Chapter 1: Why ABM is useful for economists

The 2008 economic crisis has led to a review of economic modelling. Agent-based modelling (ABM) has been identified as a possible way forward. The history of economic modelling is briefly reviewed to set the scene. We then give an overview of ABM to show how it complements the traditional methods by bringing together the micro and macro and facilitating the modelling of heterogeneity, dynamics and interactions between people and between people and their environment

Key words: dynamics, interaction, micro-foundations, heterogeneity, representative agent

Introduction

This book provides an introduction to the power of using agent-based modelling (ABM) in economics. ABM is sometimes referred to as multi-agent modelling and in the context of economics, ACE (Agent-Based Computational Economics). It takes some of the usual topics covered in undergraduate economics and demonstrates how ABM can complement more traditional approaches to economic modelling, and better link the micro and the macro.

This Chapter starts with a brief review of the history of economic modelling to set the context. There follows an outline of ABM: how it works and its strengths. Finally, we set out the plan for the rest of the book.

A very brief history of economic modelling

> The Method I take to do this, is not yet very usual; for instead of using only comparative and superlative Words, and intellectual Arguments, I have taken the course (as a Specimen of the Political Arithmetick I have long aimed at) to express my self in Terms of Number, Weight, or Measure; to use only Arguments of Sense, and to consider only such Causes, as have visible Foundations in Nature.
>
> Sir William Petty (1690)

Whether Sir William Petty was the first economic modeller is arguable. Was Quesnay's *Tableau Economique* dated 1767 the first macroeconomic model? Or Ricardo's 1821 model of a farm the first microeconomic model? (Those interested in these early models should read Morgan, 2012: 3-8). Nevertheless, books of political economy such as Smith's *Wealth of Nations* (1776) or Marshall's *Principles of Economics* (1890) had no modelling or mathematics. There is almost none in Keynes' *General Theory of Employment, Interest and Money* (1936).

Traditional macroeconomic models

For our purposes we shall start with the macroeconomic models produced in the 1930s by Frisch and Tinbergen (Morgan, 2012: 10). These models comprised a set of equations relying on correlations between time series generated from the national accounts. There was no formal link between these macroeconomic models and micro economic analysis despite the traditional view that 'the laws of the aggregate depend of course upon the laws applying to individual cases' (Jevons, 1888: Chapter 3, para 20). Not all saw benefit in these new models. For example Hayek (1931: 5) wrote:

> …neither aggregates nor averages do act upon each other, and it will never be possible to establish necessary connections of cause and effect between them as we can between individual phenomena, individual prices, etc. I would even go as far as to assert that, from the very nature of economic theory, averages can never form a link in its reasoning.

Nevertheless, macroeconomics became identified as separate field from microeconomics with the publication of Samuelson's *Economics* in 1948 (Colander, 2006: 52).

Dynamic Stochastic General Equilibrium (DSGE) models

The separation of macro and micro economics continued until the economic crisis of the mid-1970s prompted what is now known as the Lucas critique. In essence, Lucas (1976) pointed out that policy changes would change the way people behaved and thus the structure being modelled and this meant that existing models could not be used to evaluate policy. The result was Dynamic Stochastic General Equilibrium (DSGE) models that attempt 'to integrate macroeconomics with microeconomics by providing microeconomic foundations for macroeconcomics' (Wickens, 2008; xiii). This integration is achieved by including 'a single individual who produces a good that can either be consumed or invested to increase future output and consumption.' (Wickens, 2008; 2). They are known as either the Ramsay (1927 & 1928) models or as the representative agent models. In effect, the representative agent represents an average person. And this average person bases their decision on optimisation. The limitations of using representative agents have been long recognised (e.g. by Kirman, 1992). But they have continued to be used because they make the analysis more tractable (Wickens, 2011: 10). However, this is changing. Wickens noted in 2008 (2008: 10) that 'more advanced treatments of macroeconomic problems often allow for heterogeneity' and the technical problems of using heterogeneous agents in DSGE models are now (in 2014) being addressed in cutting edge research projects.

