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**Article**

## The economics of radical uncertainty

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# The Economics of Radical Uncertainty

*Paul Ormerod*

## Abstract

In situations of what we now describe as radical uncertainty, the core model of agent behaviour, of rational autonomous agents with stable preferences, is not useful. Instead, a different principle, in which the decisions of an agent are based directly on the decisions and strategies of other agents, is offered as a relevant core model. Preferences are not stable, but evolve. It is not a special case in such circumstances, but the general one. The author provides empirical evidence to suggest that as a description of behaviour in the modern world, economic rationality is applicable in a declining number of situations. He discusses models drawn from the modern literature on cultural evolution in which imitation of others is the basic strategy, and suggests a heuristic way of classifying situations in which the different models are relevant. The key point is that in situations where radical uncertainty is present, we require theoretical 'null' models of agent behaviour which are different from those of economic rationality. Under uncertainty, fundamentally different behavioural rules are 'rational'. The author gives an example of a very simple pure sentiment model of the business cycle, in which agents use very simple heuristic decision rules. It is nevertheless capable of approximating a number of deep features of output growth over the cycle.

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## **1 Introduction: Alchian, uncertainty and evolution**

Much of the discussion in economics about decision making under uncertainty is framed in the context of the works of Frank Knight and JM Keynes. There is a relative neglect of a brilliant paper written by Armen Alchian in 1950. Alchian considers uncertainty and economic theory from an evolutionary perspective. He anticipates by decades many of the insights of the modern mathematical articulation of the theory of evolution (for example, Solé and Manrubia 1996, Newman 1996, Ormerod 2005).

The purpose of Alchian's paper is to modify economic analysis in order to incorporate incomplete information and uncertain foresight as axioms. He argues, in a way which is now familiar, that "uncertainty arises from at least two sources: imperfect foresight and human inability to solve complex problems containing a host of variables even when an optimum is definable". Alchian's own discussion is set in the context of the behaviour of firms in such situations, but he suggests that the argument is readily transferable to consumer behaviour.

I argue below that there are important differences in the role of uncertainty in the types of decisions which firms and government often have to make, and the typical decision facing consumers. However, modern variants of the 'null' model put forward by Alchian are the relevant ones for both individuals and companies. By 'null' is meant the principles underlying the basic model of behaviour, which can obviously be adapted and extended if necessary.

Alchian begins by considering a model, albeit descriptive rather than formal, in the context of firms. Profits remain the criterion by which the economic system selects survivors. However, "It does not matter through what process of reasoning or motivation such success was achieved. The fact of its accomplishment is sufficient". In this model, individual rationality, motivation and foresight are temporarily abandoned, and the outcome is determined by sheer chance. It is as if the environment adopts the successful survivors, rather than the survivors adapting their own behaviour to the environment. Ormerod and Roswell (2003) show that a formal model of this kind generates results which are consistent both with the highly non-Gaussian distribution of the size-frequency relationship of firm extinctions (for example, Di Guilmi et al. 2004), and with the probability of extinction of any given firm with respect to its age (for example, Carroll and Hannan 2000).

This model is very similar to the modern unified theory of biodiversity (Hubbell 2001), which was developed to explain both the diversity and the relative abundance of species at a point in time in ecological communities. The postulate is that no species has any particular fitness advantage. In other words, the attributes of a species are irrelevant to their relative success or failure. The outcome in terms of relative abundance is ‘neutral’ with respect to the attributes of species. The theory is not without its critics, but it does seem to be consistent with the non-Gaussian distributions which are observed empirically.

## 2 Purpose and intent under uncertainty

Alchian then goes on to take into account that humans are not like other species. We can imagine the future, act with purpose and intent and consciously adapt our behaviour. He postulates that, even in the face of uncertainty, at least a local optimum might be found if firms follow what we would now term a Bayesian learning process. However, for convergence to an equilibrium, he argues that two conditions need to be satisfied. A particular trial strategy must be capable of being deemed a success or failure *ex post*, and the position achieved must be comparable with results of other potential actions. Alchian argues that it is unlikely that such conditions will hold in practice, for the simple reason that the external environment of a firm is not static but changing. Comparability of resulting situations is destroyed by the changing environment.

