Computable General Equilibrium Models & Agent-Based Models: Comparisons & Potential Linkages

Institute for New Economic Thinking
Oxford University
17 November 2016

Dr Brett Parris
Adjunct, Monash Sustainable Development Institute
MPhil Candidate, Faculty of Oriental Studies

Outline

- A brief overview of Computable General Equilibrium (CGE) models.
- Limitations of CGE models
- Advantages of Agent-Based Models (ABMs)
- Potential for interfacing CGE models and ABMs
- Reflections on the success of CGE models compared to ABMs

Outline

- A brief overview of Computable General Equilibrium (CGE) models.
- Limitations of CGE models
- Advantages of Agent-Based Models (ABMs)
- Potential for interfacing CGE models and ABMs
- Reflections on the success of CGE models compared to ABMs

Computable General Equilibrium Models

- Very large systems of simultaneous equations linked to massive economic databases. Eg …
  - GTAP database: GTAP 9 Data Base, features 2004, 2007 and 2011 reference years as well as 140 regions for all 57 GTAP commodities.
  - VU-National mode of Australia: distinguishes up to 140 industries, 56 regions and 340 occupations.
  - USAGE: 500 industries, 50 states plus DC, 700 occupations.

- Have been linked to household survey data. Eg …
  - 3,373 HHs for Nepal CGE (Cockburn, 2001)
  - 24,979 HHs for CGE of the Philippines (Cororaton & Cockburn, 2005)
  - 55,000 HHs for Russian CGE (Rutherford *et al.* 2005)
  - 3,278 HHs for CGE of Senegal (Annabi *et al.* 2005)

- Used by World Bank, WTO, GTAP network, national governments

GTAP:
A tiny sample of the data …

Disposition of imported goods across:
1 prd = private production,
2 cons = private consumption
3 gov = government.

ViewHAR - c:\rungtap5\Tanzan1\baseview.har

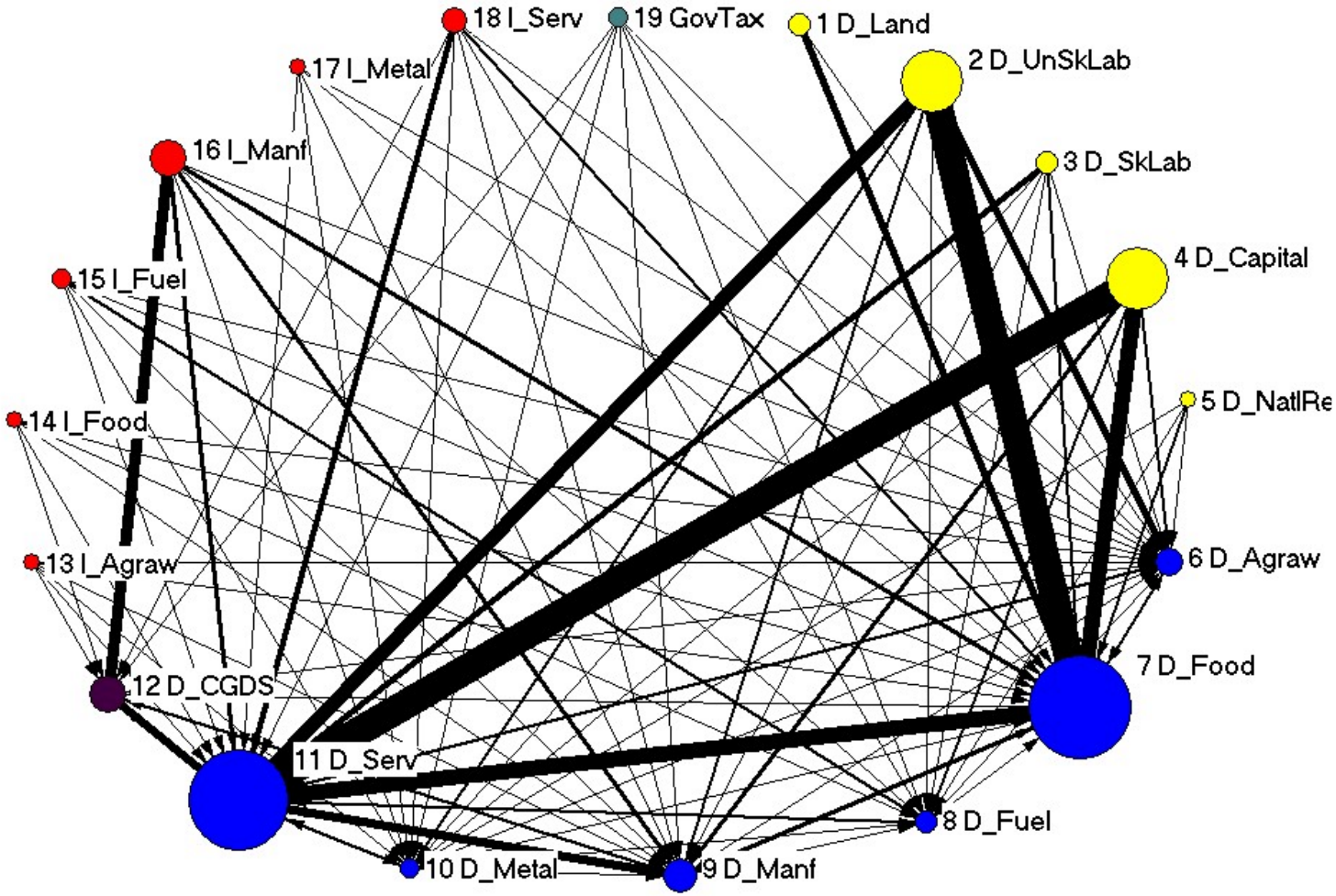
File Contents Export History Search Programs Help

