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SCHUMPETERIAN INNOVATION IN MODELLING DECISIONS, GAMES, AND ECONOMIC BEHAVIOUR

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Von Neumann's standard paradigm of a game in extensive form and Kolmogorov's standard model of a stochastic process both rely on constructing a fixed state space large enough to include all possible future eventualities. This allows a typical single-person decision problem to be represented as a decision tree. Yet not all eventualities can be foreseen. Also, any practical decision model must limit the state space rather severely. In this way the standard paradigm excludes not only Schumpeter's ideas regarding entrepreneurship, innovation and development, but also Shackle's «unexpected events». This paper proposes an alternative approach using 'decision jungles' with an evolving state space.

1. Introduction

1. 1. *Schumpeter's Concept of Development*

The key to Schumpeter's (1912) concepts of entrepreneurship and development may be contained in the following two passages:

> ...economic life changes; it changes partly because of changes in the data, to which it tends to adapt itself. But this is not the only kind of economic change; there is another which is not accounted for by influence on the data from without, but which arises from within the system, and this kind of change is the cause of so many important economic phenomena that it seems worth while to build a theory for it, and, in order to do so, to isolate it from all the other factors of change.. . . what we are about to consider is that kind of change arising from within the system *which so displaces its equilibrium point that the new one cannot be reached from the old one by infinitesimal steps*. Add successively many mail coaches as you please, you will never get a railway thereby.
>
> (Schumpeter 1961, footnote to p. 64)

> To produce means to combine materials and forces within our reach... To produce other things, or the same things by a different method, means to combine these materials and forces differently. In so far as the 'new combination' may in time grow

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out of the old by continuous adjustment in small steps, there is certainly change, possibly growth, but neither a new phenomenon nor development in our sense. In so far as this is not the case, and the new combinations appear discontinuously, then the phenomenon characterising development emerges…

This concept covers the following five cases: (1) The introduction of a new good – that is one with which consumers are not yet familiar – or of a new quality of a good. (2) The introduction of a new method of production… (3) The opening of a new market… (4) The conquest of a new source of supply of raw materials or half-manufactured goods… (5) The carrying out of the new organisation of any industry, like the creation … or the breaking up of a monopoly position.

(Schumpeter 1961, 65-66)

These concepts are certainly very broad. They go beyond standard ideas of innovation to admit virtually any significant discrete or 'lumpy' shock to the economy that is created by some leap of the human imagination.

On the other hand, von Neumann (1928) devised what has become the standard paradigm in decision and game theory, which assumes that all possible future eventualities are included in an extensive game form. For the particular case of a single-person decision problem, this allows it to be represented as a decision tree, in which nature also has a once-and-for-all strategy represented by a member of a fixed state space, as in Kolmogorov's (1933) standard model of a stochastic process.

Shackle is one writer who has pointed out some serious defects in this framework. In Shackle (1953, p. 113) he defines a «counterexpected hypothesis» as what we might now call a 'counterfactual' – *i.e.*, 'a hypothesis that has been looked at and rejected'. Then, on the same page:

In contrast with this I define an *unexpected event* as one which has never been formulated in the individual's imagination, which has never entered his mind or been in any way envisaged.

Indeed, in many realistic situations that contemporary economists routinely model as decision trees or extensive games, the range of all possible uncertain future eventualities must expand over time to include *ex post* actual events that were entirely unpredictable *ex ante*, or at least outside the limitations of any practical ex ante model. Moreover, the best current action may not have the best pattern of uncertain consequences in the usual sense; instead, the relevant consequences emerge in stages from an evolving retrospective analysis applied to an adapting decision model. In a revised decision theory, such evolving consequences can be fitted within a coherent probabilistic framework embodying all possible relevant results of applying retrospective analysis to a sequence of increasingly detailed models.

1. 2. *Outline of Paper*

The rest of the paper begins in section 2 by describing von Neumann's standard paradigm in somewhat more detail. It also argues that both Savage's concept of «small worlds» and Simon's concept of «bounded rationality» fail to capture even the most pedestrian ideas of unforeseen contingencies or Shackle's «unexpected events», let alone the leaps of imagination and genius that often lie behind entrepreneurship, innovation, and Schumpeter's concept of «economic development».