How, then, are agents to behave in the face of uncertainty? It is here that, in my view, his paper is at its most profound. Alchian argues that “in general, uncertainty provides an excellent reason for imitation of observed success”. He also suggests that there is also a role for innovation, in addition to the dominant behavioural rule of imitation. I return to the combination of these two motivations shortly, but first consider the implications of imitation.

Economic theory certainly contains models in which imitation is the main driver of behaviour in, for example, herding models. But these are seen as a special case compared to the more generally applicable model in which agents have fairly stable preferences and select on the basis of the attributes of the alternatives which are available. Alchian argues, all those years ago, that under changing external environments—under uncertainty—the model in which agents imitate the

behaviour of others is the general principle of behaviour, and not just the special case.

### 3 Experimental and empirical evidence

An important paper in *Science* confirms this intuition (Rendell et al. 2010). It is worth quoting from this paper at some length. Rendell and his co-authors come from a wide range of disciplines, although there are no economists. For them, “Social learning (learning through observation or interaction with other individuals) is widespread in nature and is central to the remarkable success of humanity”. A list of references is cited in support of this point. In other words, they start from Alchian’s position that imitation is a key driver of behaviour. However, the motivation for the paper is that “it remains unclear why copying is profitable and how to copy most effectively. To address these questions, we organized a computer tournament in which entrants submitted strategies specifying how to use social learning and its asocial alternative (for example, trial-and-error learning) to acquire adaptive behavior in a complex environment”.

A computer tournament was organised in which strategies competed in a complex and changing simulation environment. My fellow economists will be pleased to know that, in addition to the prestige of designing the winning strategy, there was a cash prize of 10,000 Euros. Entered strategies had to specify how individual agents in a finite population choose between three possible moves in each round, namely Innovate, Observe, and Exploit. Innovate represents individual learning, in which accurate information is relayed to the agent about the pay-off to a potential strategy. Observe gave noisy information about the behaviour and payoff currently being demonstrated in the population by one or more other agents playing Exploit. Finally, Exploit involved an agent actually playing a strategy and obtaining a pay-off. A key feature of the tournament was that the pay-offs to any given strategy were not time-invariant.

The results of the tournament were a surprise to the organisers: “Most current theory predicts the emergence of mixed strategies that rely on some combination of the two types of learning. In the tournament, however, strategies that relied heavily on social learning were found to be remarkably successful.... Indeed, the winning strategy relied nearly exclusively on social learning”. In other words,

Alchian's view that imitation—social learning—is a very sensible behavioural rule for agents operating in the face of uncertainty is supported strongly by the results of the tournament.

An obvious question which follows from this is an empirical one. Namely, to what extent do real life markets exhibit key features of uncertainty—essentially, an environment which is too complex to permit rational analysis? From a consumer perspective, there is certainly evidence that this is increasingly a feature of many markets. The number of alternative choices which is available has expanded dramatically in recent decades. Further, their attributes often differ in numerous minor ways which are difficult to comprehend.

Beinhocker (2007), for example, notes that: “The Wal-Mart near JFK Airport has over 100,000 different items in stock, there are over 200 television channels offered on cable TV, Barnes and Noble lists over 8 million titles, the local supermarket has 275 varieties of breakfast cereal, the typical department store offers 150 types of lipstick, and there are over 50,000 restaurants in New York City alone.” At the stock keeping unit level (SKU), the level of product detail at which retailers specify their restocking orders, Beinhocker estimates that on a single day in New York, there are 10 billion (!) such choices available. There may indeed be objective differences between the various offers, but in such numerous, minor and often incomprehensible ways that they exemplify what has come to be called ‘decision quicksand’ by Sela and Berger (2011) or ‘decision fatigue’ by Baumeister and Tierney (2011).

