Chapter 11: Summary and Conclusions

Introduction

We start this final chapter by summarising the models produced. We then go on to discuss the usefulness of agent-based models and the pros and the cons of using ABM in economics. We finally leave the reader with a list of further reading and resources.

The models

We have presented 19 models in this book. These include modules which are inputs to other models, models to illustrate theory, models for policy and a model of a real world event. Some models have just two agents, but most have 1 000 and the largest has 10 001. In many models, the agents represent individuals or households. But in some they represent institutions: firms or countries. In one case, they even represent non-human actors, namely cows. These basic features are summarised in Table 11.1. The common characteristic is that all are parsimonious in that they make the minimum number of assumptions required to produce the desired result, following Doran & Palmer's (1995) advice:

> A standard modelling principle is that the level and complexity of a model should be chosen so that it answers the questions and embodies the theoretical elements we are interested in, but is otherwise as simple as possible.

We started in Chapter 3 with a model of the distribution of household income that matches the distribution observed in the UK. This introduced heterogeneity and established a micro-macro link in that it can be seen how each household contributes to the overall pattern observed. Next we used this distribution alongside neoclassical utility theory to model consumer demand. But we then went on to show that for practical purposes, consumer demand can be modelled using budget constraints and price elasticities.

In Chapter 4 we introduced dynamics and interaction by allowing consumers to influence one another. We presented a simple way to model social networks, based on the idea of social circles. We then used this to explore the potential impact of positive feedback on consumer demand using threshold models. We showed how agent-based modelling is particularly suitable for threshold models because it can deal with both local influence and the influence of society as a whole. We then combined these two models, with other procedures, to examine the adoption of fixed-line phones in the UK between 1951 and 2001. That model showed that economic factors – prices and incomes – are not sufficient to explain the pattern observed: social interaction is essential. Overall, this Chapter demonstrated that ABM offers a very powerful approach to the modelling of positive feedback because it can also allow for both heterogeneity and interaction.

In Chapter 5, we moved on to interaction in a market through barter. We started with the neoclassical framework of the Edgeworth Box and used ABM to explore its dynamics. First, we assumed the existence of a Walrasian auctioneer, but then we relaxed this assumption and allowed the agents to negotiate with one another directly. We then extended this to model a simple trading system involving 200 agents and two products. The model allowed us to explore various trading arrangements and we showed that a simple stochastic peer-to-peer trading mechanism can produce a large increase in welfare, even if total utility is not actually maximised.

In Chapter 6 we introduced firms, starting with a model of a Cournot-Nash equilibrium. We introduced a simple dynamic system in which each firm based its output on what it believed the other firm produced in the last period. With ABM, it is easy to explore the dynamics and to allow for incomplete information. We show how even small errors in agents' knowledge can result in oscillations in output. We then added consumers. We started with the neoclassical perfect competition scenario to establish a baseline and then relaxed its assumptions, so that prices were simply a mark-up on costs and the shops adjust their supply, altering both their short and long term costs. Consumer demand was based on willingness-to-pay. Firms that did not compete successfully went out of business. This simple model produced the result that the greater competition, the higher are sales. Next we adapted this model for digital products and services, such as selling software, music and games. Here the diminishing returns to scale assumed in neoclassical economics does not hold. For simplicity, we ignored capacity constraints altogether. The model illustrated why firms selling such products should initially price high and then drop to increase quantity.

In Chapter 7, we turned to the labour market. The labour market is dynamic and there is great diversity among the participants, both workers and employers. We started by creating a model of the wage distribution, similar, but not the same as, the distribution of household

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income modelled in Chapter 3. We then produced a simple model of job search and explored the implications of our assumptions. Both modules were then incorporated into a model of a labour market based on our home town of Guildford. We were able to show how the large flows between different employment statuses observed in the UK labour market are consistent with stability at the macro level and how the greater is wage flexibility, the lower is the rate of unemployment, the lower the proportion of unemployed who are long-term unemployed and the greater the probability of moving from unemployment into work.