Next, section 3 sketches an alternative approach using 'decision jungles' with an evolving state space. Each jungle is associated with an evolving sequence of bounded decision models that really does allow scope for events which go beyond what has been modelled earlier. Then section 4 lays out an agenda for developing the basic theory and demonstrating whether it is relevant in explaining some aspects of actual economic behaviour. Finally, after some remarks concerning Schumpeter's vision of innovation, section 5 briefly discusses some of the many possible applications of these ideas to economics, and to social science more generally.

2. von Neumann's Standard Paradigm

2. 1. *Babbage and Zermelo on Chess*

> ...I soon arrived at a demonstration that every game of skill is susceptible of being played by an automaton.
>
> Further consideration showed that if *any position* of the men upon the board were assumed (whether that position were possible or impossible), then if the automaton could make the first move rightly, he must be able to win the game, always supposing that, under the given position of the men, that conclusion were possible.
>
> Whatever move the automaton made, another move would be made by this adversary. Now this altered state of the board is *one* amongst the *many positions* of the men in which, by the previous paragraph, the automaton was supposed capable of acting.
>
> Hence the question is reduced to that of making the best move under any possible combinations of positions of the men.
>
> [...]
>
> Now I have already stated that in the Analytical Engine I had devised mechanical means equivalent to memory, also that I had provided other means equivalent to foresight, and that the Engine itself could act on this foresight.
>
> (Babbage 1864, as quoted in Levy and Newborn 1991, 26)

Thus does Babbage describe how, in abstract theory, his Analytical Engine could be an automaton that played Chess perfectly, in the sense of making the 'right' move in every possible position. The same argument applies also to Go and to any other 'game of skill' involving 'men' (or stones) 'upon the board'.

Whereas Babbage's argument was verbal and informal, Zermelo (1912) used backward induction to prove formally that Chess, starting from any (legal) position, has a definite result with best play: either White can force a win; or Black can; or the game should be drawn. Zermelo's proof also applies to Go and similar two-person board games which are deterministic. It works even though exhaustive analysis of all the possibilities in chess remains completely impossible to this day (except in greatly simplified 'endgame' positions with only a few pieces remaining on the board).[1]

2. 2. *Games in Extensive Form*

Following Zermelo, von Neumann (1928) laid out many of the key features of modern noncooperative game theory.[2] In particular, he provided a very general definition of what we now call an *extensive form game* (with *n* players, not just two; and very general payoff functions, not just zero sum). Later Kuhn (1953) pointed out how von Neumann's definition had presumed that the order in which different players move is common knowledge, but only a minor correction was needed.

I shall refer to this tremendous breakthrough as 'von Neumann's standard paradigm'. It is routinely applied in 'dynamic' models, including even those with an infinite horizon, following Ramsey's (1928) famous article on optimal saving. There is a fairly obvious link to the standard mathematical model of a stochastic process, following Kolgomorov's (1933) book laying out the measure-theoretic foundations of modern probability theory, especially for stochastic processes, also in continuous time, whose random values belong to infinite-dimensional function spaces.

2. 3. *Unrealistic Models of Economic Behaviour*

Despite von Neumann and Morgenstern (1944) choosing the title *Theory of Games and Economic Behavior* (and one of the two leading journals in game theory bearing the title *Games and Economic Behavior*), von Neumann's standard paradigm is too limited to serve as a realistic model of actual economic behaviour in complex settings. It reduces decision trees and extensive games to their normal form, in which each agent or player makes a single once and for all choice of strategy. This makes unrealistic demands on real decision makers' modelling and planning abilities, and on their imagination of what events could occur. In particular, for the games of Chess and Go, there is no possibility of either

[1] See Aumann and Hart 1992, 2-42 for more discussion of Chess, Go, and related games.

