

Varieties of uncertainty: a survey of the economic literature

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The treatment of knowledge and uncertainty is one of the main issues in the theoretical and methodological distinction among different schools of thought and approaches in economics. This paper surveys the economic literature to associate several economists and schools of economic thought with a particular concept or combination of concepts of uncertainty.

It does so by applying to this literature a typology and refinements of concepts developed elsewhere (Dequech, 2008a). This typology can be summarized as follows. As defined by Giovanni Dosi and Massimo Egidì (1991), *substantive uncertainty* results from ‘the lack of all the information which would be necessary to make decisions with certain outcomes’ and is contrasted with *procedural uncertainty*, which arises from ‘limitations on the computational and cognitive capabilities of the agents to pursue unambiguously their objectives, given the available information’ (p. 145). As defined by myself, *strong uncertainty*, in contrast to the *weak* variety, is characterized by the absence of unique, additive and fully reliable probability distributions, used either explicitly or implicitly by individuals (a unique distribution is the only admissible one and has only point probabilities, as distinct from intervals. An additive distribution has probabilities that add up to unity or 100%). Strong uncertainty may be substantive and/or procedural.¹ When it is substantive, strong uncertainty may be subdivided into two categories: *ambiguity* and *fundamental uncertainty*. Ambiguity, in the terms used by Colin Camerer and Martin Weber (1992: 330), is ‘uncertainty about probability, created by missing information that is relevant and could be known’. This definition can be refined by noting that, even though the decision-maker under ambiguity does not know with full reliability the probability that each event (or state of the world) will obtain, he/she usually knows *all the possible events*. Even when not completely known, the list of all possible events is already *predetermined or knowable ex ante*. Fundamental uncertainty, in contrast, is characterized by the possibility of creativity and non-predetermined structural change. The list of possible events is *not predetermined or knowable ex ante*, as the future is yet to be created. This is the basic notion of fundamental uncertainty. It can be refined by bringing institutions and some features of the process of technological change into consideration, so that there need not be complete ignorance about the future.

These basic distinctions are described in the following table.

¹ Information that, if available, would transform strong into weak uncertainty must be relevant and good-quality information.

Table 1: Three distinctions

Type of uncertainty	Weak uncertainty: unique, additive, and fully reliable probability distribution	Strong uncertainty: absence of such a distribution
Substantive uncertainty: lack of some relevant and good-quality information	Weak uncertainty	Ambiguity: uncertainty about probability, caused by missing information that could be known; predetermined list of states
		Fundamental uncertainty: possibility of non-predetermined structural change; non-predetermined list of states
Procedural uncertainty: Complexity in relation to limited capabilities		Procedural uncertainty

As in the article where this typology was developed, the main focus of this paper is on uncertainty about the future.

1. Weak uncertainty in the economic literature

Neoclassical economics as a whole has adopted a notion of weak uncertainty, in either of its varieties. Indeed, this notion can be seen as one of the defining characteristics of neoclassical economics. Weak uncertainty can be subdivided into two categories: Knightian risk and Savage's uncertainty (see Table 2). In situations of Knightian risk, or simply risk, individuals can act on the basis of a probability that is objective (in the sense that any reasonable person would agree on it) and known. Savage's uncertainty (named after Leonard Savage) involves subjective probabilities – combined or not with objective ones – and is handled by the subjective version of standard expected utility theory.

Table 2: Weak uncertainty, Savage's uncertainty and Knightian risk

Weak uncertainty: unique, additive, and fully reliable probability distribution	
Knightian risk: known objective probabilities	Savage's uncertainty: subjective probabilities, with or without objective probabilities

1.1. Knightian risk in the economic literature

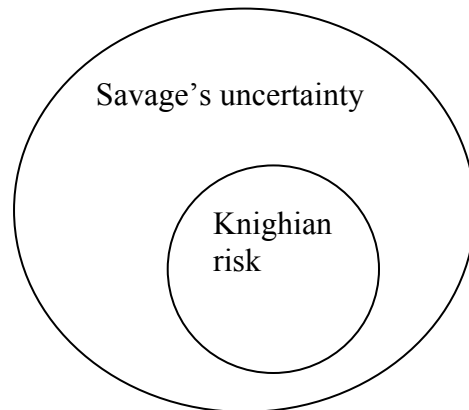
Frank Knight (1921) himself discussed this notion of risk, of course, but pointed out severe limitations in its scope of application. Proponents in economics include John (Johan) von Neumann and Oskar Morgenstern (1944), who provided the first axiomatic version of (standard) expected utility theory, on the basis of objective probabilities. Three decades later, Robert Lucas identified situations of risk as those in which the rational expectations hypothesis has 'usable content',² while 'in cases of uncertainty economic reasoning [by which Lucas means standard economic theory or his strand thereof] will be of no value' (1977: 224).

² In its strong version, this hypothesis consists in assuming that the agents' subjective probability distributions coincide with the objective probability distribution presumably governing the occurrence of events. As in other situations of risk, the relevant objective probabilities exist and are known by the decision-makers. This presupposes a process of learning and convergence.

1.2. Savage's uncertainty in the economic literature

The notion of Savage's uncertainty has so far dominated neoclassical microeconomics. Moreover, if Savage's uncertainty is seen as the more general form of weak uncertainty, including Knightian risk as a special case (as in Figure 1), it has dominated the whole of neoclassical economics. Only someone whose conception of probability is exclusively objectivist would not accept this. In contrast, a moderate defender of subjective probability theory can accept the existence of some objective probabilities.

Figure 1: Savage's uncertainty and Knightian risk from a moderate subjectivist viewpoint



2. Strong uncertainty in the economic literature

The discussion of procedural uncertainty, ambiguity, and fundamental uncertainty will show that there are several economists who adopt a strong notion of uncertainty. However, using the term 'strong uncertainty' does not indicate whether one has in mind procedural uncertainty, ambiguity, fundamental uncertainty, or any combination of these.

The same applies to two other expressions that have appeared in the economic literature in contrast with what has been called here weak uncertainty: Knightian uncertainty and Keynesian uncertainty. Let us take Knightian and Keynesian uncertainty, respectively, to mean the type of uncertainty about which Knight and Keynes wrote, particularly when using the term 'uncertainty' or 'uncertain'. If so, the expressions 'Knightian uncertainty' and 'Keynesian uncertainty' may be sufficient to indicate that one is not referring to risk in an objectivist approach or to uncertainty in standard subjective expected utility (SEU) theory; they fail, however, to reveal which type of strong uncertainty one is considering, because different conceptions of uncertainty exist whose proponents may claim a Knightian or a Keynesian lineage (I shall discuss Keynes and Knight in a separate paper, relating their approaches not only to strong uncertainty in general, but also to different varieties of this type of uncertainty).³

³ Let us consider some examples from the best-known variety of contemporary institutionalism, the new institutional economics. Ronald Coase's classic 1937 article includes a few references to Knight and uncertainty, without an explicit concept (pp. 40, 48-50). In any case, as Coase (1991: 49) later made clear, the distinction between risk and uncertainty was not what interested him in Knight's work. Douglass North, together with Arthur Denzau, considers '[s]trong, or Knightian, uncertainty', which 'would occur when a chooser cannot be viewed as capable of having even subjective probability distribution functions defined over a set of possible outcomes' (Denzau and North, 1994: 9). Among the main reviewers of new institutional economics, another example is that of Furubotn and Richter (1998: 140, 182, 469). They refer somewhat vaguely to Knightian uncertainty as equivalent to 'incomplete foresight of what the future will bring' (p. 182) and identify this as one of the key assumptions of the incomplete contract model, which attempts to formalize Williamson's transaction-cost approach. As Furubotn and Richter explain that the 'imperfect foresight'

Another source of confusion should be avoided. In contrast with neoclassical notions of uncertainty, some authors write about non-probabilistic uncertainty. This is not very helpful, however. It has already been shown that standard subjective expected utility theorists deal with what they call uncertainty by using probabilities. Moreover, even strong uncertainty is not necessarily non-probabilistic. Depending on how strong uncertainty is treated, it may exclude precise numerical probabilities (or point probabilities, as they are also called), but not intervals. Moreover, probability is not always quantitative, for it can also be qualitative. Even precise probabilities may be used in some approaches to strong uncertainty, but these probabilities are not deemed very reliable as guides to practical conduct.

There are also other expressions that seem to be more restrictive than strong uncertainty but still somewhat vague in comparison with the labels for each of the types of strong uncertainty discussed here.

This is the case of ‘*structural uncertainty*’ in Richard Langlois’s characterization. By this term Langlois means ‘a lack of complete knowledge on the part of the economic agent about the very structure of the economic problem that agent faces’, in contrast to ‘*parametric uncertainty*, ... that is, a lack of complete knowledge ex ante about the values that specific variables within a given problem structure will take on ex post’ (1994: 118, original emphasis). Among the things that a structurally uncertain agent does not know are ‘a complete list of all possible states of the world’ (Langlois, 1994: 120) and ‘the [decision] outcomes themselves’ (Langlois and Everett, 1992: 69; for a somewhat fuller description, see Langlois, 1984: 29). ‘Parametric uncertainty’ is meant by Langlois to describe the type of uncertainty considered by the neoclassical theory of Savage and others (1994: 119-20). To this type of uncertainty Langlois opposes the structural one. It would be hasty, however, to equate the latter to strong uncertainty, for two reasons. First, although Langlois does not discuss ambiguity, I would argue that structural uncertainty does not include ambiguity, at least as the latter is formally treated by most economists and discussed below. Second, strictly in the terms mentioned so far, structural uncertainty could be thought to include both procedural and fundamental uncertainty, but this characterization may be just a first approximation (see further references to Langlois below).

