Trade and Industrial Policy in Developing Countries:

What Scope for Interfaces between Agent-Based Models and Computable-General Equilibrium Models?

Paper submitted for the International Workshop on
'Agent-Based Models for Economic Policy Design'
(ACEPOL05)
Bielefeld University, 30 June to 2 July 2005

Brett Parris[1]

31 May 2005
Draft – Please do not quote without permission

ABSTRACT

How best to assess trade and industrial policy in developing countries is a controversial question that unlocks a host of modelling complexities. Large computable general-equilibrium (CGE) models dominate many economic policy debates, but recent developments in the field have demonstrated that it is by no means clear that they give reliable results to questions of how trade reforms affect the poor. Over the last decade or so, a new approach to modelling complex systems has emerged using agent-based models (ABMs). This paper explores the question of whether ABMs are useful for economic policy-makers seeking to quantitatively model the effects of trade and industrial policies and whether constructive interfaces could be developed between CGE models and ABMs. The paper argues that in developing economic policy, ABMs can and should be used in conjunction with CGE models and that there is much to be gained from a greater understanding of the strengths and weaknesses of different modelling approaches, and what domains are most appropriate for their use. It concludes with some reflections on the reasons for the success of CGE approaches and ways in which ABMs could be made more widely understood and used among economists.

---

[1] PhD candidate, Department of Econometrics & Business Statistics, Monash University. I would like to thank my supervisors Brett Inder (Monash), John Madden (Monash), David Green (Monash) and David Batten (CSIRO) for their valuable assistance. Comments are welcome. Please direct correspondence to Brett.Parris@buseco.monash.edu.au

1. Introduction

This paper arises from what is for me, an as-yet unresolved question: How best to assess trade and industrial policy in developing countries? I worked with an international development NGO for over ten years, and in that time I witnessed countless debates and a number of riots because of fundamental disagreements over this question. The 'anti-globalisation' riots from Seattle to Genoa had many causes, but at least one important cause was a perception by ordinary citizens that the economists' models left out too much to be credible, and that as a result, the policies based on them were ruining many people's livelihoods across the world.

Large computable general-equilibrium (CGE) models dominate many economic policy debates, particularly in international trade, but also in the domestic policy sphere. Whenever you hear a prediction of a certain trade deal bringing '$300 million' in benefits, you can be sure a CGE model somewhere has produced the figures.

In recent years however a new approach to modelling complex systems has emerged using agent-based models (ABMs), often called agent-based computational economics (ACE) in the economic field. But are ABMs useful for economic policy-makers seeking to quantitatively model the effects of trade and industrial policies on entire countries? This paper explores that question and whether constructive interfaces may be developed between CGE models and ABMs.

2. Computable General-Equilibrium and Agent-Based Models

The key strengths of modern CGE models such as the recursive dynamic MONASH model of Australia (Dixon & Rimmer, 2002), the Global Trade Analysis Project (GTAP) comparative static model of world trade (Hertel, 1997), and its dynamic version (Ianchovichina and McDougall, 2000), are their detailed data coverage and rigorous application of accounting identities, ensuring that stocks and flows are represented and tracked as accurately as possible.[2] The GTAP database for example, covers 57 sectors and five factors or production in each of 87 regions of the world, an extraordinary achievement by any reckoning. The MONASH model covers 113 industries and 115 commodities in standard applications and can be extended to 830

[2] The importance of rigorous adherence to accounting identities is also emphasized by Bruun (2003, p. 4) and Deguchi (2004) for ABMs.

sub-commodities, 57 sub-national regions and 341 occupation types.[3] A similar model, MONASH-USA, was built for the US International Trade Commission with 500 industries, 50 states and the District of Columbia, and around 700 occupations.[4] CGE models also tend to be firmly grounded in conventional microeconomic theory – though there are also many examples of CGE applications which attempt to reflect local conditions more faithfully than the standard models, such as the structuralist models described in Taylor (1990).

It should also be pointed out that 'general-equilibrium' in a CGE context simply means that a solution exists for the massive system of simultaneous equations. It does not mean that all markets necessarily clear, (in other words you can have unemployment), nor that the models are necessarily confined to purely neoclassical assumptions.

There have however, been a number of challenges to the standard microeconomic theory underlying most CGE models in top mainstream economics, mathematics and physics journals (eg. Radner 1968, 1970; Greenwald & Stiglitz, 1986; McCauley, 2000; Kirman 1989, 1992; Saari, 1995; Stiglitz 1989, 1996; Felipe & Fisher, 2003). These critiques tend to cluster around the use of assumptions such as representative agent, perfect and costless information and contract enforcement, complete markets, constant returns to scale in production, aggregate production functions, firms always operating on their production possibility frontier, and perfectly rational agents with infinite computational capacity. These problems are acute enough in modelling OECD economies, but in many developing countries they make models based on standard microeconomic assumptions potentially highly misleading.

