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Complexity and the evolution of market structure

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Introduction

Peter Allen was one of the pioneers of the application of complex systems to problems in the social sciences. This view of the world stands in marked contrast to the rational agent, rational expectations (RARE) model of conventional economics.

A key feature of the complex systems approach is that the understanding which individual agents have of the world is inevitably imperfect. They cannot be ascribed the cognitive powers of gathering and processing information which exist in conventional economic theory.

Within economics itself in the late 20th/early 21st centuries there has been increasing recognition of this. From the conventional paradigm of the fully rational agent with full information and using a universal behavioural rule of maximisation, economics initially relaxed the assumption of full information, creating the concept of bounded rationality. Now, experimental and behavioural economics point to the use of limited information and rules of thumb, each one customised to particular circumstances (for example, Akerlof 2002, Kahneman 2003, Smith 2003).

In a complex system, there is a low (or even zero) ability to predict the state of the system at any given point in the future. There may very well be stable statistical distributions from which describe the range of behaviours of the macroscopic factors, so that we can reasonably estimate the proportion of time which the system spends in any particular state. But we cannot predict consistently at particular points in time with any reasonable accuracy.

Further, complex systems will typically exhibit multiple possible histories. By definition there can only ever be one actual history, but at any point in time the system has the potential to move in a variety of different ways.

Again, complex systems restore the concepts of time and process into modelling. Orthodox economics is essentially concerned with comparing successive equilibriums. A system is in equilibrium, a change of some kind takes place, and economic theory deals with the properties of the new equilibrium following the change. But in reality, systems spend much of their time out of equilibrium, and understanding the time path and the evolution of the system along it is crucial.

Peter was developing models as long ago as the 1980s which exhibited these features. Peter and I met shortly after I published the *Death of Economics* in 1994. I was captivated by his model of fishing fleets. Here was someone who not only shared my criticisms of RARE economics, but was successfully working with the new paradigm of model building. This was a great inspiration to me.

His fishing fleet model was not only intellectually appealing, for someone like me who had been actively engaged in running a company, it struck an immediate chord. Yes, this was what business was actually like. Just like the fishing boat crews in Peter's model, we didn't sit around trying to discover our marginal cost curve and trying to work out optimal strategies. We acted, took decisions which seemed reasonable. Sometimes they worked, sometimes they did not. We could never tell in advance, no matter how hard we thought about it, which it would be.

Of course, this was in the context of a small and medium sized enterprise (SME). But here is an account of what life is actually like inside Microsoft, one of the world's largest companies, given in Marlin Eller's book *Barbarians Led by Bill Gates*. Eller was from 1982 to 1995 Microsoft's lead developer for graphics on Windows. Windows now of course dominates the PC operating systems world. But its success was based far more on a series of accidents than on a far-sighted, planned strategy.

Eller's introductory remarks are worth quoting at some length: 'There was a great disconnect between the view from the inside that my compatriots and I were experiencing down in the trenches, and the outside view... in their quest for causality [outsiders] tend to attribute any success to a Machiavellian brilliance rather than to merely good fortune. They lend the impression that the captains of industry chart strategic courses, steering their tanker carefully and gracefully through the straits. The view from the inside more closely resembles white-water rafting . "Oh my God! Huge rock dead ahead! Everyone to the left! NO, NO, the *other* left!"'

In this contribution to the *Festschrift*, I discuss two models of how firms operate which have more realistic behavioural foundations than does the standard RARE model. Firms and consumers both react to incentives, but do so on the basis of imperfect information and use of rules of thumb to make decisions rather than so-called 'optimal' decision rules. Time and process are both important features of the models, and there is a great deal of contingency around the outcomes.

I first of all offer some brief remarks on the concept of competition and market structure in the history of economic thought, before setting out the first of the models. The results raise important methodological issues for agent-based models, which I discuss before going on to consider the second model.

Competition and market structure

During the 19th century and the opening decades of the 20th, a great deal of work had been done on the standard paradigm of firm behaviour and markets in economics, namely that of so-called perfect competition. The key simplifying assumption in this model is that the number of firms in a particular market is so large that no single firm can influence the price by its decisions on output. The firms are 'price-takers'. This of course immediately raises the question that if no firm can influence price, how is

price determined? This may seem an obvious point, but it is one which is so neglected by mainstream economists on an everyday basis that Vernon Smith referred to it specifically in his Nobel prize lecture: 'As a theory the price-taking parable is also a non-starter: who makes price if all agents take price as given?' (Smith, op.cit.).

A substantial amount of work had also been carried out on a market with a single supplier, and a market with a very small number of suppliers, oligopoly. Cournot's analysis in 1838 is a classic example of the latter. The extension to a market with a large number of suppliers each of whom could exercise some influence over price, so-called imperfect competition, took until the 1930s to develop (Chamberlin 1933, Joan Robinson 1933).

This analysis completed the set, as it were, in economic theory which classifies markets according to the number of firms. In general, price would be lower under perfect competition, and then gradually rise through imperfect competition, oligopoly and finally monopoly.

However, doubt about the neatness of this paradigm began to emerge within economics. Joan Robinson herself, for example, writing in 1960 stated that 'the number of firms in any particular market is largely a matter of historical accident'. John Sutton, a leading industrial economist and former head of department at LSE, takes up a similar theme four decades later (Sutton, 2000). Writing in the context of market structure, Sutton notes that even relatively mild relaxations of the assumptions of the basic model rapidly lead to indeterminate outcomes characterised by multiple equilibria. He notes that in most practical contexts, the 'search for a true model becomes futile', not least because of the huge amount of precise information which would be needed about the competing firms and their strategies.

I illustrate the above themes with two models of the decisions of firms. First, a market in which the various products on offer are in general identical, but they are differentiated with respect to a single attribute. Consumers have preferences with respect to this attribute. Firms have to consider the offer which they make in order to maximise their market share.

Second, a model of entry into a market in which there is a single monopoly supplier. A change in regulation permits other firms to enter the market. Using reasonable rules of behaviour in which both firms and consumers react to incentives, a wide variety of outcomes is possible in terms of the evolution of price, quality, and the number of firms in the market.