As discussed by Ormerod et al. (2012), given the huge amount of choice which has emerged in recent decades, the behavioural model of economics, namely that of rational selection on the basis of objective information, faces challenges, even when it is modified to take into account imperfect and asymmetric information. If rationality is defined as maximizing utility subject to constraints, but every possible good is effectively indistinguishable in terms of the computability of its impact upon consumer utility, then every good will be in the argmax of the utility function, and therefore every good will be chosen with equal probability.

## 4 Models of agent behaviour under uncertainty

The dominant paradigm within economics for how agents make decisions which have consequences in the future, rational expectations, requires considerable knowledge on the part of agents of the ‘true’ model which describes the operation of the economy. Agents either are already in possession of the relevant model, or discover it through some form of Bayesian learning. However, in many situations, especially in macroeconomics, there is unresolved uncertainty about the model itself. For example, in the context of macroeconomic models of the US economy, a major survey by Ramey (2011) shows that even in this rather narrow methodological context, the size of the fiscal multiplier, a basic concept in this area, varies between 0.8 and 1.5 according to whichever model one selects. Looking back to the policy debates in the immediate aftermath of the collapse of Lehman Brothers in September 2008, prominent economists, including Nobel Laureates, could be found on both sides of the argument as to whether or not to allow banks and other financial institutions to fail. It is hard to imagine that these groups of protagonists had the same model of the economy in mind.

More generally, within the statistics literature, there is a widespread understanding that model uncertainty is often an inherent feature of reality. It may simply not be possible to decide on the ‘true’ model. Chatfield (1995) is a widely cited paper on this topic. In an economic context, Onatski and Williams (2003), for example, in a survey for the European Central Bank of sources of uncertainty, concluded that “The most damaging source of uncertainty for a policy maker is found to be the pure model uncertainty, that is the uncertainty associated with the specification of the reference model”. Gilboa et al. (2008) note that “the standard expected utility model, along with Bayesian extensions of that model, restricts attention to beliefs modelled by a single probability measure, even in cases where no rational way exists to derive such well-defined beliefs”.

In short, in situations in which there is uncertainty about the true model which describes the system, it may not be possible for agents to form rational expectations. As a result, agents are uncertain about the probability distribution of potential outcomes.

Alchian (1950) suggest that in such circumstances of radical uncertainty, the appropriate decision rule is for agents to imitate the behaviour of others. Simon (1955a) developed a model for the purpose of explaining the highly non-Gaussian

right-skewed distributions which are a feature of many circumstances in both the socio-economic and the natural sciences. Ormerod (2012) gives examples of quite disparate right-skewed non-Gaussian outcomes from the social sciences: downloads on YouTube; film producers' earnings; the number of sexual partners people have; the size of price changes in financial assets; crowds at soccer matches; firm sizes; the size and length of economic recessions; the frequency of different types of endgames in chess; sizes of cities; the ratings of American football coaches in *USA Today*; the distribution of £1 million homes across London boroughs; unemployment rates by county in America; deaths in wars; the number of churches per county in William the Conqueror's Domesday Book survey of England in the late eleventh century.

Simon's model is a good heuristic for imitative behaviour. Agents essentially choose with a probability equal to the number of times any given alternative has been selected as a proportion of the total number of selections made across the agents to which the agent is connected. They may, for example, regard other agents as having more information than they do, and hence copy their behaviour. This has become known as the principle of preferential attachment, following the rediscovery of Simon's model in the highly cited paper by Barabasi and Albert (1999). The proposition has an even longer pedigree in economics than the work of Alchian and Simon in the 1950s. Keynes (1937), for example, in responding to criticisms of his *General Theory*, wrote that "Knowing that our own individual judgment is worthless, we endeavour to fall back on the judgment of the rest of the world which is perhaps better informed. That is, we endeavour to conform with the behavior of the majority or the average. The psychology of a society of individuals each of whom is endeavouring to copy the others leads to what we may strictly term a conventional judgment" (p. 214).