Critics of standard neoclassical analysis (such as Amsden 1989, 1997, 2001; Lall, 1996; Shin 1996; Temple, 1997; Wade 1990) argue that industrial policy can and has worked in the UK, Germany, Japan, South Korea, Taiwan and elsewhere. Moreover, they contend, it is precisely in the analysis of industrial policy that the short-comings of standard microeconomics are most apparent, since it involves complex long-term dynamics between firms and government, technological learning and adaptation, bounded rationality and more – as will be discussed later.

ABMs seek to address some of the criticisms of standard microeconomics by employing heterogeneous agents with bounded rationality and imperfect information, who learn adaptively

[3] See: http://www.monash.edu.au/policy/monmod.htm.
[4] See: http://www.monash.edu.au/policy/mon-usa.htm. The model is known as USAGE-ITC in the USA.

in a dynamic setting (Holland & Miller, 1991; Tesfatsion, 1997, 2003; Batten, 2000; Dawid, 2006). ABMs can also explicitly model the spatial dimensions of economic and social changes using Geographical Information Systems data (Dibble & Feldman 2004; Gimblett, 2002), a consideration often neglected in standard CGE approaches.[5]

Many ABMs however, tend to focus on the micro-level, and the choices between multiple possible combinations of parameter settings may appear somewhat arbitrary. The goal of many ABMs is simply to demonstrate that a particular macroscopic phenomenon can emerge 'from the bottom up' as a result of the dynamic interactions of autonomous agents (eg. Epstein & Axtell, 1996, p. 177). There is no pretence of designing the models for the purpose of policy evaluations. Bruun (1999, p. 3) for example, argues that we "need to give up quantitative prediction and settle for qualitative understanding." If that is the only option though, the ground and the policy debates are ceded entirely to CGE and microsimulation modellers. A key question then that will be taken up later in this paper is: can ABMs be used for quantitative economic policy making?

Meanwhile, it is worth reflecting on the fact that ABMs are not immune from criticism about unrealistic assumptions either. Common 'unrealistic' assumptions in economic ABMs include:

- No external (rest of the world) sector
- Little attention to margins and shipping costs
- An arbitrary approach to modelling taxation and tariff structures
- Little attention to detailed inputs and outputs of industries
- Arbitrary choices on updating schemes – whether synchronous, asynchronous or ordered asynchronous updating (see Cornforth *et al.* 2005). The more asynchronous the updating scheme, the more varied will be the information sets used by agents (Pyka & Fagiolo, 2005, p. 14).
- Lack of clarity about how much 'real time' a model's 'tick' represents

Models must have an upper limit to their size and complexity, so certain simplifying assumptions have to be made. For example, while traditional CGE models may be criticised for using a representative agent, unless a (closed economy) ABM of Germany is going to model 82

[5] Though some CGE models such as Monash's TERM (The Enormous Regional Model) do model sub-national regional changes. See: http://www.monash.edu.au/policy/term.htm

million separate heterogeneous agents, even an ABM will to have to engage in some aggregation. ABMs will therefore be rich in certain areas and poor in others.

The question is, as Bruun (2003, p. 4) notes: what should guide the simplification? Bruun starts with macroanalysis in order to guide the simplification choices, arguing that if “macroanalysis tells us that a decision is not all that important to the macro-properties of a system, we can be more careless in designing the decision rules.” But this begs the question however, of *how* we know that certain types of decision rules are not important for macroanalysis. Bruun insists that economic simulations should be grounded in economic theory, so that “simulations should be used not as a substitute for theory, but as an extension of theory.” (p. 4). Clearly simulations must be guided by theory. But theory based on what? The reason ABMs are used is precisely because traditional analytic theory becomes intractable once a certain level of heterogeneity and uncertainty is introduced. That suggests that analytic theory will have limits in terms of the guidance it can offer in an ABM framework, and that new economic theory needs to be developed iteratively with sophisticated ABMs. Epstein and Axtell (1996, p. 137) observe for example that “there is very little cogent theory of performance degradation in real markets resulting from incomplete information, imperfect foresight, finite lives, evolving preferences, or external economies…”. One of the hallmarks of complex systems is that the multilayered dynamic feedback loops can produce previously unexpected outcomes, including, I would suggest, theoretical results that are not reducible to analytic proofs.

