk in Everyday Life.* McClelland & Stewart Inc.,Toronto: 193.

34 European Environment Agency (EEA), Environmental Issue Report No. 22, *Late Lessons From Early Warnings: The Precautionary Principle 1896–2000* (EEA Copenhagen 2001. http://www.epa.gov/climatechange/science/stateofknowledge.htm).

35 Robert B. Laughlin, *A Different Universe. Reinventing Physics from the Bottom Down,* Basic Books, A Member of the Perseus Book Group, Cambridge MA, 2006: 210.

36 A. F. M. Smith, "Present position and potential developments: Some personal views of Bayesian statistics," *Journal of the Royal Statistical Association* 147 (3): 245-259.