The model of behaviour in which agents select on the basis of preferential attachment is capable of explaining many observed distributions of popularity amongst alternatives at a point in time. However, the second key distinguishing feature is that there is turnover in rankings over time. The time-scale of turnover may differ very substantially depending on the particular example. Changes in, say, the rankings of popular songs change rapidly, whereas changes in the relative sizes of cities are slow, but nevertheless they do take place (Batty, 2006).

Models of choice arising from the principles of cultural evolution are capable of generating both non-Gaussian outcomes of relative popularity at a point in time



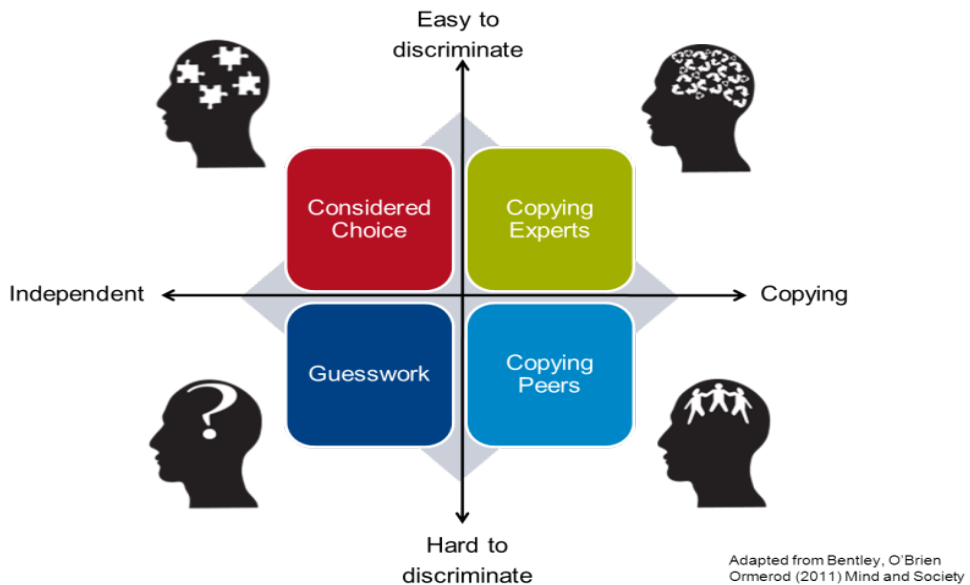
and turnover in rankings at a point in time. The seminal work in this area was by the biological anthropologists Boyd and Richerson (1985). Essentially, agents select using the principle of preferential attachment with probability  $(1-\mu)$ , and with probability  $\mu$  innovate in the sense that they select an alternative which no-one has previously selected (for example, Hahn and Bentley 2003, Shennan and Wilkinson 2001). The model has been generalised to include the effects of memory (Bentley, Ormerod, Batty 2011), and a spatial dimension (Bentley et al. 2014). It is important to note that this modelling approach differs from that based upon the concept of rational addiction with preferences which are learned and are intertemporally dependent (for example, Becker and Murphy 1988, Britto and Barros 2005). In this model, agents are not required to learn preferences over time. At any point in time, an agent makes a choice based simply on the choices made by others, with a small probability of random innovation in making their selection.

Models of decision making such as these, derived from the evolutionary literature, may very well seem strange to economists. In complete contrast to the rational choice model of economics, agents pay no attention to the attributes of the alternatives in any given situation, but simply use a heuristic of whose behaviour to copy when making the choice. Obviously, in practice a combination of these two different motivations may very well operate. But, in the cyber society of the 21<sup>st</sup> century, it is increasingly difficult to argue that rational choice, even when modified to take imperfect information into account, is the way in which agents make decisions in most circumstances.