Economics finds itself in a similar situation to modern mathematics, as it asks: what is acceptable as a theoretical proof? For centuries, a mathematical proof meant an analytic or geometric proof. Yet in 1976 one of the great unconquered mathematical citadels, the four-colour problem, fell to another type of proof – computer calculations. The four colour problem, dating from 1852, was the conjecture that a maximum of four colours was needed to colour a map of adjoining shapes without any two contiguous areas sharing the same colour. Various approaches were tried until Kenneth Appel and Wolfgang Haken solved the problem in 1976 using both hand calculations, and 1200 hours of computer time for billions of calculations which no human could reproduce (Appel & Haken, 1977a&b). The use of computers in a mathematical proof was highly controversial and remained so into the 1990s until other teams began to report the same result with different algorithms. “These days” concludes Devlin (1999, pp. 164-5), “almost all mathematicians acknowledge that the arrival of the computer has changed not only the way much mathematical research is carried out but also the very concept of what is regarded as proof. Checking the program that produces the 'proof' must now be allowed as a valid mathematical argument."

So while the simplification process essential to building a model must be guided by theory, that theory should not remain shackled to what can be proven analytically with currently available mathematics. Computer simulation is a legitimate tool, not only to test theory, but also to guide its development and to prove its conjectures.

In constructing quantitative policy-oriented ABMs there is a trade-off between two competing aims: On the one hand, there is the desire and indeed the ability within an ABM framework to design agents, rules of interaction and accounting frameworks of great complexity, as we seek to faithfully reproduce 'real world' processes. On the other hand, computational limitations and, probably more importantly, the limitations on human time and comprehension, suggest the need for parsimony and simplification whenever this will not detract from the accuracy of the model's results for its intended purpose. Appropriate parsimony is also important because of the fact that the more variables a policy-oriented model contains, the heavier the data requirements and the greater the chances of having to rely on poor-quality data. Having said that, Gross and Strand (2000, p. 30) are right to remind us that "there is no a priori reason to believe that Occam's razor (or similar rules) is a rational strategy toward the problem of selection among model candidates."

The trade-off between the desire for realism and burdensome complexity suggests that links between dynamic CGE models and ABMs could offer a useful approach to balancing these competing aims. The CGE framework can offer a theoretically rigorous and transparent way to model macroscopic processes while the ABM could provide a more 'realistic' simulation of specific sectors or processes of interest where heterogeneity and uncertainty are known to be important.

In one of the few papers to directly compare ABMs with equation-based models (EBMs) Paranuk *et al.* (1998) make some useful observations: EBMs begin with sets of equations expressing relationships among observables – 'measurable characteristics of interest'. ABMs, conversely, begin "not with equations that relate observables to one another, but with behaviors through which individuals interact with one another… Direct relationships among the observables are an output of the process, not its input." (p. 10). A second major difference between the two approaches is in the levels at which they focus:

> EBM tends to make extensive use of system-level observables, since it is often easier to formulate parsimonious closed-form equations using such quantities. In contrast, the natural tendency in ABM is to define agent behaviors in terns of observables accessible to the individual agent, which leads away from reliance on system-level information. …The two approaches can be combined: within an individual agent in an ABM, behavioral decisions may be driven by the evaluation of equations over particular observables, and one could implement an agent with a global view whose task it is to access system level observables and mane them visible to local agents … (p. 11).

In summary (p. 12) they conclude that: "ABM's are better suited to domains where the natural unit of decomposition is the individual rather than the observable or the equation … EBM's may be better suited to domains where the natural unit of decomposition is the observable or equation rather than the individual." They also point out that the ordinary differential equation processes of EBMs are best suited to purely physical processes, rather than systems which include step-by-step processes and conditional decisions, such as the discrete 'if-then' decision making which dominates business processes.

Paranuk *et al's* (1998) analysis reinforces the view that ABMs are most suitable for the micro-analysis of economic and social dynamics among heterogeneous agents. It also suggests however, that there could be a rightful place for equation-based modelling of overall system processes, depending on the system, and certain processes within the agents themselves. Hybrid models that incorporate both ABMs and EBM approaches such as CGE models may therefore be appropriate for some purposes. It is useful then to look at some of the ways in which CGE modelling is being extended by making links between global, national and microsimulation models.