Chapter 8 examined the demand and supply of foreign currency. We focussed on the determination of exchange rates under different policy regimes. One agent represented a country and another, the rest of the world. The modeller could assign different characteristics to the country agent and choose the policy environment, either a floating or a fixed exchange rate. The model was used to explore different scenarios and highlighted the contrast between the dynamic systems of countries with floating exchange rates, like the UK and the USA, and those in the Eurozone.

Next, Chapter 9 examined the banking system, focussing on the dynamics of the fractional reserve system. Our model showed how potentially explosive this system is, which is not evident in the standard textbook presentation, and demonstrated the importance of liquidity and capital adequacy rules for the stability of the banking system. The model distinguished between borrowers and savers, and was therefore able to allow for the fact that only a minority are savers (unlike representative agent models), and to suggest the effect of the banking system on the distribution of savings and loans. It also brought together in one model the micro and the macro, usually treated quite separately in economic textbooks.

Finally, Chapter 10 illustrated how ABM can be used to model the interaction between humans and the environment. Taking the tragedy of the commons as its theme, the first model created an environment – a meadow – and allowed the modeller to assess how many grazing animals – cows – it could support. People were then added and different management systems of this common pool resource explored. The model was able to generate a wide variety of outcomes because there are so many dynamic processes interacting, which is perhaps why it can be so difficult to reach sustainable stability. Furthermore, the commoners are not assumed to optimise, but use only two heuristic behavioural rules, which nevertheless still produce useful benefits. Also because the system is grown from the action of individual agents, it is possible to drill down from the top level to see how it was created by individual actions.

Table 11.1 summarises the 19 models. It divides them into four types:

- Modules: models can stand alone but which are later incorporated into larger models.
- Theoretical: models designed to implement economic theory.
- Policy: practical models that could be used to address policy questions.
- Case study: a model designed to reproduce an observed event.

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Table 11.1: Summary of models

Models	Type of model	No. of agents	Type of agents	Key features: Hetero-geneity	Dyna-mics	Inter-action	Macro-micro
Chapter 3							
Distribution of household budgets	Module	1 000	Households	✓			✓
Utility function-based demand	Theoretical	1 000	Households	✓			✓
Practical demand model	Policy	1 000	Households	✓			✓
Chapter 4							
Social circles	Module	1 000	Individuals/households	✓	✓	✓	✓
Threshold	Module	1 000	Individuals/households	✓	✓	✓	✓
Phone adoption	Case study	1 000	Households	✓	✓	✓	✓
Chapter 5							
Edgeworth Box game	Theoretical	2	Individuals	✓	✓	✓	
Edgeworth Box random	Theoretical	2	Individuals	✓	✓	✓	
Red Cross Parcels	Theoretical	200	Individuals	✓	✓	✓	
Chapter 6							
Cournot-Nash	Theoretical	2	Firms	✓	✓	✓	
Shops	Theoretical	1 000	Firms & consumers	✓	✓	✓	
Digital world	Theoretical	1 000	Firms & consumers	✓	✓	✓	
Chapter 7							
Wage distribution	Module	1 000	Individuals	✓			✓
Job search	Module	1 100	Firms & individuals	✓	✓	✓	
Guildford labour market	Policy	1 100	Firms & individuals	✓	✓	✓	✓
Chapter 8							
International trade	Policy	2	Countries		✓		
Chapter 9							
Banking	Policy	10 001	Firm & individuals	✓	✓	✓	✓
Chapter 10							
Carrying capacity	Module	100-2 000	Cows		✓	✓	
Meadow management	Policy	110-1 010	Individuals & cows	✓	✓	✓	✓

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What makes a good model?

We have mentioned in Chapter 2 and elsewhere the importance of verification i.e. of ensuring that the program is doing what the modeller intended. This is clearly essential. But a bigger and more difficult question is: what makes a model a good one? This assessment is called validation. As Windrum *et.al*. (2007) noted, the validation of agent-based models in economics is not straightforward.