[2] The title is officially translated as «On the Theory of Games of Strategy», but more accurate would be 'On the Theory of Parlour Games'.

player 'outwitting' the other, since both players are assumed to make perfect moves all the time.

Von Neumann's idea also rules out unforeseen contingencies. It is a tautology that any extensive form game model can only include contingencies that the model, at least, takes into account. Anything else, such as an earthquake (or a young child's temper tantrum) upsetting the Chess board and pieces, is not foreseen. No fixed model will do – not even models as rich as von Neumann's (or Kuhn's), or Kolmogorov's very general model of a stochastic process.[1] Realism therefore creates a need to investigate how a decision maker may be forced to adapt to unpredicted events.

Thus, unforeseen contingencies force models to be revised. This is obvious if something unforeseen actually occurs. But it is also true if models which have been developed to respect practical limitations are then subsequently revised to include more detail concerning proximate possibilities.

2. 4. *Savage's Small Worlds and Microcosms*

Savage ([1972], 8) begins his discussion of small worlds by setting out several examples:

> The person might be uncertain about: 1. Whether a particular egg is rotten. 2. Which, if any, in a particular dozen eggs are rotten. ... 7. The exact and entire past, present, and future history of the universe, understood in any sense, however wide.

He then uses these examples to illustrate his idea of a series of increasing worlds (pp. 9-10):

> The sense in which the world of a dozen eggs is larger than the world of the one brown egg in the dozen is in some respects obvious. It may be well, however, to emphasize that a state of the smaller world corresponds not to one state of the larger, but to a set of states. Thus, 'The brown egg is rotten' describes the smaller world completely, and therefore is a state of it; but the same statement leaves much about the larger world unsaid and corresponds to a set of 2^{11} states of it. In the sense under discussion a smaller world is derived from a larger by neglecting some distinctions between states, not by ignoring some states outright. The latter sort of contraction

[1] The question arises whether one could define a 'meta' stochastic process on the space of all possible models involving a sequence of stochastic processes in which the state space is continually being enriched unpredictably. The stochastic process model, however, is based on Kolmogorov's extension theorem in probability. This theorem demonstrates that any 'consistent' family of probability laws on finite Cartesian subproducts of an arbitrary collection of measurable spaces can be extended to a probability law on the whole Cartesian product. The theorem, however, depends on a significant assumption: for example, that the probability distribution on each single measurable space is *tight* – *i.e.*, the probability of any set must equal the supremum of the probabilities of all compact subsets. See Aliprantis and Border 1999, which also includes a significant generalization due to Neveu 1965. It seems difficult to find a suitable topology on the space of all potentially relevant sequences of stochastic process models which allows an interesting probability measure to exist.

may be useful in case certain states are regarded by the person as virtually impossible so that they can be ignored.

So smaller worlds are derived from larger ones by coarsening the partition of the state space of, for instance, Example 2 into that of Example 1, and that of the 'grand' state space (Example 7, presumably) into different events regarded as 'small world' states.

Later (pp. 16-17) he discusses the need for a sequence of decision models:

The point of view under discussion may be symbolized by the proverb, 'Look before you leap,' and the one to which it is opposed by the proverb, 'You can cross that bridge when you come to it.' When two proverbs conflict in this way, it is proverbially true that there is some common truth in both of them, but rarely, if ever, can their common truth be captured by a single pat proverb. One must indeed look before he leaps, in so far as the looking is not unreasonably time-consuming and expensive; but there are innumerable bridges one cannot afford to cross, unless he happens to come to them.
[...]
Though the 'Look before you leap' principle is preposterous if carried to extremes, I would none the less argue that is the proper subject of our further discussion, because to cross one's bridges when one comes to them means to attack relatively simple problems of decision by artificially confining attention to so small a world that the 'Look before you leap' principle can be applied there.
[...]
In view of the 'Look before you leap' principle, acts and decisions, like events, are timeless. The person decides 'now' once and for all; there is nothing for him to wait for, because his one decision provides for all contingencies.