3. Linking CGE Models with Social Surveys & Microsimulations

A growing recognition among CGE modellers of some of the weaknesses of using representative agents has lead to an outpouring in recent years of studies linking global models such as GTAP (which has a single representative household for each country), with more disaggregated national and regional models. In several recent papers the GTAP model has been linked to microsimulation models (Cogneau and Robilliard 2000), country-level models (Evans 2001, Horridge & Ferreira Filho, 2003), detailed household survey data (Hertel *et al.* 2003) and more detailed multiple household social accounting matrices (Decaluwé *et al*. 1999) to ascertain the effects of economic shocks on households at different income levels.

Savard (2003, pp. 3-4) has outlined a useful typology of CGE approaches to evaluating the effects of economic policy proposals on poverty and inequality:

1. A standard CGE analysis with a representative household, which analyses poverty effects by varying the average income of the representative household (CGE-RH)
2. An Integrated Multi-Households CGE analysis (CGE-IMH)
3. A Sequential Micro-Simulation approach, which uses the CGE model to generate prices that links into a micro-econometric household micro-simulation model (CGE-SMS).

While the CGE-RH approach has been used extensively, it suffers from the presupposition that "there is no intra-group income distribution change, or that this intra-group distribution change is linked to a theoretical statistical relationship between [the] average (μ) and variance (σ^2) of the distribution" (Savard, 2003, p. 4).

The Integrated Multi-Households (CGE-IMH) method consists of adding as many households to the CGE model as are found in the national surveys. Cockburn (2001) for example studies the effects of trade liberalisation on the poor in Nepal by using all 3373 households from the Nepalese Living Standards Survey in a national CGE model. Cororaton and Cockburn (2005) combine a CGE model with a microsimulation analysis of the effects of trade policy changes on poverty in the Philippines integrating all 24,979 households from the 1994 Family Income and Expenditure Survey. Rutherford *et al*. (2005) use all 55,000 households from the Russian Household Budget Survey as 'real' households in their CGE model, analysing the poverty effects of Russia's impending accession to the WTO. Annabi *et al.* (2005) use a dynamic microsimulation CGE model of Senegal with 3278 households.

Savard (2003, p. 5) observes that the main disadvantage of the CGE-IMH approach is that it rapidly multiplies the number of equations necessary for solving the model and data reconciliation can become very difficult, since both household incomes and expenditures need to be accounted for and reconciled with the national accounts data. Moreover, including switching regimes, such as the shift from employment to unemployment presents particular difficulties since the equation systems cannot adapt mid-stream to the new regimes.

The Sequential Micro-Simulation (CGE-SMS) method uses prices generated by the CGE model as inputs to the microsimulation model. This permits far more flexible modelling of behaviours but offers no guarantee that the CGE and microsimulation models will cohere. The effects of household behaviours may also not be fed back into the CGE model (Savard, 2003, p. 6). To deal with these challenges, Savard developed a "top-down/bottom up" (CGE-TD-BU) approach, whereby links between the CGE and micro-simulation model provide bidirectional feedback and the models are iterated until they converge on a solution.

One study which has adopted Savard's top-down/bottom up method is that by Ferreira Filho and Horridge (2004) in their study of the effects of trade liberalisation on poverty in different regions of Brazil. Using a detailed mapping of expenditure and income sources for 112,055 Brazilian households covering 263,938 adults, 42 activities, 52 commodities and 27 regions, they link a comparative static CGE model of Brazil to a microsimulation model of household incomes and expenditures, solving them iteratively until the models converge. This study is particularly interesting for two additional reasons. Firstly, it incorporates Horridge and Ferreira Filho's (2003) earlier work in which the global GTAP model was used to transmit shocks to the Brazilian CGE model. In effect, the simulation in their 2004 paper is a 'triple-decker' model. Secondly, it uses an innovative 'quantum weights method' for modelling employment regime switching.

In another recent paper, Savard (2004) compared the results of a standard CGE regional household model, to results from his top-down/bottom up method in an analysis of poverty in the Philippines. While the macroeconomic and sectoral results were similar for each type of model, the analysis of poverty and inequality produced *opposite* results: the representative household model suggested a policy change was pro-poor, while in fact the top-down/bottom up approach revealed it to be pro-rich. Why the discrepancy? Savard (2004, p. 14) argued that:

> [R]epresentative agents in traditional CGE models are not true representative agents. In fact, in these models, behaviors (in terms of allocations and consumption structure) have been modeled based on aggregates depending on the information contained in social accounting matrix (SAM) accounts. These structures therefore do not reflect those of an average or median household. In social accounting matrices, the information contained in

> a representative household is an aggregate of that account. This constraint guarantees that the sum of the accounts is coherent with national accounting totals. Model representative agents therefore have factor allocation and consumption structures that reflect more those of the wealthy than those of the poor. … in the traditional RA-CGE approach, we represent much more the structure of wealthy households than that of poor ones.

