NAEC Integrative Economics Conference

Session 2, Systems modelling. Thursday 5th 14-15.30

Background brief.

In 2008, Jean-Philippe Bouchaud wrote that the financial crisis highlighted the need for a shift of mindset in economics and financial engineering away from dogmatic axioms and towards more focus on data, orders of magnitudes, and plausible, albeit non-rigorous, arguments. The OECD's New Approaches to Economic Challenges (NAEC) initiative was created in the same spirit, and invited Professor Bouchaud to discuss his ideas at a seminar in April 2017 on complexity. The seminar highlighted the potential of an approach to economic challenges based on agent-based modelling, and this was confirmed in June 2017 when Rick Bookstaber outlined his work on applying agent-based models to financial markets, in another NAEC seminar.

The two NAEC events also revealed that despite some work on this kind of modelling carried out by OECD Directorates in the past, there were gaps in our knowledge concerning the latest technical developments and applications.

What are agent-based models?

Agent-based models (ABM) use computer simulation to explore emerging dynamical patterns, free from any top-down assumptions. In contrast to conventional models, ABM make no assumptions about the existence of efficient policies or general equilibrium. These may or may not emerge due to the dynamical rules. The policies and social behaviours they generate are more like the weather system, subject to constant storms and seizures of all sizes. Big fluctuations and even crashes are often inherent features, not shocks coming from the outside to upset the system's normal state of equilibrium. This is because ABM allow feedback mechanisms that can amplify small effects, such as the herding and panic that generate bubbles and crashes. In mathematical terms the models are non-linear, meaning that effects need not be proportional to their causes.

Agent-based models use a dynamic system of interacting, autonomous agents to allow macroscopic behaviour to emerge from microscopic rules. The models specify rules that dictate how agents will act based on various inputs. Each agent individually assesses its situation and makes decisions on the basis of its rules. The agents (people, institutions, physical objects...) are typically heterogeneous and can act with some degree of independence or autonomy, so there is no centralised control of the system. At the start of each time period, each agent observes its environment and acts according to its heuristic. The agent's environment is only a local view of the overall system. The agents' actions change the environment. In the next period, each agent sees its new environment, altered based on the actions of the previous period, and takes action again. Thus there is an interaction between the agents and the environment, and between one agent and another.

Since the agents are heterogeneous, they may widely differ in their utility functions, goals, views, resources etc. This makes them especially useful to study scenarios or cases where different groups of stakeholders are involved. The system does not need to be populated with representative agents such as identical decision-makers, firms or governments whose individual behaviour mirrors the system as a whole. In models that produce equilibrium states, the dynamics comes to an end. In social systems, on the other hand, there are a large number of different equilibrium states between which the system erratically jumps, a phenomenon known as punctuated equilibrium which can be reproduced by ABM.

What are agent-based models used to study?

Agent-based models are used to study complex systems, including ecosystems, pandemics, markets, energy generation and distribution, weather and climate, as well as societal phenomena such as urbanisation, traffic flows and migration.

Such systems are open (they exchange energy and information with their surroundings). They are dynamic (they contain numerous internal couplings and feedback loops – often nonlinear ones, operating on multiple spatial and temporal scales). They are far from equilibrium, and continually transition between states that, individually, are inherently unstable.

A pile of sand is a simple example of the type of phenomenon in question. It's a "self-organising critical system", keeping its basic cone shape even as more sand is added, provoking little landslides and other local instabilities. If you only look at the big picture, the sand pile may seem stable, whereas if you look at a particular area closely, you'll see grains tumbling down the slope in avalanches of sand: lots of small ones, fewer intermediate-size ones and, much less frequently, major events where a significant fraction of the whole cone collapses. The probabilities of occurrence of avalanches of various sizes is not random, but is in fact governed by a strict mathematical "power law".

Flocking behaviour of starlings is another widely-quoted example. The birds appear to operate as a system, yet the flight is based on the decisions of the individual birds. Building a macro, top-down model will miss the reality of the situation, because at the macro level the movements of the flock are complex, non-linear, yet are not based on any system-wide programme. But you can model the flock based on simple rules as to how a bird reacts to the distance, speed and direction of the other birds, and heads for the perceived centre of the flock in its immediate neighbourhood.

Why are agent-based models useful to study economic issues?

In *The End of Theory: Financial Crises, the Failure of Economics, and the Sweep of Human Interaction* Rick Bookstaber explains four characteristics of human experience that cannot be addressed well by the methods of traditional economics.

The first of these is *computational irreducibility*. You may be able to reduce the behaviour of a simple system to a mathematical description that provides a shortcut to predicting its future behaviour, the way a map shows that following a road gets you to a town without having to physically travel the road first. Unfortunately, for many systems, you only know what is going to happen by faithfully reproducing the path the system takes to its end point, through simulation and observation, with no chance of getting to the final state before the system itself. Not being able to reduce the economy to a computation means you cannot predict it using analytical methods, but economics requires that you can.