None 6

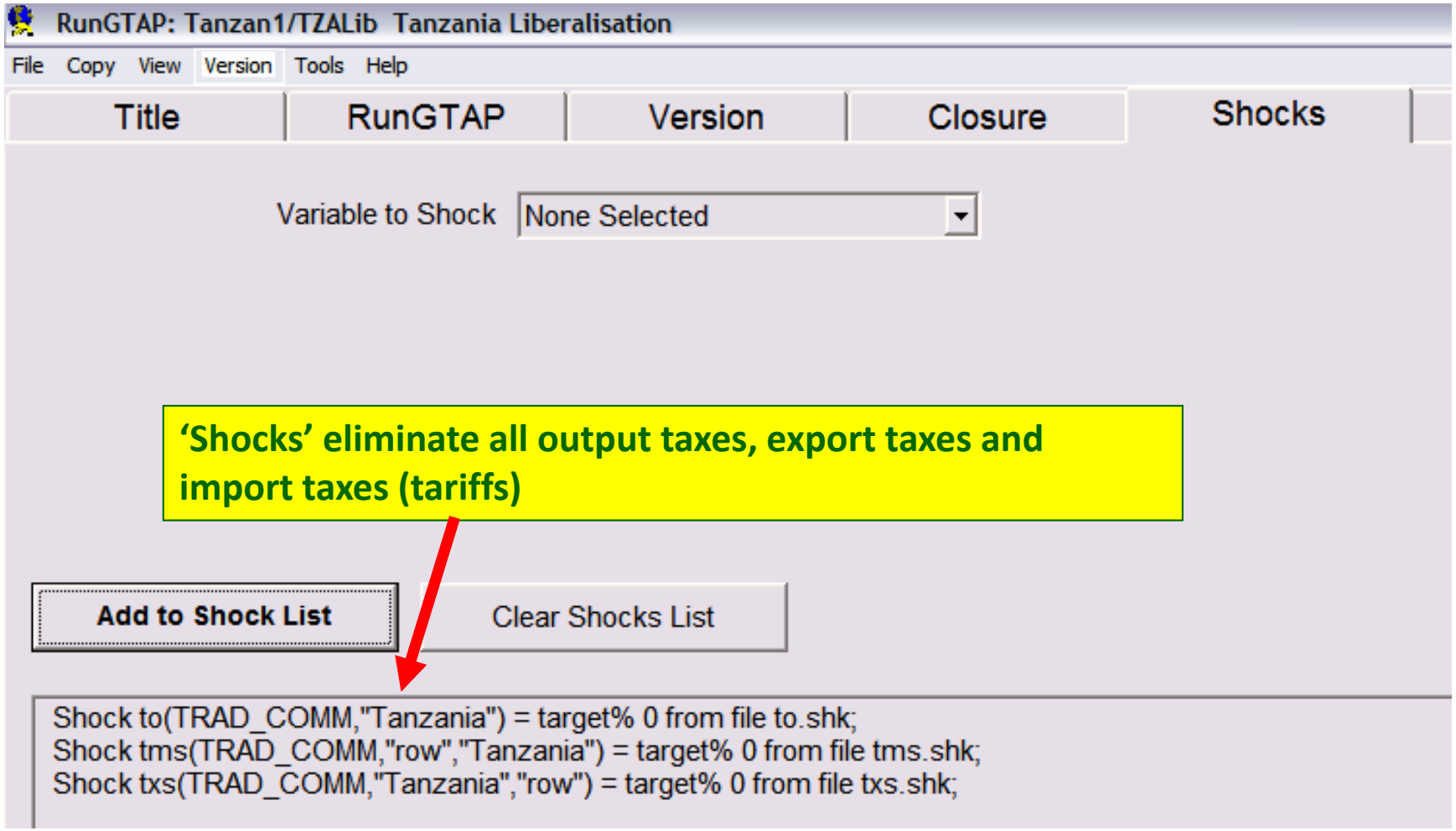
57 sectors

IMPSALESDISP	1 prd	2 cons	3 gov	Total
1 pdr	1370.984497	679.548279	0.963401	2051.496094
2 wht	21059.388672	3666.356201	33.993538	24759.738281
3 gro	19749.644531	2866.824219	39.262283	22655.730469
4 v_f	20977.140625	34627.457031	111.230682	55715.828125
5 osd	18536.322266	3346.354492	8.870758	21891.546875
6 c_b	59.972530	18.965502	0.043075	78.981110
7 pfb	8955.782227	1782.797363	12.019574	10750.599609
8 ocr	29928.673828	15970.802734	273.575623	46173.050781
9 ctl	6617.042480	812.571045	1.990229	7431.603516
10 oap	12373.795898	4286.486328	17.919680	16678.201172
11 rmk	132.904526	47.774384	2.115653	182.794556
12 wol	2140.168457	562.408203	0.501879	2703.078613
13 for	10567.137695	1602.979858	2.283658	12172.401367
14 fsh	7177.129395	3860.220947	8.027331	11045.377930
15 col	24728.482422	409.463226	0.083455	25138.029297
16 oil	249073.312500	3.686557	0.020924	249077.015625
17 gas	42170.925781	7613.690430	0.009849	49784.625000
18 omn	41287.421875	526.020630	45.694481	41859.136719
19 cmt	10849.672852	15736.199219	205.354340	26791.226563
20 omt	17593.123047	19601.074219	185.509201	37379.707031

The input network structure of Tanzania



Specifying the liberalisation 'shocks' …



A tiny sample of results: Welfare decomposition

ViewHAR - c:\docume~1\brettp~1\locals~1\temp\gptemp\rungtap\decomp.har

File Contents Export History Search Programs Help

None 6

WELFARE	1 alloc_A1	2 endw B1	3 tech C1	4 pop D1	5 tot E1	6 IS F1	7 pref G1	Total
1 Tanzania	25.063910	0	0	0	-52.630619	-125.250694	0	-152.817398
2 ROW	16.465532	0	0	0	51.316490	122.299644	0	190.081665
Total	41.529442	0	0	0	-1.314129	-2.951050	0	37.264263

So total trade liberalisation for Tanzania leads to 'welfare' loss of US$152.8 million, made up of:

- **US$25 m gain from increased efficiencies in resource allocations**
- **US$52 m loss from terms of trade movements and**
- **US$125 m loss from changes in the price of capital goods**

What's under the hood?