So in the end, Savage is reluctant to abandon von Neumann's standard paradigm. Eventually (p. 83) he does recognise, however, that a person over his or her lifetime is bound to consider nothing richer than a series of small world decision problems:

Making an extreme idealization, which has in principle guided the whole argument of the book thus far, a person has only one decision to make in his whole life. He must, namely, decide how to live, and this he might in principle do once and for all. ... Any claim to realism made by this book – or indeed by almost any theory of personal decision of which I know – is predicated on the idea that some of the individual decision situations into which actual people tend to subdivide the single grand decision do recapitulate in microcosm the mechanism of the idealized grand decision.

Yet nowhere does Savage seek to explore systematically the implications of a decision-maker using an evolving sequence of small models.

2. 5. *Simon and Bounded Rationality*

The games of Chess and Go are so complicated that playing them perfectly is humanly impossible, and even computationally infeasible.

At the time of writing the best computer Chess programs are worthy of being challenged by the very best humans in sponsored matches; in Go, the computer programs remain significantly worse.[1] All competent Chess and Go players know this already. So should all economists, especially after Herbert Simon (who himself devised an early computer chess program). Indeed, when it comes to describing actual behaviour, many decision models in social science do feature 'bounded rationality', or 'procedural rationality'. Usually, however, this involves what Simon (1955, 1957) called «satisficing» – making a decision that seems good enough rather than optimal.

The normative framework proposed in this paper, however, suggests that satisficing behaviour should occur, not within a given decision model, but in how much detail to include within the model. The framework also suggests that retrospection can play a significant role in a multiperiod framework. By contrast, very little existing work, even on bounded rationality or in economic psychology, recognizes that decision-makers may be forced to adapt their models to accommodate unpredicted events that have actually occurred.

3. Rationally Bounded Decision Jungles

3. 1. *An Evolving State Space*

Usually a fixed decision or game model contracts over time as history rules out many possibilities that did not occur. These possibilities become counterfactual, or what Shackle calls «counter expected». As time passes, one progresses along a branch through a decision tree (or extensive form game), leaving fewer and fewer future possibilities.

On the other hand the state space must expand over time to include events that were not modelled initially. This breaks the standard paradigm. Then there must be an evolving state space to recognise that any usable model of uncertainty must be incomplete.

3. 2. *Evaluating Consequences in a Decision Jungle*

According to von Neumann's standard paradigm, any decision strategy results in a 'Bayesian' consequence pattern which becomes successively refined as one proceeds through the tree and excludes decisions and events that are no longer possible. In a general decision jungle, however, the usual Bayesian approach to decision-making is inadequate,

[1] See http://www.intelligentgo.org/en/index.html, the website of the Intelligent Go Foundation.

even with subjective or personal probabilities. Then the best current action at the start of an arbitrarily long sequence of successive decisions may not have the best pattern of uncertain consequences in the usual sense.

In a static choice setting, Koopmans (1964) and Kreps (1992) explain why a «preference for flexibility» might result when there could be «unforeseen contingencies». A more formal analysis is set out in Dekel *et alii* (1998, 2001, 2007). However, some of their writing (1998, 528) seems to assume that there is an analyst who can foresee all possible contingencies:

> [N]o 'standard state-space model' can deliver a nontrivial model of unforeseen contingencies. A rough intuition for this result is that in standard state-space models, states play two distinct roles: they are the analyst's descriptions of ways the world might be and they are also the agent's descriptions of ways the world might be. If the agent is uanaware of some possibility, 'his' states should be less complete than the analyst's. Hence, any model which does not explicitly distinguish between the agent's descriptions and the analyst's will fail to capture unforeseen contingencies.

This appears to exclude a model where the agent's and analyst's descriptions match exactly, yet both fail to foresee some contingencies. Or even a model where the agent foresees more contingencies than an analyst.

Indeed, the implicit hypothesis seems to be that, even if human Chess and Go players are fallible, there is an analyst who understands everything! That analyst would know the best move in any given situation, including the start of the game. He would be a perfect critic of any particular game, as well as a perfect player. No person and no computer can achieve such perfection (except in especially simple positions, with relatively few moves left before the end of the game).