For example, there is little or no connection across the individual solutions between the price which eventually obtains and the number of firms which survive in the market. This is much more in keeping with the experiences of deregulated industries than the standard economic view that the fewer the firms, the closer is price to that set by the initial monopolist.

Entry into a simple market

Hotelling (1929) introduced an interesting model in this context. Imagine a crowded beach at the height of summer. Two rival ice-cream sellers are deciding whereabouts to locate on the beach. They know three basic facts. First, the bathers are spread completely evenly across the entire range of the beach.

This much may be obvious from simple inspection. Second, each person on the beach will at some point during the day want an ice-cream, although no-one will buy more than one. This is much less obvious, but we might suppose that the sellers are able to deduce this on the basis of previous experience. Third, no matter where the sellers locate on the beach, everyone will still want an ice cream. This is even less obviously true, but suppose for the moment that it is, and that it is known to the prospective vendors.

Where should the rivals choose to set up their stalls? We make a final assumption, that there are no costs to the sellers of re-locating from any location they might choose. In this highly simplified model, the firms (the ice cream sellers) are assumed to have accurate, detailed knowledge of consumer preferences, and their products are absolutely identical except for the place at which they are located. In the jargon of economics, their products are homogeneous except with respect to one attribute. This latter assumption is actually very restrictive when one thinks of the proliferation of ways in which even staple products such as milk are differentiated in practice: whole fat, semi-skimmed, skimmed, flavoured, available in bottles, cartons and plastic containers of different sizes.

Under these assumptions, Hotelling demonstrated that there is only one equilibrium location. Both firms locate exactly half way along the beach. At this point, each firm obtains half the total market, and neither can increase its market share by re-locating. For descriptive purposes, the consumers are distributed evenly in the interval $[0, 100]$, and this point is 50. There is an unstable equilibrium at $(25, 75)$, where each firm also obtains a market share of one-half. It is obvious that this is more convenient for consumers, since no-one would have to travel a distance of more than 25, compared to a maximum of 50 if the firms locate at $(50,50)$. However, a firm can always increase its share by moving towards 50.

This very simple model becomes much more complicated purely by extending the number of potential entrants to more than two firms. The theoretical work on this is summarised by Huck et.al. (2002): 'only the two and four agent cases yield unique pure and symmetric equilibrium configurations that give identical payoffs to each agent'. For six or more firms, the equilibria cease to be unique.

In the case of four firms, the unique equilibrium involves two located at 25 and two at 75. However, as Huck et.al. (2002) note, this is 'not entirely intuitive and is also conflicting with casual empirical evidence'. They point out that there are no cities without shops in the central location, nor are there democracies with no political parties in the centre ground. They go on to carry out experiments with economics and business school students, and find that a W-shape distribution tends to emerge, with agents clustered around not just the two equilibrium points but also around 50. So although a stable equilibrium exists, in practice it appears to be hard to discover. The situation is even more complicated in the case of three and five firms, where the equilibrium involves entrants using a randomised strategy. And it is 'a well established fact that experimental subjects have difficulties in randomising'.

So far, the assumption has been made that the firm can re-locate without cost. This is clearly unrealistic in most contexts, even in the current one where many simplifying assumptions are being made. Hotelling used for illustrative purposes a physical location decision. But the phrase 'location' can obviously be used more generally to indicate the positioning of an attribute of a product or offer which differentiates it from its competitors. Once the firm has selected the attribute and entered the market

with it, changing the position of the attribute may not be easy. Apart from any direct costs involved, consumer perceptions of the attribute of the product may be difficult to alter.

As it happens, by making the model somewhat more realistic and assuming that the initial location which is chosen cannot be altered at all, it becomes easier to derive a practical rule of thumb for would be entrants. With two firms, for example, we can make a random draw for each from a uniform distribution on $[0,100]$ as to where they locate, and observe the market shares which result. We can repeat this exercise many times, and plot market share against location. A rather well-defined inverted 'U' shape is observed, which is well fitted by a regression of market share on location and location squared. With the resulting regression coefficients, it is easy to show that in general market share will be maximised by locating at 50.

This result continues to hold as the number of firms is increased, but not as strongly. Figure 1 plots for illustration the result of 200 separate solutions of the model in which each time 5 firms locate at a fixed position at random

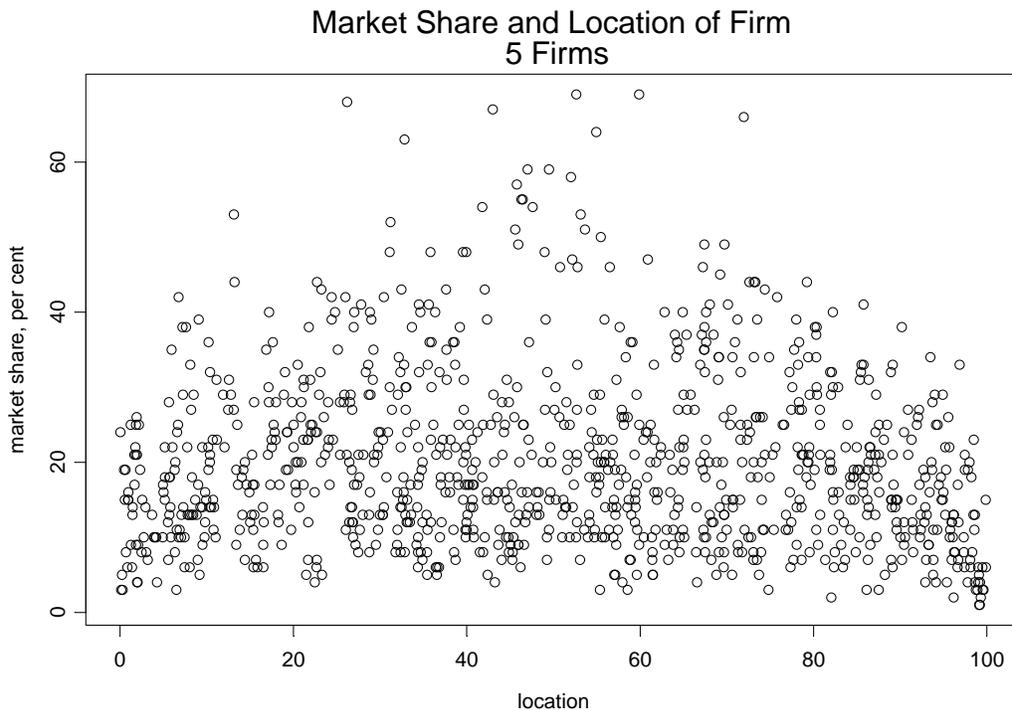


Figure 1 *5 firms entering a market in the Hotelling model, with only one feature differentiating the rival offers. Consumer evenly spread between (0, 100). 200 solutions of the model, no re-location allowed.*