TABmate

File Edit Search Tools Options Programs Help

Open Save Reload Print Cut Copy Paste Undo Check Next Warn Gloss See Log STI Code

GTAP.TAB | DECOMP.TAB

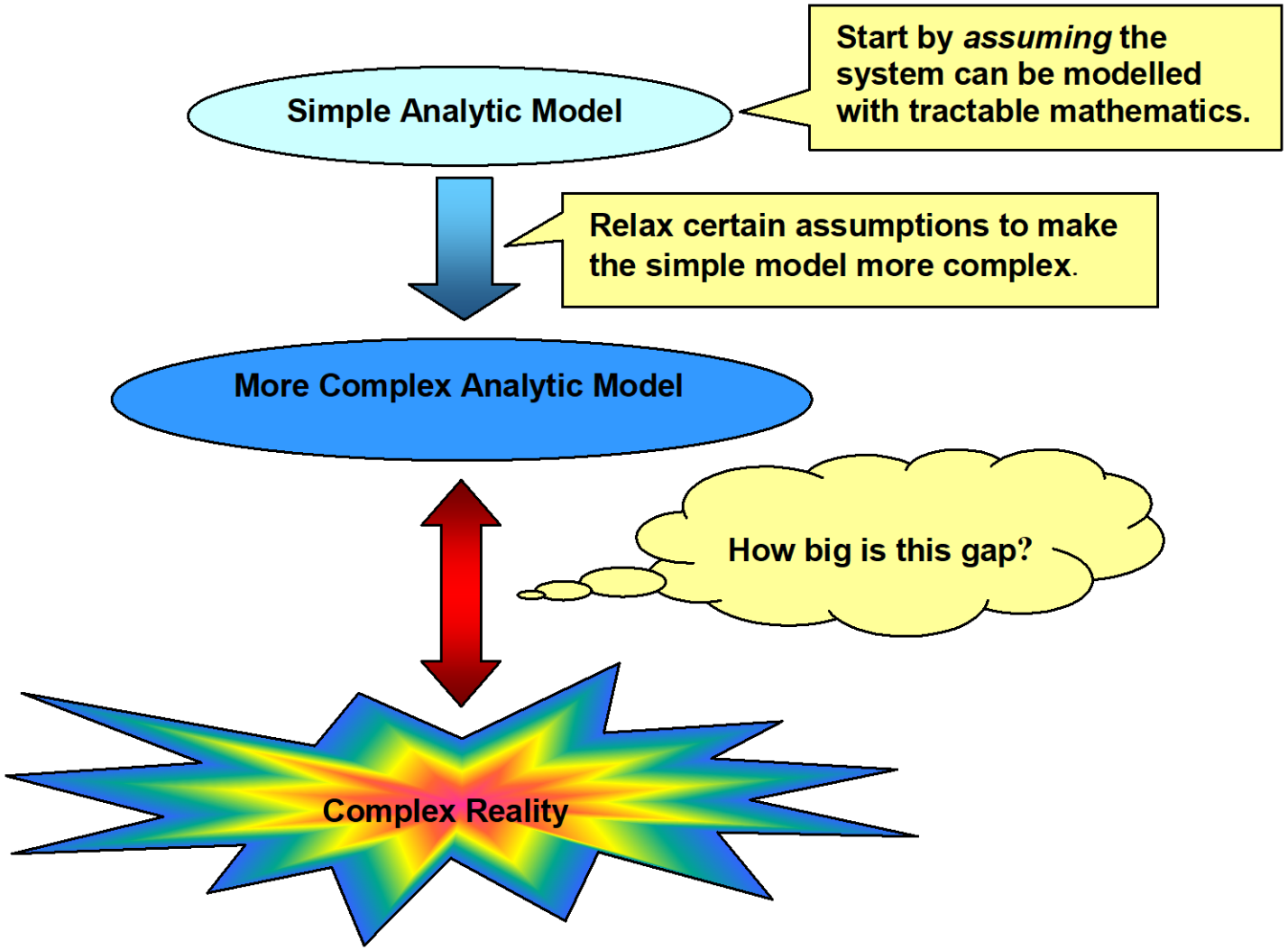
```
3705 Variable (linear,change) (all,i,DEMD_COMM)(all,r,REG)
3706     CNTalleffir(i,r)
3707     # total contribution to regional EV of allocative effects #;
3708 Equation CONT_EV_alleffir_E
3709 (all,i,ENDW_COMM)(all,r,REG)
3710     CNTalleffir(i,r)
3711         = [0.01 * EVSCALFACT(r)]
3712         * [PTAX(i,r) * [qo(i,r) - po
3713             + sum(j,PROD_COMM, ETAX(i,
3714 Equation CONT_EV_alleffir_T
3715 (all,i,TRAD_COMM)(all,r,REG)
3716     CNTalleffir(i,r)
3717         = [0.01 * EVSCALFACT(r)]
3718         * [PTAX(i,r) * [qo(i,r) - pop(r)]
3719             + sum(j,PROD_COMM, IFTAX(i,j,r) * [qfm(i,j,r) - pop(r)])
3720             + sum(j,PROD_COMM, DFTAX(i,j,r) * [qfd(i,j,r) - pop(r)])
3721             + IPTAX(i,r) * [qpm(i,r) - pop(r)]
3722             + DPTAX(i,r) * [qpd(i,r) - pop(r)]
3723             + IGTAX(i,r) * [qgm(i,r) - pop(r)]
3724             + DGTAX(i,r) * [qgd(i,r) - pop(r)]
```

5000 lines of this!

Outline

- A brief overview of Computable General Equilibrium (CGE) models.
- Limitations of CGE models
- Advantages of Agent-Based Models (ABMs)
- Potential for interfacing CGE models and ABMs
- Reflections on the success of CGE models compared to ABMs