Putting aside the questions that apply to the validation of all modelling, such as the quality of the data used to validate the model, agent-based modelling produces special problems because of the stochastic processes involved and its modelling of complex, in the sense of non-linear, systems. For instance, simply counting the number of times the model reproduces the observed phenomenon may not be a good indicator of the model's quality. It may be that under the circumstances described by the model, the observed outcome is unlikely, but is nevertheless what actually happened. The problem is that we do not, and can never, know which is the case: the model is wrong or the actual situation is rare, although we may be able assess probabilities. That is why sensitivity analysis, important in all modelling, is arguably more so in agent-based modelling.

For real-world models like that of phone adoption, which we presented in Chapter 4, we followed a standard approach in simulation modelling: to see whether the model can reproduce the observed macro data. Goodness-of-fit can be measured using standard statistical measures. But a good fit is not sufficient to make a good model. As Morgan (2012, pp. 330-334) pointed out, just because the simulated data 'mimics' the real world does not mean that the process generating the data in the model is equivalent to the process operating in the real world. But Morgan was not discussing agent-based models. Epstein, commenting on the issue in relation to ABM, argued that 'generative sufficiency is a necessary but not sufficient condition for explanation' and that, to be judged a good model, it must also make sense at the micro level (Epstein, 2006, p.53). In other words, the model as a whole must tell a convincing 'story'. Thus in the phone adoption model, we used both the goodness-of-fit criterion and the plausibility of the underlying assumptions, such as households influencing one another. The model of the Guildford labour market in Chapter 7 illustrates Epstein's point well in that the overall macro level could be easily replicated by a much simpler model but the value of the model lies in reproducing the underlying micro activity and showing that it does generate the observed macro phenomenon.

However, for abstract models, there is no real-world data with which to compare the output. That is true of many of the models presented in this book. But the models allowed us to investigate theories, so as to

- move away from the textbook focus on comparative statics to dynamic processes: for example the dynamics of the Cournot-Nash model in Chapters 6 suggested a source of economic instability, as did the potentially explosive dynamics in the banking system identified in Chapter 9;
- investigate non-equilibrium positions as in the labour market model in Chapter 7;
- discard assumptions about actors optimising in favour of various types of bounded rationality using heuristics, for example in Chapter 10.

Whether an abstract ABM is of value depends on its contribution to our understanding of the economic system.

To sum up, the aim of validation is to assess the quality of the model. One approach is to measure the extent to which the observed macroeconomic data can be explained by micro level interactions. But that alone is not sufficient. To be good, an agent-based model must also make sense at the micro level, both in the characteristics of the agents and the manner in which they interact. Doing such assessments in a consistent and coherent way remains a challenge. For more on the general issues of the validation of agent-based models, see Gilbert (2007, pp.64-76) and with special reference to agent-based economic models, Windrum *et al*. (2007).

Pros and cons of ABM

We have demonstrated the ease with which ABM can handle heterogeneity, dynamics and interaction, and we have shown how it can be used to bridge the gap between micro and macro. We have also shown that ABM can be used to model systems without assuming that agents – be they people or institutions – are optimising or that the system reaches an equilibrium. This is in stark contrast to the economic mathematical models that are based on optimisation or equilibrium or both (Morgan, 2012, pp.394-396). To make the mathematics tractable, it has been necessary to rely on a set of highly unrealistic assumptions which have been widely criticised by the complexity and 'post-Walraisian' economists mentioned in

Chapter 1 and by many others. With ABM, we can move away from this restrictive, traditional approach. Repeatedly we have shown that useful models can be built without these assumptions. Rather than optimising with full information, the agents follow rules-of-thumb based on limited information. For example, in the practical demand model in Chapter 3, households managed their budget rather than maximised their utility and in Chapter 5, shops did not maximise profits but followed simple pricing rules.