Independently from Langlois, Itzhak Gilboa and David Schmeidler, in their case-based decision theory, have coined the term ‘structural ignorance’ to designate a similar particular form of strong uncertainty: ‘decision under “structural ignorance” refers to decision problems for which states are neither (i) naturally given in the problem; nor (ii) can they be easily constructed by the decision maker’ (2001: 45). This excludes ambiguity – as the authors (*idem, ibidem*) make clear by referring to their own work on the latter, although calling it uncertainty – but may include both procedural and fundamental uncertainty. On the other hand, case-based decision theory does not seem designed to handle situations of fundamental uncertainty, as briefly discussed below.

Yet another term with possibly similar connotations is ‘genuine uncertainty’, as employed by Gerald O’Driscoll and Mario Rizzo. They refer to the same type of problem as Gilboa and Schmeidler (2001) and, like Langlois, treat it as one of the central features of their main variety of uncertainty: the unlistability of all possible (future) outcomes (O’Driscoll and Rizzo, 1996: 4, 71, 132). This is also what Denzau and North place behind Knightian uncertainty: ‘Such uncertainty is likely to occur when the chooser cannot even state a list of outcomes ranked in terms of their values. Without such a list, one cannot act as though the situation is one of Knightian risk or of Savage subjective probabilities’ (1994: 9).⁴

assumed by the incomplete contract model is related to the idea that ‘it would be too costly to write down in advance all the possible contingencies’ (1998: 232-33), the implication, at least in this case, is that Knightian uncertainty is interpreted as procedural uncertainty. It will be seen below that North’s more recent work and other passages of Furubotn and Richter do point to fundamental uncertainty.

⁴ As Denzau and North also call this ‘strong uncertainty’, their use of the latter term is different from mine, which includes ambiguity. Like North (1990), Denzau and North (1994) make, on the one hand, abundant references to

In my terms, unlistability of states and consequences may be associated with procedural uncertainty⁵ and/or with the fundamental variant. In any case, even if not separating procedural from fundamental uncertainty, some of the terms just discussed may be used to separate ambiguity from a class of situations in which what is missing are not only pieces of information but also a more complete knowledge of how to interpret the situation.

3. Procedural uncertainty in the economic literature

There are several examples of uses of the notion of procedural uncertainty in the economic literature, even if the label itself is very rarely used.

Nearly every time the idea of bounded rationality appears in the literature, either in Herbert Simon's original sense or in weaker forms, it implies the adoption of a notion of procedural uncertainty. The possible exceptions are attempts to express bounded rationality in standard maximizing terms.

Limitations in people's mental and computational capabilities before a complex decision situation are especially prominent in the field of behavioral economics. Simon's writings are seminal in this regard (some of them, dealing with bounded rationality, are collected in Simon, 1982). Also salient are the economic contributions of the heuristics and biases research program of psychologists Daniel Kahneman and Amos Tversky (e.g., Kahneman and Tversky, 1979; Tversky and Kahneman, 1986; Kahneman, 1996), as well as the work of economists Richard Thaler (e.g., 1991, which includes some influential articles co-authored with Kahneman and others), Matthew Rabin (e.g., 2002, Rabin and Schrag, 1999), and a growing number of others.

When examining Kahneman and Tversky's writings, for example, one can acknowledge the usefulness of the point that some situations of procedural uncertainty are so because of the limitations of the agents; they could be situations of weak uncertainty if only the agents were more competent or sophisticated. Like several other authors, Kahneman and Tversky distinguished between risk and uncertainty on the basis of whether probabilities are known or not. Some of the challenges to the standard model to which Kahneman and Tversky offer a non-neoclassical answer occur in situations with known probabilities; they therefore apply the term 'risk' to the corresponding experiments (as in the title of their famous 1979 article, which presents prospect theory as 'an analysis of decisions under risk'). There is, however, more to these situations than known probabilities: some limitations of the subjects prevent them from complying with the standard axioms of rational behavior. Even when probabilities are known by (or, in experiments, given to) the decision-makers, the latter may be subject to framing effects, for example. In the terms adopted here, these are cases of procedural uncertainty. So are the cases in which subjects form probability judgements and predict values in ways that are inconsistent with some basic principles of probability and statistics. One example is that these judgements, like people's choices under risk, are subject to framing effects; in another example, as in the famous Bill and Linda story by Tversky and Kahneman (1982: 91-96), these judgments violate the conjunction rule, according to which $P(A \& B) \leq P(A)$, where P designates probability and A and B are events. Again, more competent or sophisticated decision-makers could be in a situation of weak uncertainty (even without having probabilities given to them in the experiments).

Important proponents of the so-called complexity approach, like Brian Arthur (1994a, b), H. Peyton Young (1998), and Samuel Bowles (2004: 97), among others, have also implicitly adopted a notion of procedural uncertainty. So have numerous new institutional economists, like Douglass North (from 1990 onward) and Oliver Williamson (1985, chapter 2; 1996)⁶.

complexity. On the other hand, their article contains only a few references to factors that may point to, without necessarily implying, a substantive type of uncertainty.

⁵ See, for example, Schmid (2004: 64) on bounded rationality implying the incompleteness of this list.

⁶ Williamson (1985: 178) refers in passing to contingencies that are 'even unforeseeable', but presents this as a reason for the incompleteness of *complex* contracts. Thus, it is possible that for him complexity rather than the characteristics

Farther from contemporary mainstream economics, the forerunners of the concept of procedural uncertainty appear in the original institutional economics and in the work of Friedrich von Hayek (e.g., 1945, 1960, 1967a).⁷ More recently, one can find the implicit notion of procedural uncertainty in contemporary versions of the original institutionalism (e.g., Hodgson, 1988, 1997; Schmid, 2004, esp. chapter 3), in the Austrian wing of the new institutional economics (e.g., Langlois, 1986a) and other segments of Austrian economics, particularly under Hayek's influence (e.g., Boettke, 1996, Koppl 2002: 196)⁸, as well as in the neo-Schumpeterian economics⁹ (e.g., Nelson and Winter, 1982, in addition to Dosi and Egidi, 1991, of course), and the French economics of conventions (e.g., Storper and Salais, 1997: 15)¹⁰. Perhaps not so often, this also happens within Post Keynesian economics (e.g., Lavoie, 1992: 51; Arestis, 1996: 116; Katzner, 1998: 25; Dow, 1996: 15) and postmodern Marxism (e.g., Resnick and Wolff, 2006: 51; 1987: 185). Also worth mentioning here are authors who are not especially associated with any single school of thought, including those who combine contributions from different schools.¹¹ This is the case, to cite just a few examples, of Ron Heiner (1983), Peter Earl (1983), and Alessandro Vercelli (1991, 2005).

Gilboa and Schmeidler's (2001) case-based decision theory (which is especially meant to apply to economics) also can be said to deal with procedural uncertainty. The authors themselves accept that it is valid to interpret theirs as a theory of bounded rationality, except that they are against seeing their agents as less rational than those in expected utility theory (1999: 222; 2001: 97). In strict terms, their characterization of 'structural ignorance' could also include fundamental uncertainty, as mentioned above, and they do refer to 'a complex and ever-changing environment' (1999: 222), but their approach restricts choice to be among acts that performed well in the past and in this sense prevents innovative acts from happening.

As shown below, some of these authors dealing with procedural uncertainty also incorporate fundamental uncertainty into their work. This is generally truer of those that are farther from mainstream economics.

The complexity of the *situation* is often emphasized by those who advocate a notion of procedural uncertainty (with different words), and sometimes the term 'complexity' is even used to designate a type of uncertainty (e.g., Schmid, 2004: 124-25). Other times the emphasis is placed on

of reality leading to fundamental uncertainty is what makes contingencies unforeseeable. On the other hand, Williamson (1985: 58) does refer to unique events, novelty and surprise, with citations of Ludwig von Mises and George Shackle. These references notwithstanding, fundamental uncertainty does not seem important for Williamson (for similar assessments, see Foss, 1999: 119-20, Slater and Spencer, 2000, and Dunn, 2000).

⁷ Thorstein Veblen wrote ironically: 'The hedonistic conception of man is that of a *lightning calculator* of pleasures and pains' (1898: 389, emphasis added). On Veblen, see also Arrow (2004: 47). Simon acknowledged his debt to the early American institutionalists, particularly John Commons regarding bounded rationality (Simon, 1979: 499; Forest and Mehier, 2001: 595, 597). Regarding bounded rationality, Simon also noticed some general similarity between his views and Hayek's, but after having written much of his *oeuvre* (Egidi and Marris, eds., 1992: 26-27).

⁸ For a comprehensive discussion of uncertainty in Austrian economics, see Wubben (1995).

⁹ Hodgson (1993) has forcefully argued that evolutionary economics would be a better label for this approach than neo-Schumpeterian economics, but I have kept the latter in order to facilitate the distinction between this and other approaches that already were or (particularly within the mainstream of the profession) came to be classified as evolutionary.

¹⁰ In earlier formulations of his view of the French economics of conventions, Olivier Favereau even identified the assumption of bounded rationality as one of the main defining characteristics of this approach (1995). The emphasis on this link with Simon has diminished over time, but uncertainty related to complexity remains central to several conventionalists, even if in a specific form that is not common in economics, as discussed elsewhere (Dequech 2008b).