## **5 A classifying heuristic**

Bentley, O'Brien, Ormerod (2011) develop a heuristic for classifying the circumstances in which different kinds of models are the relevant 'null' models of behaviour with which to account for how agents select amongst alternatives. To emphasise, it is a heuristic and not in any way intended to be a complete set of criteria for such classification.

On the horizontal axis, we represent the extent to which agents select either independently or by copying/imitation. The vertical axis shows the relative ease with which the attributes of the alternatives can be distinguished.



**Figure 1** A heuristic for classifying situations in which different ‘null’ models of agent behaviour are appropriate

The top left hand box can be thought of as the area in which standard rational consumer choice theory is relevant. Social influence on choice is weak, and agents select primarily in an independent manner. The attributes of the alternatives are relatively easy to distinguish.

This latter point can be unbundled into a number of different layers, which cannot be captured in a simple 4-box heuristic chart such as Figure 1. For example, the costs of gathering information about the alternatives should not be large. The number of alternatives should be relatively small, so that the agent is able to process the information. This much is obvious.

But there is an implicit time dimension to the costs of gathering and processing information. Choices which have implications into the future may not have time-invariant costs associated with them. So, for example, at a point in time an agent can readily compare the rates of return of alternative asset portfolios. But attempting to understand the future rates of return is an altogether more challenging problem. In principle, an agent can attempt to gather and process

information autonomously about the potential future rates, but this exercise starts to move us down into the bottom left-hand quadrant, where attributes are hard to distinguish.

As we move to towards the right of Figure 1, and social influence becomes more important as a driver of behaviour, uncertainty becomes more important as a feature of the environment. The suggestion underlying the two quadrants in this part of the chart is that the network structure which influences agents might plausibly differ. In the top right, for example, agents may copy a small number of other agents who either actually have, or are believed to have, genuine expertise in being able to distinguish the attributes of alternatives. A simple example is that of a wine columnist in a newspaper. Readers may reasonably believe that he or she has more ability to differentiate the qualities of different wines than they have. So implicit in this is a network which may have scale-free features. A small number of people may influence large numbers of others. In the bottom right, we have situations in which agents may rely more on the judgments of friends or family, or even work colleagues, people known to them. The networks of influence here will have more of a small world quality to them.

Figure 1 is, at the risk of repetition, simply a heuristic for classifying different situations in which different ‘null’ models of how agents make choices are appropriate. The key point is that the postulates of rational choice theory in economics are most relevant in situations in which uncertainty is low, the top left-hand quadrant of the chart.

## **6 Sentiment, uncertainty and the business cycle**

The behavioural models discussed above are particularly relevant to consumers. A new dimension is introduced, when we consider many of the major decisions made by companies and governments. The most basic difference between these and almost all consumption decisions is that these are often one-off situations, where copying may have limited applicability simply because of a lack of comparable situations in which other agents are making, or have already made, decisions.

To take an actual example from the UK at the present time, the government is contemplating building, at huge expense, a new high speed rail line between the North of England and London (High Speed 2, as it is known). Now, many high

speed lines have been built around the world, and there is some value in examining the costs and impacts of such lines. However, each of these lines has many unique features, and it is hard to generalise from these examples to provide evidence either for or against HS2, which also has its own very specific characteristics. A major infrastructure project, the largest in Western Europe, which is actually taking place, is Crossrail, a project which involves massive new tunnels underneath the whole of Central London. In making the decision to go ahead with this project, it would not have made sense to look for examples to copy, because there are none. The same difficulty in finding reasonably comparable situations characterises many major capital investment decisions made by companies.

A further distinguishing feature of large government and corporate investment decisions is that they are hard to reverse. The capital stock, to use the jargon of the growth theory of the 1960s, is 'putty-clay'. *Ex ante*, many configurations are possible. *Ex post*, it is very difficult to turn it into something else.