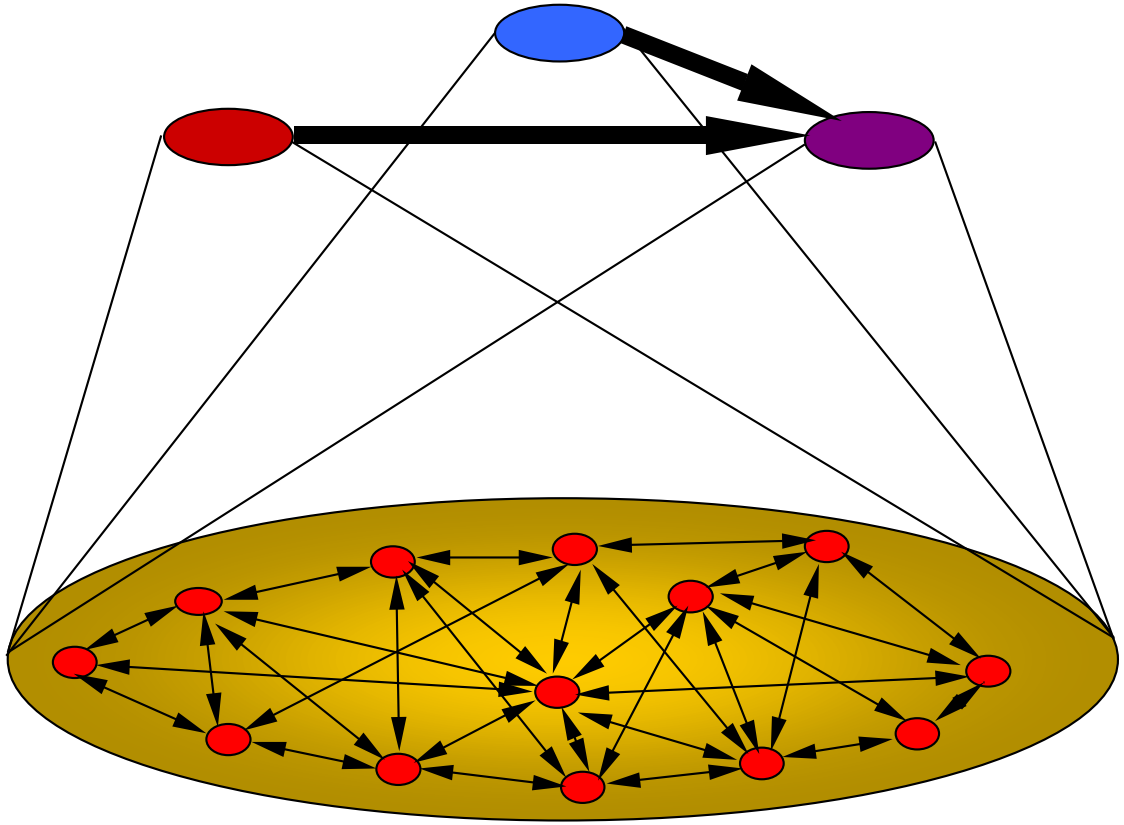
Top-down modelling



What kind of system are we dealing with?

Is it like this?

Neat separation of micro and macro causal networks?

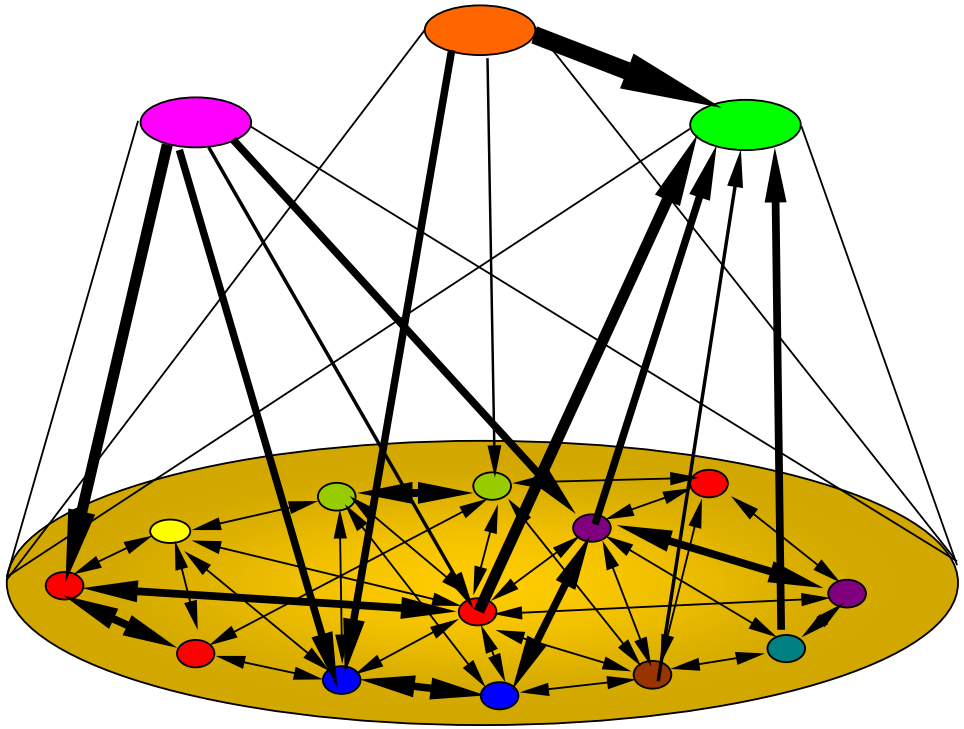


- Identical agents interacting with same strengths
- Complete network
- Complete causal network at macro-level
- Neat separation of micro & macro analysis.
- Often a static view – hence “comparative statics”.

If so: Analytic or statistical mechanical approach OK

Or is it more like this?

Interleaving of micro and macro causal networks



- Heterogeneous agents interacting asymmetrically with varying strengths.
- Emergent macro-variables influencing micro-entities. Eg. business confidence, “irrational exuberance”, inflation, interest rates etc.
- *Incomplete* causal network at macro-level
- Dynamic, nonlinear feedback effects critical
- Analytic or statistical mechanical approach not OK – have to integrate too many equations of motion.

“Well, I’ve got to tell you: I’ve never really understood macro. What I mean by this is that my idea of understanding is having a model that captures what is going on. In macro we don’t have that; instead we have empirical generalizations, and those generalizations tend to break down quite quickly.” - Ken Arrow (in Colander *et al.* 2004).

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).

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**

Common CGE modelling assumptions

- Many assumptions of analytic & CGE models are not appropriate for real-world policy modelling & integrated assessment. E.g.
  - Representative agents, ignoring heterogeneity (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 (Kirman, 1989, 1992)
  - Perfect competition
  - Perfect and costless information and contract enforcement (Stiglitz, 2002)
  - Aggregate production functions (Felipe & Fisher, 2003)
  - Infinite, smooth substitution between factors – but production is 'lumpy' – only a few combinations are technically possible
  - Distribution of wealth according to marginal products rather than bargaining power

Common CGE modelling assumptions (cont.)