Savard (2004, pp. 16-17) also warns that the top-down/bottom up results show that intra-group inequalities are almost as significant as inter-group inequalities. Since the model mainly captures household structural heterogeneity rather than behavioural heterogeneity, he concludes that models that do explicitly capture agent's behaviour are likely to produce even more significant intra-group distributive effects, surpassing the importance of inter-group effects. Finally, in a footnote (p. 17) he reports: "In fact, extensions of the work have shown this intuition to be valid. We experimented with an almost ideal demand system and with endogenous labor supply and we found that the increase [in] behavioral heterogeneity reinforces the conclusions ..."

Savard's results have far-reaching implications for traditional CGE analysis of the effects of economic policy changes on the poor. They suggest that analysis of the poverty effects of economic policies using standard representative agent CGE models are likely to be seriously flawed (*contra* the more sanguine assessment of Hertel *et al.* 2004) and that as a minimum, CGE analyses should be linked with micro-simulation models that allow for agent structural and behavioural heterogeneity. Note that this is a critique entirely from *within* the neoclassical framework. But as Savard and others have also noted, even minor increases in heterogeneity or the introduction of stochastic uncertainty soon place tremendous computational stress on analytic simulation models. If that was not bad enough, the reality is that that as innovative as Savard's top-down/bottom-up CGE-microsimulation coupling is, and as revolutionary as its results are for traditional CGE analysis, it hardly begins to account for the heterogeneity, uncertainty and complexity found in real economies.

It is worth pausing then at this point to think through some of the factors that would need to be considered for a more adequate modelling of industrial policy in developing countries.

4. MODELLING INDUSTRIAL POLICY FOR DEVELOPMENT

Industrial policy is broader than simply trade policy. Industrial policy concerns the long-term economic structure, growth and stability of an economy. It is not simply about the optimal short-term allocation of resources. It is not simply actualizing current comparative advantage. It is about achieving potential comparative advantage and appropriate risk-reducing economic diversification. Moreover, industrial policy *for development* is concerned not only with the changes in industrial structure, but in their effects on the poor. To begin to adequately assess the prospects and effects of various industrial policy options a large number of considerations should ideally be incorporated into a model:

Government

- Government policy over tariffs, subsidies to research and development, funding for infrastructure, health and education
- Government budget including taxes, debt-payments, aid flows and bonds
- The degree of government corruption and adherence to rule of law
- The degree of government legitimacy and support among citizens

Firms

- Firm investment under uncertainty about government policy reliability and follow-through, future trade concessions and the technology or direct entry of foreign firms
- The 'stickiness' of entry and exit of firms – eg. registration and start-up costs, minimum capital requirements, bankruptcy procedures etc.
- The availability of credit for firms to enable them to force their way into the circular flow
- The extent of local versus foreign ownership
- Firm innovation and learning
- Heterogeneous firms sizes and production technologies within industries
- Firm inputs and outputs
- The interaction between firms and governments as firms lobby for protection and governments insist on export targets, quality control etc

Macroeconomic environment

- Rigorous adherence to accounting identities

- Exports, imports and balance of payments, particularly the availability of foreign-exchange for imported inputs
- Endogenous economic growth
- Nominal and real exchange rates
- Terms of trade
- Interest rate changes linked to changes in prices and the central bank
- Money and credit (real economies are not barter economies)

Citizens

- Heterogeneous citizens with evolving preferences
- Labour market demand and supply, wages and taxes
- Heterogeneous levels and changes in human capital, particularly changes in education, skills and health – which means population dynamics, the growth and development of children, and the burden of disease (eg. HIV/AIDS, malaria) has to be explicitly modelled
- Degrees of ethno-linguistic fragmentation and tension between groups
- Income distribution and degrees of poverty and inequality

External

- Export demand schedules and elasticities
- Import supply schedules and elasticities
- Foreign technological developments, particularly in competing industries

Geography & Environment

- Degree of firm concentration and agglomeration in particular sub-national regions
- Quality of infrastructure in different sub-national regions
- Wealth distribution across different sub-national regions
- The extent and location of pollution or environmental destruction by various industries
- The existence and location of areas of significant political tension or insurrection

Such a list is by no means exhaustive and yet it is already rather daunting. This is why modelling long-term industrial policy is so much more difficult than modelling the short-term effects of particular trade policy changes. There is no space here to go into the reasons why each of the above is necessary but let me make one remark on an area usually considered well outside the set of factors that need to be considered for modelling the effects of trade policy on the poor: ethnic tension.