Perhaps the most important aspect of investment decisions is that their impact takes place over many years. The environment can change in so many completely unanticipated ways that attempting to compute the optimal decision now is an exercise which makes very little sense. This is the context in which Simon (1955b) introduced, in his seminal paper on behavioural economics, the concept of satisficing. Modern economics has neutered the impact of this concept, and redefined it to mean that it is simply a way in which agents deal with the costs of gathering and processing information. An agent examines alternatives, and once a satisfactory one is found, judges that the costs of further searching and processing for the optimal choice outweigh the increase in benefits.

Simon, however, regarded satisficing as meaning a heuristic rule of behaviour which agents used in situations where the optimal choice can never be known, even *ex post*. He used the game of chess as an example. The game of chess is in principle very simple. There are about a dozen rules, which can be learned easily. The object of the game is unequivocal, to capture the opponent's King. And you know everything which your opponent has done. But in most situations in the game, the optimal move cannot be computed. Many bad options can be eliminated, and players like Carlsen, the world champion, will do this much more effectively than an average player. Even at world championship level, this is how most games are lost and won. It is not often a matter of superior rational calculation of the consequences of a move. It is the judgment about what constitutes a good move.

Do computers help? All positions with seven pieces have now been solved. But there are 32 pieces in chess, and the computational complexity scales super-exponentially with the addition of each piece.

How, then, do agents make decisions in such situations? Faced by massive uncertainty, lacking reliable comparator examples to form the basis for a strategy of copying, how are they able to make any decision, rather than being paralysed by the complexity of the situation?

The fact is that people *do* make decisions. Throughout history innovation and investment repeatedly take place despite the ready availability of “rational” objections to action. Canal builders, railway builders, opera house builders, airport builders, dotcom entrepreneurs and many others all took action without knowing what the outcome would be. The results of their willingness to act on their vision allow us to use what they left behind, albeit that in many cases expectations were not fulfilled and actions led to bankruptcy and disappointment. In the long run there can be little doubt that their decisions enhanced welfare.

This is the context in which, of course, Keynes introduced his famous concept of animal spirits. The animal spirits which drive the marginal efficiency of capital are a psychological concept rather than one which is amenable to rational calculation. In the *General Theory* (Keynes 1936), he writes, for example, that ‘Most, probably, of our decisions to do something positive ...can only be taken as a result of animal spirits—of a spontaneous urge to action rather than inaction, and not as the outcome of a weighted average of quantitative benefits multiplied by quantitative probabilities’ (p.161). He goes on: ‘Enterprise only pretends to itself to be mainly actuate by the statements in its own prospectus...only a little more than an expedition to the South Pole is it based upon benefits to come. Thus if the animal spirits are dimmed and spontaneous optimism falters, leaving us to depend on nothing but mathematical expectation, enterprise will fade and die’.

## **7 A pure sentiment model of the business cycle under uncertainty**

Of course, the animal spirits of any given agent are influenced by the behaviour and opinions of other agents to whom any given agent is connected. Understanding how competing opinions emerge and how some percolate across a

network whilst most fail is the next task in incorporating uncertainty into firm behaviour.

I did set out over a decade ago a simple model of the business cycle incorporating networks in this way (Ormerod 2002), which is able to account for a number of important empirical properties of output growth over the business cycle. The model should be regarded as a basic building block. It is essentially a pure sentiment-driven model of the cycle, and is populated only by firms. This simplification is not completely unrealistic, because the national accounts data of Western economies shows quite clearly that most of the fluctuations in aggregate output arise from the corporate sector and its decisions on inventories and fixed capital formation. There is no government and no monetary sector. The size distribution of the firms is given by a power law, which approximates the actual empirical distribution of firm sizes.

This is by no means the only possible alternative approach to macroeconomics to the dynamic stochastic general equilibrium models which, along with real business cycle models from which they have been developed, have dominated academic economics for well over two decades. Keen (for example, 2013) has developed models in which money and debt play key roles in the cycle, and in particular in the major recessions of the 1930s and late 2000s. This sentiment-driven model might be thought of in the context of the much shorter, shallower recessions which are more typical, though much less dramatic and damaging.