¹¹ More generally, the existence of economists not associated with any single school (among which I include myself) implies that labels that classify economists are imperfect and must be used with caution.

the *agent's* limited capabilities, and the term 'bounded rationality' has also been (implicitly) used to designate a type of uncertainty (e.g., Dunn, 2001). As argued above, however, procedural uncertainty results from a *contrast* between the agent's mental and computational capabilities, on the hand, and the complexity of the situation, on the other. If the situation were complex but those capabilities were unlimited, procedural uncertainty would not exist; neither would those capabilities matter if the situation were extremely simple.

This comparison of the complexity of the situation with people's capabilities is in fact what Simon (1959: 273 and 1978: 8-9, among several writings), North (1990: 25) and others make).

Several of these and other authors (e.g.: Simon, 1958; Hayek, 1960: 66 and 1973: 13-14; Langlois, 1986a: 237; North, 1990: 25) have suggested that institutions, in particular, contribute to reducing complexity¹² – and therefore, I would say, to reducing procedural uncertainty (see also Dosi and Egidi, 1991, on routines). On the other hand, Hayek (1960: 30) suggests that what he considers 'foolish' institutions may *increase* uncertainty.¹³

4. Ambiguity in the economic literature

Conceptual discussions and applications of the concept of ambiguity to various fields of economics have appeared in increasing numbers in the most prestigious journals. This indicates that ambiguity has been incorporated into mainstream economics – even if it cannot be part of neoclassical economics, by definition, since the latter has been partly defined by its adoption of a notion of weak uncertainty.

Both Knight and Keynes have had their treatments of uncertainty cited as forerunners of the concept of ambiguity in the current mainstream economic literature.

The classic reference is Daniel Ellsberg's 1961 article, particularly because of his discussion of some urn problems, which resulted in what later became known as the Ellsberg paradox. Ellsberg may have meant to apply the term 'ambiguity' to situations of stronger uncertainty than that involved in his urn problems. For example, he states that 'the results of Research and Development, or the performance of a new President, or the tactics of an unfamiliar opponent are all likely to appear ambiguous' (Ellsberg, 1961: 661). He also maintains that 'the ambiguities surrounding the outcome of a proposed *innovation*, a departure from current strategy, may be much more noticeable' than in the case of a familiar, ongoing pattern of activity (p. 666). As Ellsberg does not elaborate on this, it is not clear that he has in mind an uncertainty as strong as that emphasized by economists in the Post Keynesian, Neo-Schumpeterian, and Austrian traditions, for example, in connection with innovation and Schumpeterian entrepreneurship (see references below). At any rate, Ellsberg's references to innovation and the like, even if insufficiently clear, have apparently been lost in the ambiguity literature, with very few possible exceptions, as we shall see. Perhaps to a lesser degree, the same applies to Ellsberg's statement that 'sample-size is not a universally useful index of [ambiguity]. Information about many events cannot be conveniently described in terms of a sample distribution; moreover, sample-size means to focus mainly on the quantity of information. "Ambiguity" may be high (and the confidence in any particular estimate of probabilities low) even where there is ample quantity of information, and particularly where there is *conflicting* opinion and evidence' (1961: 659). This may suggest that Ellsberg thought his concept of ambiguity useful to cases more complicated than the gambles he discusses.

¹² This argument may be seen as implicit in some segments of the new institutional economics where bounded rationality is used to explain the existence of institutions. In the new economic sociology, the argument has been most explicitly and generally supported by Jens Beckert (1996).

¹³ A few works in economics have related uncertainty to a different kind of complexity, associated with the coexistence of different logics of action, conflicting goals and the like. This has also occasionally been examined in the sociological literature under the heading of ambiguity. For references and a brief discussion, see Dequech (2008b). The term 'ambiguity' has a different usage in economics, as mentioned above and discussed in detail in the next section.

As far as terminology is concerned, what matters most is the usual sense in which ambiguity has been discussed, and this seems to be well reflected in Camerer and Weber's (1992) above-cited reference to missing information that could be known. The acceptance of this more restrictive conception among economists tends to be reinforced by its implicit or explicit prevalence in the formal literature on ambiguity (sometimes called uncertainty or 'Knightian uncertainty') and on Ellsberg (1961). This prevalence can be seen in the case of two of the major formal approaches that generalize expected utility (EU) theory beyond weak uncertainty: the multiple-priors approach and the nonadditive prior approach. I shall refer very briefly and non-formally to them. For a detailed discussion of these and other alternatives to standard EU and particularly standard SEU theory, see Kelsey and Quiggin (1992), Camerer and Weber (1992) and Vercelli (1999).

The multiple-priors approach abandons the standard idea that decision-makers have a unique probability distribution. Ellsberg (1961: 661) himself introduces a set of probability distributions and also refers to the confidence that the decision-maker has in his/her estimates. Thus, the idea of full reliability is also abandoned, which explains the paradox, since in Ellsberg's experiments people prefer more reliable information. In their debate with economists, Hillel Einhorn and Robin Hogarth (1986) also define ambiguity in relation to multiple distributions (although they do not restrict their informal discussion to Ellsberg's urn problems, as shown below). In the case of an urn with an unknown proportion of balls of different colors, several probability distributions over the proportion of the different types of balls are admissible and equally likely. For Einhorn and Hogarth, 'ambiguity results from the uncertainty associated with specifying which of a set of distributions is appropriate in a given situation' (1986: S229). In economics, an axiomatization of the multiple prior approach was provided by Gilboa and Schmeidler (1989), after which many other formal works have been written along these lines.

The nonadditive prior approach, again axiomatically developed by Schmeidler (1989) and Gilboa (1987), retains the commitment to point probabilities – and for this is criticized by Runde (1995, 349n) – but replaces the Bayesian prior with a nonadditive measure or capacity. This results from the introduction of weaker axioms than Savage's sure thing principle and allows for an explanation of the Ellsberg paradox¹⁴. A nonadditive measure may exhibit uncertainty [ambiguity] aversion (Schmeidler, 1989: 574) – or ambiguity perception, as shown shortly.

In either approach, ambiguity can be treated as a matter of degrees. With multiple probabilities, 'the amount of ambiguity is an increasing function of the number of distributions that are not ruled out by one's knowledge of the situation', as Einhorn and Hogarth put it (1986: S229). At one extreme, no distribution is ruled out. This corresponds to what Einhorn and Hogarth call ignorance. If people were gradually given information about the contents of the urn, ambiguity would decrease. With a single probability distribution, the degree of subadditivity may be taken to represent one's faith in probability assessments (Karni and Schmeidler, 1991: 1803; Camerer and Weber, 1992: 348). It is therefore a measure of ambiguity. In a dynamic setting, the degree of ambiguity may not only vary, but even get down to zero¹⁵.

¹⁴ This principle is the analogue in Savage's theory to the independence axiom in Von Neumann-Morgenstern's (actually, in a theory named after Von Neumann and Morgenstern, who did not state the independence axiom explicitly). It can be stated as follows: if the lottery L^* is preferred to the lottery L , then the mixture $\alpha L^* + (1-\alpha)L^{**}$ will be preferred to the mixture $\alpha L + (1-\alpha)L^{**}$ for all $\alpha > 0$ and L^{**} (Machina, 1987, 127). Mixing each of two lotteries with a third one - in the same proportion in the two cases - does not change the ranking. Ellsberg's examples show that the comparison between these alternatives depends also on the reliability of the available information. The preferences revealed in Ellsberg's experiments are inconsistent with the existence of additive probabilities, and in Savage's theory the sure thing principle is mainly responsible for the additivity of probabilities (Karni and Schmeidler, 1991, 1803).

¹⁵ This possibility could also be envisaged by some of the interpreters of procedural uncertainty, but others would find this reasoning problematic, as suggested in Dequech (2008a) when discussing procedural uncertainty over time.

A few other works are worth mentioning because they somehow change the scope of application of the concept, perhaps extending it beyond its usual confines.

Although ambiguity has been distinguished from procedural uncertainty, some recent papers seem to point toward a connection between ambiguity and complexity, particularly through unforeseen contingencies. Paolo Ghirardato (2001), for example, who relates the nonadditivity of beliefs – which has been usually associated with ambiguity – to unforeseen contingencies. Like Sujoy Mukerji (1997), he argues that beliefs can be nonadditive as a result of the decision-maker's awareness that unforeseen contingencies may occur. Complexity seems to be the reason why unforeseen contingencies are possible in Ghirardato's analysis – indeed, Ghirardato (2001) describes his decision-maker as boundedly rational. In Mukerji's (1997) framework, 'the state set is exhaustive; the point of departure from the standard theory is that here it is not assumed that the agents knows it' (p. 37).¹⁶ The exhaustiveness of the state set excludes fundamental uncertainty, but not the more limited variant of procedural uncertainty. This variant of procedural uncertainty also seems to underlie Dekel, Lipman and Rustichini's (1998) analysis. When discussing contracts, they state that "the agent could typically include the unforeseen contingencies *if he took enough time*, but that he does not get around to doing so" (1998: 524, emphasis added). However, Dekel, Lipman and Rustichini (1998: 540) note that the distinction between unforeseen contingencies and ambiguity is difficult to make formally precise. I would add that further investigation may clarify whether scholars are combining ambiguity and procedural uncertainty as conceptualized above or merely using the term 'ambiguity' to mean procedural uncertainty and applying a formal framework originally restricted to issues of ambiguity. This is particularly necessary in the case of formal approaches. Informally, Einhorn and Hogarth, for example, follow Ellsberg in allowing factors others than the amount of information (such as sample size) to cause ambiguity. In particular, they can be said to open the door to procedural uncertainty – more clearly than Ellsberg might have done – when they illustrate this by arguing that 'ambiguity will generally be high [...] when the causal process generating outcomes is poorly understood' (1986: S229).