Amy Chua has written a number of academic articles (1995, 1998, 2000) and a bestselling book (2003) on the interactions between economic inequalities and ethnic tensions. I am not aware of a single CGE model that attempts to link policy-induced economic changes with changes in income distribution among ethnic groups and the resulting changes in ethnic tension and potential for conflict.[6] At one level this is to be expected, as CGE models in general tend to be blind to children, gender and ethnicity. But at another level the omission is surprising, since the prediction of a net benefit for an economic policy surely depends on the ongoing stability and credibility of the government and the avoidance of civil strife.

ABMs however are ideally suited to modelling civil strife. Epstein (2002) created an ABM to model civil tension and violence. Once of his most important results was that a *gradual* decline in government legitimacy, coupled with the gradual arrest of leading dissidents, led to almost no sudden uprisings. Conversely, a sudden decline in government legitimacy, particularly one accompanied by spontaneous public assemblies of dissidents, led to the kinds of sudden outbursts of dissent and violence that trigger revolutions. A sudden decline in government legitimacy is precisely the kind of effect that significant changes in economic policies can have – as witnessed by riots in several countries in response to IMF-imposed cuts in subsidies. Epstein also modelled intra-group tension, which, under plausible conditions, often led to genocide – except when there was adequate policing. Again, since tariff reductions affect the economic distribution between ethnic groups as well as the government's tax base, and therefore its ability to maintain law and order, it is arguable that the likely effects of economic policy changes on ethnic tension is just the sorts of thing that should be included in a model of trade policy reform.

Once a dynamic model includes uncertainty, learning, transaction costs, regime-switching and multiple, interacting firms and households which are heterogeneous not only in parameters but in behaviour, an analytic solution is impossible. An ABM is the only way to proceed. But as the 'wish-list' above shows, such an ABM would be very complex, with substantial data requirements. It could also be subject to the charge of arbitrary selection of parameter combinations. As with most complex systems the model is likely to be highly sensitive to the initial conditions, such as the initial distribution of wealth (Bruun 2003, p. 484). To (brutally) paraphrase Leo Tolstoy's opening sentence in *Anna Karenina:* Perfectly competitive economies are all alike; every imperfectly competitive economy is imperfect in its own way. How imperfect

[6] The CGE model of South Africa described in Horridge *et al.* (1995) does distinguish four ethnic groups but it does not seek to model the degree of ethnic tension and potential for conflict.

is the information in agricultural markets? How imperfect is the competition in the steel industry? How incomplete is the credit market? A Pandora's Box of unanswered and probably unanswerable questions is opened once the assumptions of perfect competition, perfect information and perfect rationality are abandoned. That is no reason *not* to abandon them, but it does mean that the choices of parameters and learning algorithms to model these imperfections must be closely scrutinized. Validation procedures which include thousands of runs with varying parameters values, behaviour and decision rules are be essential for producing robust and believable results.

Gross and Strand (2000, p. 30) are pessimistic about the prospects for validation, arguing that: "Trying to build a model with the purpose of true and valid representation of the system's microstructure may in many cases be likened to try[ing] to get to the moon by climbing a higher tree." They conclude that there can probably be no proper validation of highly complex models with system uncertainties and complex causal chains and that the use of such models should be restricted to aids to learning, such as discovering new scenarios, or exploring the implications of particular theories.

In contrast, Werker and Brenner (2004) are more positive. They adopt a critical realist methodology after Lawson (1997), using Monte-Carlo methods to explore the sets of model specifications and realisations. A large number of model specifications are randomly picked from the set of possible specifications and the results of these models are studied for consistent patterns. A single model specification can produce different results because of the stochastic elements built into the model. These stochastic elements are separate from the specific model parameters, which vary between model specifications. Werker and Brener (2004, p. 13) conclude:

> [I]nstead of arguing that there is one model that explains all systems within a certain class, we argue that a subset of model specifications can be obtained by abduction. This subset of model specifications contains all possible bundles of assumptions that cannot be rejected by the empirical data about the systems that are to be studied. If the model specifications in this subset share characteristics, these characteristics can be expected to hold also for the real systems (given the development of the model has not included any crucial and false premise). Hence, we obtain robust knowledge about the characteristics of a certain kind of systems. If the characteristics within a group of model specifications differ, the causes of these differences can be studied. It can be examined which factors in the models are

> responsible for the differences. Hence, although we will not know the characteristics of the real systems in this case, we will obtain knowledge about which factors cause different characteristics.