The inverted U-shape of the plot is apparent, but with a great deal of noise around it. The choice of 50 again turns out to be the best. But as the number of entrants gradually increases, the result becomes even less well determined, and by the time we reach 10 entrants it has disappeared altogether.

Even retaining the strong assumptions about consumer behaviour and firms' knowledge of it, the results can readily be made much less clear. We could, for example, allow for entrants to fail if they do not obtain a specified number of customers, and their sales are then re-allocated to the nearest survivors. We can give some firms knowledge of the above result, and let others enter at random. We can give all firms this knowledge, but then the problem becomes the well-known one of the order of degree of reasoning used by agents when forming expectations on the expectations of others. So, for example, if a firm believes that the others will not try to anticipate what any other agent does but will locate at 50, then it is sensible to locate at 49 or 51. But what to do if the firm believes that others will look one step ahead, as it were, and none of them will locate at 50?

Even if under any particular set of assumptions about the model, a Nash equilibrium could be proved to exist, knowledge of this might be of little or no value in a practical context. For example, in the Beauty Contest game, the Nash equilibrium solution is to choose zero. But played against humans, such a strategy is guaranteed to lose (or more precisely not win), except possibly in the latter stages of an iterated game played with the same agents throughout (Duffy and Nagel 1997), because humans appear to use a low (but indeterminate) order of reasoning.

Methodological reflections

The Hotelling model can readily be made even more complicated. The above discussion, for example, is all on the assumption that consumer demand is inelastic with respect to the attribute of the product – everyone will buy one no matter where firms locate. But if this ceases to be true, quite different results can be obtained, all of which rely on firms having knowledge of the shape of the demand curve (for example, d'Aspremont et.al. 1979).

An implication of the above is that the level of knowledge required, whether about consumers or their potential competitors, to make optimal decisions, even if they can be shown to exist, is so great that in practice a firm cannot possibly hope to obtain it.

A standard response to such arguments in economics is to invoke the 'as if' clause. In this context, it is held that successful firms, although they may not consciously do this, act 'as if' they had the information on which to take an (approximately) optimal decision. However, simple inspection of Figure 1 illustrates the problem with this argument. If other firms are choosing their locations at random, on average 50 is the best location to choose. But selecting this can, on occasions, lead to the poor outcome of a market share of less than 10 per cent in a market containing 5 firms. History is only played once, and even the fittest agent can become extinct in any particular play of the evolutionary game (for example, Newman 1997, Solé and Manrubia 1996).

So there seem to be good grounds for the type of behavioural rules which are usually used in complex systems models, such as Peter Allen's model of fishing fleets. Namely, simple rules of thumb which avoid obvious loss.

However, the above discussion can also be seen in a rather nihilistic context. It appears that a very large variety of results can be obtained, often with what may be small changes in the assumptions. In order

to be able to form a reasonable view on what assumptions to make in any given context, a very considerable amount of knowledge seems to be required.

An important methodological approach in agent based modelling of complex systems offers a potential way out of this problem. These models have as their foundation a set of behavioural rules for individual agents. The rules themselves should be capable of justification using evidence from outside the model. But the rules, and the way in which agents react to each other's decisions, should also be capable of accounting for the emergent properties of the system. In other words, the micro level rules for individual agents should give rise to key macroscopic empirical features of the system being analysed.

A way of selecting an appropriate set of agent rules, which avoids the problem of having to acquire huge amounts of information about the system, is to use *micro* level rules which a) seem plausible judged by evidence outside the model and b) are able to generate selected key *macroscopic* features of the system. I discuss these issues at greater length in two papers co-authored with Bridget Rosewell, a pioneer of complex systems analysis in her role as Chief Economic Advisor to the Mayor of London and the Greater London Assembly (Ormerod and Rosewell, 2004 and 2008).

The fact that macro features which are compatible with the empirical evidence emerge from a set of rules on agent behaviour does not mean that these are necessarily the only rules which are capable of doing so. But this approach enables us to narrow down dramatically in any given context the potential set of rules to consider, without having to acquire huge amounts of detailed information about the system.

A criticism encountered from mainstream economists of this approach is that there may be a very large number of such rules, all of which can generate the relevant macro properties. In principle this may be true. But good agent based models are by no means easy to construct, and my standard reply to anyone making this argument is to ask them to produce an alternative set of micro rules from which the empirically observed macro behaviour emerges. The conventional postulate of the rational, representative agent which is used in real business cycle and dynamic stochastic general equilibrium models, for example, really struggles to generate the most basic features of the time series on, say, American GDP growth, namely its properties in the time and frequency domains, the autocorrelation function and the power spectrum. So to a large extent, this type of criticism of agent based models by the economic mainstream is very much a case of the pot calling the kettle black.

In the next section, I give a simple illustration of this methodology with a model developed to account for the evolution of market structure following deregulation of an industry.

The evolution of market structure and competition

Consider the evolution of a market in which a single product is produced, which can be differentiated both on price and quality. The specific focus is upon the consequences of new entrants into a market in which, initially, there is a single monopoly supplier. The model is an agent-based one of firms and consumers, each following particular rules of behaviour for pricing and purchasing. The model extends beyond the comparative statics of conventional theory. In this model, the market evolves over time,

and solutions to the model describe the market structure which evolves and emerges from the process of competition.