Truman Bewley (1989) deserves a special mention for making one of the first attempts to deal not only with the Ellsberg paradox, but also with innovation and entrepreneurship. In this sense, he goes beyond the ambiguity literature and recovers Ellsberg's references to innovation. Bewley drops the assumption of complete preferences, but keeps the assumption of an exhaustive list of states. Thus, his view of innovations is quite limited. Innovations are treated as new alternatives that change the available choice set but do not create new 'states'. States are thus still conceived of as independent of what people do. People form multiple subjective probability distributions and there is a 'true distribution' or a 'true stochastic mechanism governing the environment' (Bewley, 1989, 4-5). For a more recent attempt to model innovation along these lines, see Rigotti, Ryan and Vaithianathan (2005).

5. Fundamental uncertainty in the economic literature

There are several references to what amounts to fundamental uncertainty in the economic literature (in addition to those already mentioned in the companion piece to this paper).

5.1. The basic notion

Several authors have adopted at least the basic notion of fundamental uncertainty (and some of them have extended their views beyond this). Among the first economists to clearly do so –

¹⁶ Mukerji's (1997) approach implies that unforeseen contingencies may occur even when the state space is exhaustive (or, I would say, predetermined). Contrast this with, for example, Dosi and Egidi (1991: 154). In another article, Mukerji (1998: 1208, n.1) sticks to the usual concept of ambiguity as referring 'purely to the *fuzzy perception of the likelihood* subjectively associated with an event. ... It *does not* refer to a lack of clarity in the description of contingent events and actions'.

arguably after Knight and Keynes – is George Shackle (e.g., 1969, 1972). Shackle has inspired several heterodox economists, especially within Post Keynesian and Austrian economics.

Among the Post Keynesians, Paul Davidson has associated his version of the (basic) notion of (fundamental) uncertainty with an ontological conception of reality as ‘transmutable’, as opposed to ‘immutable’ (1996). More formally, Davidson (e.g., 1982-32) has expressed this notion in terms of ‘non-ergodicity’, but this expression has been surrounded by controversy (as discussed elsewhere).

More visibly influenced by Shackle’s work, including his formal apparatus (1969), are Douglas Vickers (1994), Donald Katzner (1998) and Randall Bausor (1983, 1984). The Post Keynesian side of Earl’s (1983) work also arrives at fundamental uncertainty via Shackle.

Davidson is particularly reminiscent of Shackle when he resorts to the Schumpeterian entrepreneur to explain the Post Keynesian idea that the future is a result of ‘*human creativity*’, while other theories, such as one based on the rational expectations hypothesis, ‘restrict entrepreneurship to robot decision-making’ (1982-83: 192-93, original emphasis). See also Dow (1996: 147) and Lavoie (1992: 44).

Not surprisingly, the connection between innovations and a more radical type of uncertainty appears in the Neo-Schumpeterian literature – for instance, Freeman (1982: 149-150), Nelson and Winter (1982: 132)¹⁷, Dosi and Orsenigo (1988: 18), and especially Dosi and Egidi (1991: 148).¹⁸ Horst Hanusch and Andreas Pyka (2007: 276) even argue that ‘the focus on novelties and uncertainty is ... the most distinguishing mark of Neo-Schumpeterian economics’. Authors who espouse a notion of fundamental uncertainty in their discussion of innovation and are not associated with any single school of thought include Michael Piore (1995: 120) and, particularly regarding the design of new products, Lester and Piore (2004: 41-42). Vercelli (1991: 96) may also be mentioned here, as someone who often works in the intersection of Post Keynesian and neo-Schumpeterian economics, while Ulrich Witt’s work (e.g., 2003) is located in the intersection of neo-Schumpeterian and Austrian economics.

Among the Austrian economists, Ludwig Lachmann (1976, among others) is arguably the closest to Shackle. O’Driscoll and Rizzo seem on several occasions to point toward fundamental uncertainty (1996: 2, 4, 5, 9, 65; see also Runde 1993: 396, n. 28, on O’Driscoll and Rizzo’s dynamic conception of entrepreneurship, with profit opportunities being endogenously generated rather than already existing), although what they call ‘genuine uncertainty’ sometimes appears to be entwined with procedural uncertainty (e. g., 1986: 258-59; 1996: 24, 133). Jochen Runde (1993) embraces fundamental uncertainty from a critical realist perspective.¹⁹ Probably influenced by Hayek (see Caldwell, 2004: 295), several Austrians share with the original institutionalists a view of socio-economic evolution as an open-ended process, which is compatible with fundamental uncertainty (e. g., Boettke, Horwitz, and Prychitko, 1994: 66).

The latter comment applies equally to constitutional political economy, as represented by James Buchanan and Viktor Vanberg (e.g., 1991), and to postmodern Marxism, as represented by Stephen Resnick and Richard Wolff (2006: 54-55, 157) and Ruccio and Amariglio (2003: 247). These latter authors defend Keynes’s mature statements on what they call ‘true or radical uncertainty’ (Ruccio and Amariglio, 2003: 74). What is specific to their postmodern approach is the

¹⁷ Richard Nelson and Sidney Winter refer to the *results* of the organizational activity aimed at innovation, as distinct from this activity itself, which may become routinized and therefore predictable. The radicality of uncertainty is even clearer in Nelson’s (2003) account of the intellectual trajectory of his work with Winter.

¹⁸ Dosi, Marengo and Fagiolo (2005: 277, n. 28) point out the proximity between their view and the Post Keynesian one, approvingly referring to Shackle, Vickers, Katzner, and Davidson.

¹⁹ Runde (1993: 385) sees a convergence between ‘most’ Austrians and Post Keynesians regarding nonergodicity (as do O’Driscoll and Rizzo, 1996: 9), but this assessment is not unanimous. For a diametrically opposed opinion, see Prychitko (1993: 375, cited by Dunn, 2002: 16). In any case, its validity depends on what one means by this controversial term.

claim that '[u]ncertainty (and, by the same token, certainty and all other forms of knowledge) is understood to exist only in and through discourse, in the form of "texts" in which uncertainty is recognized as such' (idem; also p. 78), although the authors do not deny the existence of a world outside discourse (p. 76, n. 20).

The concept of fundamental uncertainty is also implicitly or explicitly present in different strands of institutional economics. In the French economics of conventions, one may cite the works of André Orléan (1989: 242, 249) and Olivier Favereau (1988: 158, 1998: 222).

In the original institutionalism, one of the strongest links to fundamental uncertainty may be established through the already-mentioned treatment of the process of economic evolution. William Kapp puts it well when he states that institutionalists (influenced by the pragmatist philosophers) question 'the widespread belief that social processes move toward a pre-established and determined end – a fixed telos; instead of this teleological bias' they stress 'indeterminacy and uncertainty' (1968: 5; see also Gruchy 1987: 22).²⁰ More recently, Hodgson has emphasized not only this general openness, but also, like Malcolm Rutherford (1984: 381), the uncertainty associated with innovation, more specifically (Hodgson, 1999: 259). Allan Schmid (2004: 126) explicitly uses the label 'fundamental uncertainty' in a Shacklean manner.

One may also attribute a notion of fundamental uncertainty to some proponents of the new institutional economics. In this respect, it is important to consider what Rutherford (1994) has called the Austrian wing of the new institutionalism. The work of Richard Langlois (1984, 1986a) must be highlighted for not reducing 'structural uncertainty' (mentioned above) to the procedural type and, in particular, for associating structural uncertainty with novelty and entrepreneurship (1994: 120, figure 1; 1984: 29, n. 13).²¹ Similarly, the conception of reality underlying the notion of fundamental uncertainty is backed up by Wolfgang Kasper and Manfred Streit in Shacklean tones (1998: 151). Douglass North is not usually associated with the Austrian wing of new institutionalism, but in recent years has become gradually closer to it. As part of this process, since the mid-1990s he has made significant steps toward a notion of fundamental uncertainty, as he wrote: "If this were an ergodic world – that is, one whose fundamental underlying nature was constant – then once we understood that nature and developed the proper theory, we would get it right, today and in the future. But uncertainty is our inevitable lot because the world keeps on changing in novel ways. That is due in part to natural, physical causes, but it is primarily a consequence of human beings' altering the world and creating new conditions and new problems"

²⁰ This antiteleological stance started with Veblen, for example in his critique of Marx (Veblen, 1907: 305). Wallace Peterson (1996: 153) goes as far as to argue that '[u]ncertainty provides a crucial link between institutionalism and Keynes'. Original institutionalists that emphasize fundamental uncertainty are often also Post Keynesians, such as Hyman Minsky and Randy Wray. Hodgson implies that the link has to be qualified at least regarding the founding institutionalists, as he maintains that their conception of uncertainty was less radical than that of Keynes and Shackle (Hodgson, 2000: 68-69).

