MONASH University

World Vision

Evaluating Modelling Frameworks

Dr Brett Parris
Chief Economist, World Vision Australia
Research Fellow, Monash University

CGE Model Limitations

- Many assumptions of analytic CGE models are not appropriate for integrated assessment modelling. E.g.
  - Perfect information, rationality & foresight
  - Assumption that all individual people & firms are perfect optimisers
  - Underlying theory presumes infinite computational capacities of all agents
  - Multiple equilibria ruled out by assumption and design
  - Ignoring money, credit, debt & finance (most are effectively barter models). Can't model credit crunches, major swings in exchange rates, financial crises, firm balance sheets etc.
  - Assumption that all firms are already using best technology
  - Representative agents (eg. single household for country) used to disguise impossibility of obtaining market demand curves from individual demand curves. Cannot presume welfare improvement of representative agent implies improvements in individual welfare.

CGE Model Limitations (cont.)

- Ignores gender effects and growth & development of children (eg. feedback from government budgets on health & education of children & later impacts on workforce quality, ability of firms to innovate).
- Complete markets & networks for goods, services, capital, risk
- Costless redeployment of labour
- No interaction between firms & governments except through taxation (ignores lobbying, corporate influence, government incentives etc)
- Weak on hyseteris & path dependency (eg. bankrupted firms can't magically reappear after recessions, loss & dispersal of tacit knowledge & networks; lock-in of poor technologies defended through political lobbying)
- Assumes zero corruption, costlessly enforced contracts and property rights & costless dispute resolution
- Use of comparative statics – snapshot of one 'equilibrium' solution to equations which is perturbed and solution recalculated to new 'equilibrium'. Transition path is assumed but there's no theoretical justification for belief that new equilibrium could actually be reached. Need genuinely evolutionary dynamics.

CGE Model Limitations (cont.)

- Weak treatment of increasing returns in order to rule out non-convexities & multiple equilibria
- Ignores informal economy (~ 50% of economy in some countries – not represented in official statistics)
- Weak treatment of spatial effects (eg. Constraints on mobility of labour due to different work locations of household members, locations of family & friends, inability to afford housing &/or transport close to work)
- Use of optimisation over real number field (R^+) rather than *integer* optimisation of prices & quantities. Real optimisation is *not* a good approximation for Diophantine (integer) optimisation problems. It cannot be known in advance whether given Diophantine problem has a solution in integers (Hilbert's 10th problem, proven in 1970 that there is no solution.) Agent's facing integer problems *can't* optimise because they can't know optimal resources to devote to searching for solution.

What do we need?

- Evolutionary dynamics – not equilibrium
- Hetereogeneity of people, firms & technologies
- Spatial variation & spatial networks (social, infrastructure – transport, energy ...)
- Political & legal underpinnings of social stability, incentive structures & markets
- Economic system that includes money, debt, finance, insurance
- Better modelling of innovation, learning & technological change & diffusion
- Interactions between firms, governments & households – heterogeneous responses to different incentives (eg. Firms respond to government incentives)
- Dependence of economy on ecosystems (eg. agriculture, tourism, public health)
- Nonlinear potentially catastrophic impacts of climate on societies & economies (eg. 1 billion + severely short of water in South Asia by 2050; No chance of adapting smoothly to 5+ degrees)
- Threshold effects of climate system – loss of Arctic sea-ice, outgassing from melting permafrost, dieback of Amazon, instability of Indian monsoon, acidification of the oceans - & feedback from nonlinear changes on economies.
- Dependence of economic stability on political and social stability - potential for social breakdown, conflict, anarchy and mass people movements

Modelling challenges

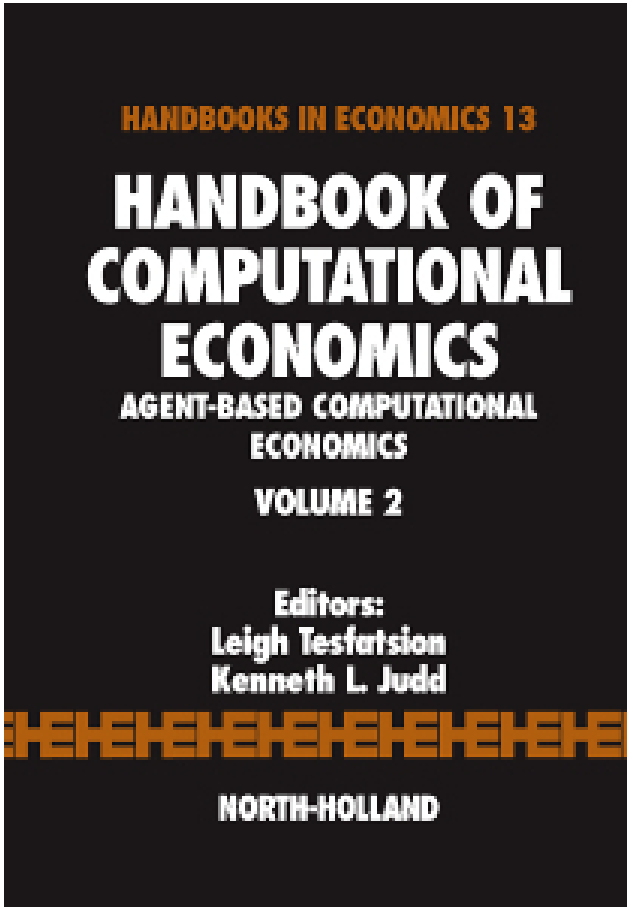
- In making a simple analytic model more complex, it is often *not possible* to relax enough assumptions *simultaneously* and still remain tractable.
- Model has to be simulated – either equation-based or agent-based simulation. Agent-based models can relax more assumptions.
- ***The solvability of mathematical models***

Source: Keen (2001, Table 12.1, p. 265) adapted from Costanza (1993, p. 33).

