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Introduction: Fundamental Uncertainty and Plausible Reasoning

Silva Marzetti Dall’Aste Brandolini and Roberto Scazzieri

1.1 Uncertainty, plausible reasoning and the continuum of inductive methods

Uncertainty and rationality are closely related features of human decision making. Many practical decisions are traditionally reconstructed as attempts to frame uncertain outcomes within the domain of rule-constrained reasoning, and much established literature explores the manifold ramifications of rationality when choice among uncertain outcomes has to be made (as with choice criteria associated with maximization of expected utility). However, this overall picture is changing rapidly as a result of recent work in a variety of related disciplines. Research in cognitive science, artificial intelligence, philosophy and economics has called attention to the open-ended structure of rationality. This point of view stresses the active role of the human mind in developing conceptual possibilities relevant to problem solving under contingent sets of constraints. Rationality is conceived of as a pragmatic attitude that is nonetheless conducive to rigorous investigation of decision making. In particular, conditions for rational decision are moved back to its cognitive frame (the collection of concepts and predicates that makes any given representation of problem space possible), and the cognitive frame is associated with the context-dependent utilization of cognitive abilities. This view of rationality distances itself from received conceptions of deductive and inductive inference as it is related to a situational conception of reasoning. This means that reasoning comes to be considered as a mental state in which a prior (and only partially structured) set of cognitive abilities takes definite shape, as shifts from one context to another activate one particular set of cognitive procedures after another. As a result, rationality appears to be intertwined with utilization of
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justified procedures. However, the reduction of rational procedure to any single-minded criterion of instrumental rationality (or rational success) is avoided. Any given problem space is considered, at least partly, as a mental construction, so that identification of problem setting and selection of justified procedure go hand in hand (see also Galavotti, Scazzieri and Suppes, 2008a, 2008b).

The above view of problem spaces and solution procedures suggests a description of rationality as a specific configuration of capabilities and procedures, rather than as a particular selection of choice strategies and actions. In particular, a rational cognitive agent is considered as an agent capable of effectively reconfiguring itself after a cognitive shock. In other words, rationality is associated not only with effective utilization of a given set of cognitive rules but also with the effective use of cognitive abilities. As regards cognitive abilities, however, not all abilities are used at the same time, and new abilities may become available as the cognitive process unfolds. If this point of view is adopted, rationality appears to presuppose a cognitive system capable of self-reference and reflective states. In other words, rational cognitive systems should be endowed with the ability to make sense of their own structure and behaviour. At the same time, a rational cognitive system should be open to the possibility of self-correction and structural change (see above). Reflective rationality is inherently dynamic, due to the emphasis upon reconfiguration ability. It may also be conjectured that reconfiguration is associated with feedback processes (primarily of the non-linear type). The above view of rationality suggests a pragmatic approach highlighting the variety of patterns of reasoning by means of which it is possible to identify effective strategies. It also suggests a cognitive and experimental twist in the analysis of decisions. In this connection, the available bundles of concepts and predicates (frames) and the active principles calling attention to particular sets of concepts and predicates (focal points) may be more relevant than standard computational skills in reaching satisfactory (not necessarily optimal) solutions (see Bacharach, 2003, pp. 63–70).

More specifically, research work in cognitive science and artificial intelligence, decision science and economics suggests an understanding of rationality through a reformulation of the relationship between cognitive states and their material (physical) conditions (the classical mind–body problem). In particular, rationality appears to be grounded in the recognition of associative structures to which the human mind is disposed but which cannot be reduced to any deterministic model of its neural structure. This calls attention to the open-ended configuration of
justified procedures, in which the standards of classical epistemology and rational choice decision theory are complemented by close attention for interactive outcomes, analogical reasoning and pattern identification. Contingent constraints and situational reasoning are often associated with uncertainty of individual outcomes. The shift from one set of constraints to another (from one space of events to another) could make it difficult to rely upon any fixed set of inferential rules. It also suggests that cognitive (and pragmatic) success may reflect the individual (or collective) ability to make use of a diversity of cognitive frames and to switch from one frame to another as the need arises.

Reasoning under uncertainty is the most important field of human cognition in which the active role of the human mind is clearly in view. This is primarily because assessment of greater or lower likelihood is critically dependent on the way in which alternative conceptual spaces may give rise to alternative configurations of strategies and outcomes. Uncertainty itself may be assessed in terms of the degree to which the cognitive agent is free to ‘structure’ the situations associated with it. This manipulative view of uncertainty implies that, for any given state of nature, any given situation would be more uncertain (or, respectively, less uncertain) depending on whether agents are more (or, respectively, less) capable of configuring (or reconfiguring) that situation, its antecedents and its likely successors. Consideration of the specific domain in which the ‘active power’ of cognitive agents may be exerted is closely associated with a classification of situations ranging from lower to higher uncertainty. A situation in which the cognitive agent has virtually no freedom in giving shape to the configuration of possible events is one of lower uncertainty. Maximum uncertainty is associated with situations in which the cognitive agent is completely unconstrained in terms of which configuration of possible events he might reasonably consider.