The model was initially developed for British Telecom and the specific application was landline telephones. In this market, and others across the West, deregulation of the market by legislation undoubtedly led to improvements in the overall offer available to consumers in terms of both price and quality. Yet in general, the initial monopoly supplier retained a large market share, sufficiently large that, under most standard criteria, it would still be deemed to hold a near-monopoly position.

The model was developed to account for this empirically observed phenomenon. The behavioural rules for both firms and consumers are rooted in the principle that they both react to incentives. However, they do not necessarily do so in a completely rational way.

Agents operate with imperfect information under bounded rationality in this model. Yet, in the limit, if the model is allowed to run for a sufficiently long time with a very large number of potential entrants, a result from standard economic theory is recovered. Eventually, under these conditions, both p and q will in general converge towards zero. So from initial conditions with (p,q) at $(1,1)$, with unlimited entry and over unlimited time, the market will converge on the perfectly competitive solution $(0,0)$.

However, a key feature of the model is that it is not intended to describe the outcomes of two equilibria, the first with the monopolist and the second a perfectly competitive outcome. Rather, it is recognised that economic processes are rooted in time. It is not at all useful to say that, once a monopoly has been opened up to competition, *eventually*, at some unspecified point in the future, a different equilibrium will prevail in which (p,q) is no longer at $(1,1)$ but is arbitrarily close to $(0,0)$. We are interested in how the market evolves over a specified and realistic time-scale – up to 10 years, say. And we are interested in the relationship between (p,q) and the market structure which evolves over such a time scale.

The market is populated by n consumers. We assume for simplicity that they each consume an identical amount of the product in any given period. The amount spent per period by each consumer, and hence total sales of the product, may change over time, but our interest is on, amongst other things, the market shares of the producers rather than on the total size of the market. So the amount spent by each consumer is the same in any *given* period.

Initially, the market contains a single monopoly supplier, selling the product at a price of p_{mon} (using the subscript 'mon' to indicate the incumbent firm's monopoly price), and with a quality q_{mon} . The model evolves on a step-by-step basis, in which each step is a period of time.

We specify a process by which other firms enter the market, both in terms of frequency and in terms of the total numbers entering each period. We specify as an input to the model the maximum number of new entrants into the market. With the incumbent monopolist, this makes a maximum number of k firms, where $k \ll n$. It is perfectly reasonable to assume that the maximum number of new entrants, $(k - 1)$, will in general be relatively small, for two reasons. First, the entry of new firms generally reduces price and improves quality, so that the opportunity for profitable entry of additional firms is reduced.

Second, capital stock and skills are by no means malleable in the real world, and even very large companies rarely undertake ventures which are well outside their established spheres of activity.

In the first step of the model, a potential entrant is drawn at random and enters the market. Both this firm and all subsequent new entrants come into the market with a (p,q) drawn at random from a uniform distribution on $[p_{min}, p_{mon}]$ and $[q_{min}, q_{mon}]$. The price p_{min} is the lowest possible price at which, after the process of technological innovation is complete, the product can be offered and a normal rate of profit obtained by the most efficient supplier. The quality q_{min} is the best quality at which the product can be offered, again subject to a normal rate of profit being obtained. Note that, for simplicity, quality is measured inversely, so that the *lower* the quality measure in the model, the *better* the quality is. Note also that quality is also expressed on a single dimension. This does not mean that the product necessarily has only one feature which measures its quality. There could well be several features, which are concentrated into a single measure of overall quality.

In the second step of the model, each of the remaining $(k - 2)$ firms enters the market with probability π , where $\pi = (p_{av} + q_{av})/2$, where p_{av} and q_{av} are the average market price and quality which obtain at the relevant time. We specify below how firms capture consumers from competitors. The rationale for this entry process is straightforward. The lower is the value of π , in other words the lower is the market price and the higher is market quality, the less likely it is that a new entrant will be able to make a sufficiently attractive profit to justify the costs and risks of entry into a new market.

In subsequent steps of the model, all potential entrants who have not previously entered consider the prevailing value of π , and decide probabilistically on entry in just the same way.

All n consumers are connected on a network to the initial monopoly supplier. This could be in the case of telecommunications quite literally a physical network, but the use of the word 'network' in this physical sense is too limiting. 'Network' in this context means that consumers on the network of firm f_i are both aware of the offer from firm f_i and are willing to consider buying from it.

Each new entrant obtains potential access to a network of consumers. Each new entrant obtains potential access to a proportion of the total number of consumers drawn at random from a uniform distribution on $[v_{min}, v_{max}]$, where $v_{min,max} \in [0, 1]$. Once the group of customers to which a firm has potential access has been chosen, it is set up immediately. A further simplification is that the group then remains fixed during all subsequent steps in that particular solution of the model.

There are three obvious reasons why new firms in the market do not have potential access (in general) to all consumers, which can obtain either singly or in combination. First, the regulator could impose restrictions so that, for example and purely by way of illustration from the telephone market, a new entrant could be permitted to offer international calls but not domestic ones. Second, the marketing strategy of the firm may be such that not all consumers are aware that the firm is making an offer in the market. In reality, marketing strategies vary widely in effectiveness, and this is reflected in our model. Third, the firm itself may deliberately target only a small percentage of consumers. In the context of British land line phone calls, for example, several firms now specialise in offering cheap calls to India, say, or to the United States.

In each period, each consumer reviews the price and quality of each of the firms to which he or she is connected. The consumer at any point in time is only permitted to buy from a single supplier. This is not always completely realistic, but is a reasonable assumption to make in this initial specification of the model. The consumer is allocated from the outset a weight w_i , which expresses his or her preference between price and quality (w_i is chosen from a uniform distribution on $[0,1]$). The consumer calculates for each of the firms on his or her network $w_i * p + (1-w_i) * q$. For the k th firm, we describe $w_i * p_k + (1-w_i) * q_k$ as being the overall value to the i th consumer of this offer – v_{ik} for short.