In any given period, a firm has to make two decisions. These are made using very simple heuristics. Firms are myopic, and make no attempt to carry out optimising behaviour.

First, a firm sets its output growth for the period and, second, it sets what I describe as the firm's 'sentiment' about the future. The concept of sentiment here should be thought of as being the animal spirits of Keynes. It is not a precise mathematical calculation about the future.

The output of any given firm is set according to a weighted average of its output growth in the previous period and the overall state of sentiment in the economy in the previous period. The first term captures a simple autoregressive process, which is then modified by aggregate sentiment. The latter is the sum of the level of sentiment held by each individual firm, weighted by its output. So the firms are assumed to operate on a completely connected network in this context. They do not assign particular importance to any other firm, except in so far as a

very large firm carries more weight in the measure of overall, sentiment than a smaller one.

The sentiment of any given firm depends on its sentiment in the previous period and negatively upon the overall rate of growth of output in the previous period. This latter term reflects the Keynesian basis of the model. Keynes (1936) never articulated a formal theory of the business cycle. In Chapter 22 of the *General Theory*, however, he wrote that: ‘By a cyclical movement we mean that as the system progresses in, e.g., the upward direction, the forces propelling it upwards at first gather force and have a cumulative effect on one another but gradually lose their strength until at a certain point they tend to be replaced by forces operating in the opposite direction; which in turn gather force for a time and accentuate one another, until they too, having reached their maximum development, wane and give place to their opposite’. A mathematical approximation to this description is, of course, that of a simple oscillator, and hence the negative sign on output growth in the previous period. Further justification for the negative sign can be found in the growth cycle model of Goodwin (1967). Goodwin’s model can be reduced to two dynamic identities:

- The employment rate will rise if economic growth exceeds the sum of population growth and growth in labor productivity.
- The share of wages in output will rise if wage demands exceed growth in labor productivity.

These two factors imply that—at least in some stages of the trade cycle—economic growth reduces profits, as the growth causes increases in wage costs that reduce aggregate profit.

A more formal statement of the model is as follows:

$$x_i(t) = (1-\alpha) x_i(t-1) + \alpha[Y(t-1) + \varepsilon_i(t)] \quad (1)$$

where  $x_i(t)$  is the rate of growth of output of agent  $i$  in period  $t$  and  $Y$  is the overall sentiment of all agents (the weighted sum of the levels of sentiment of the  $N$  individual agents).

The variable  $\varepsilon_i(t)$  is a random variable drawn separately for each agent in each period from a normal distribution with mean zero and standard deviation  $sd_1$ . Its role is to reflect both the uncertainty which is inherent in any economic decision

making and the fact that the agents in this model, unlike mainstream economic models which are based on the single representative agent, are heterogeneous.

The implications of any given level of overall sentiment for the growth rate of output of a firm differ both across the  $N$  agents and over time. Firms are uncertain about the precise implications of a given level of sentiment for the exact amount of output which they should produce. Further, the variable  $Y$  is based upon an interpretation of a range of information which is in the public domain. Agents again differ at a point in time and over time in how they interpret this information and in consequence the value which they attach to  $Y$ .

The sentiment of the  $i$  th agent is determined by the following:

$$y_i(t) = \beta y_i(t-1) - \gamma[X(t-1) + \eta_i(t)] \quad (2)$$

where  $X$  is the overall rate of growth of output of the economy (the weighted sum of the  $x_i$ ), and where  $\eta_i(t)$  is again drawn from a normal distribution.

The variable  $\eta_i(t)$  again reflects agent heterogeneity and uncertainty. At any point in time, each agent is uncertain about the implications of any given level of  $X(t-1)$  for its own level of sentiment. A further practical point is that, although estimates of  $X$  are provided in the national accounts of the economy, they are both estimated with potential error and are subject to future revision.