Complexity economics

Not all economists think that the DSGE models are the right way to proceed. For example, in 2006 Collander published *Post Walrasian Macroeconomics: Beyond the Dynamic Stochastic*

General Equilibrium Model, a collection of papers that set out the agenda for an alternative approach to macroeconomics that did not make the restrictive assumptions found in DSGE models and in particular did not assume that people operated in an information-rich environment.

The DSGE approach assumes that the economy is capable of reaching and sustaining an equilibrium, although there is much debate about how equilibrium is defined. Others take the view that the economy is a non-linear, complex dynamic system which rarely if ever reaches equilibrium (see, for example, Arthur, 2014). While in a linear system, macro level activity amounts to a simple adding up of the micro actions, in a non-linear system, something new may emerge. Arthur (1999) concluded:

> After two centuries of studying equilibria—static patterns that call for no further behavioral adjustments— economists are beginning to study the general emergence of structures and the unfolding of patterns in the economy. When viewed in out-of-equilibrium formation, economic patterns sometimes simplify into the simple static equilibria of standard economics. More often they are ever changing, showing perpetually novel behavior and emergent phenomena.

Furthermore 'Complex dynamical systems full of non-linearities and sundry time lags have been completely beyond the state of the arts until rather recently' but 'agent-based simulations make it possible to investigate problems that Marshall and Keynes could only 'talk' about' (Leijonhufvud, 2006). More recently, Stiglitz & Gallegati (2011) have pointed out that use of the representative agent 'rules out the possibility of the analysis of complex interactions'; and they 'advocate a bottom-up approach, where high-level (macroeconomic) systems may possess new and different properties than the low-level (microeconomic) systems on which they are based.' ABM is therefore seen by many as offering a way forward.

The impact of the 2008 economic crisis

Once again it has taken an economic crisis to prompt a re-evaluation of economic modelling. Indeed, the 2008 economic crisis caused a crisis for economics as a discipline. It is now widely recognised that a new direction is needed and that ABM may provide that. Farmer & Foley (2009) argued in *Nature* that 'Agent-based models potentially present a way to model the financial economy as a complex system, as Keynes attempted to do, while taking human adaptation and learning into account, as Lucas advocated.' A year later, *The Economist* (2010) was asking if agent-based modelling can do better than 'conventional' models. Jean-

Claude Trichet (2010), then President of the European Central Bank, spelt out what was needed:

> First, we have to think about how to characterise the *homo economicus* at the heart of any model. The atomistic, optimising agents underlying existing models do not capture behaviour during a crisis period. We need to deal better with heterogeneity across agents and the interaction among those heterogeneous agents. We need to entertain alternative motivations for economic choices. Behavioural economics draws on psychology to explain decisions made in crisis circumstances. Agent-based modelling dispenses with the optimisation assumption and allows for more complex interactions between agents. Such approaches are worthy of our attention.

The Review of the Monetary Policy Committee's Forecasting Capability for the bank of England concluded that 'The financial crisis exposed virtually all major macro models as being woefully ill-equipped to understand the implications of this type of event' (Stockton, 2012: 6). In early 2014, the UK's Economic and Social Research Council (ESRC) sponsored a *Conference on Diversity in Macroeconomics*, subtitled *New Perspectives from Agent-based Computational, Complexity and Behavioural Economics* to bring together practitioners of the new approaches, mainstream academic economists and policy makers (Markose, 2014).

Furthermore, by 2013, the call for change had spread to the teaching of economics (*Economist*, 2013) and in 2014, *Curriculum Open access Resources in Economics* (CORE) was launched, providing an interactive on-line resource fora first course in economics, and it is planned to include agent-based simulations in this new way of teaching economics (Royal Economic Society, 2014; CORE, 2014).

So, what is ABM? We give an overview in the next section.

What is agent-based modelling?