The consumer switches all of his or her business to the firm offering the lowest v_{ik} of the k firms on his/her network (which may not correspond the lowest $w_i * p + (1-w_i) * q$ then on offer to other consumers, because the particular consumer concerned may not be aware of such offers), subject to the following condition. At the outset, each consumer is allocated a 'switching propensity', s_i , which is drawn at random within $[0, 1]$. If the customer identifies a v_{in} , which is lower than that of his or her existing supplier, v_{im} , he or she will then switch to firm n from firm m , with probability s_i .

There are several reasons for introducing this probabilistic element into the choice. Although the product offers of the firms are very similar, they are not perfect substitutes, for two reasons. First, the lowest (p,q) supplier may specialise in an offer which is not very important to a given consumer. Someone who makes only local phone calls will not be interested in a firm which provides only cheap international calls. Second, even within the same segment of the market, such as local calls, the product is not completely homogenous in that consumers may have doubts about the reliability of a previously unknown supplier.

There are two other possible reasons why consumers will not in general switch to the lowest price producer. First, there may be costs involved in switching. To take an obvious example, if changing suppliers involved having to change telephone number – staying with the telecomm example - for most people the savings on price would have to be considerable to offset the inconvenience involved. Second, consumers may simply exhibit inertia and stay with their existing supplier, perhaps because the savings involved are small.

At the start of the next period, each firm already in the market is given the opportunity to reduce its (p,q) offer. Firms are not certain about the distribution of preference across consumers regarding price and quality, and so assign equal weight to price and quality in each of the (p,q) offers which they observe. They aspire to move to the (p,q) of the firm for which $\omega * p_i + (1 - \omega) * q_i$ is minimised, where ω is the average of the w_i across all consumers.

However, firms differ in their ability to adapt their organisation in order to deliver the desired (p,q) offer. We can think, for example, of firms as differing in their level of X-efficiency. The ability of the firm to do achieve the desired (p,q) depends on the firm's flexibility level φ_i . At the outset, each firm is allocated a flexibility level, φ_i , which is drawn at random from a uniform distribution on $[\varphi_{min}, \varphi_{max}]$, where $\varphi_{min, max} \in [0, 1]$. In each period, each firm switches to the lowest $\omega * p_i + (1 - \omega) * q_i$ with probability φ_i .

Consumers then review their choice of suppliers given the revised set of (p,q) from existing suppliers, and given the (p,q) offered by new entrants (if any) in that period.

Once a firm has entered the market, it is able in principle to acquire customers both in the period in which it enters, and in each subsequent period. We do not specify an explicit cost function for firms, but assume there is a minimum level of sales, x , which any firm needs to be able to continue to exist. We specify x in terms of market share, with x being a parameter of the model. If a firm fails to secure x per cent of the market for two successive periods, it is deemed to then exit the market.

The properties of any individual solution of the model are contingent on a number of factors, and no two solutions are the same. For example, an important element is the combination of the (p,q) with which the first competitor enters the market and the proportion of consumers, v , to which it gains access. If the former is sufficiently low and the latter sufficiently high, the probability of any additional entrant deciding to join becomes low, because the average (p,q) which consumers face is low, and so the prospective ability of a further entrant to make a profit is low.

The results below illustrate the properties of the model when it is populated by 1000 consumers and a total of 20 firms can in principle enter the market. 1000 separate solutions of the model are obtained. The model is solved for 40 steps, the rationale for this being that, in the context of a utility such as telecoms consumers are usually billed quarterly, so that it is reasonable to regard each step as a quarter, 40 steps making a total of 10 years.

Figure 1 plots the histogram of average price over the 1000 separate solutions of the model.

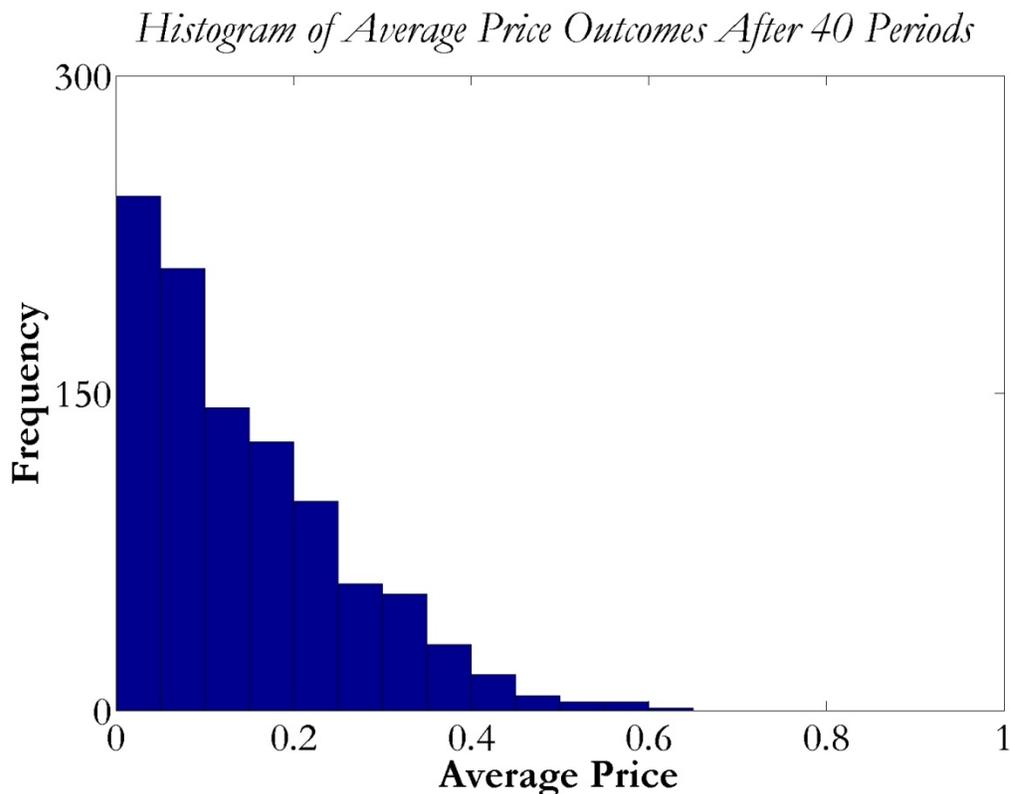


Figure 1 *Histogram of average price outcomes in 1,000 solutions of the model*

The single most frequently observed outcomes for the market price is in the range 0.00-0.05. In other words, price does fall to a level close to the minimum which is feasible. Occasionally, however, the price remains relatively high. In terms of the distribution of outcomes across a number of solutions of the model, the quality of the product evolves similarly to price, although the outcome of the two may obviously differ in any given scenario.