²¹ Also suggestive of fundamental uncertainty is the following criticism that Langlois raises against Simon: 'He often writes as if there really does exist a well-defined optimization problem *out there* (...); the only difficulty is computational complexity. This is why analogies to chess games or the solution of complex differential equations ... appear so frequently in his discussions' (Langlois, 1986a: 226-27, emphasis added). On the other hand, it still unclear to me whether 'structural uncertainty' is synonymous with fundamental uncertainty or may include both fundamental and procedural uncertainty. Langlois (1984: 41, n. 15) refers to 'a formulation in which there is perfect structural knowledge – but in which the known structure is so complex that the agent acts in effect as if he were uncertain of the structure'. Langlois seems to suggest that this formulation (which Langlois, rightly or wrongly, see as Simon's) is different from his own approach, despite having some implications in common with it. This is not enough, however, to exclude procedural uncertainty and thus, by elimination, to equate structural and fundamental uncertainty. I have in mind the following question: what about a formulation in which the structure is indeed not known because of its complexity? I would say this case falls under the rubric of structural uncertainty, as strictly defined in the terms cited above. If so, structural uncertainty would include both procedural and fundamental uncertainty. In any case, regardless of the labels chosen, the most important point is that Langlois sees both procedural and fundamental uncertainty as relevant.

(North, 1999: 59). This view of uncertainty also marks North's most recent book (2005).²² A few signs of fundamental uncertainty appear in Furubotn and Richter (1998), even though they are not clearly separated from procedural uncertainty.²³ Still in connection with new institutional economics, an explicit definition of fundamental uncertainty has been proposed by Hansjörg Siegenthaler (1997).²⁴

As the references made above indicate, there are some authors who demonstrate their direct or indirect approval of the notions of both procedural and fundamental uncertainty, or something equivalent: Earl, Favereau, Katzner, Langlois, Lavoie, and, among the most emphatic, Dosi and Egidi, Hodgson, Vercelli, and myself (Dequech, 2004, 2006).²⁵ Even Hayek and Simon, authors who tended to emphasize complexity and human limitations, sometimes combined this emphasis with aspects that add a flavor of fundamental uncertainty.²⁶ In addition, Shackle's notion of fundamental uncertainty may be closely linked to procedural uncertainty: '*Complexity* of the event is therefore ... a circumstance which must be present if the individual is to be in fact exposed to the occurrence of an unexpected event' (Shackle, 1953: 114, cited by Madan and Owings, 1988: 28).

Finally, some uses of complexity theory in economics may signal that the term 'complexity' has also been applied to the same type of reality underlying the notion of fundamental uncertainty. For instance, some eminent authors associated with the Santa Fe Institute branch of complexity theory see this approach as concerned with "perpetual novelty", among other features of reality not easily dealt with the traditional mathematics used in economics. This feature is conceived of as resulting from the fact that 'new niches are continually created by new markets' (Holland, 1988, 118) and also by 'new technologies, new behaviors, new institutions' (Arthur, Durlauf and Lane, 1997, 4). Moreover, they maintain that agents 'inhabit a world ... that is complicated by the presence and actions of other agents and that ever changes. It follows that agents generally do not optimize in the standard sense, not because they are constrained by finite memory or processing capability, but because the very concept of an optimal course of action often cannot be defined' (p. 5). On the other hand, to the best of my limited knowledge, perpetual novelty and the introduction

²² This signals an interesting convergence between North's variety of new institutionalism and Davidson's branch of Post Keynesian economics. Indeed, chapter 1 in North's 2005 book is entitled 'Uncertainty in a Non-ergodic World' and cites Davidson favorably.

²³ These are passages where they present their own views (rather than surveying the work of other authors). See, for example, Furubotn and Richter (1998: 466), as well as Furubotn (e. g., 2001: 149).

²⁴ For Siegenthaler, fundamental uncertainty characterizes a situation in which actors lose confidence in the mental models they apply. This is not the same definition of fundamental uncertainty as the one employed here; it can be understood as referring to the possible *consequences* of a sufficiently large increase in the degree of what is called in the present paper fundamental uncertainty. Regardless of this conceptual difference, in this case too there is a (somewhat loose) connection with Post Keynesianism: Siegenthaler's concept is based on his own interpretation of Keynes (1937). See Dequech (1999) for an alternative theoretical view on how to connect fundamental uncertainty and confidence and for another interpretation of Keynes on this. See also Thráinn Eggertsson's (2000: 264) comment on Siegenthaler's notion of fundamental uncertainty, in particular his references to the possible lack of knowledge about some elements in choice sets and to the non-stationarity of economic systems.

²⁵ In economic sociology, Beckert (1999) has moved toward the more fundamental type of uncertainty associated with innovation, in addition to his earlier emphasis on procedural uncertainty.

²⁶ For example, Hayek (1960: 290) referred to a 'complex and ever changing system' (also 1973: 103, 106, while Simon (1959: 256), very similarly, pointed out 'the complexity and instability' of the environment and, dealing more specifically with the theory of firm, maintained that '[t]he economic environment of the firm is complex, and it changes rapidly; there is no a priori reason to assume the attainment of a long-run equilibrium' (p. 263). Furthermore, in a way that may remind us of his student Shackle, Hayek wrote: 'Liberty is essential to leave room for the unforeseeable and unpredictable' (1960: 29. See also 1965: 90). John Gray (1980) seems to derive something similar to fundamental uncertainty from Hayek's views on evolution and knowledge. See also Schumpeter (1911: 85).

of innovations (as distinct from their diffusion) do not seem to be prominent in models adopting the Santa Fe complexity perspective. One exception is the narrative approach of David Lane and Robert Maxfield (1997), who describe as ‘complex’ (and different from merely ‘complicated’) the foresight horizon of a firm whose world’s structure is undergoing cascades of rapid change. More recently, Lane and Maxfield (2005) have closely related innovations to what they call ‘ontological uncertainty’, without subsuming the latter under the rubric of ‘complexity’. Even more recently, Arthur (2007) has become interested in the process of invention of radically new technologies, as something previous to innovation. In this work, Arthur does not explicitly discuss the uncertainty involved in, or possibly resulting from, invention, but at least conceives of reality as subject to this kind of structural change.

In addition, two other comments should be made at this point that are not limited to the Santa Fe perspective. First, complex systems may exhibit structural change²⁷, ‘novelties’ in the specific sense of mutations, and non-predictability, but some of the complex systems with these properties do not even need to be inhabited by human beings, so that creativity in the sense used in the concept of fundamental uncertainty adopted here is absent from such systems. Second, treatments of novelty or mutations in economics can be quite limited, as in some theories of entrepreneurship that impute a rather passive role to the entrepreneur or in evolutionary game-theoretic approaches where mutants adopt suboptimal strategies.

Nevertheless, some authors concerned with innovation, evolutionary change and the like have described economies with these characteristics as complex systems or sometimes, more specifically, as complex adaptive systems (see, for example, Foster and Metcalfe, eds., 2001; Metcalfe and Foster, eds., 2004). Some of these authors are proponents of neo-Schumpeterian economics or in any case closer to the latter than most of those associated with the Santa Fe Institute.

All this indicates that the conceptual relation between fundamental uncertainty and ‘complexity’ still needs further investigation.²⁸

5.2. The extended notion of fundamental uncertainty

Several economists dealing with what amounts to fundamental uncertainty have gone beyond the basic notion, elaborating it by considering institutions and some features of the process of technological change.

Regarding technology, neo-Schumpeterian economists have explained the relatively ordered character of the patterns of technological change mostly by the paradigmatic cumulative nature of technological knowledge (e.g., Dosi, 1982, 1988. See Dequech 2008a for further discussion and references). A more diverse set of authors has linked fundamental uncertainty with institutions.

The discussion of the role of market makers, contracts, the law of contracts and the State as its enforcer (Dequech, 2008a) owes much to the contributions of Post Keynesian economists, most notably Davidson and Hyman Minsky. So does the argument in favor of the potential stabilizing effect of the announcement of long-term policies by market makers – and, for that matter, by State agencies more generally (see, e. g., Carvalho, 1992: 211). The debate within Post Keynesianism on contracts and uncertainty is, however, double-sided: in James Crotty’s view, contracts do not always reduce uncertainty; sometimes they may exacerbate it (1994: 135) – his argument is based on Minsky’s idea that a growing amount of contractual debts generates financial fragility for the agents and the whole economy. Much less emphasis has been placed by Post Keynesians on the

²⁷ For a treatment by an author that is clearly sympathetic to something equivalent to the notion of fundamental uncertainty, see Vercelli (1991, chapter 4).

²⁸ Relating complexity more specifically to Post Keynesian economics, Rosser (2001: 559) wrote: ‘The question of how complexity in the economic environment influences decisionmaking and whether or not this leads to uncertainty for ontological or epistemological reasons is one that remains very controversial and unresolved’ (also Rosser, 2004). In my terms, this might be translated as a comment on how complexity relates to procedural and fundamental uncertainty.

other side of the debate on government intervention, particularly regarding excessive variation in discretion (see the comment below on the Austrians) and the need for policy makers to persuade the public that a long-term program of market making and public spending is not harmful to the economy.

Post Keynesians have also dealt with informal institutions, especially following the lead of Keynes's references to conventions in *The General Theory* (1936, chapter 12) and his 1937 *Quarterly Journal of Economics* article – see Harcourt (1981: 261), Lawson (1985), Hamouda and Smithin (1988: 163), Dow (1996: 19, 100), and several others, including, in the intersection of Post Keynesianism and Marxism, Crotty (1994).

Although Shackle may sometimes have suggested that fundamental uncertainty is synonymous with complete ignorance, he not only argued that awareness of the insufficiency of knowledge is part of knowledge (1969: 281), but also pointed out that there are bounds to our 'unknowledge' (*idem*, p. 5). Some Post Keynesians strongly influenced by Shackle have also done this by recognizing the importance of contracts (e.g., Bausor, 1984: 372-74; Vickers, 1995: 210) and conventions (Vickers, 1979-80: 244-45; 1994: 157-60; Katzner, 1998: 370).