The development of computational social simulation modelling started in the early 1960s with microsimulation (Gilbert & Troitzsch, 2005: 6; Morgan, 2012: 301-315). Microsimulation takes a set of data about a population – of people, households or firms – and applies rules to reflect changes, enabling the modeller to look at the overall impact (Gilbert & Troitzsch, 2005: 8). Such an approach is particularly useful for modelling policy changes, for example to see who is made better or worse off by tax changes. However, although allowing for heterogeneity, microsimulation does not allow interaction. Only with the arrival of agent-based modelling did modelling interaction between agents become possible.

Agent-based modelling grew out of research on nonlinear dynamics and artificial intelligence and was facilitated by the arrival of personal computers in the 1980s and early 1990s. An agent-based model is a computer program that creates an artificial world of heterogeneous agents and enables investigation into how interactions between these agents, and between agents and other factors such as time and space, add up to form the patterns seen in the real world. The program creates agents located with different characteristics and tells them what they can do under different circumstances. Early work such as Epstein & Axtell's (1996) *Sugarscape* model demonstrated the potential power of this approach and Squazzoni (2010) describes what has been achieved since the mid-1990s.

Usually, an agent represents a person, but it can represent a household, a firm or even a nation, as we shall illustrate. Heterogeneity of agents is a key feature: each agent may have a unique set of characteristics and behaviour rules (Epstein, 2006: 51). The agents are distributed across a space envisaged by the modeller which may represent a landscape or a social network or more abstract 'spaces' (Epstein, 2006: 52). They may be distributed randomly across the whole space or according to some other principle. The space is typically two dimensional and may have boundaries or be continuous.

The behaviour rules specify how agents interact with neighbours or their local landscape. Modellers can draw on a range of sources, from national statistics to information provided by small, ethnographic studies, to explore the underlying mechanisms. While they can draw on standard economic theories, they can also use other theories such as those based on behavioural economics. The computer model can then be used to generate possible future scenarios and to study the effects of economic policies. ABM enables the testing of the validity of assumptions gleaned from different sources to see whether or not they generate the observed patterns.

Agent-based models can range from simple, abstract models to very complicated real-world case studies. They may have just two agents or millions of agents. And within a model, agents can represent different kinds of entities: people, households, firms, governments, or countries or even animals.

Agents' characteristics fall under four possible headings:

- perception: agents can see other agents in their neighbourhood and their environment
- performance: agents can act, such as moving and communicating
- memory: agents can recall their past states and actions
- policy: agents can have rules that determine what they do next.

Chapter 2 provides an introduction to doing agent-based modelling. For more background, see Gilbert and Troitzsch (2005) and Gilbert (2007).

The three themes of this book

Howitt (2012) suggested that agent-based economics models are 'the polar opposite to that of DSGE'. DSGE models in effect assume that 'people have an incredibly sophisticated ability to solve a computationally challenging intertemporal planning problem in an incredibly simple environment' while the agent-based models assume that 'people have very simple rules of behavior for coping with an environment that is too complex for anyone fully to understand'. In short, Howitt argued that agent-based economic models can portray an economic system in which orderly behaviour can emerge as a result of interaction between heterogeneous agents, none of whom has any understanding of how the overall system functions.

In agent-based models, agents follow rules and react and interact over time. They may well be optimising, but it is within their perceived constraints and they may not have full information. In contrast, neoclassical economics assumes people can optimise using full information. (See, for example, Axtell 2007.) In particular, in agents-based models, agents cannot foresee the future because it is determined by stochastic processes. And they may correct their behaviour following a mistake or not, depending on the learning algorithm used. DSGE models assume mistakes are not repeated.

The book focuses on using agent-based models to provide:

- the possibility of modelling heterogeneity
- an easy way to address dynamics

- the opportunity to model interactions between people and between people and their environment.

We now take a brief look at each of these.

Heterogeneity

Traditional approaches to economics have long been criticised for 'lumping' things together. Think, for example, of a Cobb-Douglas production function in which two variables, labour and capital, are combined to produce output. Clearly there are different types of labour and different types of capital and one kind cannot replace another overnight: a bricklayer cannot just become a software designer, nor vice versa, and a factory producing cars cannot produce computer chips. Nor are all consumers the same: a rich household will have a very different spending pattern to a poor household. Some must save so that others can borrow. Indeed, without heterogeneity there would be no scope for trading. Agent-based modelling allows for such heterogeneity to be represented explicitly and without causing insuperable complications.