The mean level of market price after 40 periods is 0.147, with a minimum of 0.0001 and a maximum of 0.581. The inter-quartile range is between 0.069 and 0.225.

Figure 2 plots the histogram of the outcomes, again after 40 periods, across the 1000 solutions of the model of the market share of the initial monopolist.

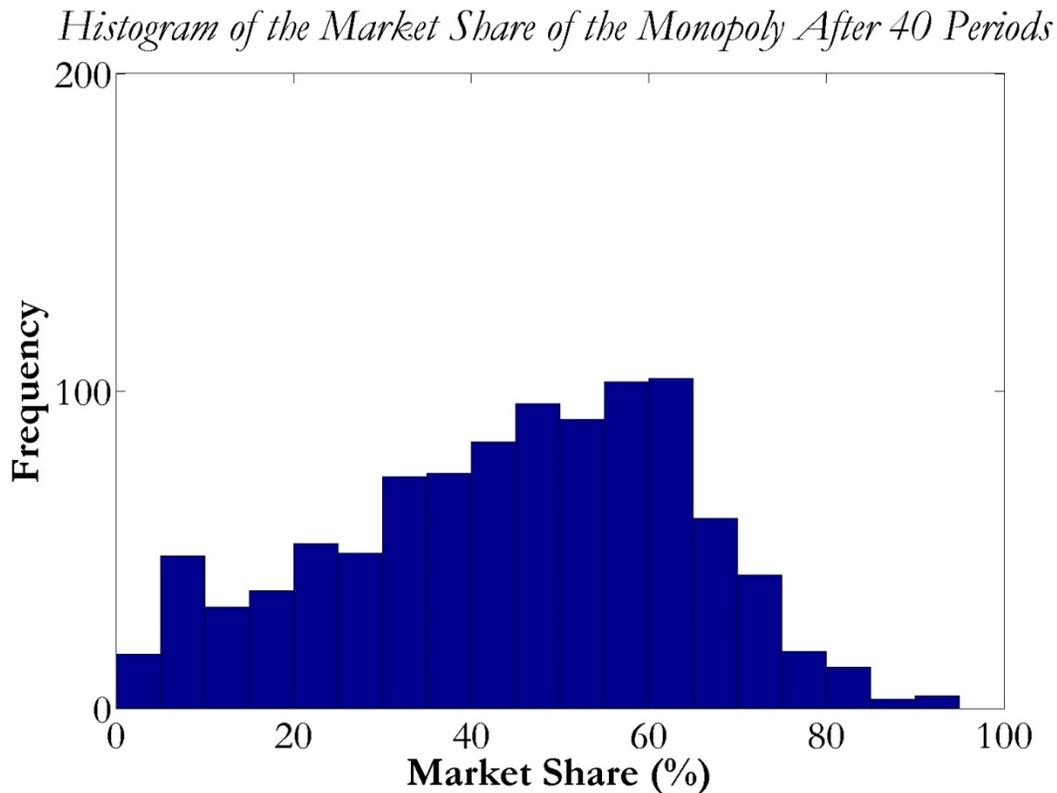


Figure 2 *Histogram of market share of the initial monopolist in 1,000 solutions of the model after 40 periods*

Quite frequently, the incumbent monopolist retains a very high market share. Despite this, as Figure 3 shows, the market price usually falls very sharply. The average market share of the monopolist after 40 periods is 46.2 per cent, with a minimum of 3.5 and a maximum of 95.5 per cent. The inter-quartile range is wide, between 32.4 and 60.0 per cent.

So the model captures the key stylised fact of deregulated markets, namely that the offer to consumers improves markedly in terms of price and quality, but the market share of the initial monopolist remains high.

This is confirmed in Figure 3, which plots the eventual market price and the market share of the initial monopolist. The simple correlation between the two variables is -0.06.