Type of Equations	***Linear***			***Nonlinear***		
Equations	*One equation*	*Several equations*	*Many equations*	*One equation*	*Several equations*	*Many equations*
Algebraic	**Trivial**	**Easy**	**Possible**	**Very difficult**	**Very difficult**	**Impossible**
Ordinary Differential	**Easy**	**Difficult**	**Essentially impossible**	**Very difficult**	**Impossible**	**Impossible**
Partial Differential	**Difficult**	**Essentially impossible**	**Impossible**	**Impossible**	**Impossible**	**Impossible**

Agent-Based Models

- Dynamic computer simulations involving interactions between discrete heterogeneous 'agents'.
- ABMs are based on object-oriented computer programming: i.e agents are 'objects', encapsulating both attributes (data) and methods (actions).
- Agents can represent anything: people, firms, governments, land types, pathogens.
- Agents interact with each other and their environment according to rules which may themselves evolve.
- The system evolves dynamically – it need not converge to an 'equilibrium'
- ABMs can be non-spatial (a 'soup') or spatial – naturally incorporating real Geographic Information Systems (GIS) data or realistic network structures.
- Models run thousands of times to get probabilistic 'landscape' of outcomes.



Handbook published 2006
23 chapters

Where are ABMs being used?

- Ecology
- Geography
- Epidemiology
- Political science
- Anthropology
- Economics
- Finance
- Innovation and organisation theory
- Combat simulation
- Terrorism research
- Peacekeeping
- Transport & logistics
- Operations research

… and *combinations* thereof.

- Hundreds of papers now published – many in top journals: *Nature*, *Science*, *PNAS*, *The Lancet*, even *AER, Economic Journal*.

ABMs naturally lend themselves to multidisciplinary studies since they can seamlessly integrate the social, political, legal, economic, environmental, geographic and epidemiological dimensions of development.

EURACE – ABM of Europe

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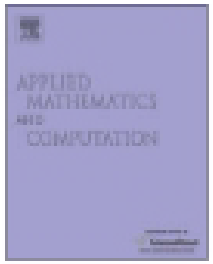

EURACE: A massively parallel agent-based model of the European economy

Christophe Deissenberg [a,*], Sander van der Hoog [a], Herbert Dawid [b]

[a] GREQAM, Université de la Méditerranée, Château Lafarge, Route des Milles, 13290 Les Milles, France
[b] Department of Business Administration and Economics, Bielefeld University, Universitätsstrasse 25, D-33615 Bielefeld, Germany

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ABSTRACT

EURACE is a major European attempt to construct an agent-based model of the European economy with a very large population of autonomous, purposive agents interacting in a complicated economic environment. To create it, major advances are needed, in particular in terms of economic modeling and software engineering. In this paper, we describe the general structure of the economic model developed for EURACE and present the Flexible Large-scale Agent Modelling Environment (FLAME) that will be used to describe the agents and run the model on massively parallel supercomputers. Illustrative simulations with a simplified model based on EURACE's labor market module are presented.

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ABMs & Parameters

- A lot of statistical & econometric work required for ABMs, in data preparation, parameter specification & output analysis.

- Verification & validation of ABMs is an active area of research - eg. best approaches to sample over possible parameter space – Latin hypercube sampling etc.

- "[N]umerical errors can be reduced through computation but correcting the specification errors of analytically tractable models is much more difficult. **The issue is not whether we have errors, but where we put those errors.** The key fact is that economists face a trade-off between the numerical errors in computational work and the specification errors of analytically tractable models."

  Ken Judd (2006) *Handbook of Computational Economics*, Vol. 2, *Agent-Based Computational Economics, p. 887.*

Estimating parameters

- The parameter estimation problem *still exists* for tractable models – but it is often dealt with by *arbitrarily* assigning values of 0 (non-existent) or 1 (perfect) with standard deviation always assumed to be zero. Eg:

- Agent's rationality = 1
- Agent's info processing capacity = 1
- Prevalence of mental illness = 0
- Prevalence of addictive behaviour = 0
- Spatial heterogeneity = 0
- Spatial separation of markets = 0
- Cost of travel between markets = 0
- Prop. of agents able to access info = 1
- Info search costs = 0
- Learning costs = 0
- Heterogeneity of preferences = 0
- Rate of change of preferences = 0
- Prop. of contracts enforced = 1
- Cost of contract enforcement = 0
- Ratio of wealth to wellbeing = 1
- Cost of evaluating choices = 0
- Firms' barriers to entry = 0
- Prop. of capital (K) employed = 1
- Mobility of K between countries = 0
- Accuracy of expectations = 1
- Cost of redeploying L = 0
- Rate of skill loss of unemployed L = 0
- Degree of corruption = 0
- Time required for consumption = 0

The assumptions of tractable models *are* assignments of parameter values. These arbitrary values are no more scientifically valid than the estimations required for ABMs. Often less.

What can economic ABMs contribute to integrated assessment modelling?

- Naturally evolutionary dynamics
- Seamless integration of economic, financial, political, social, environmental, geographic & epidemiological dimensions.
- Heterogeneous agents (age, gender, rationality, health, education etc)
- Taxonomies (code libraries) of market types, behaviours, institutions, networks etc., based on existing data, field observations and lab experiments.
- Spatial dimension – linked to real GIS, land-use data, infrastructure networks (roads, electricity, pipelines), epidemiology (malaria zones, etc)
- Localised &/or costly information & genuine uncertainty
- Bargaining power and price jumps in value chains
- Explicit modelling of children's growth & development over time.
- Natural modelling of integer problems facing economic agents.