- Perfect rationality & foresight (Conlisk, 1996)
- All individual people & firms are perfect optimisers
- Infinite computational capacities of all agents (Radner, 1968)
- A unique equilibrium - multiple equilibria ruled out by assumption and design
- Ignoring money, credit, debt & finance – many policy models are effectively barter models. (Dillard, 1988)
- Assumption that firms are already using best technology on the production possibility frontier
- Spatial dimensions of economy often ignored (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)
- Complete markets & networks for goods, services, capital, risk
- Simplistic approach to firms' pricing decisions

Common CGE modelling assumptions (cont.)

- Costless redeployment of labour
- No interaction between firms & governments except through taxation (ignores lobbying, corporate influence, government incentives etc)
- Weak on hysteris & 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)
- 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.

Common CGE modelling assumptions (cont.)

- Weak treatment of increasing returns in order to rule out non-convexities & multiple equilibria
- Ignore informal economy (Average ~ 41% of GDP in developing countries, 38% in transition & 17% in OECD countries; Schneider, 2005 – not represented well in official statistics)
- 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 (Veluppilai 2005, 2007)

Common CGE modelling assumptions (cont.)

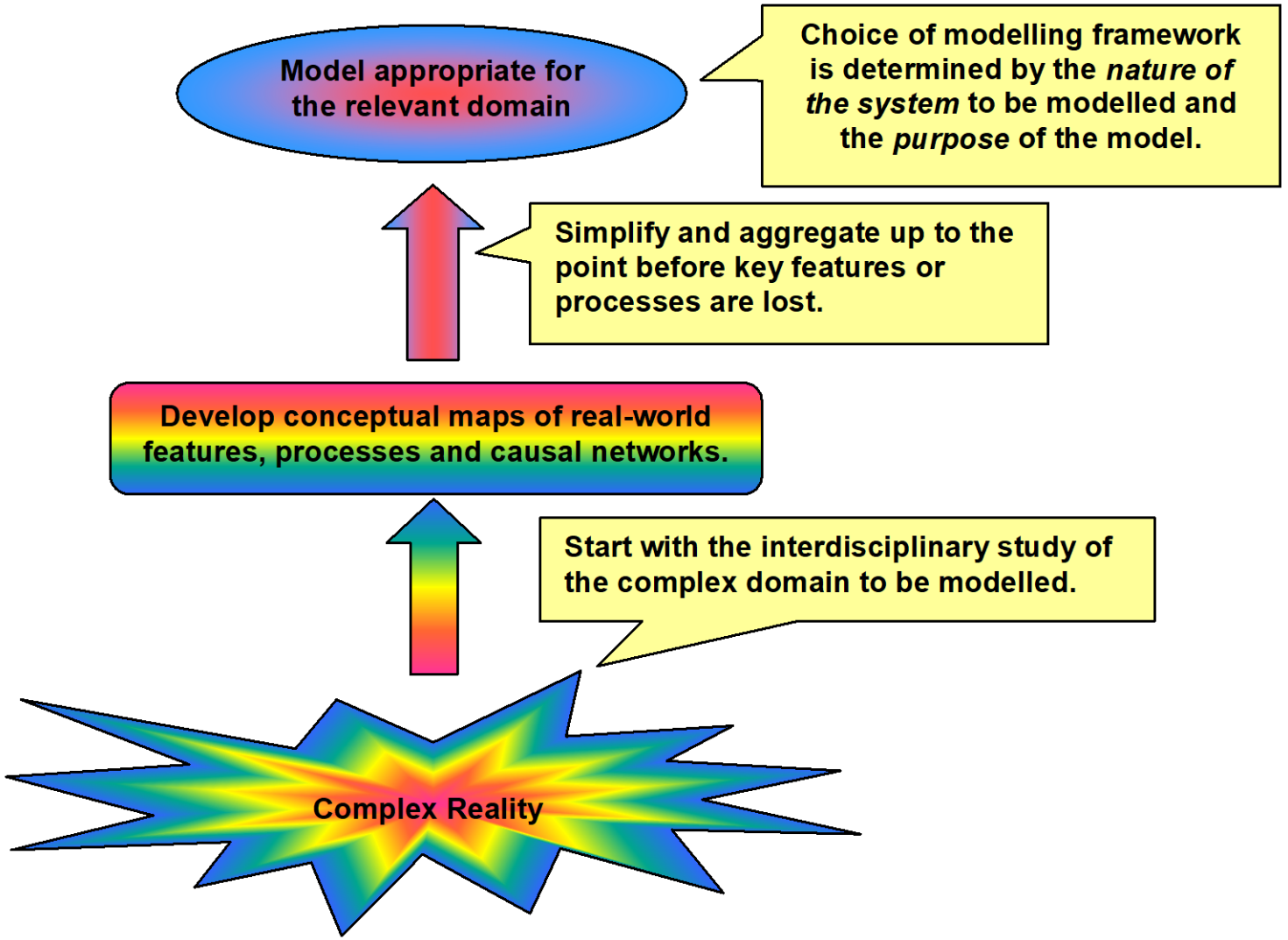
- Perfect substitutability between natural and human capital (Ayres, 2007; Neumeyer 1999)

- Assumption of ‘putty’ capital that can be simply aggregated and valued independently of prevailing rate of profit and interest rate. (Cohen & Harcourt, 2003)