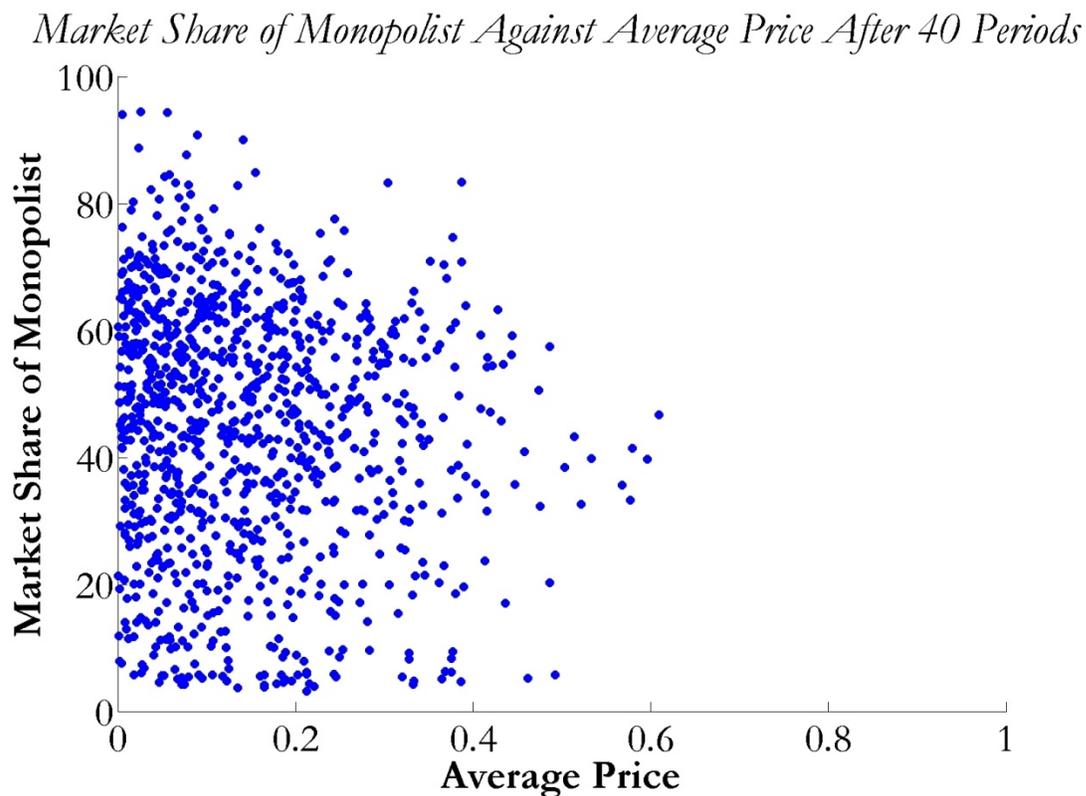


Figure 3. Scatter plot of 1,000 solutions of the model between the eventual market share of the initial monopolist and the average price after 40 periods

Figure 4 shows that, more generally, there is little connection between the market price and the eventual number of firms surviving in the market.

Number of Firms Selling Against Average Price After 40 Periods

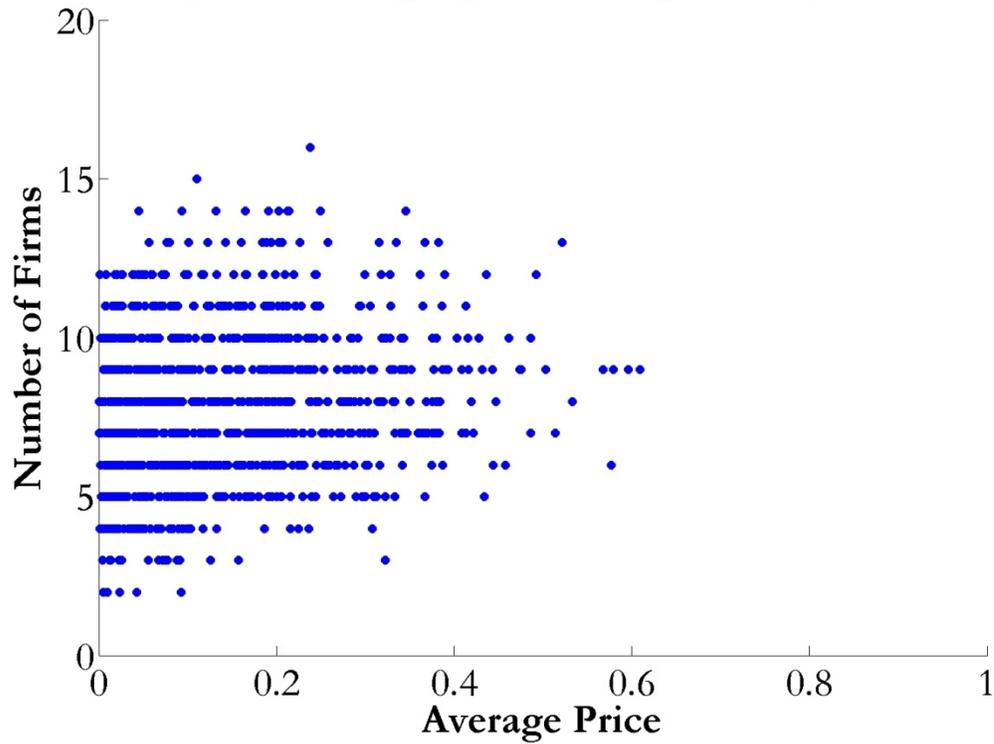


Figure 4 *Scatter plot of 1,000 solutions of the model between the number of firms in the market and the average price after 40 periods*

The model also captures two more general properties of evolving markets in which firms both enter and exit over time, as Figures 5 and 6 illustrate. The model was not intended to capture these stylised facts, but nevertheless does so.

A wide range of outcomes is possible for the number of firms who remain in the market after 40 periods, as Figure 5 shows.

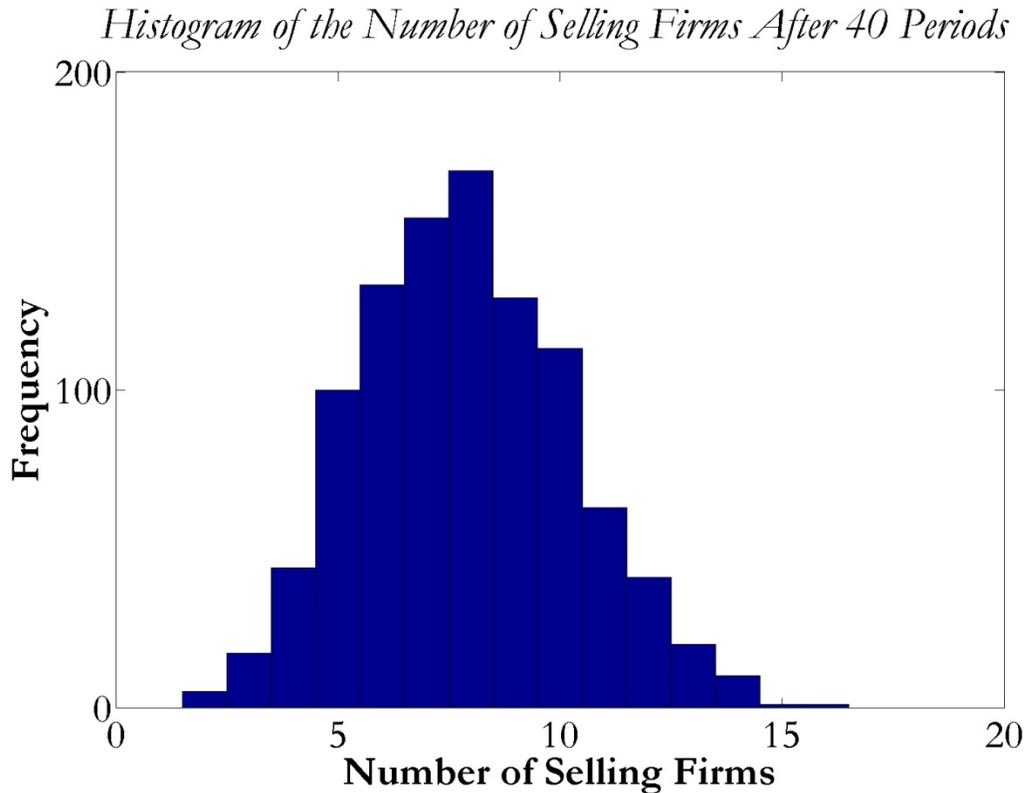


Figure 5 *Histogram of number of firms who remain in the market after 40 periods, 1000 solutions*