The above point of view is consistent with a primary research avenue in cognitive science, which is to assess the formation of categories and its roots in dispositional attitudes concerning the detection of similarity (see Tversky, 1977; Gardenfors, 2000; Scazzieri, 2001; 2008). It is also consistent with research work in artificial intelligence addressing the interplay of ontological and epistemic abilities (see Gardenfors, 1990; Giunchiglia, 1993; Sánchez, Cavero and Marcos, 2009) as well as with a well established tradition in decision theory and economics recognizing the pervasive and multidimensional character of situations characterized by lack of certainty (see Hishiyama, Chapter 10, Vercelli, Chapter 7, and Zadeh, Chapter 6, in this volume). Among
the latter contributions, we mention the classical distinction between risk and uncertainty (see Kregel and Nasica, Chapter 11, this volume), introduced by John Maynard Keynes in 1907 and in 1921 by pointing out that ‘if we are given two distinct arguments, there is no general presumption that their two probabilities and certainty can be placed in an order’ (Keynes, 1973 [1921], p. 41); Frank H. Knight’s view that ‘a measurable uncertainty, or “risk” proper, […] is so far different from an unmeasurable one that it is not in effect uncertainty at all’ (Knight, 1946 [1921], p. 20; author’s emphasis); and John Hicks’s belief that ‘of two alternatives, on given evidence, either A is more probable than B, or B [is] more probable than A, or they are equally probable, or […] they are not comparable’ (Hicks, 1979, p. 114; author’s emphasis). Following those acknowledgements, it is increasingly recognized that reasoning under lack of certainty is inherently associated with a complex mix of inferential and representational abilities, and that plausible judgements under those conditions presuppose first the ability to identify the cognitive context (most) suitable for the situation and problem(s) in view (see, for example, Suppes, 1981; Gilboa and Schmeidler, 2001, pp. 29–61; Drolet and Suppes, 2008; Suppes, 2010).

The aim of this volume is to address lack of certainty on the basis of the most general conditions for plausible reasoning, that is, reasoning that is defensible but not ‘beyond controversy’ (Polya, 1990 [1954], p. v; see also Polya, 1968; Collins and Michalski, 1989). Fundamental uncertainty provides the framework of the cases of plausible reasoning considered in the following chapters. It is associated with probabilistic ignorance (no relevant probability distribution is known, nor can it be assumed) and, in particular, ex ante structural ignorance (the space of events is unknown, or only partially known). In particular, lack of certainty is examined from both the ontic and the epistemic viewpoints, reliability of evidence is assigned a central role, and similarity judgements are considered a necessary condition of probability judgements. The above setting lends itself to a theory of uncertainty associated with the analysis of concept formation, likeness and distance more than with the inferential structure of probabilistic reasoning. The latter part of the volume explores the implications of the above point of view in the analysis of economic decisions, and carries out that investigation by examining the weight of rational arguments under uncertainty, the objective conditions of stochastic equilibrium, and the general structure of economic and social laws in a universe of interacting decision makers. Finally, the volume examines the character of plausible reasoning about moral issues in the light of the theory of uncertainty outlined in the previous chapters.
1.2 A refinement of the distinction between risk and uncertainty: fundamental uncertainty

Rationality may be compatible with a variety of uncertainty assessments, which often reflect different ways of structuring the space of events. Acknowledgement that identification and representation of the space of conceivable events is a necessary condition of plausible reasoning under uncertainty suggests a refinement of the distinction between risk and uncertainty (see section 1.1). In particular, as argued by Itzhack Gilboa and David Schmeidler, it may be reasonable to introduce

a third category of structural ignorance: ‘risk’ refers to situations where probabilities are given; ‘uncertainty’—to situations in which states are naturally defined, or can simply be constructed, but probabilities are not. Finally, decision under ‘structural ignorance’ refers to decision problems for which states are neither (i) naturally given in the problem; nor (ii) can they be naturally constructed by the decision maker.

(Gilboa and Schmeidler, 2001, p. 45)

This conceptual setting is close to that considered by Keynes in his Treatise on Probability (TP) (Keynes, 1973 [1921]). There Keynes examined conditions for rational choice when probabilities may not be known and/or could be expressed only in a non-numerical way. Keynesian uncertainty is a setting in which rational decisions are possible but depend upon highly distinctive bodies of information depending on situation and context (see Marzetti Dall’Aste Brandolini, Chapter 12, this volume; see also Marzetti Dall’Aste Brandolini and Scanzieri, 1999, Introduction and pp. 139–88). In this case ‘The principles of probability logic need not mandate numerical degrees of belief that $a$ and that $ab$ on the evidence $h$ but only that agent $X$ is required to be more certain that $a$ than that $ab$. According to Keynes, probabilities of hypotheses on given information could even be non comparable’ (Levi, Chapter 3, section 3.3, this volume; see also Kyburg, Chapter 2, this volume). Keynes’s discussion of the weight of argument (and of the associated issue of the weight of evidence) calls attention to the reliability of human judgement under fundamental uncertainty. In particular, it suggests a way to assess the influence of evidence in attaining a plausible (but not uncontroversial) inference (‘proximity to proof’). It also allows a formal treatment of unexpected events (potential surprise or disbelief). As some contributors to this volume point out (see Levi, Chapter 3; Vercelli, Chapter 7), this point of view opens up a whole set of
new issues, since consideration of the weight of evidence ‘turns upon a balance, not between the favourable and the unfavourable evidence, but between *absolute* amounts of relevant knowledge and of relevant ignorance respectively’ (Keynes, 1973 [1921], p. 77). In particular, assessment of the degree of relevance calls attention to the fact that ‘[w]here the conclusions of two arguments are different, or where the evidence for the one does not overlap the evidence for the other, it will often be impossible to compare their weights, just as it may be impossible to compare their probabilities’ (Keynes, 1973 [1921], p. 78; see also Runde, 1990).

