The Role of Expressiveness in Modelling Structural Change

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Abstract

It is argued that to effectively model situations involving structural change, purely numerical methods may not be sufficiently expressive. Some alternative, some more expressive formal systems are suggested, which are borrowed from artificial intelligence, logic, formal language theory and abstract mathematics. These allow the modelling of knowledge: internally to represents an agent's picture of the world, externally to model its communication with other agents and also to model context-dependent aspects of their environment. Three examples in each of these areas is presented.

1 Without Structural Change

Economists have been concerned principally with situations where the context of a situation is broadly fixed so as to focus on modelling changes that occur to within this framework (price, expected utility, stock etc.). In other words, economics has not so much been concerned with the effects of knowledge on economic processes, but has focused more on cases where suitable restrictions or assumptions rule out such effects to make the situation more tractable. Examples of these have included:

- the assumption of perfect knowledge - this makes communication and information search by the agent redundant (as well as eliminating the problems of uncertainty and limited attention);
- of perfect computational ability - thus the *form* of an agent's knowledge becomes irrelevant, only the content matters;
- that agents have the correct model of the economy in their head - this by-passes the whole process of learning and model development;
- that systems will tend to a equilibrium - this eliminates the necessity for studying the dynamic processes of its development;
- and that an agent's actions can be determined by a numerically represented utility function - this (as usually applied) eliminates the effects of context on an agent's choice of action.

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All of these can have the effect that the complex interaction of an agent's knowledge and the economy is reduced to simpler cases - ones that can, on the whole, be represented numerically. Innovations as chaos theory have expanded the range of mathematical techniques slightly, in that they now allow for systems of numerical equations which are ultimately sensitive to initial conditions, but they still keep broadly to the dame range of numerical techniques.

2 Some complications that can occur with Structural Change

2.1 Context dependency

In the real world, humans act predominately in a context-dependent way: perception, reasoning, memory. In many cases this may be a justified assumption or, at least, an acceptable approximation, but rapid changes in behaviour due to a change in context (e.g. in the collapse of the East European centralised economies) can be a key factor in structural change. Thus, in this case, the effect of context-dependency can not be safely ignored.

2.2 Imperfect Communication

Communication is often imperfect. It can be dependent upon its form as well as its content. It can be often passed along local and unpredictable paths. It can be limited by the time, capacity and attention of the communicants. Some economic models have assumed that communication is perfect, so that all participants have the same information at the same time (e.g. as theories of pricing in stock-markets). In situations where there is a lack of reliable and generally accessible information agents may well have to fall back on more imperfect local communication with those they know (or trade with). In situations of rapid structural change there will inevitably be less reliable information that in a comparable stable situation. Thus in such situations the effect of local and partial communication may be greater.

2.3 Limited deductive ability

The difference between substantive and procedural rationality (or bounded rationality) is reasonably well documented. In situations without rapid structural change the effects of limited rationality can merely mean that the processes of adjustment (in reaching a stable solution) takes more time. In such cases there will not be any significant change to the equilibrial analysis. When you do have rapid structural change, then it can be the case that the agent's model of its environment lags permanently behind this changing reality. In this case there may be no stable solution. Thus the difference between bounded and infinite rationality might well make the difference between the possibility of a broadly stable and a purely dynamic result. This seems to be the case in Belorus where there is a long lag in the change of firm's actions, now that there is little possibility of debts being written off by the government.

2.4 Open-ended possibilities

Innovation occurs when the space of possibilities is too big for a single agent to effectively search, otherwise the innovation would be accessible to many different agents. This often occurs where there is a combinatorial explosion of such possibilities with size, as occurs in language. There is no possibility of blindly searching english language constructions for a good poem. Likewise searching through possible electronic circuits, computer programs, or machines is completely infeasible without the addition of considerable domain knowledge to constrain the search. This is in stark contrast to the situation where an agent is choosing between a very simple set of alternatives, be they products, strategies or technologies. Sometimes in situations of structural change, when the context of a whole system is being mutually determined, innovations can have a critical effect in shaping its whole future development. Contrawise innovations can have the effect of changing the economic context sufficiently to cause situations of rapid structural change.

2.5 Genuine surprise

Although uncertainty is dealt with in mainstream economics, it is frequently characterised in a limited way, for example as an uncertain *value* drawn from a *known* probability distribution. The possibility of something outside an agent's conception of its environment occurring is difficult to express using only traditional numerical mathematical techniques. In a relatively stable situation there will be few such surprises, and so such limitations may well be acceptable. In situations of rapid structural change, one would expect such genuine surprises to be much more frequent and hence more significant.

3 The Need for More Expressive Formal Systems when Modelling Structural Change

Purely numerical modelling is not well suited to encapsulating the context-dependent effects of imperfect knowledge. Principally there what is lacking is a distinction drawn between form and meaning (syntax and semantics). This allows for the effects listed above: the form can be the same, but the meaning dependent on the context; a communicated form may have different meanings for sender and recipient; bounded rationality is only possible if there is not a perfect immediate correspondence between form and its meaning; innovation can only occur if the form is not obvious from its intended use; and genuine surprise can only occur if one does not have prefect knowledge of one's environment but a model with only an indirect correspondence with reality.