Among the neo-Schumpeterians, Coricelli and Dosi (1988: 137, 138) also highlight institutions as a way of structuring individual behavior and reducing the problem of unpredictability – not to mention the general emphasis that this approach places on routines.

Likewise, in the Austrian camp, Lachmann has referred to institutions as means of orientation that help coordination (see Langlois, 1986b, and Lewis and Runde, 2007). Other Austrians that may be mentioned here include Runde (1993: 388-90) and, with some qualifications, O'Driscoll and Rizzo (1996: 6, 32, 39). Specifically on a type of formal institutions, Hayek (1973: 102) argued that the law can give protection against the disappointment of some, although not all, expectations in an ever changing society. On the other hand, Austrian economists have also been concerned with the destabilizing effects of discretionary actions by some formal organizations (see, e.g., Koppl, 2002, on big players).

Almost by definition, all institutional economists who work with a notion of fundamental uncertainty have emphasized the role of institutions in affecting this uncertainty or how people cope with it. This includes some original and new institutionalists, as well as French conventionalists, who obviously focus on conventions (see section 5.2 above for a few names and references, as well as the discussion on the cognitive role of institutions in Dequech, 2006).

8. Concluding remarks

This article uses a previously developed typology to provide a fairly comprehensive survey of how different economists and different schools of economic thought have implicitly or explicitly dealt with the varieties of uncertainty.

It shows that the concept of uncertainty is a matter of profound disagreement between neoclassical economists and others, but the dialogue can be improved if we specify the type of uncertainty that we have in mind. The same comment applies to communication among non-neoclassical economists. In their case, the article also reveals that there is much room not only for dialogue, but also for cooperation among supporters of different schools of economic thought, based on the potential compatibility and complementarity of their views. On the other hand, the article helps the identification of points of divergence among these different economists. Sometimes, the treatment of uncertainty itself is a major reason for discordance; other times, the main source of dissension will have to be found elsewhere, such as in the political-ideological visions, especially regarding the role of the State, and in the methodological stances, particularly regarding mathematical formalization.

References

Arestis, Philip (1992), *The Post-Keynesian Approach to Economics*, Aldershot, UK, Elgar.

- Arrow, Kenneth (2004), 'Is Bounded Rationality Unboundedly Rational? Some Ruminations', in March, James and Augier, Mie (eds.)(2004), *Models of a man: Essays in Memory of Herbert A. Simon*, Cambridge, MA, MIT Press.
- Arthur, W. Brian (1994a), *Increasing Returns and Path Dependence in the Economy*, Ann Arbor, University of Michigan Press.
- Arthur, W. Brian (1994b), 'Inductive Reasoning and Bounded Rationality', *American Economic Review*, 84(2): 406-11.
- Arthur, W. Brian (2007), 'The structure of invention', *Research Policy*, 36(2): 274-87.
- Arthur, W. Brian, Durlauf, Steven and Lane, David (1997), 'Introduction', in Arthur, W. Brian, Durlauf, Steven and Lane, David (eds.)(1997), *The Economy as a Complex, Evolving System II*. Reading, MA, Addison-Wesley.
- Bausor, Randall, (1983), 'Time and the Structure of Economic Analysis', *Journal of Post Keynesian Economics*, 5(2): 163-79.
- Bausor, Randall (1984), 'Toward a historically dynamic economics: example and illustration', *Journal of Post Keynesian Economics*, 6(3): 360-76.
- Beckert, Jens (1996), 'What is sociological about economic sociology? Uncertainty and the embeddedness of economic action', *Theory and Society*, 25(6): 803-40.
- Beckert, Jens (1999), 'Agency, Entrepreneurs, and Institutional Change. The Role of Strategic Choice and Institutionalized Practices in Organizations', *Organization Studies*, 20(5): 777-99.
- Bewley, Thomas (1989), 'Market Innovation and Entrepreneurship: A Knightian View', *Cowles Foundation Discussion Paper*, 905.
- Bianchi, Marina (1990), 'The unsatisfactoriness of satisficing: from bounded rationality to innovative rationality', *Review of Political Economy*, 2(2): 149-67.
- Boettke, Peter (1996) 'What is wrong with neoclassical economics (and what is still wrong with Austrian economics)', in Foldvary, Fred (ed.)(1996), *Beyond Neoclassical economics*, Aldershot, UK, Elgar.
- Boettke, Peter, Horwitz, Steven, and Prychitko, David (1994), 'Beyond Equilibrium Economics: Reflections on the Uniqueness of the Austrian Tradition', in Boettke, Peter and Prychitko, David (eds.)(1994), *The Market Process: Essays in Contemporary Austrian Economics*, Aldershot, UK Elgar.
- Bowles, Samuel (2004), *Microeconomics: Behavior, Institutions, and Evolution*, Princeton, Princeton University Press.
- Buchanan, James and Vanberg, Viktor (1991), 'The Market as a Creative Process', *Economics and Philosophy*, 7: 167-186.
- Caldwell, Bruce (2004), *Hayek's Challenge*, Chicago, University of Chicago Press.
- Camerer, Colin and Weber, Martin (1992), 'Recent Developments in Modelling Preferences: Uncertainty and Ambiguity', *Journal of Risk and Uncertainty*, 5(4): 325-70.
- Carvalho, Fernando (1992), *Mr. Keynes and the Post Keynesians*, Aldershot, UK, Elgar.
- Coase, Ronald (1937), 'The nature of the firm', *Economica*, 4(16): 386-405.
- Coase, Ronald (1991), 'The nature of the firm: meaning', in Williamson, Oliver and Winter, Sidney (eds.)(1991), *The Nature of the Firm*, Oxford, Oxford University Press.
- Coricelli, Fabrizio and Dosi, Giovanni (1988), 'Coordination and order in economic change and the interpretative power of economic theory', in Dosi *et alli* (eds.)(1988).
- Crotty, James (1994), 'Are Keynesian Uncertainty and Macrotheory Compatible? Conventional Decision Making, Institutional Structures, and Conditional Stability in Keynesian Macromodels', in Dymski, Gary and Pollin, Robert (eds.)(1994), *New perspectives in monetary macroeconomics*, Ann Arbor, University of Michigan Press.
- Davidson, Paul (1982-83), 'Rational expectations: a fallacious foundation for studying crucial decision-making processes', *Journal of Post Keynesian Economics*, 5(2): 182-98.
- Davidson, Paul (1996), 'Reality and economic theory', *Journal of Post Keynesian Economics*, 18(4): 479-508.
- Denzau, Arthur and North, Douglass (1994), 'Shared Mental Models: Ideologies and Institutions', *Kyklos*, 47(1): 3-31.
- Dekel, Eddie, Lipman, Barton and Rustichini, Aldo (1998), 'Recent developments in modeling unforeseen contingencies', *European Economic Review*, 42: 523-42.
- Dequech, David (1999), 'Expectations and confidence under uncertainty', *Journal of Post Keynesian Economics*, 21(3): 415-30.
- Dequech, David (2004), 'Uncertainty: individuals, institutions and technology', *Cambridge Journal of Economics*, 28(3): 365-78.
- Dequech, David (2006), 'The New Institutional Economics and the theory of behaviour under uncertainty', *Journal of Economic Behavior and Organization*, 59(1): 109-131.
- Dequech, David (2008a), 'Uncertainty: a typology and refinements of existing concepts', unpublished paper.
- Dequech, David (2008b), 'Uncertainty, complexity, ambiguity, and multiple logics of action', unpublished paper.
- Dosi, Giovanni (1982), 'Technological paradigms and technological trajectories', *Research Policy*, 11: 147-62.
- Dosi, Giovanni (1988), 'Sources, Procedures, and Microeconomic Effects of Innovation', *Journal of Economic Literature*, 26(3): 1120-71.
- Dosi, Giovanni *et alli* (eds.)(1988), *Technical Change and Economic Theory*, London, Pinter.
- Dosi, Giovanni and Egidi, Massimo (1991), 'Substantive and procedural uncertainty - an exploration of economic behaviour in changing environments', *Journal of Evolutionary Economics*, 1(2): 145-68.
- Dosi, Giovanni, Marengo, Luigi and Fagiolo, Giorgio (2005), 'Learning in Evolutionary Environments', in Dopfer, Kurt (ed.)(2005), *The Evolutionary Foundations of Economics*, Cambridge, Cambridge University Press.