Fundamental uncertainty calls attention to the role of mental frames in assessing evidence and guiding rational decisions. Probability is associated with degree of rational belief, but different probabilities are not always comparable (primarily because their weights may be different). It may be argued that probabilities ‘lie on paths, each of which runs from 0 to 1’ (Kyburg, Chapter 2, section 2.1.3, this volume). Indeed, the same numerical probability could have entirely different implications for rational choice depending on the weight attached to it. To put it in another way, the same information could be associated with different probabilities depending on the weight we attach to available evidence. In particular, ‘probabilities are only partially ordered: two probabilities may be incomparable. The first may be neither greater, nor less than, nor yet equal to the third’ (Kyburg and Man Teng, 2001, p. 80). The existence of different ‘orders of probability’ (Keynes) makes *switches* between probability orders conceivable. This in turn makes the relationship between degrees of rational beliefs and available information to be of the non-monotonic type. Further evidence could initially increase our confidence in a given hypothesis and then prompt us to withdraw it, either because we have shifted to a different order of probability or because new background knowledge has drastically reduced the weight of our evidence. There is an important connection between the cognitive demands of fundamental uncertainty and the idea that probability judgements are always relative to a certain state of mind. This property is clearly stated in Chapter 1 of Keynes’s *TP*:

> when in ordinary speech we name some opinion as probable without qualification, the phrase is generally elliptical. We mean that it is probable when certain considerations, implicitly or explicitly present to our minds at the moment, are taken into account […] No proposition is in itself either probable or improbable, just as no place is intrinsically distant; and the probability of the same statement
This point of view is closely related to the formalization of fundamental uncertainty in terms of conditional probability, a possibility explored in a number of contributions to this volume (see Costantini and Garibaldi, Chapter 8; Fano, Chapter 4; Kyburg, Chapter 2). Keynes called attention to the ‘coefficient of influence’ (Carnap’s ‘relevance quotient’ as introduced in Carnap, 1950), which may be defined as a measure of the relevance of additional evidence for the degree of acceptance of any given hypothesis (see Costantini and Garibaldi, Chapter 8, this volume). In general, additional evidence has more or less impact upon the degree of acceptance of any given hypothesis $H$ depending on whether the weight of argument leading to its acceptance (or rejection) is increased or reduced. For example, we may conjecture that additional evidence would have greater influence upon acceptance/rejection of $H$ if the weight of the corresponding inductive inference is increased. In other words, the coefficient of influence provides a link between the epistemic and the ontic aspects of probabilities. This is because the coefficient of influence is related at the same time to the degree of rational belief in hypothesis $H$ for any given evidence $e$ and to the way in which stochastic interdependence influences the structure of observations (that is, the internal configuration of $e$). Given a certain amount of new evidence $e^*$, it is reasonable to conjecture an inverse relationship between the degree of stochastic interdependence and the weight of inductive inference. For a high degree of interdependence makes the configuration of $e$ unstable and reduces the likelihood that new evidence $e^*$ will be conclusive with respect to the given hypothesis. On the other hand, a low degree of interdependence makes the configuration of $e^*$ more stable and increases the weight of inductive inference.

### 1.3 Plausible reasoning under fundamental uncertainty

Emphasis on the cognitive dimension of rationality enhances the domain in which the plausibility of reasoning criteria can be assessed and compared. In other words, moving beyond the circumscribed assumptions of ‘standard’ rational choice theory does not lend (by itself) to relaxation of general rationality conditions, such as the propensity to deliberately draw conclusions from premises, to follow any given chain
of reasoning step by step, and to identify on that basis connections among seemingly disjointed objects or ideas. It is fully consistent with the recognition that problem spaces are to a large extent a product of the constructive work of the human mind, and that assessment of that work presupposes careful consideration of situation and context (see also note 1, and Marzetti Dall’Aste Brandolini, Chapter 12, this volume). However, under conditions of fundamental uncertainty, classical rules for inductive inference (such as the Humean multiplication of instances) may be replaced by a strategy in which inductive arguments are associated with the identification of stochastic regularities for relatively independent sets of objects or agents. This approach calls attention to the possibility of representing any given set of heterogeneous objects or agents as a universe of agent types, in which each type would be associated with a specific collection of attributes (see Costantini and Garibaldi, Chapter 8, this volume).

Under fundamental uncertainty, rational choices are guided by ‘the degree of belief that it is rational to entertain in given conditions’ (Keynes, 1973 [1921], p. 4). This means that guesswork is fundamental to rational understanding and acting. Keynes carefully argued this point when he wrote: ‘[g]iven the body of direct knowledge which constitutes our ultimate premises, [...] further rational beliefs, certain or probable, can be derived by valid argument from our direct knowledge’ (Keynes, 1973 [1921], p. 4). The close intertwining of subjective perceptions and objective (intersubjective) relations is outlined by Keynes in the passage that immediately follows the previous quotation:

\[ \text{This involves purely logical relations between the propositions which embody our direct knowledge and the propositions about which we seek indirect knowledge. What particular propositions we select as the premises of our argument naturally depends on subjective factors peculiar to ourselves; but the relations, in which other propositions stand to these, and which entitle us to probable beliefs, are objective and logical.} \]

(Keynes, 1973 [1921], p. 4)