Outline

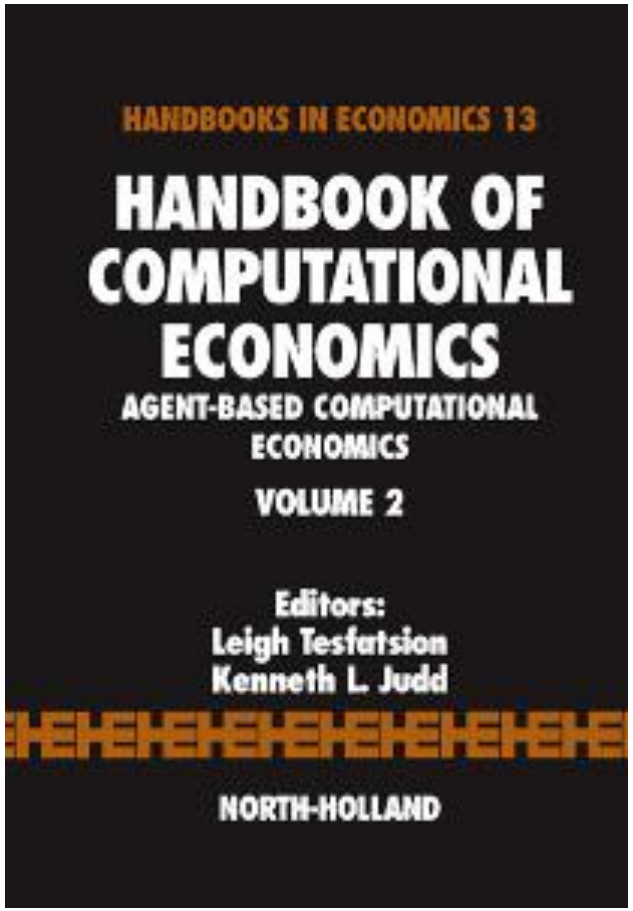
- A brief overview of Computable General Equilibrium (CGE) models.
- Limitations of CGE models
- Advantages of Agent-Based Models (ABMs)
- Potential for interfacing CGE models and ABMs
- Reflections on the success of CGE models compared to ABMs

Bottom-up modelling



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

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
  - Proportion of capital employed = 1
  - Mobility of capital 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.

Outline

- A brief overview of Computable General Equilibrium (CGE) models.
- Limitations of CGE models
- Advantages of Agent-Based Models (ABMs)
- Potential for interfacing CGE models and ABMs
- Reflections on the success of CGE models compared to ABMs

Existing Approaches:
Linking CGE & Microsimulation Models

- Three main approaches:

1. Integrating Multiple Households (CGE-IMH)

2. Sequential Micro-Simulation (CGE-SMS)

3. Iterative Top-Down/Bottom-Up (CGE-TD-BU)

1. Integrating Multiple Households (CGE-IMH)

- CGE-IMH consists of adding as many households (HHs) to CGE model as there are in household survey. Eg.
  - 3,373 HHs for Nepal CGE (Cockburn, 2001)
  - 24,979 HHs for CGE of the Philippines (Cororaton & Cockburn, 2005)
  - 55,000 HHs for Russian CGE (Rutherford *et al.* 2005)
  - 3,278 HHs for CGE of Senegal (Annabi *et al.* 2005)

- No longer true that CGEs must rely on representative households *but* heterogeneity only really in structural characteristics (income, family numbers, occupations) not *behaviour*

- Data matching can be difficult (eg. total household income & expenditure compared with national accounts)

- Regime switching (shifts between employment & unemployment) also presents problems

2. Sequential Micro-Simulation (CGE-SMS)

- CGE-SMS uses prices generated by CGE model as inputs to microsimulation model

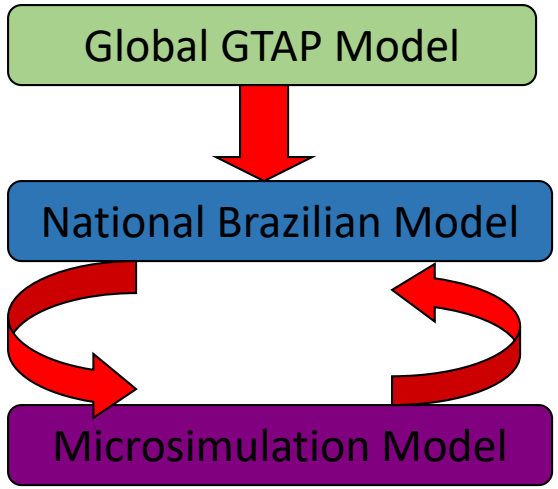
- Permits more flexible modelling of behaviours at micro level but no guarantee models will be coherent

3. Iterative Top-Down/Bottom-Up (CGE-TD-BU)

- CGE-TD-BU: links between CGE and microsimulation model provide bidirectional feedback until models converge (Savard 2003)

- Ferreira Filho & Horridge (2004) use this approach for comparative static model of Brazil with 112,055 HHs covering 263,938 adults, 42 activities, 52 commodities & 27 regions. In fact a 'triple-decker' model:

  - Macro: Global: GTAP model
  - Meso: National: National model of Brazil
  - Micro: Microsimulation model



- Savard (2004) compares representative HH with CGE-TD-BU approach and gets similar results for macroeconomics but *opposite* results for poverty & inequality effects. He concludes that models with behavioural heterogeneity likely to show *even more* significant intra-group distributive effects.

Linking CGE Models & ABMs?

- Trade off between desire for realism and need to avoid unnecessarily burdensome complexity suggests links between dynamic CGE models and ABMs could offer a useful approach to balancing competing aims

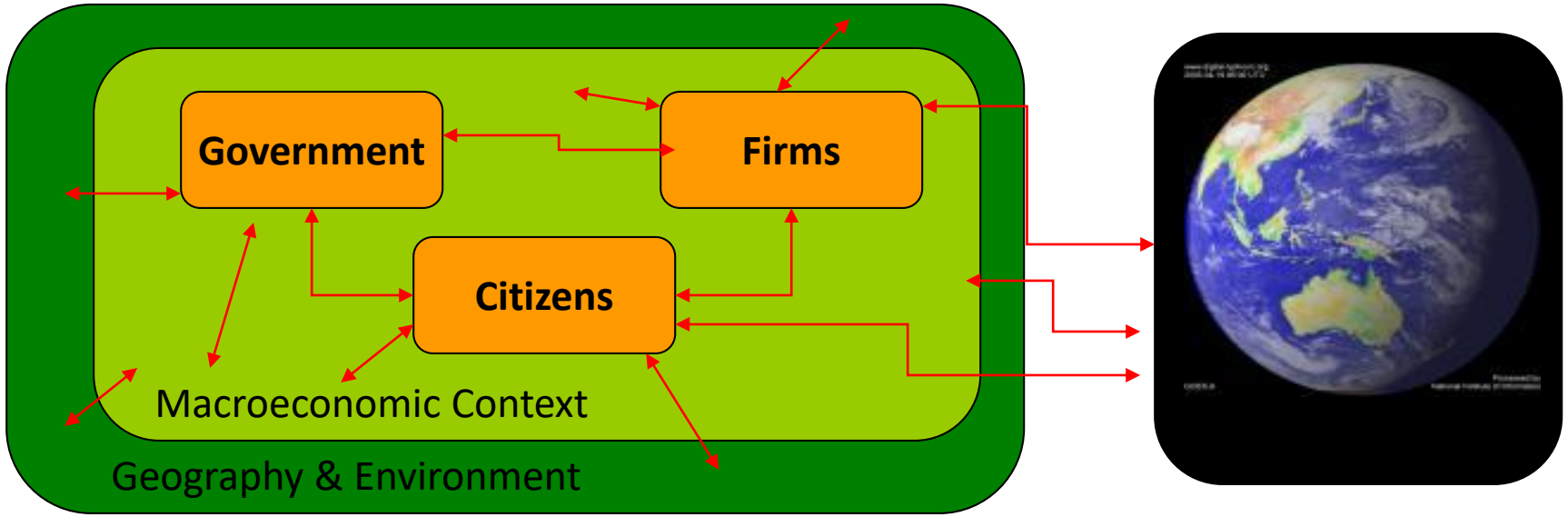
- CGE framework can offer a theoretically transparent way to model macroscopic processes