ABM certainly has potential to improve our understanding of economics, but there are many issues still to be addressed and ABM is not without its critics. Some of the criticisms result from a failure to understand simulation (Waldherr & Wijermans, 2013). This implies that ABM practitioners have to explain better and be more transparent, by, for instance, making their code available.

An example of the sort of criticism made by traditional economists is when they ask 'where are the equations?' As shown in this book, it is possible to express some of the key processes in equations. Mathematics is used in ABM but usually not to solve sets of equations in order to optimise or find an equilibrium. A possibly related criticism is that ABMs have too many variables (Waldherr & Wijermans, 2013). Yet surely one of the advantages of ABM is that it exposes the assumptions that have to be made in formulating any kind of model. Is it really better that these are left unidentified?

However, there is a real and major problem with the use of ABM in economics and that is the lack of standardisation as noted, for example, by Windrum *et al*. (2007). Once modellers move away from optimisation, they are faced with an enormous choice of alternative behavioural rules. There are no standards and each modeller uses their own, often probably without thoroughly exploring the implications of their assumptions. For example, Balke & Gilbert (2014) identified 14 types of decision-making processes used in ABM. Much more work of this kind is needed. The lack of standardisation is recognised within the ABM community: for example, Heath *et al.* (2009) called for 'standard techniques, practices, philosophies and methodologies' and Squazzoni (2010) called to move on from the current 'hand-crafted' approach to use instead 'standard practices, methods and scientific communication'. This situation is perhaps inevitable given that ABM is relatively new. The time and effort devoted to Agent-based Computational Economics (ACE) has to date been very small. (See Farmer, 2014, for an estimate.) In contrast, neoclassical economics has been

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the focus of economists for 100 years or more; and Dynamic Stochastic General Equilibrium (DSGE) models have been developed over some 40 years. The ACE community needs to develop suites of modules that are based on widely agreed assumptions and accepted behavioural rules which can be plugged together to build models.

Not only do models need to be standardised but also, better data is needed For example, for some policy work we need demographic modules that reflect reality. The phone adoption model in Chapter 4 showed just how difficult modelling the real world is, and how it required an enormous amount of detail about demographic dynamics. This need is becoming recognised and is starting to be addressed, for example, by France's *Agence Nationale de la Recherché.* Its project *Gen** is developing tools and methods to generate realistic synthetic populations for agent-based social simulation. More work of this kind is needed. There is a related issue: lack of data. As Keynes' theories and the development of macroeconomic models in the 1930s gave rise to identifying the need for new types of data, so ABM requires new data. Often, modellers do not know how economic agents will behave and have to resort to stochastic processes. Behavioural economics will help to fill this gap.

Practitioners of ABM are keen to use their skills in the policy context. We touched on this when we modelled the labour market in Chapter 7. However, policy analysts will only adopt ABM if it provides something better than they already have. For example, in the early 1980s, microsimulation was adopted because it provided a much better way of examining the impact of changes in tax and benefits than the method then used, applying changes to hypothetical families. ABM needs to demonstrate that it can offer more than existing models. We have shown that it does have this potential, but that much work needs to be done for that potential to be realised. We hope that this book provides the incentive to develop further the use of ABM in economics.

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Agent-based modelling (ABM)

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Online resources

Agent-Based Computational Economics http://www2.econ.iastate.edu/tesfatsi/ace.htm [Accessed 3 February 2015].

Journal of Artificial Societies and Social Simulation http://jasss.soc.surrey.ac.uk/JASSS.html [Accessed 3 February 2015].

NetLogo. https://ccl.northwestern.edu/netlogo [Accessed 3 February 2015].

Open ABM: tutorials, model library and forums run by Network for Computational Modeling for SocioEcological Science (CoMSES Net) http://www.openabm.org/ [Accessed 3 February 2015].

Mailing lists and forums

NetLogo Users Group email list. https://groups.yahoo.com/neo/groups/netlogo-users/info [Accessed 3 February 2015].

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