Plausible reasoning under fundamental uncertainty gives prominence to the identification of what ‘given conditions’ (in Keynes’s sense) are, and the identification of those conditions becomes increasingly important as one moves away from known circumstances to largely unknown sets of possibilities. Fundamental uncertainty is likely to be associated with event fluctuations around the mean that are not self-averaging, that is, they do not tend to 0 as the model size \( n \) tends to infinity (see Aoki,
Chapter 9, section 9.1, this volume). Once fundamental uncertainty is acknowledged, the constraints associated with a cognitive frame become relevant and may be central for the utilization of available and relevant knowledge in choice situations. In short, fundamental uncertainty is bound to ‘twist’ our attention towards the ontological and epistemic premises for rational arguments, but does not make rationality constraints redundant. Indeed, there are grounds for believing that those constraints may become increasingly important when the ‘imprecision’ of possibility spaces does not allow unambiguous identification of what may be likely (or unlikely). For in this case rationality constraints narrow down the epistemic source of uncertainty and reduce the set of possibilities that it is reasonable to conceive of. The above argument entails that, under conditions of fundamental uncertainty, rationality may have a twofold role to play. On the one hand, the guesswork needed in identifying suitable problem spaces must be grounded in reasons: cognitive agents should be suitably equipped to sort out relevant information and to construct an effective representation of the world. On the other hand, that preliminary guesswork is often conducive to rationality constraints circumscribing the range of options to be considered for any such representation. It may be interesting to note that the twofold role of rationality in cognition has an equivalent in the domain of reasons for acting. For in this case, too, reasons for accepting a certain view of the world are often associated with reasons inducing us to act upon that particular representation of the world. Conditions of fundamental uncertainty strengthen the relationship between knowing and acting because of the greater freedom acquired by the constructive power of the human mind. Again, we owe to Keynes an effective picture of that relationship: ‘[t]o believe one thing in preference of another, as distinct from believing the first true or more probable and the second false or less probable, must have reference to action and must be a loose way of expressing the propriety of acting on one hypothesis rather than another’ (1973 [1921], p. 339).

The above argument calls attention to the relationship between situational judgement and rationality standards (see Marzetti Dall’Aste Brandolini, Chapter 12, this volume). When probability distributions are unknown and even the space of possible events is not fully explored, agents are likely to fall back on judgements of likeness in their search for a suitable representation of problem space and an effective set of epistemic criteria. It is primarily the type of rationality called forth in judgements of similarity rather than in processes of inference. Indeed, the connection between judgements of similarity and judgements of probability had been
recognized long ago. Joseph Butler noted that it is a distinctive feature of reasoning under uncertainty: ‘when we determine a thing to be probably true, suppose that an event has or will come to pass, it is from the mind’s remarking in it a likeness to some other event, which we have observed has come to pass’ (Butler, 1834 [1736], p. 2). In this connection, however, the objective (or intersubjective) character of rational judgement might be questioned. As noted by Arthur Cecil Pigou, ‘it seems paradoxical to speak of its being rational for me to perceive something, which, from the constitution of my mind, it is impossible for me to perceive’ (Pigou, 1921, p. 507). Fundamental uncertainty enhances the dependence of similarity recognition on human judgement (see above). At the same time, the active role of judgement in similarity assessment calls attention to criteria and constraints that make judgement reasonable in any given situation.

The language used for describing uncertain situations also deserves attention, since situations may be described in different ways according to the language used. In this connection, Lotfi A. Zadeh (Chapter 6, section 6.1, this volume) highlights the fact that ‘more often than not uncertain knowledge is described in a natural language’. This condition introduces a constraint on the range of descriptions that are feasible for any given language and highlights the need to distinguish between possibility and probability, as well as between ‘probabilistic uncertainty and possibilistic uncertainty’ (Zadeh, ibid.). In particular, it is emphasized that, since standard probability theory is based on the belief that information is statistical in nature, when information is expressed in a ‘natural language’, considered as propositions or a system of propositions, uncertainty cannot be dealt with by standard theory. This point of view suggests a generalized theory of uncertainty based on non-bivalent (fuzzy) logic and indicates that different patterns of rational behaviour may coexist within the same social universe due to a variety of linguistic constraints.7

1.4 The scope of the volume and its contributions

This volume explores fundamental uncertainty in the light of a set of connected research lines that have taken shape in recent years as a result of investigation in a variety of experimental and theoretical fields. Prominent features of the above research scenario are (i) a shift from general to context-specific (or context-specifiable) canons of rationality; (ii) increasing attention to the heterogeneity of cognitive attitudes; (iii) the central role assumed by framing and focusing; and (iv) interest
in non-monotonic inferences and discontinuous changes of cognitive state (cognitive jumps). In particular, lack of certainty is examined from both the ontological and the epistemic viewpoints, reliability of evidence is assigned a central role, and similarity judgements are considered a necessary condition of probability judgements. The above setting lends itself to a theory of uncertainty associated with the analysis of concept formation, likeness and distance more than with the inferential structure of probabilistic reasoning.

The essays in this volume address fundamental uncertainty from the points of view of philosophy, information science, decision theory and statistics, and economic analysis. Many themes are recurrent across those disciplines and the chapters of the volume suggest manifold opportunities for cross-fertilization. In particular, the volume highlights fields of interest such as the justification of intersubjective grounding of judgement under uncertainty after Ramsey's criticism of Keynes (see below), the distinction between individual decisions and the properties of the overall system within which those decisions are taken, and the specific features of plausible decisions (that is, defensible but not uncontroversial decisions) in the economic and moral domains under fundamental uncertainty.