Other authors have made efforts to develop 'history-friendly' models of particular industries that attempt to capture the dynamics of particular sectors such as the computer industry (Malerba *et al.* 2001).

5. Linking CGE Models and ABMs

In light of the preceding discussions, a number of possible constructive interfaces could be envisaged between CGE models and ABMs:

1. ABM to CGE

The results of an ABM could provide inputs into more macro-level CGE models such as GTAP – particularly by providing estimates of parameters based on agents' observed behaviours.

2. CGE to ABM

The CGE model results could provide inputs for the agents in an ABM in the form of realistic shocks, constraints or 'system boundaries'. The ABM could then be used to model the likely dynamic responses of particular industries, income groups, institutions or ethnic groups to those inputs. Such an approach could be particularly useful in predicting the likely effects of economic reforms on industrial innovation, on poverty in different regions, or on the likelihood of civil conflict arising from the uneven impacts of economic changes on different ethnic groups.

Applications such as simple ABM to CGE and CGE to ABM may be of some use under certain circumstances but they are a long way from properly integrated dynamic models.

3. Incorporate an ABM within a dynamic CGE

A third alternative is to incorporate an ABM model within a dynamic CGE model. In other words, the dynamic CGE model 'envelopes' the ABM, so that the macrodynamics of the system are governed by the CGE equations and impose structure and boundaries on the realisations available to the ABM. This approach could be useful for a system suitable for modelling in a dynamic CGE framework, in which certain subsystems were more appropriately modelled as ABMs – such as the dynamics of particular firms within overall industry boundaries set by the CGE model. For example, the input-output data for a particular industry could be disaggregated across a distribution of firms, so that the total inputs and outputs remain true for the industry as a whole but individual firms have heterogeneous inputs and outputs, reflecting differences in both firms' sizes and their technologies. The distribution could be estimated from detailed industry data, trade journals and interviews with industry staff.

It would be possible to develop the ABM in a computational laboratory framework (such as the Trade Network Game Laboratory developed by McFadzaen *et al.,* 2001) in such as way that its software and data inputs and outputs linked seamlessly with those of a CGE model such as GTAP. The ABM could take its inputs from an initial shock to the national economy, and then the results of the ABM could in turn be fed back into the CGE model to adjust some of its key parameters for the next iteration. Such an 'add-on' module to a widely used and influential CGE model could help expose more mainstream trade economists and policy makers to the virtues of the ABM approach.

4. Incorporate a CGE within an ABM

The fourth alternative is more an extension of the third rather than its opposite. Here the ABM envelopes the CGE model. In other words, the model is fundamentally an ABM in its overall structure, but certain subsystems are modelled as a CGE in order to reduce model size and computational burden. For example, in an open economy model where our interest lies in the dynamics of agricultural innovation and poverty among peasant farmers in response to liberalisation of an agricultural trade deal in the WTO, we may want the innovation and income distribution responses to be modelled as an ABM, along with the overall national economy, but the rest of the world, and the changes in global commodity prices might well be more appropriately approximated with a CGE equation-based component to the model. Deguchi (2004) has recently developed a framework for large ABMs which enables the System of National Accounts (SNA) to be reconstructed from the bottom-up.

Data for the ABM could come from the GTAP database, national household surveys, national social accounting matrices and commonly available data on social indicators, poverty, infrastructure, governance, business regulation, corruption and so on, collected by organisations such as the World Bank, UN, and Transparency International. Certain parameters for the ABM could also be estimated econometrically.

An ABM written in Java using Repast (2004) would not only be fully functional with respect to its agent-based components, but Java can also call up and run CGE software such as GEMPACK through the DOS command line in Windows systems. A CGE model could therefore be fully integrated with a Java-based ABM. In my view, this would be the most appropriate path to modelling industrial policy in developing countries.

6. Some Reflections on the Success of CGE Models and on Promoting Policy-Oriented ABMs

Before concluding, since the ABM approach is an emerging field, it may be useful to reflect on some of the factors that have contributed to the success of policy-oriented CGE modelling and on how to promote ABMs in a policy environment dominated by CGE models.

First, the software commonly used for CGE simulations, such as GEMPACK and GAMS, is excellent and very well documented.[7] With GEMPACK, modellers can easily conduct systematic sensitivity analysis for parameters and can also track the effects of individual equations with AnalyseGE. The datasets such as the GTAP dataset are extraordinarily rich and come packaged with sophisticated data aggregation and data manipulation packages called GTAPAggN and ViewHAR.