The second is *emergence*. Emergent phenomena occur when the overall effect of individuals' actions is qualitatively different from what each of the individuals is doing. You cannot anticipate the outcome for the whole system on the basis of the actions of its individual members because the large system will show properties its individual members do not have. For example, some people pushing others in a crowd may lead to nothing or it may lead to a stampede with people getting crushed, despite nobody wanting this or acting intentionally to produce it. Likewise no one decides to precipitate a financial crisis, and indeed at the level of the individual firms, decisions generally are made to take prudent action to avoid the costly effects of a crisis. But what is locally stable can become globally unstable.

The name for the third characteristic, *non-ergodicity*, comes from the German physicist Ludwig Boltzmann who defined as "ergodic" a concept in statistical mechanics whereby a single trajectory, continued long enough at constant energy, would be representative of an isolated system as a whole, from the Greek *ergon*, energy, and *odos*, path. An ergodic process is one that does not vary with time or experience. It follows the same probabilities today as it did in the distant past and will in the distant future. The mechanical processes that drive of our physical world are ergodic, as are many biological processes. We can predict how a ball will move when struck without knowing how it got into its present position – the past doesn't matter. But the past matters in social processes and you cannot simply extrapolate it to know the future. The dynamics of a financial crisis are not reflected in the pre-crisis period for instance because financial markets are constantly innovating, so the future may look nothing like the past.

Radical uncertainty is the fourth characteristic. It describes surprises—outcomes or events that are unanticipated, that cannot be put into a probability distribution because they are outside our list of things that might occur. Electric power, the atomic bomb, or the internet are examples from the past, and of course by definition we don't know what the future will be. As Keynes put it, "There is no scientific basis to form any calculable probability whatever. We simply do not know." Radical uncertainty is sometimes called "Knightian uncertainty", after Frank Knight, who distinguished between risk, for example gambling in a casino where we don't know the outcome but can calculate the odds; and what he called "true uncertainty" where we can't know everything that would be needed to calculate the odds.

Agent-based models allow us to recognise aspects of the world that are especially apparent during crises, in particular the following.

- People interact in complex and sometimes surprising ways, and actions work through the system with surprising and nonlinear results. We have real institutions with their particular idiosyncrasies. We have regulations that are not elegant but are real that both reduce risk and constrain activities but can also lead to collateral damage and create vulnerabilities.
- We are not starting with axioms and deriving a top-down deductive theory. We are not trying to determine a model that will work for some economy unpolluted by the actual market where any theory will be applied.
- The real world means understanding real financial entities and the actual structure in which they operate. Neoclassical models not only assume homogeneity but also lump everyone together into a single representative agent.
- We affect the environment. Large financial institutions cannot take meaningful action in the face of a crisis without affecting the broader system, due to their liquidation of large positions and to its effect on the funding market and related counterparty and credit risk. They can take actions that are locally prudent but imprudent when the effect is extended to the broader system. And sometimes actions are taken to deliberately alter the environment.
- We affect one another. Contrary to the notion of a representative agent, there are many forces interacting, and even those that are similar, which we would think could be compressed into a representative agent, generate a complex and unpredictable world. If these affect the environment and the environment affects them, and then they all affect one another.
- The heuristics of the individual actor are not fixed; they can change with changes in the environment, with changes in context.

All these characteristics reside within the critical limit to knowledge that we only know the future as we live it. If we alter the environment based on our actions, and if that in turn affects others who then change the environment further, and all of this occurs within actions that depend on the resulting changes in context, the notion that we can use a deductive approach is mistaken. It will work some of the time, particularly when there is no change in context, and where people are all pretty much the same. But this is rare.

Examples of ABM at OECD

- *OECD Reviews of Risk Management Policies: Systemic Financial Risk* analyses the results of simulations using an agent-based model of financial markets to show how excessive leverage can lead to a systemic crash.
- *Systemic financial risk: agent based models to understand the leverage cycle on national scales and its consequences* shows that the size of the fiscal multiplier is an increasing function of the degree of credit rationing in the economy; and that the effects of fiscal policy are stronger in more leveraged economies.
- *Landscape cohesion and the conservation potential of landscapes for biodiversity* proposes a spatial explicit agent-based model to evaluate the impact of agri-environment schemes on the spatial cohesion of agricultural landscapes in the light of habitat network patterns.
- *Environmental change and the risk posed by new host-vector-pathogen interactions* uses an agent-based model to examine how exposure to malarial infection depends on how individuals use ecosystems.
- *Social unrest* examines the applicability of agent-based models to past and future cases of social unrest.
- The International Transport Forum (ITF) uses ABM in numerous applications, for example urban road freight
- The ELS Health Division is devloping ABM for its work on antimicrobial resistance

Online resources

OpenABM *Introduction to agent-based modelling*.

On-Line Guide for Newcomers to Agent-Based Modeling in the Social Sciences Leigh Tesfatsion, Department of Economics, Iowa State University.