In Chapter 2, ‘Keynes and Ramsey on Probability’, Henry E. Kyburg calls attention to the discussion between Keynes and Frank P. Ramsey on the proper epistemological role of probability. The author argues that neither side understood the other, and even that they failed to understand the issue that separated them. In particular, Kyburg argues that, although Keynes was at times unclear, he was basically right about the methodological issues. His contribution starts from acknowledgment that ‘in the philosophical world of the nineteenth century, “intuition” did not carry overtones of arbitrariness or personal whimsy’ (section 2.1.1) so that Keynes's appeal to an intuitive conception of probability would be entirely consistent with his view that ‘in the sense important to logic, probability is not subjective’ (Keynes, 1973 [1921], p. 4; as quoted in Kyburg, 2.1.2). Kyburg builds upon Keynes’s analysis of different ordered series of probabilities (Keynes, 1973 [1921], pp. 36–43) a theory of probabilities as forming ‘a lattice structure’ such that ‘[u]pper and lower bounds for any probabilities exist [...]—namely 0 and 1’ (Kyburg, section 2.1.3). In this connection, the conjecture that probability values could be conceived as *intervals* is seen as providing an answer to Keynes’s problem whether ‘the meet and join of any two probabilities exist’ (section 2.1.3). After detailed presentation of the exchange between
Keynes and Ramsey, Kyburg goes back to Keynes's interest in partial rankings of probabilities and argues that, from that point of view, ‘those probabilities to which Ramsey’s arguments apply may constitute a small fraction of probabilities’ (section 2.3).

In Chapter 3, ‘The Weight of Argument’, Isaac Levi examines the role of ‘balancing reasons’ in inductive arguments and discusses what Keynes called the ‘somewhat novel question’ of the balance between favourable and unfavourable evidence. In particular, Levi takes up Charles Peirce’s criticism of the ‘conceptualist’ approach to decision making under uncertainty (the approach interpreting terms such as ‘certain’ and ‘probable’ as describing degrees of rational belief) and stresses that, according to Peirce, the amount of knowledge relevant to decision making ‘cannot be accounted for on the conceptualist view but can on the view that insists that belief probabilities be derivable via direct inference from statistical probability’ (section 3.2). Peirce’s view presupposes that belief probability can be grounded on statistical probability. Keynes was critical of this assumption while acknowledging that belief probability can itself be indeterminate. Differently from Peirce, Levi thinks that ‘one needs to be in a position to make moderately determinate judgements of belief probability without grounding in objective or statistical chance’ (section 3.4). He also emphasizes the cognitive-value dimension attached to Keynes’s discussion of evidential weight, which ‘is in this sense independent of the specific goals of the practical decision problem’ (section 3.6). The essay concludes with the proposal of stepping beyond Keynes’s own analysis by acknowledging the symmetrical roles of belief and disbelief functions and recognizing that the formal properties of belief and disbelief according to G. L. S. Shackle are closely parallel to the properties that any given argument should have in order to be sufficiently close to proof or disproof.

Chapter 4 by Vincenzo Fano, ‘A Critical Evaluation of Comparative Probability’, takes up the discussion of probability judgements as judgements concerning relative (comparative) probability, and outlines an assessment of the Keynes–Ramsey debate starting from the idea that ‘it is often possible to establish a comparison between probabilities, but not to determine their quantitative value’ (section 4.2). For example, as acknowledged by Keynes, even brokers dealing with disaster insurance ‘have to establish only that the probability of the disaster happening is lower than a certain value’ (section 4.2; see also Keynes, 1973 [1921], p. 23). However, recognition of widespread use of comparative (not quantitative) probability judgements exposes the epistemological dilemma between circumscribing the treatment of uncertainty to the
special cases in which Ramsey’s argument applies (and quantitative probabilities are identifiable), and extending it to cases beyond Ramsey’s circumscription, that is, to cases in which probability can be only of the comparative type and in which rules governing the updating of probability in view of augmented evidence cannot be established. At this point of his argument, Fano turns his attention to comparability itself, and introduces the distinction between homogeneous probabilities, which have either the same hypothesis or the same evidence, and inhomogeneous probabilities: the former are always comparable, whereas this is not generally true for the latter. Comparative probability is shown to have epistemological advantages, such as the possibility to assess comparative probabilities from relative frequencies. However, comparative probability, too, is marred by the lack of a probability measure making it possible to update rational belief in view of augmented evidence.