Dynamics

By dynamics, we here refer to adaptive processes, which, according to Leijonhufvud (2006), is the sense in which it was original used in economics. Most economic textbooks only use comparative statics i.e. compare equilibrium situations. Yet as long ago as 1941, Samuelson pointed out that comparative statics were inadequate for the analysis of a range of economic problems. But as the examination of any basic economics textbook will show, comparative statics still dominates teaching. The question of how the economy moves from one equilibrium to another is not addressed. This is only now starting to change under the auspices of CORE, which gives prominence to dynamics (CORE, 2014). However, modelling dynamics by traditional methods is difficult as the mathematics quickly become unmanageable. Using ABM, simple rules can be applied and tested through simulation.

Interactions

People influence each other's behaviour: herd behaviour is common in economics; people copy fashion, markets take flight. Indeed, markets are based on interactions: sellers and buyers trade. The traditional economic models do not allow for this kind of interaction but it is easily modelled using agents. ABM can also model in a simple manner how people can interact with the environment; for example, using up scarce resources.

Details of chapters

It is clearly impossible to cover everything presented in standard economics textbooks, which typically run to hundreds of pages (e.g the British Begg *et al*.'s *Economics* (2011) and, from the US, Varian's *Intermediate Economics* (2010)). So we have chosen topics within areas that seem to be particularly suitable for agent-based modelling, that is, where heterogeneity, interaction and dynamics are important.

Markets are a key theme of this book. We start with consumer choice in Chapter 3 and include fashion dynamics in Chapter 4 before introducing markets, through barter, in Chapter 5 with a fuller development in Chapter 6. The later chapters cover markets in the contexts of labour in Chapter 7 and international trade in Chapter 8. We have deliberately avoided discussion of financial markets as the usefulness of ABM has already been well established in this area by LeBaron (2006) and others. But Chapter 9 demonstrates the potentially explosive dynamics of the fractional reserve banking system. Chapter 10 shows how ABM can be used to model not only the interaction between economic agents but the interaction between agents and their natural environment.

Chapter 2 Starting agent-based modelling

Chapter 2 shows how to create a simple agent-based model and introduces the programming environment, NetLogo, that will be used for the models described in the rest of the book. The model simulates consumers shopping for fruit and vegetables in a produce market. The consumer agents are initially programmed to choose a market stall to purchase from at random, and then successive enhancements are made to record the cost of purchases, to stop them revisiting a stall they have previously been to, and to try to find the cheapest stalls to buy from. Many of the basic building blocks of NetLogo programming are described.

Chapter 3: Heterogeneous Demand

Chapter 3 introduces ABM by showing how it can be used to create heterogeneous agents whose characteristics and behaviour can be summed to generate observed macro patterns. Three models are presented in which agents represent households. The first model generates a budget distribution to replicate the observed distribution of income in the UK. The second adds a Cobb-Douglas utility function to draw both individual and aggregate demand curves and demonstrates how consumers' choices can be tracked from their preferences to their contribution to aggregate demand. The third model provides a practical way of examining the effect on demand of price changes. Finally, the chapter compares the results from these simple models using heterogeneous agents with those from a 'representative agent' analysis.

Chapter 4: Social Demand

Chapter 4 adds interaction between agents and dynamics. Consumers' behaviour is now not just influenced by prices and incomes but also by what others do, especially family and friends. Agent-based modelling is well-suited to modelling such social networks and the first model in this Chapter does this very simply using the concept of social circles. Next we introduce threshold models and show how these can be combined with the social network model to examine possible adoption patterns of new products. The Chapter then reviews the adoption of new technology by households in the UK and finally presents a case study of the adoption of fixed-line phones in the UK from 1951 to 2001.