Even at the risk of over-emphasising the point, it is worth repeating that in each time period firms do *not* share the same  $\varepsilon_i$  and  $\eta_i$ . The variables  $\varepsilon_i$  and  $\eta_i$  are *not* degrees of uncertainty which are common to all firms, but each firm in each period has its own  $\varepsilon_i$  and  $\eta_i$ . In other words,  $\varepsilon_i$  and  $\eta_i$  must *not* be regarded as a common, exogenous shock which all firms experience.

The agent-based model is solved 1000 times, after calibrating the parameter values. The model can reasonably be described as minimalist. Nevertheless, it is capable of capturing key features of output growth over the cycle, a number of which are set out in Ormerod (2010), and are based upon an analysis of annual real GDP growth in 17 capitalist economies 1871–2007. The main features are as follows:

- The autocorrelation function has a low positive value at lag one and is zero elsewhere.
- In the frequency domain, the power spectrum has a relatively weak concentration at a frequency of 5–10 years.



These features are perhaps reasonably well known. Less well known is the highly non-Gaussian distribution of the cumulative size of recessions. Further, most recessions are very short, with 70 per cent lasting just a single year. The model above gives a good approximation of the distributions of both the size and duration of recessions, key aspects of the capitalist economies. This does not appear to be the case with any mainstream economics model of the cycle.

In addition, there is positive cross-correlation of output growth over the cycle across the firms. This of course was identified by Lucas (1977) as being a key reason why we can speak of a business cycle, when to people with a natural science background, for example, a time series plot of real GDP growth does not immediately give the impression of being a cycle.

In this model, cycles are endogenous and arise through both uncertainty and the fact that companies operate on completely different scales. The latter point was discovered independently a decade later by Gabaix (2011).

## 8 Conclusion

The rational choice model of economics is by no means an empty box. In particular, the insight that agents respond to changes in incentives is a powerful one. However, in a world in which uncertainty is important, economists need to consider other models of decision making as part of their basic toolkit.

Uncertainty is increasingly a feature of the real world, considerably more so than it was when economic theory was first formalised in the late 19<sup>th</sup> century. Consider Simon's statement in his seminal paper on behavioural economics: "Broadly stated, the task is to replace the global rationality of economic man with a kind of rational behaviour that is compatible with the access to information and the computational capacities that are actually possessed by organisms, including man, in the kinds of environments in which such organisms exist" (Simon 1955b, p. 99).

Limits on computational capacity apply more and more in seemingly everyday situations. As noted above, Beinhocker has estimated that at the stock keeping unit level, an individual in New York City on any single day is faced by no less than 10 billion alternatives. Even if he is wrong by one, or even two, orders of magnitude, the computational task of evaluating the alternatives is such that it is as if agents

operated under uncertainty. In addition, many products are increasingly complex, and the alternatives differ in a large number of minor but nevertheless complex ways, which makes the attributes again difficult to compare in a systematic way.

Agents cope with such situations by using heuristics as a basis for decision making, and abandon any attempt to optimise. Imitating other agents, using some form of heuristic to select the relevant peer group to be potentially copied, is a very sensible way to behave in such situations.

Similar concepts apply in the circumstances envisaged by Alchian, in which the environment evolves sufficiently rapidly to make systematic Bayesian learning difficult. As he argued, Bayesian learning essentially requires that particular trial strategy must be capable of being deemed a success or failure *ex post*, and that the position achieved must be comparable with results of other potential actions. Such conditions also apply to the evaluation of actions with important consequences for the future, and which are not easily reversible.

A key task is to develop formal models of agent decision making which are better placed to cope with the challenges posed by Alchian (1950) and Simon (1955b). The tools were simply not available when they wrote their seminal papers, but agent-based models and simulation techniques free us from the restriction of being obliged to work only with models for which analytical solutions can be obtained.

In this paper, I discuss two such models, both of which are effectively based upon the principle of imitation. One is derived from cultural evolution, in which agents are indifferent to the attributes of alternatives, and the other offers micro foundations for a pure sentiment based model of the business cycle. In neither case do agents attempt to optimise, and instead use ‘satisfactory’ heuristics.

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