The relationship between the ontological and epistemic features of uncertainty is taken up by Roberto Scazzieri in his contribution ‘A Theory of Similarity and Uncertainty’ (Chapter 5). This chapter starts from the premise that, under most general assumptions, uncertainty entails at the same time a lack of determinacy and imprecise knowledge. The former is an ontological property of the universe under consideration; the latter is an epistemic property of the agents in that universe. Scazzieri conjectures that there may be a trade-off between ontological and epistemic precision, and that the domain of reasoning under uncertainty coincides with the collection of intermediate situations between ontological precision and epistemic precision. The two polar cases point to the existence of intermediate situations in which ontological precision (‘circumscription’) is sufficiently low to allow identification of partial similarity but similarity itself is not too high, so that occurrences beyond uniformities (that is, novelties) are possible. Following a suggestion in Keynes’s TP, Scazzieri examines the analogy between similarity and probability and emphasizes that, like standard similarity judgements, likelihood judgements presuppose a plurality of ordered series in terms of which a reasonable judgement may be expressed. In particular, this contribution highlights the role of crossovers between different serial orders, which may be interpreted as corresponding to situations in which different ontologies coincide at a given point of time. This means that the very plurality of uncertainty dimensions that makes it difficult in general to assess any given situation may turn out to be an advantage when one faces the special circumstances in which the same assessment of the situation in view is grounded in a plurality of different orders of likelihood.
In Chapter 6, ‘Generalized Theory of Uncertainty: Principal Concepts and Ideas’, Lotfi A. Zadeh outlines a theory of uncertainty in which uncertainty is considered an attribute of information, and information itself is seen as subject to a ‘generalized constraint’ that determines which propositions, commands and questions can be expressed by means of any given language. Reasoning under uncertainty is thus treated as ‘generalized constraint propagation’, that is, as a process by which constraints upon the uses of language determine which inferences are possible on the basis of available information (section 6.2). This point of view leads Zadeh to delve into the relationship between the ontological and the epistemic sides of uncertainty and in particular to examine the role of prototypical forms (or protoforms), which are considered as abstracted summaries needed to identify ‘the deep semantic structure’ of the corresponding objects to which they apply (section 6.14). Prototypical forms lead to the concept of granular structure, in which attention is focused on ‘a clump of values [for any given variable X] drawn together by indistinguishability, similarity, proximity or functionality’ (section 6.1). This approach leads Zadeh to introduce the distinction between probability and possibility and to conjecture that there are manifold kinds of uncertainty: probabilistic uncertainty, uncertainty associated with ontological possibility (possibilistic uncertainty), and various combinations of those two kinds. In short, information should be considered a generalized constraint, with statistical uncertainty being a special case; fuzzy logic should be substituted for bivalent logic; information expressed in natural language should be assigned a central role. This strategy is considered to be the most effective tool in dealing with real-world constraints, which are mostly elastic rather than rigid and have a complex structure even when apparently simple.

The relationship between information and the nature of uncertainty is also central to Keynes’s proposal that the probability of arguments cannot be fully assessed unless we also introduce a measure of our confidence in those arguments (Keynes’s ‘weight of arguments’). Chapter 7 by Alessandro Vercelli, ‘Weight of Argument and Economic Decisions’, sets out to clarify the relationship between the ‘weight of argument’ in Keynes’s TP and some crucial passages of The General Theory of Employment, Interest and Money (Keynes, 1973 [1936]) (GT). In particular, Vercelli points out that Keynes’s most innovative contribution should be found in the utilization of this concept in interpreting economic decisions. After discussing alternative definitions of the weight of argument in TP and GT, Vercelli emphasizes the need to establish a hierarchical relation between probability and weight of argument: probability is considered a first-order uncertainty measure while ‘uncertainty’ in the
strict sense is associated with second-order uncertainty as measured by the weight of argument. It is nowadays increasingly acknowledged that there are no binding objections that preclude the analysis of different modalities of uncertainty. In particular, Keynes’s reaction to Ramsey’s criticism should now be reassessed, as Keynes was induced to broaden the scope of non-demonstrative inference that could be seen as relative not only to the premises and background knowledge of arguments but also to their pragmatic and semantic context. Keynes’s revised view is central to the treatment of uncertainty and the weight of argument in GT, and explains his growing attention to social psychology. According to Vercelli, Keynes’s view that it is impossible to insure against the (negative) effects of a change in the weight of argument provides strong decision-theoretical foundations for his fundamental message that the market may be unable to regulate itself, so that full employment can be restored and maintained only through a well thought-out economic policy.

Fundamental uncertainty raises the issue of whether we may be justified in accepting the principle of indifference. In Keynes’s words, this principle asserts that ‘if there is no known reason for predicating of our subject one rather than another of several alternatives, then relatively to such knowledge the assertions of each of these alternatives have an equal probability’ (Keynes, 1973 [1921], p. 45). The principle of indifference entails comparing ‘the likelihood of two conclusions on given evidence’ (Keynes, 1973 [1921], p. 58) and must be distinguished from a criterion of relevance, according to which we should consider ‘what difference a change of evidence makes to the likelihood of a given conclusion’ (ibid.). In the former case (likelihood of conclusions versus indifference), we are asking ‘whether or not \( x \) is to be preferred to \( y \) on evidence \( h \)’ (Keynes, 1973 [1921], p. 58); in the latter case (relevance versus irrelevance), we should evaluate ‘whether the addition of \( h_1 \) to evidence \( h \) is relevant to \( x \)’ (Keynes, 1973 [1921], p. 59). Likelihood of conclusions and relevance of evidence are symmetrical features of inductive knowledge under the assumption of a fundamental regularity in nature and society. Chapters 8 and 9 examine the structure of induction by discussing, respectively, Keynes’s concept of ‘coefficient of influence’ and the implications of lack of regularity under uncertainty due to very large coefficients of variation. Chapter 8 by Domenico Costantini and Francesco Garibaldi, ‘The Relevance Quotient: Keynes and Carnap’, discusses the issue of relevance (that is, the influence of conclusion \( b \) upon conclusion \( a \) on hypothesis \( h \)) by comparing Keynes’s ‘coefficient of influence’ with the concept of ‘relevance quotient’ introduced by Rudolph Carnap. The authors introduce a condition of invariance for the relevance quotient
close to Keynes's coefficient of influence; they argue that the above condition rules the stochastic dependence of a new observation upon data, and is an important tool in solving inductive problems. In particular, they maintain that ‘the notion of relevance quotient […] cannot be introduced without having at one's disposal a relative notion of probability’ (section 8.7), and suggest that their relevance quotient is especially useful in contexts, like physics, biology and economics, where probability can be regarded as ontological. Examples of probabilistic dynamics are discussed and the fact is highlighted that changes of long-term expectations are ‘indissolubly tied to a probability which is changing with evidence’ (ibid.). The authors also call attention to the central role of the invariance condition ensuring that mean values are unaffected by changes in individual distribution. Finally, Chapter 8 asks whether the probability studied in Keynes's *Treatise on Probability* is epistemic or ontic, and concludes by calling attention to the fact that Keynes emphasized his 'fundamental sympathy' with the stochastic approach to biology and statistical physics.