- ABM can provide more realistic simulation of specific sectors or processes of interest where heterogeneity and uncertainty are critical

- NB: Added realism of ABMs compared with CGE is dependent not only on theory of model and scope for dynamic interaction but quality of *data* – particularly parameters governing agent behaviour and interaction. Where does such data come from?

Case Study: Modelling Industrial Policy for Development

- Large number of considerations necessary



- Characterised by: Long run structural change involving innovation, firm heterogeneity, adaptive learning, uncertainty, transaction costs, interactions between firms & governments etc. Precisely the areas in which ABMs are well suited

But …

- Such an ABM would be extraordinarily complex with massive data requirements – much of which does not exist.

- Given existing controversies about model validation some argue that ABMs are inappropriate for this level of modelling

- Does that mean that we abandon quantitative economic policy modelling to CGE/microsimulation modellers?

An alternative?

- An alternative is to adopt an approach similar to the linking of CGE and microsimulation models and link a CGE with an ABM.

- Aren't ABMs & CGE models completely different species?

- Yes, but just as CGEs solved each period, so also ABMs are solved at each 'tick. So in principle, there are opportunities for passing information between model types between ticks/periods.

- Since any model of an economy must involve aggregation, in general, a CGE could be used to model the macro characteristics, and an ABM a particular area of interest. Agents though can also be 'macro' features such as institutions, the environment etc.

- A number of possible approaches to linking the models

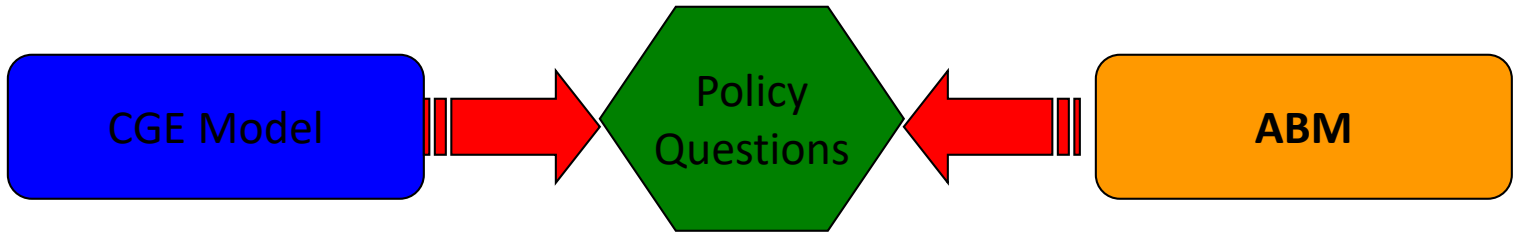
Type 0 Link: No formal link

- Use CGE and ABM to examine similar issue from different perspectives but no formal link between models:

  eg. CSIRO studies of Great Barrier Reef region:

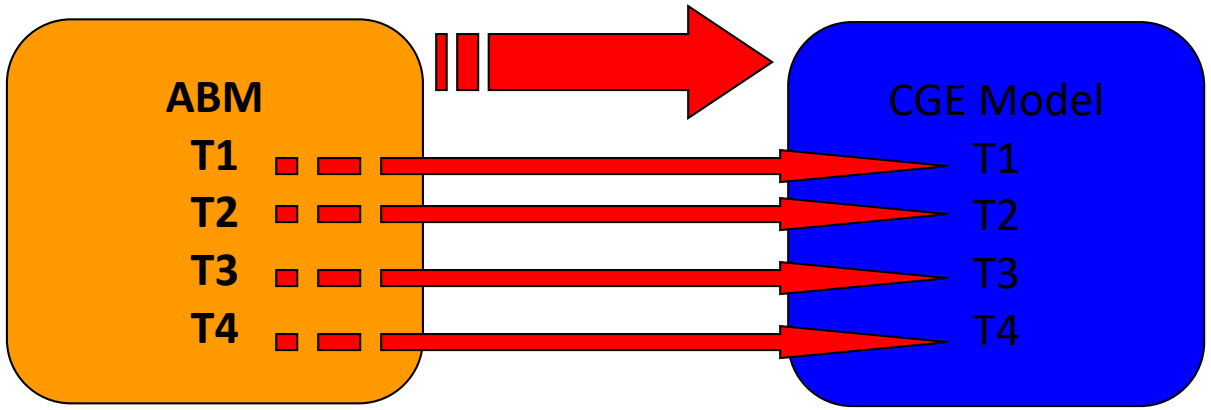
  Smajgl (2004) CGE model of water usage of Great Barrier Reef region