- Dosi, Giovanni and Orsenigo, Luigi (1988), 'Coordination and transformation: an overview of structures, behaviours and change in evolutionary environments', in Dosi, G. *et alli* (eds.)(1988).
- Dow, Sheila (1996), *The Methodology of Macroeconomic Thought*, Cheltenham, Elgar.
- Dunn, Stephen (2000), 'Fundamental Uncertainty and the Firm in the Long Run', *Review of Political Economy*, 12(4): 419-33.
- Dunn, Stephen (2001), 'Bounded rationality is not fundamental uncertainty: a Post Keynesian perspective', *Journal of Post Keynesian Economics*, 23(4): 562-87.
- Dunn, Stephen (2002), 'Towards a transmutable economics? A comment on Wynarczyk', *Economic Issues*, 7(1): 15-20.
- Earl, Peter (1983), *The Economic Imagination*, Armonk, NY, M. E. Sharpe.
- Eggertsson, Thráinn Eggertsson, (2000), 'Comment on Hansjörg Siegenthaler', in Streit, Manfred, Mummert, Uwe and Kiwit, Daniel (eds.)(2000), *Cognition, Rationality, and Institutions*, Berlin, Springer.
- Egidi, Massimo and Marris, Robin (eds.)(1992), *Economics, Bounded Rationality and the Cognitive School*, Aldershot, UK, Elgar.
- Einhorn, Hillel and Hogarth, Robin (1986), 'Decision Making under Ambiguity', *Journal of Business*, 59(4): S225-50.
- Ellsberg, Daniel (1961), 'Risk, ambiguity and the Savage axioms', *Quarterly Journal of Economics*, 75(4): 643-69.
- Favereau, Olivier (1988), 'Probability and uncertainty: "after all, Keynes was right"', *Économies et Sociétés*, série PE, 10: 133-67.
- Favereau, Olivier (1995), 'Convention et régulation', in Boyer, R. and Saillard, Y. (eds.)(1995), *Théorie de la régulation: état des savoirs*, Paris, La Découverte.
- Favereau, Olivier (1998), 'L'incomplétude n'est pas le problème, c'est la solution', in Reynaud, B. (ed.)(1998), *Les limites de la rationalité – Les figures du collectif*, Paris, La Découverte.
- Forest, Joelle and Mehier, Caroline (2000), 'John R. Commons and Herbert AA. Simon on the Concept of Rationality', *Journal of Economic Issues*, 35(3): 591-605.
- Foss, Nicolai (1999), *The Austrian School and Modern Economics: Essays in Reassessment*, Copenhagen, Copenhagen Business School Press.
- Foster, John and Metcalfe, Stanley (eds.)(2001), *Evolution and Economic Complexity*, Aldershot, UK, Elgar.
- Freeman, Christopher (1982), *The Economics of Industrial Innovation*, London, Pinter, 2nd edition.
- Furubotn, Eirik (2001), 'The new institutional economics and the theory of the firm', *Journal of Economic Behavior and Organization*, 45: 133-53.
- Furubotn, Eirik and Richter, Rudolf (1998), *Institutions and Economic Theory: The Contribution of New Institutional Economics*, Ann Arbor, University of Michigan Press.
- Ghirardato, Paolo (2001), 'Coping with ignorance: unforeseen contingencies and non-additive uncertainty', *Economic Theory*, 17(2): 247-76.
- Gilboa, Itzhak (1987), 'Expected utility with purely subjective non-additive probabilities', *Journal of Mathematical Economics*, 16(1): 65-88.
- Gilboa, Itzhak and Schmeidler, David (1989), 'Maximin expected utility with a non-unique prior', *Journal of Mathematical Economics*, 18: 141-53.
- Gilboa, Itzhak and Schmeidler, David (1999), 'An overview of case-based decision theory', in Luini, Luigi (ed.)(1999), *Uncertain Decisions*, Boston, Kluwer.
- Gilboa, Itzhak and Schmeidler, David (2001), *A Theory of Case-based Decisions*, Cambridge, Cambridge University Press.
- Gray, John N. (1980), 'F. A. Hayek on Liberty and Tradition', *Journal of Libertarian Studies*, 4(2): 119-37.
- Gruchy, Allan (1987), *The Reconstruction of Economics*, New York, Greenwood.
- Hamouda, Omar and Smithin, John (1988), "Some remarks on 'Uncertainty and economic analysis'", *Economic Journal*, 98: 159-64.
- Hanusch, Horst and Pyka, Andreas (2007), 'Principles of Neo-Schumpeterian Economics', *Cambridge Journal of Economics*, 31(2): 275-89.
- Harcourt, Geoffrey (1981), 'Marshall, Sraffa and Keynes: Incompatible Bedfellows?', *Eastern Economic Journal*, 7: 39-50. Reprinted in Harcourt, G. (1992), *On Political Economists and Modern Political Economy*, London, Routledge.
- Hayek, Friedrich (1945), 'The use of knowledge in society', *American Economic Review*, 35(4): 519-30.
- Hayek, Friedrich (1960), *The Constitution of Liberty*, Chicago, University of Chicago Press.
- Hayek, Friedrich (1965), 'Kinds of rationalism', in Hayek, Friedrich (1967b).
- Hayek, Friedrich (1967a), 'The Theory of Complex Phenomena', in Hayek, Friedrich (1967b).
- Hayek, Friedrich (1967b), *Studies in Philosophy, Politics and Economics*, Chicago, University of Chicago Press.
- Hayek, F. (1973), *Law, Legislation and Liberty – Volume I*, Chicago, University of Chicago Press.
- Heiner, Ronald (1983), 'The origin of predictable behavior', *American Economic Review*, 73(4): 560-95.
- Hodgson, Geoffrey (1988), *Economics and Institutions*, Philadelphia, University of Pennsylvania Press.
- Hodgson, Geoffrey (1993), *Economics and Evolution*, Cambridge, Polity.
- Hodgson, Geoffrey (1999), *Evolution and Institutions*, Cheltenham, UK, Elgar.

- Hodgson, Geoffrey (2000), 'Shackle and Institutional Economics: Some Bridges and Barriers', in Earl, P. and Frowen, S. (eds.)(2000), *Economics as the Art of Thought*, London, Routledge.
- Holland, John (1988), 'The Global Economy as an Adaptive Process', in Anderson, P., Arrow, K. and Pines, D. (eds.)(1988), *The Economy as an Evolving Complex System*, Redwood City, CA, Addison-Wesley.
- Kahneman, Daniel (1996), 'New Challenges to the Rationality Assumption', in Arrow, Kenneth et al. (eds.)(1996), *The Rational Foundations of Economic Behavior*, New York, St. Martin's Press.
- Kahneman, Daniel and Tversky, Amos (1979), 'Prospect theory: An analysis of decisions under risk', *Econometrica*, 47: 263-91.
- Kapp, K. William (1968), 'In Defense of Institutional Economics', *Swedish Journal of Economics*, 70: 1-18.
- Karni, Edi and Schmeidler, David (1991), 'Utility Theory with Uncertainty', in Hildenbrand, W. and Sonnenschein, H. (eds.)(1991), *Handbook of Mathematical Economics*, vol. IV, Amsterdam, Elsevier, pp. 1763-1831.
- Kasper, Wolfgang and Streit, Manfred (1998), *Institutional Economics*, Cheltenham, UK, Elgar.
- Katzner, Donald (1998), *Time, Ignorance and Uncertainty in Economic Models*, Ann Arbor, Michigan University Press.
- Kelsey, David and Quiggin, John (1992), 'Theories of choice under ignorance and uncertainty', *Journal of Economic Surveys*, 6(2): 133-53.
- Keynes, John Maynard (1936), *The General Theory of Employment, Interest and Money*, London, Macmillan. 1964 edition, Harvester/HBJ.
- Keynes, John Maynard (1937), 'The General Theory of Employment', *Quarterly Journal of Economics*, 51: 209-23.
- Knight, Frank (1921), *Risk, Uncertainty and Profit*, Boston, Houghton Mifflin.
- Koppl, Roger (2002), *Big Players and the Economic Theory of Expectations*, Basingstoke, Palgrave Macmillan.
- Lachmann, Ludwig (1959), 'Professor Shackle on the Economic Significance of Time', *Metroeconomica*, 11: 64-73
- Lachmann, Ludwig (1976), 'From Mises to Shackle: An Essay on Austrian Economics and the Kaleidic Society', *Journal of Economic Literature*, 14(1): 54-62.
- Lane, David and Maxfield, Robert (1997), 'Foresight, complexity and strategy', in Arthur, W. Brian, Durlauf, Steven and Lane, David (eds.)(1997), *The Economy as a Complex, Evolving System II*. Reading, MA, Addison-Wesley.
- Lane, David and Maxfield, Robert (2005), 'Ontological uncertainty and innovation', *Journal of Evolutionary Economics*, 15(1): 3-50.
- Langlois, Richard. (1984), 'Internal organization in a dynamic context: some theoretical considerations', in Jussawalla, M. and Ebenfield, H. (eds.)(1984), *Communication and Information Economics: New Perspectives*, Amsterdam, North-Holland, pp. 23-49.
- Langlois, Richard (1986a), 'Rationality, institutions, and explanation', in Langlois, R. (ed.)(1986), *Economics as a process: essays in the new institutional economics*, Cambridge, Cambridge University Press.
- Langlois, Richard (1986b), 'Coherence and Flexibility: Social Institutions in a World of Radical Uncertainty', in Kirzner, Israel (ed.)(1986), *Subjectivism, Intelligibility and Economic Understanding*, New York, NYU Press.
- Langlois, Richard (1994), 'Risk and uncertainty', in Boettke, P. (ed.)(1994), *The Elgar companion to Austrian economics*, Aldershot, UK, Elgar.
- Langlois, Richard and Everett, Michael (1992), 'Complexity, Genuine Uncertainty, and the Economics of Organization', *Human Systems Management*, 11: 67-75.
- Lavoie, Marc (1992), *Foundations of Post-Keynesian Economic Analysis*, Aldershot, UK, Elgar.
- Lawson, Tony (1985), 'Uncertainty and economic analysis', *Economic Journal*, 95: 909-27.
- Lester, Richard and Piore, Michael (2004), *Innovation: The Missing Dimension*, Cambridge, MA, Harvard University Press.
- Lewis, Paul and Runde, Jochen (2007), 'Subjectivism, social structure and the possibility of socio-economic order: The case of Ludwig Lachmann', *Journal of Economic Behavior and Organization*, 62(2): 167-86.
- Lucas Jr., Robert (1977), 'Understanding Business Cycles', *Carnegie-Rochester Series on Public Policy*, 5: 7-29. Reprinted in Lucas Jr., R. (1981), *Studies in Business-Cycle Theory*, Cambridge, MA, MIT Press.
- Machina, Mark (1987), 'Choice Under Uncertainty: Problems Solved and Unsolved', *Journal of Economic Perspectives*, 1(1): 121-54.
- Madan, Dilip and Owings, James (1988), 'Decision theory with complex uncertainties', *Synthese*, 75: 25-44.
- Metcalf, Stanley and Foster, John (eds.)(2004), *Evolution and Economic Complexity*, Aldershot, UK, Elgar.
- Minsky, Hyman (1986), *Stabilizing an Unstable Economy*, New Haven, Yale University Press.
- Mukerji, Sujoy (1997), 'Understanding the nonadditive probability decision model', *Economic Theory*, 9(1): 23-46.
- Mukerji, Sujoy (1998), 'Ambiguity Aversion and Incompleteness of Contractual Form', *American Economic Review*, 88(5): 1207-31.
- Nelson, Richard (2003), 'Origins and Factors Shaping Our Joint Work Developing an Evolutionary Theory of Economic Change', available at <http://jonescenter.wharton.upenn.edu/2003/intellectual%20history%20of%20Nelson-Winter.pdf>.
- Nelson, Richard and Winter, Sidney (1982), *An Evolutionary Theory of Economic Change*, Cambridge, MA, Harvard University Press.
- Neumann, John von and Morgenstern, Oskar (1944), *Theory of Games and Economic Behavior*, Princeton, Princeton University Press.