Chapter 9 by Masanao Aoki, ‘Non-Self-Averaging Phenomena in Macroeconomics: Neglected Sources of Uncertainty and Policy Ineffectiveness’, addresses lack of regularity by examining the behaviour of macroeconomic non-self-averaging models, that is, the behaviour of models in which the coefficient of variation of some random variable (the ratio of standard deviation divided by its mean) does not tend to zero as $n$ tends to infinity. This chapter examines policy effectiveness questions in such models, and shows that in general the larger the coefficient of variation, the smaller is the policy multiplier. There are examples in which policy actions become totally ineffective as the value of the coefficients of variation tends to infinity. It is argued that a particularly important feature of non-self-averaging in macroeconomic simulation is that it can give rise to uninformative or misleading policy results. Specifically, the convergence of non-self-averaging models when simulated using Monte Carlo methods is much slower than in self-averaging models. Policy-effect simulations tend to become uninformative or misleading because a very large number of simulation runs may be required for extreme values to appear to upset the sorts of conclusion based on small numbers of simulations in which only most probable simulation results appear. It is argued that conventional simulations or analysis with quadratic cost criteria are all associated with self-averaging results and do not say anything about behaviour of non-self-averaging models, which points to a serious fault in using representative agents. Aoki's contribution is an important warning that microeconomic exercises leading to
'a better understanding of the dynamics of the mean or aggregate variables’ cannot lead to a better understanding of the overall dynamics of the economic system if non-self-averaging fluctuations are considered (section 9.1; see also Aoki, 2002).

Non-regularity in individual behaviour has far-reaching implications for what concerns the analysis of the economic (or social) system as a whole and the method most suitable to that objective. In particular, non-regularity points to the existence of a wedge between the universe of individual decision makers (micro-world) and the system as a whole (macro-world) as traditionally conceived, and calls for innovative theoretical effort to overcome the problem. Thus, in Chapter 10, ‘A Critical Reorientation of Keynes’s Economic and Philosophical Thoughts’, Izumi Hishiyama addresses the above issue by first considering ‘the difficult core of Keynesian thought—“the logical justification of inductive methods”’ (Keynes, as quoted in section 10.1). The specific route followed by Keynes in order to justify induction leads to the analysis of the epistemic conditions for inductive knowledge, that is, of the assumptions of ‘atomic uniformity’ and ‘limitation of independent variety’. According to Hishiyama, this point of view may be connected with ethical individualism (as suggested by Keynes himself in TP) but it is explicitly rejected in GT when Keynes deals with the economic system as an organic unit. In particular, the author deals with the methodological assumptions behind GT and takes up Luigi Pasinetti’s view that the effective demand principle is ‘quite independent of any behavioural relations and thus of any particular adaptation mechanism’ (Pasinetti, as quoted in section 10.7). On the other hand, fundamental (non-measurable) uncertainty characterizes Keynes’s representation of the micro-world. The dual character of Keynes’s thinking calls attention to the whole versus parts issue and leads Hishiyama to look for a way of making Keynes’s treatment of uncertainty consistent with the organic approach in the analysis of the economic system as a whole. In this connection, Hishiyama calls attention to Pasinetti’s proposal that sectorally differentiated demands should be considered, and to Pasinetti’s proposal that one should substitute a general macroeconomic condition (expressed in a multi-sectoral framework) for Keynes’s original formulation of effective demand theory. In this way, a criterion for moving back and forth between aggregate and disaggregate levels of investigation is introduced, and fundamental uncertainty is made compatible with a certain degree of determinacy at the macro-level.9

John Allen Kregel and Eric Nasica, in Chapter 11 ‘Uncertainty and Rationality: Keynes and Modern Economics’, also highlight the fact that
'the crucial point for Keynes, as for Knight, is the inadequacy of statistical quantification in the form of a probability for the analysis of uncertainty', but this aspect of rational decisions in condition of fundamental uncertainty has been neglected by orthodox economists (section 11.2.1). According to these authors, the consideration of crucial decisions such as those leading to irreversible and non-repeated actions is the boundary line between the Keynesian and the traditional neoclassical approach of uncertainty. Nor does the ‘new’ classical theory in the version of the rational expectation hypothesis admit situations of fundamental uncertainty, since this theory assumes that the economic system moves according to a stationary stochastic process which also has the characteristic of an ergodic process. Therefore, according to the theory of rational expectations, decisions in condition of fundamental uncertainty are ‘excluded, or classified as non rational’ (see section 11.3.2); while ‘post-Keynesian analysis develops a theory of the formation of expectations applicable to situations in which the degree of rational belief is less than certain’ (ibid.). In fact, Keynesian economists admit a non-ergodic environment, and believe that the traditional conception of rationality has to be reformulated in order to describe situations of ‘expectational instability’.