  Heckbert & Smajgl (2004) ABM of Great Barrier Reef catchments



Type 1 Link : ABM to CGE

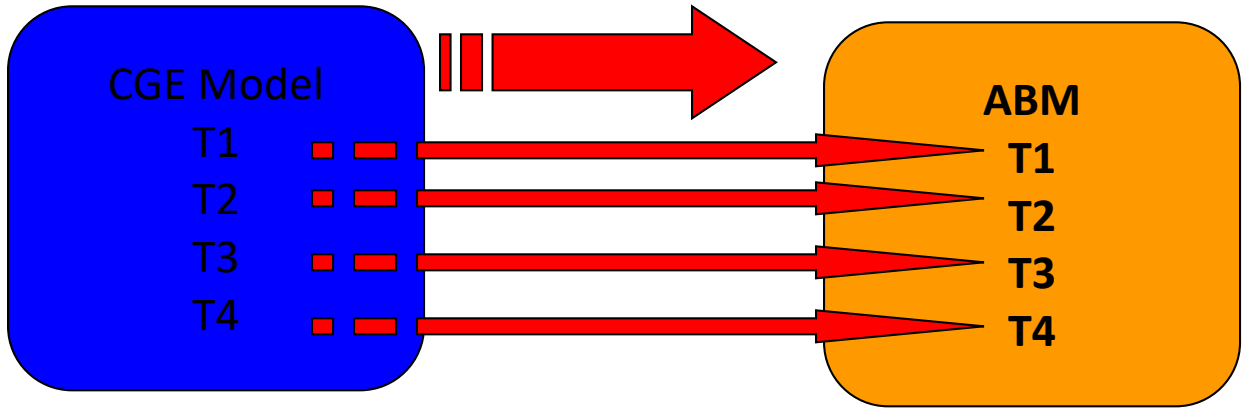
- Results of ABM could provide inputs into more macro CGE such as dynamic GTAP global trade model or dynamic national model
  - - eg. providing parameter estimates based on agent's behaviors, especially if simulations reveal stable regularities despite structural and behavioural heterogeneity



Type 2 Link: CGE to ABM

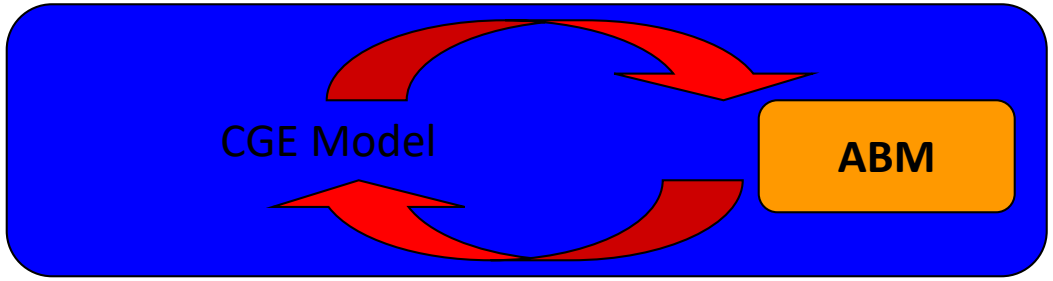
- Dynamic CGE model results could provide inputs for agents in ABM in form of realistic shocks and system boundaries.

- eg. CGE models economic changes due to macroeconomic shock, ABM models rapid changes in ethnic or political tension



Type 3 Link: Incorporate ABM within a dynamic CGE

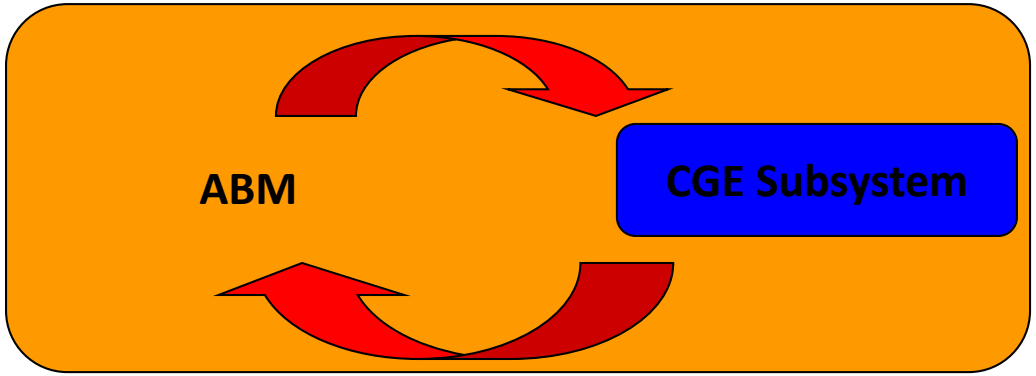
- Dynamic CGE ‘envelopes’ ABM:
  - Macrodynamics of ABM governed by CGE which imposes boundaries on realisations available to ABM
  - ABM used to model evolution and interaction within particular subsystem(s) within the CGE between CGE ‘periods’ (usually a year) – eg. industries, interactions between firms and governments
  - Perhaps develop computational laboratory ‘add-on’ to popular CGE model to link software seamlessly.



Type 4 Link: Incorporate dynamic CGE within ABM

- Similar to Type 3 except the main ‘envelope’ is an ABM system, eg. java- or python-based, which permits ‘macro-agents’ which access different sub-systems, to call other software, eg. R, CGE-software (eg. GEMPACK, GAMS).

- So ABM envelope creates overall structure and scheduling of model, as well as running detailed ABM components and a CGE sub-system.



Outline

- A brief overview of Computable General Equilibrium (CGE) models.
- Limitations of CGE models
- Advantages of Agent-Based Models (ABMs)
- Potential for interfacing CGE models and ABMs
- Reflections on the success of CGE models compared to ABMs

Reflections on CGE Success and Promoting ABMs

- Why does CGE modelling dominate trade policy debates?
  - Stable teams developed platforms over many years: GTAP, Monash Centre of Policy Studies (COPS) – now at Victoria University.
  - Software excellent (eg. GEMPACK, GAMS)
  - Low barriers to entry (standard software, lots of training courses)
  - Commitment to make model results explainable to policy-makers
  - They meet a clear demand for quantitative policy analysis
  - CGEs now dynamic, can use non-standard theory, multiple households, sectors, occupations, sub-national regions, & have capacity for systematic sensitivity analysis.

- Agent-Based modelling is a maturing field. We need to “let a thousand flowers bloom”. But, ABM community would benefit from standard platform(s), rigorous documentation, more short-courses & hybrid policy-oriented models where appropriate.