Really, this work seems to be about 'unawareness' rather than 'unforeseen contingencies'.

3. 3. *An Evolving Sequence of Rationally Bounded Models*

There is accordingly a need to investigate how a decision maker may be forced to adapt to unpredicted events. In fact, there is a need to go beyond the von Neumann standard paradigm to examine sequences of successive increasingly refined but bounded decision models. Also, apart from events that really are entirely unpredictable, also inevitable are events that only few agents, if any, manage to incorporate properly in their decision models. This is why real agents, insofar as they are conscious of anything that can be reasonably described as a decision model, must actually use a sequence of such models which gradually respond to evolving events, especially major events that were never predicted. Yet very little existing work, even that on bounded rationality or in economic psychology, recognizes that decision-makers may be forced to adjust their models to accommodate unpredicted events that have actually occurred.

Given that a sequence of decision models will be used, the best current action may no longer have the best pattern of uncertain consequences in the usual sense. Indeed, Kreps (1990) points out how bounded rationality creates a role for retrospective analysis; how good was that decision I just took in the light of the unforeseen event that has just occurred? Accordingly, the normatively relevant consequence patterns emerge in stages from an evolving retrospective analysis applied to a sequence of bounded models. Each successive model will remove counterfactual decisions and events from earlier models, but give an increasingly detailed picture of what remains.

4. Tasks for the 402nd Quinquennium (2006-2010)

«An agenda for the 21st century» makes a very nice conference subtitle. But any such agenda is undermined by the unpredictable events that give life and relevance to Schumpeter's own ideas. Five-year plans seem long enough. Here is one, broken down into several different tasks.

4. 1. *Develop a Normative Model*

In a revised decision theory, Kreps' (1992) work for the two-period case leads one to conjecture that evolving consequences can be fitted mathematically within a coherent probabilistic framework which embodies all possible relevant results of retrospective analysis. The construction of this framework may following ideas used originally to define universal type spaces for Harsanyi's (1967-1968) games of «incomplete information».[1]

4. 2. *Extend 'Overture Optimality'*

What really matters at any given time is any decision that either cannot be put off, or else should not be because an immediate commitment is best. At any decision node of a decision tree, all that really matters is the next decision; any future plans can be torn up if something unforeseen occurs.

Part of my Ph.D. thesis (see Hammond 1974) introduced infinite-horizon plans that were described as «overture optimal».[2] This meant that ultimately, the 'overture' plan for the first few periods would be

[1] Relatively brief explanations of this construction are set out in Brandenburger and Dekel 1993 and in Hammond 2004, 10.

[2] The terminology is suggested by Bliss 1975. The idea generalizes the «agreeable plans» that were originally defined in Hammond and Mirrlees 1973.

better than any alternative, provided the horizon is long enough. In an evolving sequence of decision models, this suggests looking for an immediate decision that is somehow robustly optimal when analysed retrospectively from many periods ahead.

4. 3. *Assess the Benefits of Improved Modelling*

Another task is to develop a framework that allows the benefits of decision making in improved models to be assessed. Then these can be weighed against the costs of providing expert advice concerning the available options when facing important economic or other decisions such as the choice of career, private pension scheme, investment portfolio, or setting up a business, or a doctor and patient together choosing an appropriate course of treatment for a serious ailment.

4. 4. *Develop Rationally Bounded Models*

The kind of normative model proposed in section 4. 1. suggests that satisficing behaviour should occur, not within a given decision model, but in how much detail to include within the model. This is along the lines suggested in Behn and Vaupel (1982) and Vaupel (1986), who described a theory in which the choice of whether to complicate a bounded model emerges from comparing the expected benefits of possibly changing the original decision with the costs of the extra analysis. See also Bolton and Faure-Grimaud (2005) for a related idea.