The concluding chapter by Silva Marzetti Dall’Aste Brandolini, ‘Moral Good and Right Conduct: A General Theory of Welfare under Fundamental Uncertainty’, deals with competing moral systems (often associated with competing social philosophies), and aims to identify which general characteristics a general theory of welfare (GTW) must have from the point of view of rationality when also admitting conditions of fundamental uncertainty. Welfare economics consists of a certain number of theoretical models that may be distinguished according to the conception of moral value on which they are grounded and the right conduct they suggest. As regards moral values, two fundamental conceptions of moral good exist, which justify the existence of different approaches to welfare economics: the ethics of motive, which makes reference to subjective values, and the ethics of end, which also admits objective values (see sections 12.2 and 12.4). As regards right conduct, Bayesian reductionism and rational dualism are two different ways of considering uncertainty about economic phenomena. Bayesian reductionism assumes that agents are able to identify numerical subjective probabilities, and admits the maximization procedure only; while rational dualism also admits non-measurable probabilities and procedures other than maximization (see sections 12.3 and 12.5). Since a rational choice between competing moral systems cannot be made, this awareness leads the author to think in terms of a GTW; and in section 12.6 it is shown
that, from the point of view of moral values, a GTW must admit all the possible values in which a society can believe; while from the point of view of instrumental rationality, it must admit not only situations where decision makers have all the information and computing capabilities needed by the maximization procedure, but also situations where they do not have adequate information and behave under conditions of fundamental uncertainty.

1.5 Epilogue

Uncertainty derives from the intertwining of ontological and epistemic conditions. The relationship between those two sets of conditions emerges as a unifying theme of this volume. Taken in their unity, the different contributions acknowledge that the configuration of any given situation (state of the world) determines whether or not the corresponding epistemic grasp is grounded; they also recognize that the epistemic context may be central in determining whether or not a grounded understanding of that situation is feasible. This point of view is common to the different contributions in the volume and suggests a pragmatic attitude towards uncertain real-world situations and epistemic contexts. This means that the handling of uncertainty cannot be left to a single standard criterion for the description (circumscription) of situations, nor can it be achieved by a uniform rule for the revision of inductive knowledge. Rather, uncertainty calls for agents capable of producing both situation-adequate descriptions and sophisticated inferences. This volume emphasizes that such a need becomes greater as we move towards fundamental uncertainty. It is important to emphasize that the above requirement does not make for arbitrariness in the handling of uncertainty. On the contrary, it would be necessary, in each case, to identify a suitable intersection of ontological and epistemic conditions, and this intersection would normally narrow down the number of relevant ontological and epistemic states. In short, constraints on plausible judgement are increasingly binding as uncertainty increases either for ontological or epistemic reasons (or for both). At the same time, the need to meet multiple relevance conditions (both on the ontological and the epistemic side) discloses the manifold opportunities associated with negative heuristics, that is, with a discovery and choice strategy in which descriptions and/or arguments are gradually discarded as one moves from one reasoning step to another. To conclude, fundamental uncertainty points to a requirement of extended rationality and highlights that prudence may be essential in the application of it.
Notes

2. We follow here F. Giunchiglia’s distinction between ‘situation’, as a way to record ‘the state of the world as it is, independently of how it is represented in the mind of the reasoner’ (Giunchiglia, 1993, p. 146), and ‘context’ as ‘a theory of the world which encodes an individual’s subjective perspective about it’ (Giunchiglia, 1993, p. 145).
3. According to Maria Carla Galavotti, Keynes’s attitude may be explained in terms of his adherence to ‘a moderate form of logicism, quite different from the strictly formal approach later developed by Carnap. Keynes’ logicism is pervaded by a deeply felt need not to lose sight of ordinary speech and practice, and assigns an important role to intuition and individual judgement’ (Galavotti, 2005, p. 147).
4. As noted by Anthony W. F. Edwards, ‘the quantification of surprise in terms of probability is likely to tell only half the story’ (Edwards, 1992, p. 203). Keynes’s weight of argument gives a cue into reasons for disbelief and possible causes of transition from belief to disbelief (or vice versa) as context is changed.
5. We are grateful to Domenico Costantini for calling our attention to this passage of the Treatise on Probability.
6. This entails identifying which problems can be addressed and the type of tools that may be used to that purpose. In that connection, Isaac Levi points out that ‘we cannot be obliged to recognize all the logical consequences of our full beliefs or even enough of the consequences to solve some particular complicated problem’ (Levi, 1997, p. 9).
7. The relationship between language, descriptions and permissible events is also considered in Crisma (1988).
8. The concept of ‘prototypical form’, in its association with the analysis of granular information, had been anticipated in Adam Smith’s Theory of Moral Sentiments (Smith, 1976 [1759]). See for example, the following passage: ‘[T]he beauty of each species, though in one sense the rarest of all things, because few individuals hit this middle form exactly, yet in another, is the most common, because all the deviations from it resemble it more than they resemble one another’ (Smith, 1976 [1759], pp. 198–9).
9. This point of view is rooted in the distinction between the way in which events (or situations) are described and the way in which knowledge about those events (situations) may be achieved. As Keynes noted, ‘[I]f different wholes were subject to different laws qua wholes and not simply on account of and in proportion to the differences of their parts, knowledge of a part could not lead, it would seem, even to presumptive or probable knowledge as to its association with other parts. Given, on the other hand, a number of […] atomic units and the laws connecting them, it would be possible to deduce their effects pro tanto without an exhaustive knowledge of all the coexisting circumstances’ (Keynes, 1973 [1921], pp. 277–8). Alberto Pasquinelli and Silva Marzetti Dall’Aste Brandolini argue that the above methodological standpoint may be at the root of Keynes’s apparent switch to an ‘organic’ point of view in the General Theory (Pasquinelli and Marzetti Dall’Aste Brandolini, 1994, p. xviii).
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