- North, Douglass (1990), *Institutions, Institutional Change and Economic Performance*, Cambridge, Cambridge University Press.
- North, Douglass (1999), 'Orders of the Day', *Reason*, 31(6), 58-59.
- North, Douglass (2005), *Understanding the Process of Economic Change*, Princeton, Princeton University Press.
- O'Driscoll Jr., Gerald and Rizzo, Mario (1986), 'Subjectivism, Uncertainty, and Rules', in Kirzner, Israel (ed.)(1986), *Subjectivism, Intelligibility and Economic Understanding*, New York, NYU Press.
- O'Driscoll Jr., Gerald and Rizzo, Mario (1996), *The Economics of Time and Ignorance*, London, Routledge, 2nd edition.
- Orléan, André (1989), 'Pour une approche cognitive des conventions économiques', *Revue Économique*, 40(2): 241-72.
- Peterson, Wallace (1996), 'Macroeconomics and the Theory of a Monetary Economy', in Whalen, C. (ed.)(1996), *Political Economy for the 21st Century*, Armonk, NY, Sharpe.
- Piore, Michael (1995), *Beyond Individualism*, Cambridge, MA, Harvard University Press.
- Popper, Karl (1957), *The Poverty of Historicism*, Boston, Beacon Press.
- Prychitko, David (1993), 'After Davidson, who needs the Austrians: reply to Davidson', *Critical Review*, 7(2-3): 371-380.
- Quinet, Catherine (1994), 'Herbert Simon et la rationalité', *Revue Française d'Économie*, 9(1): 133-81.
- Rabin, Matthew (2002), 'Inference by Believers in the Law of Small Numbers', *Quarterly Journal of Economics*, 117(3): 775-816.
- Rabin, Matthew and Schrag, Joel (1999), 'First Impressions Matter: A Model of Confirmatory Bias', *Quarterly Journal of Economics*, 114(1): 37-82.
- Resnick, Stephen and Wolff, Richard (1987), *Knowledge and Class*, Chicago, University of Chicago Press.
- Resnick, Stephen and Wolff, Richard (2006), *New Departures in Marxian Theory*, London, Routledge.
- Rigotti, Luca, Ryan, Matthew and Vaithianathan, Rhema (2005), 'Tolerance of ambiguity and Entrepreneurial Innovation', <http://yoda.eco.auckland.ac.nz/~mrya008/PDFs/rrv-revised.pdf>.
- Rosser Jr., J. Barkley (2001), 'Alternative Keynesian and Post Keynesian perspectives on uncertainty and expectations', *Journal of Post Keynesian Economics*, 23(4): 545-66.
- Rosser Jr., J. Barkley (2004), 'Epistemological Implications of Economic Complexity', *Annals of the Japan Association for Philosophy of Science*, 13(1): 45-57.
- Ruccio, David and Amariglio, Jack (2003), *Postmodern Moments in Economics*, Princeton, Princeton University Press.
- Runde, Jochen (1993), 'Paul Davidson and the Austrians: reply to Davidson', *Critical Review*, 7(2-3): 381-97.
- Runde, Jochen (1995), 'Chances and Choices: Some Notes on Probability and Belief in Economic Theory', *The Monist*, 78(3): 330-51.
- Rutherford, Malcolm (1984), 'Rational expectations and Keynesian uncertainty: a critique', *Journal of Post Keynesian Economics*, 6(3): 377-87.
- Rutherford, Malcolm (1994), *Institutions in Economics*, Cambridge, Cambridge University Press.
- Savage, Leonard (1954), *The Foundations of Statistics*, New York, Wiley. 2nd edition, 1972, New York, Dover.
- Schmeidler, David (1989), 'Subjective probability and expected utility without additivity', *Econometrica*, 57(3): 571-87.
- Schmid, A. Allan (2004), *Conflict and Cooperation: Institutional and Behavioral Economics*, Oxford, Blackwell.
- Schumpeter, J. (1911), *Theorie der wirtschaftlichen Entwicklung*, Leipzig, Duncker & Humblot. American translation, *The Theory of Economic Development*, New York, Galaxy, 1961.
- Shackle, George (1953), 'The Logic of Surprise', *Economica*, 20(78): 112-17.
- Shackle, George (1969), *Decision, order and time in human affairs*, Cambridge, Cambridge University Press, 2nd edition.
- Shackle, George (1972), *Epistemics and Economics*, Cambridge, Cambridge University Press.
- Siegenthaler, Hansjörg (1997), 'Learning and its Rationality in a Context of Fundamental Uncertainty', *Journal of Institutional and Theoretical Economics*, 153(4): 748-61.
- Simon, Herbert (1958), 'The Role of Expectations in an Adaptive or Behavioristic Model', in Bowman, M. (ed.)(1958), *Expectations, Uncertainty, and Business Behavior*, New York, Social Science Research Council.
- Simon, Herbert (1959), 'Theories of Decision-Making in Economic and Behavioral Sciences', *American Economic Review*, 49(1): 253-83.
- Simon, Herbert (1978), 'Rationality as Process and as Product of Thought', *American Economic Review*, 68(2): 1-16.
- Simon, Herbert (1979), 'Rational Decision Making in Business Organizations', *American Economic Review*, 69(4): 493-512.
- Simon, Herbert (1982), *Models of Bounded Rationality*, vol. 2, Cambridge, MA, MIT Press.
- Slater, Gary and Spencer, David (2000), 'The Uncertain Foundations of Transaction Cost Economics', *Journal of Economic Issues*, 34(1): 61-87.
- Storper, Michael and Salais, Robert (1997), *Worlds of Production*, Cambridge, MA, Harvard University Press.
- Thaler, Richard (1991), *Quasi Rational Economics*, New York, Russell Sage.
- Tversky, Amos and Kahneman, Daniel (1982), 'Judgments of and by representativeness', in Kahneman, Daniel, Slovic, Paul, and Tversky, Amos (eds.)(1982), *Judgment Under Uncertainty: Heuristics and Biases*, Cambridge, Cambridge University Press.

- Tversky, Amos and Kahneman, Daniel (1986), 'Rational Choice and the Framing of Decisions', *Journal of Business*, 59(4): S251-78.
- Veblen, Thorstein (1898), 'Why economics is not an evolutionary science?', *Journal of Political Economy*.
- Veblen, Thorstein (1907), 'The Socialist Economics of Karl Marx and His Followers', *Quarterly Journal of Economics*, 21(2): 299-322.
- Vercelli, Alessandro (1991), *Methodological foundations of macroeconomics: Keynes and Lucas*, Cambridge, Cambridge University Press.
- Vercelli, Alessandro (1999), 'The Recent Advances in Decision Theory under Uncertainty: a non-technical introduction', in Luini, Luigi (ed.)(1999), *Uncertain Decisions*, Boston, Kluwer.
- Vercelli, Alessandro (2005), 'Rationality, Learning and Complexity', in Agarwal, B. and Vercelli, A. (eds.)(2005), *Psychology, Rationality and Economic Behaviour: Challenging Standard Assumptions*, London Palgrave.
- Vickers, Douglas (1979-80), 'Uncertainty, choice, and the marginal efficiencies', *Journal of Post Keynesian Economics*, 2(2): 240-54.
- Vickers, Douglas (1994), *Economics and the Antagonism of Time*, Ann Arbor, University of Michigan Press.
- Vickers, Douglas (1995), *The Tyranny of the Market*, Ann Arbor, University of Michigan Press.
- Williamson, Oliver (1985), *The Economic Institutions of Capitalism*, New York, Free Press.
- Williamson, Oliver (1996), *The Mechanisms of Governance*, Oxford, Oxford University Press.
- Witt, Ulrich (2003), *The Evolving Economy*, Aldershot, UK, Elgar.
- Wubben, Emiel (1995), 'Austrian Economics and Uncertainty: on a non-deterministic but non-haphazard future', in Meijer, G. (ed.)(1995), *New Perspectives on Austrian Economics*, London, Routledge.
- Young, H. Peyton (1998), *Individual Strategy and Social Structure*, Princeton, Princeton University Press.