Chapter 5: Benefits of Barter

Chapter 5 demonstrates how agent-based modelling allows us to explore the dynamics of heterogeneous agents interacting by trading. Using the two-good economy much beloved of economics textbooks, agents trade by barter. We model an exchange economy broadly based on a description of trading that occurred in a prisoner-of-war camp. We start by creating a model that reproduces the Edgeworth Box to tease out the essentials of the barter process between two individuals. We explore the effectiveness of different price setting mechanisms in clearing the market and achieving Pareto optimality, starting with the theoretical Walrasian auctioneer. Then we extend this model to allow 200 agents to trade. We show that a simple stochastic peer-to-peer trading mechanism can produce a large increase in welfare, even if total utility is not maximised.

Chapter 6: The Market

Chapter 6 focuses on the decisions of firms and demonstrates how agent-based modelling can easily accommodate the dynamic and interactive nature of markets. We present three models. The first is based on Cournot's classic model of duopoly and its Nash equilibrium, but introduces the possibility of inaccurate information. The second model is based on small shops in the real world that do not have the benefit of the perfect foresight that is granted to firms operating under perfect competition and illustrates the dynamics of survival. The final model reflects business in the digital world, where there is no limit on capacity.

Chapter 7: Labour Market

Heterogeneity and dynamics are the central themes of Chapter 7. The UK labour market is characterised by large flows and great diversity among the participants. The Chapter starts with a model to generate the distribution of wages. It then adds the interaction between employers and workers as employers try to fill vacancies and workers seek jobs, touching briefly on the very skew distribution of firms by size. Finally, the various flows of workers between employers and into and out of the labour force are added to produce a simple, but interesting, model of the labour market of a small town. It also shows how micro and macro aspects can be combined in one model.

Chapter 8: International Trade

Chapter 8 presents a simple model of trade between one country and the rest of the world, focusing on the determination of exchange rates. Five countries are used as examples, two with floating exchange rates and three in the Eurozone. Four scenarios are examined: inflation, depreciation, exogenous change in demand for exports and the impact of fiscal policy changes. The model focuses on dynamics. Even this simple model serves to highlight the difficulty of modelling the dynamics of international trade. It also shows clearly the constraints under which Eurozone countries operate.

Chapter 9 Banking

Chapter 9 uses a simple agent-based model to explore the basic features of fractional reserve banking and shows how the reserve and capital adequacy ratios imposed by regulators can dampen an otherwise explosive system. It illustrates how agent-based modelling can accommodate heterogeneity in that both savers and borrowers can be represented; how micro and macro aspects can be combined in one model, unlike the conventional textbook treatment of banking; and the importance taking dynamic processes fully into account in modelling the banking system.

Chapter 10 The Tragedy of the Commons

Chapter 10 demonstrates how ABM can handle the interaction of agents with their environment as well as with one another by addressing the problem of the over-use of shared resources. In the 'tragedy of the commons' the pursuit of self-interest results in over-use of a common pool resource to the detriment of all. A model, inspired by English common land, is built in two stages. First, a meadow is created and its carrying capacity established. Then commoners are introduced. If there are no restrictions on the number of cows grazed on the meadow, there is overgrazing and 'the tragedy' ensues. But by following actual practice observed in England and Switzerland of setting limits on the number each commoner is allowed to graze, the model demonstrates that the tragedy can be avoided. The model can be readily adapted to accommodate other scenarios.

Chapter 11 Summary and Conclusion

The final chapter summarises the models to show how ABM has addressed the weaknesses in the existing methods identified in Chapter 1 by allowing heterogeneity, facilitating dynamics, and modelling interactions between people and their environments and thereby improving the link between micro- and macro-economics. It also sets out some of the problems that need to be addressed in order for ABM's potential to make a useful contribution to economics to be fully realised.

The Models

We present 19 models in Chapter 3 to 10, ranging from modules to be used in larger models to a real-world model. In each case, we follow Müller *et al* (2014) who suggested 'a structured natural language description plus the provision of source code' as being 'particularly suited for academic purposes'. We describe the models in natural language in the chapters. The appendices to the chapters provide more details based on the ODD system (Grimm *et al*, 2010) and include pseudo-code. The code itself is provided on the website: http://cress.soc.surrey.ac.uk/ .

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