The mean number of firms is 7.9, so that on average just over 12 out of the 20 firms exit the market. This seems compatible with the outcomes which are observed in practice (see, for example, Carroll and Hannan (2000)).

Figure 6 sets out the distribution of the average market share of the 8 largest selling firms after 40 periods. (Of course, in a number of the solutions of the model, when fewer than 8 have non-zero sales, the value for some of the 'largest' 8 in these particular solutions is zero).

Market Share of the Eight Largest Firms After 40 Periods

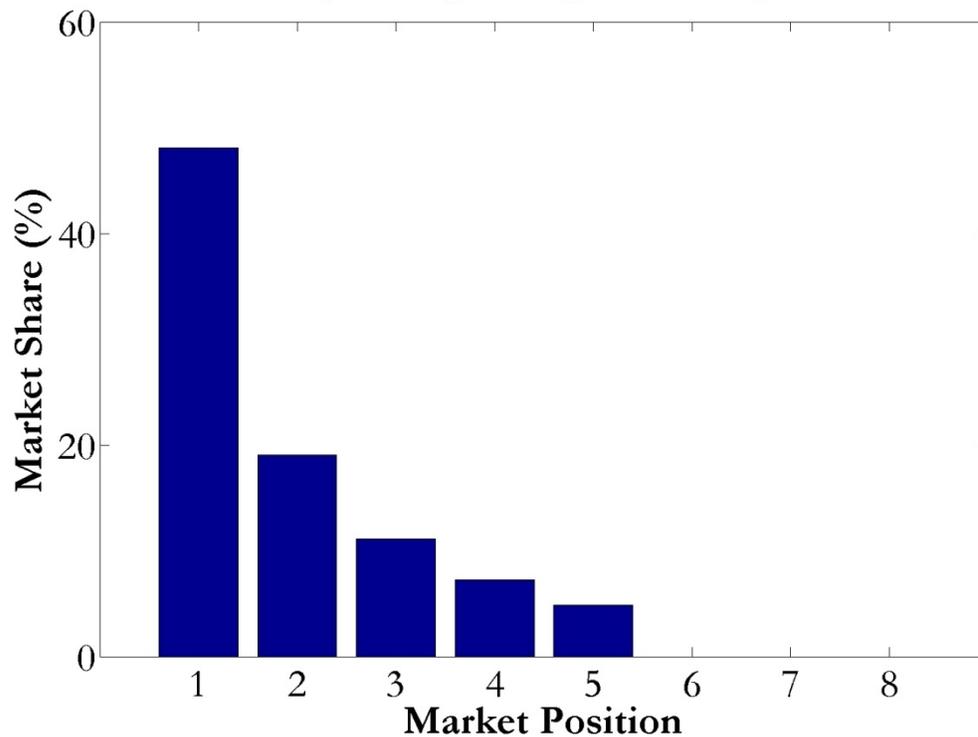


Figure 6 *Distribution of market share of the 8 largest firms in 1,000 solutions of the model after 40 periods*

The figure shows the distribution regardless of the identity of the firm. In the majority of solutions of the model, the largest firm is the initial monopolist, but this is not always the case.

A good approximation to the size distribution of the largest 8 firms after 40 periods is provided by a power law. Axtel (2001) shows that this a general characteristic of the distribution of firm sizes in the United States. A log-log least squares fit of average market share in Figure 7 on the rank of the firm by market share (largest has rank equal to 1, etc.) gives an R^2 of 0.982 and an estimated exponent of -1.67 with a standard error of 0.02. An exponential also gives a good approximation to the distribution of firm size, but the power law is better.

Conclusion

Peter Allen was one of the earliest innovators in the application of complex systems principles to the social sciences. His fishing fleet model captures some general features of the behaviour of real-life firms. They act with purpose and intent, but under conditions not only of imperfect information at any given time, but of an environment which constantly evolves. There is a great deal of contingency in the outcomes of any individual solution of the model, and time and process are important. Simple rules of thumb in general give agents better outcomes than do attempts to follow rational expectations.

In this contribution, I develop these themes in the context of two different models of firms and the evolution of competition and market structure.

An important development in complex systems analysis over the past 20 years has been the realisation that agent based modelling of such systems requires modellers from the outset to confront empirical evidence. This is not only in terms of having plausible rules of behaviour for the micro-level agents in the system, but to ensure that the macroscopic properties of the system which emerge are consistent with aspects of reality. Apart from the fundamental principle of scientific validation which this addresses, it enables agent based models to escape from the criticism of mainstream economists that, once the assumption of rational agents following rational expectations is relaxed, any outcome becomes possible. This is far from being the case. Requiring models to be compared with empirical evidence limits dramatically the range of models which can be considered as plausible in any particular context.

I illustrate this with a model of the evolution of competition and market structure of an industry where de-regulation permits entry into a market controlled by a monopoly supplier. Two key features of the real world are that, first, that the price/quality offer to consumers usually improved markedly, yet at the same time the initial monopolist typically retains a large market share. Second, the evolution of price/quality in the market bears little or no relationship to the number of firms active in the market at any point in time. The model is able to replicate these empirical features. In addition, two further stylised facts about firms emerge from the model: the majority of new entrants into a market fail, and the size/rank distribution of firms is heavily right-skewed, indeed approximated by a power law relationship.

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