4. 5. *Develop an Empirical Bounded Model*

The idea set out in section 4. 4. suggests that, given a rich feasible set of options, at the first initial stage a decision maker is likely to select, quite possibly at random, only a small subset for later serious consideration. Of course, some options are much more likely to be selected than others, and the selected options may well be correlated random variables. Then, at a later second stage, an optimal element of that subset is selected.

At least superficially, this is somewhat different from the usual statistical or econometric models of random discrete choice. Especially important here are the «multinomial logit model» due to McFadden (1974) – see also Amemiya (1981, 1985) and the discussion in Hammond (2004). In normal form games, this model is the basis of the «quantal response equilibria» due to McKelvey and Palfrey (1995). Some of the most recent analysis appears in Haile, Hortaçsu and Kosenok (2006). The precise nature of the difference from such models needs to be established, along with statistical tests to see whether the hypothesis that the relevant theoretical restrictions are satisfied must be rejected in the light of relevant data.

4. 6. *Explain Behaviour in Experiments*

The kind of empirical bounded model discussed in section 4. 5. can be applied to appropriate selections from the large body of experimental studies that have already been conducted. Specifically, one can test the hypothesis that experimental subjects do make optimal choices, though within what may be very limited models. Some interesting observations that appear to lend some support to such a hypothesis are reported in Choi *et alii* (2006).[1]

4. 7. *Explain Subjects' Thought Processes in Experiments*

Some more direct experimental tests of bounded decision models like those in section 4. 5. should be possible. For example, an interactive web page can be designed to monitor how long, if at all, each experimental subject bothers to look at different relevant factors before making a specific decision.[2] It is also possible to use digital cameras attached to computer displays in order to track subjects' eye movements as they contemplate what choice to make.[3] The two techniques may even be usefully combined, in order to see how long, how often, and how carefully a subject looks at the different options, etc. Such observations should allow one to explore more powerful hypotheses that relate the likelihood and speed of choosing an item to the degree and kind of attention that is paid to it during the decision process.

4. 8. *Test an Empirical Model Using Field Data*

Another obvious task is to develop and test empirical models designed to explain cross-section data in concrete applications, not only to many fields of economics, but to social science more generally. Just one important use of such empirical models could be to provide quantitative estimates of personal losses due to ill-advised economic and other decisions. This may allow one to assess the likely benefits of policy interventions intended to produce better advice regarding key personal decisions, following the theoretical framework developed in section 4. 3. It may even encourage broader public understanding of the extent to

[1] See also Hey 2005.

[2] See the Java program MouseLab (available at www.mouselabweb.org), first described for decision-making by Payne, Bettman and Johnson 1990, 1992, 1993. It has been applied to experimental studies of games by Camerer *et alii* 1993, Costa-Gomes, Crawford and Broseta 2001, Johnson *et alii* 2002, Gabaix *et alii* 2003, etc.

[3] See the work of Russo and Rosen 1975 and of Russo and Leclerc 1994 on «eye-fixation analysis».

which well applied decision theory, well advised decisions, even some basic training in economics, are all relevant to everyday life.

4. 9. *Welfare Significance*

Provided that an agent uses some kind of rationally bounded model, perhaps after suitable advice, in principle one can infer revealed preferences concerning the modelled consequences of the decisions that the agent seriously contemplated. What are the ethical implications of this? What about psychological or neurological biases? See Bernheim and Rangel (2005, 2007) for related ideas.

5. Some Implications and Applications

5. 1. *Schumpeterian Innovation*

The initial section, with its quotations from Schumpeter's early book on *Economic Development*, provides only the briefest glimpse into the profundities of his insight. The innovation process in economic development transcends mere novelties like improved moves in a well known chess opening. It may also transcend creativity expressed in even great works of art; truly innovative artists found entirely new schools or styles, even new media. Schumpeterian innovation certainly transcends mere technical developments in decision and game theory along the lines sketched above.