Thus despite the great success of purely numerical techniques in many areas, in order to capture some important effects occurring during structural change it is likely that more expressive formal systems will need to be introduced.

4 Some examples of more expressive systems

There are, of course, many more expressive formal systems those in the traditional numerical repetoire. Many of these come from more abstract mathematics, including those recently developed for the field of AI.

4.1 Set Theory

Set theory is perhaps the ultimately expressive mathematical language[2]. All other known mathematics and formal systems can be expressed in it, though not necessarily in a natural or easy manner. This, however is a too expressive theory for our purposes.

4.2 Logics

The field of formal logic has ballooned enormously in this century. There is now a bewildering range of logics that can be used to formalise many kinds of knowledge based interactions. These naturally have the form-meaning distinction built in to the syntactic-semantic split and have the possibility of expressing a wide range of qualitative as well as quantitative properties.

Some relevant areas of logic include:

2. Along with some other equally expressive systems, such as category theory.

- Modal logics - these allow for the expression of a variety of notions related to *necessity* and *possibility.* These have also been used for a range of epistemic logic where reasoning about such notions as knowledge and belief are formalised.
- Non-monotonic Logics - where the strict transitivity of the inference relation is relaxed to allow reasoning involving, for instance, default assumptions or reasoning based on reasonable probability.
- Temporal Logics - these allow for the study of effects over time, in a declarative framework.

4.3 Nets and Graphs

Networks and graphs are basically a set of arcs along with the nodes they join. These nodes can be labelled with various properties, such as numbers. Thus a graph can encode the relationship of a set of values to each other.

Applications of such graphs have included:

- Semantic nets - where the meaning of an expression is formalised by a network of relations between labelled nodes.
- Dependency network - this is where the dependencies of one thing upon another are represented by a directed graph.
- Finite Automata - A directed network of nodes with two arcs (one for 0 and 1) leading from each node, forms a simple computational device. This has been used to study simple learning and patterns produced by cellular automata.

4.4 Formal Languages

Logic can be viewed as a special case of formal language theory that has a strong inference machinery (and its own particular history). Formal languages encompass a variety of systems of different expressive ability, but are all formal entities following syntactic rules. Frequently expressions are closely related to tree-structures.

Example applications:

- Genetic Programming - this is similar to normal genetic algorithms except that the genotype is an expression (usually a program) from a specified formal language. This is then evolved using fitness based selection and a tree version of cross-over. See [4].
- L-systems - Lindenmayer systems; a system of formal grammars to model fractal biological growth. See [3].

5 Some Example Applications

5.1 Tree-structured expressions for modelling agent states

Here we relax the assumption that an agent has perfect knowledge of its own utility function. So it has to learn it by making trial models, comparing these with known past information and construct new models. Even given that an agent may know that more utility is likely to be gained by buying more of a product, the trade-offs between two products can be complex. The agent has an large function space to search. Further, the agent’s representation of its utility function can effect what conclusions it reaches about the best purchasing policy, if it is only boundedly rational.

A model of such an agent which dynamically develops its own guess at its utility function, shows several interesting features which are absent from the traditional utility optimization approach. For example, some consumers get locked-in to an inferior policy for considerable periods of time, because their preferred model suggests a path of action that does not discomfort this very model - this might correspond to a consumer who discovers an adequate product early on and then never experiments with others (which may be better). Another interesting feature is that the efficiency of the agent's spending depends critically on its internal language of representation and the maximum complexity of its internal models. For some more details see [2].

5.2 A network model of technical change

The intricate mutual dependencies amongst technologies, mean that innovating is a tricky and uncertain business. One needs to acquire not only the knowledge embodied in the technologies but also knowledge on what the target technology depends on, so one can acquire these. Thus knowledge of a technology confers a context-dependent benefit - it depends on what other technologies you have access to. Here representing knowledge as a numeric quality is not adequate, but a minimal level of context-dependency can be introduced by representing the technologies as a network that innovation occurs in only if the dependent technologies are also accessible. for more details on this see [5].

5.3 Communication and negotiation

The collapse of the old East European command economies have produced a very fluid situation, where nobody understands much of the total picture and it is up to each firm to establish its own ways of coping, even including such basic behaviours as to when it is advisable to pay ones debts. A simple model of such an economy, where each firm is learning how to behave from observing those it immediately trades with, shows some informative and credible features. For example if ones assumes that price behaviour is determined by agents observing and copying successful firms they trade with, one obtains a characteristically uneven inflationary price curve.

6 Conclusion

It is highly likely that to model many characteristic aspects of structural change it will be necessary to move beyond the traditional range of purely numerical techniques. Fortunately there already exist some suitably expressive formal systems for this task from abstract mathematics, AI and cognitive science. These should be now applied in this area.

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