Indeed, the paper largely spares the reader any not very informed musings I could offer on what Schumpeter might have meant by «innovation». Instead, the main point I want to make is that, regardless of how we understand innovation or economic development or whatever else we may want to call it, such phenomena are excluded by the von Neumann/Kolmogorov paradigm and just about all current ways of thinking. At the very minimum, some sort of unpredictably evolving state space is required. Otherwise the orthodox approach cannot even treat relatively pedestrian matters like unforeseeable (or unforeseen) contingencies; *a fortiori* it has no chance of encompassing Schumpeter's vision of the development process.

5. 2. *Economics, Finance, and Business*

Rationally bounded decision models surely have great potential in economics. For example, they allow a slightly different view of incomplete contracts; how can any contract ever be really complete if unpredictable events can never be ruled out entirely? They may also help explain why financial markets are incomplete, relative to the ideal mentioned in Debreu (1959, ch. 7), and allow better discussion of what gains could emerge from improved policy. Furthermore, the temporary equilibrium theory originally set out in Hicks (1946) may regain much of its appeal, because nobody can have a complete rational expectations theory of the random returns to different financial assets.

As for economic models designed to guide policy makers, there are two ways in which even rational myopia can make a major difference. First, one can conduct fairly standard policy analysis for an economy whose agents use their own myopic decision models. For example, it should be interesting to see how well earlier results on potential gains from trade and from other forms of market liberalisation extend to sequence economies subject to intermittent shocks which market agents are unable to predict. This may be a useful step toward a thorough theoretical analysis of the potential gains from financial market integration, or from enhanced competition in banking.

Among many other examples of economic and other applications, one concerns the frequency of public transport services. Nobody likes to miss the last bus home at night. Especially for the casual or infrequent traveller, it also saves much effort and planning if one can simply arrive at a bus stop or railway station knowing that the wait will not be too long. Reducing the frequency of bus or train services obviously saves labour costs, but may impel more travellers to resort to their own cars simply because they value the resulting flexibility. Even frequent travellers benefit from timetables which are memorable because they repeat themselves every hour during a large part of each day.

Another of many potential applications could include pension fund insolvency, or bankruptcy more generally. Rather too many current models in economics treat the risk of default on a loan (or other financial contract) as a predictable possible consequence of adverse circumstances that borrower and lender both voluntarily accept, even if the consequences to both may be distinctly unpleasant.

More generally, one of the economics profession's classic puzzles is why people choose to hold so much cash. Sometimes, of course, cash is used to mediate transactions where anonymity is desired because they are either illegal (for example, tax evasion or unregulated drugs), or morally dubious. But much more often there is the convenience of being able to make small routine purchases without any need to think ahead beyond the general idea that one should have a few euro notes readily available in case of sudden desire or need.

In addition, there may be ways to obtain a strategic or business advantage from deliberately manipulating what consumers believe about the possibility of unforeseen events, or the probability of unlikely ones. Why are some forms of insurance against accidental death or dismemberment so vastly overpriced? Why are lottery tickets so popular?

5. 3. *Other Disciplines*

Works like Becker (1974) would have us believe that criminals have rationally calculated that the expected benefits of crime, in the form of stolen property, etc., exceed the expected costs, which depend on the probability of detection and the severity of punishment. Yet personal testimony from 'at risk' youths living in tough American ghettos suggests that taking them on prison visits to see what may befall them has a significant deterrent effect. In other words, they find themselves expanding their decision model or 'mindset' in order to recognise that, like the criminally active members of the gangs they are tempted to join, they may be caught and experience similar harsh punishment.

As a simple example where bounded models may be relevant in politics, applying von Neumann's paradigm to voting suggests that actual runoff or second-round elections, like those commonly used in France, are equivalent to what some call 'instant runoff' voting, as is now used to elect many public officials in the City of San Francisco. Yet this equivalence claim seems dubious; an actual two-round ballot could well generate a different winner, even if the instant runoff were devised properly so that, in addition to voting for one candidate, everybody also votes in advance between the two people in every potential pair of runoff candidates.

Finally, few people like to think how awful worst case future events could be. Whether rational or not, such «myopic optimism» may be essential for psychological health. Indeed, perhaps nothing else could have survived natural selection.

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