Second, there are fairly low barriers to entry with CGE modelling. Economists don't need to learn how to program to use or develop these models. The syntax of GEMPACK and GAMS are very easy to learn and training can be conducted on 'cut down' models such as MINIMAL and Miniature MONASH. Training courses are regularly held around the world by Monash University's Centre of Policy Studies, the GTAP consortium, and the EcoMod network.[8] Hundreds of economists are being trained every year in these techniques, and there are positive

[7] GEMPACK: http://www.monash.edu.au/policy/ GAMS: http://www.gams.com/
[8] GTAP: http://www.gtap.agecon.purdue.edu/ EcoMod: http://www.ecomod.net/

feedback effects and network externalities associated with such training. The more widely understood the CGE techniques and software become, the more widely used they are likely be.

Third, there is also a strong commitment to make the model results explainable and understandable to policy-makers. Monash University's Centre of policy Studies in particular emphasises the use of 'back of the envelope' models, stylized versions of the main model which can be used to explain the main mechanisms to policy makers. Without a way of accurately communicating the mechanisms driving the main results, the models are just viewed by policy makers as 'black boxes'. Someone with a coherent and convincing story to tell will always beat someone presenting a black box's results in a policy debate because politicians need to be able to tell a story to convince their opponents why they favor one policy choice over another.

Fourth, as discussed above, modern CGE models can be dynamic, can incorporate multiple households, sectors and occupations and 'non-standard' theory such as imperfect competition.

The ACE community urgently needs a standard platform and a good, sensibly-priced textbook with accompanying software on CD-Rom and a supporting website if it is to start to attract significant numbers of younger economists. Personally I feel the Java-based RePast platform offers best combination of power and flexibility.[9] The addition of Repast Py, a tool for building RePast models based on 'Not-Quite Python' (a subset of the Python language) is also of considerable assistance. Nevertheless, modellers still need to understand Java to develop RePast models. Leigh Tesfatsion continues to provide an outstanding service to the community with her website,[10] but my impression (hopefully incorrect) is that the ACE community is still too fragmented to make substantial inroads into economic policy debates. While a growing number of publications are available online, too much good material is also locked up in prohibitively expensive hardback books and conference proceedings. If we want new generations of economists in both rich and poor countries to learn agent-based modelling, that is not the way to go. Herbert Dawid and the organizers of this conference are to be congratulated for arranging for the best papers to be published in a widely available journal, rather than an unnecessarily expensive hardback.

[9] See also Tobias & Hoffman (2004) who rated RePast most highly in a comparison with other popular platforms.
[10] http://www.econ.iastate.edu/tesfatsi/ace.htm

It is arguable that the standard training of economists should include training in object-oriented programming languages like Java, and in standard representations like UML and design patterns, but this is unlikely to happen any time soon. Policy-oriented ABMs therefore need to be user-friendly, reliable and understandable by government economists with only a few weeks training.

To ensure the continued enrichment of agent-based modelling, Chen (2005) has urged closer interactions between agent-based modellers and those studying experimental and behavioural economics. He and others have also emphasized the importance of field studies to inform model building (see Izumi *et al*. (2005) for a good example). Marietto *et al.* (2003, p. 197) even suggest the use of participatory-based simulation in which "a set of stakeholders, such as domain experts or the system end-users, contribute to discuss and negotiate the validity of the specification and the simulation results." Such a participatory process is analogous to the participatory appraisals which are now standard in development work, and the participatory processes which are meant to inform the drafting of the IMF and World Bank sponsored Poverty Reduction Strategy Papers, which all developing countries receiving assistance are required to develop. Once suggested, the idea of actually talking to some of the people a model is meant to simulate seems obvious, but as Nobel-prize wining economist Herbert Simon (1986, p. 23) once observed:

> Virtually no economic students get training in methods of observation that would lead the researcher to find out how the consumer actually makes choices, or to go inside a business firm to see how decisions are actually made there.

For both tactical and pragmatic reasons, Fonseca and Zeidan (2004) caution against economists who are enamoured with ABMs from adopting too revolutionary an approach by throwing out all of orthodox economics. They give three reasons: First, the empirical results of agent-based models do not yet warrant it. Second, it would involve a lot of rebuilding the wheel, since much of the same ground still has to be covered in model building. Third, it unnecessarily alienates some more orthodox economists who might otherwise be open to new approaches. Citing Riechmann (2000) as an example, they argue that there is scope for building models which incorporate aspects of both approaches, and this line of research is more likely to build understanding and speed the development of more realistic models. They therefore advocate a more gradualist approach in the manner of Popper (1980) who envisaged the evolution of new theories from previously dominant ones, as opposed to Kuhn (1996) who saw new theories replacing the old in a dramatic 'paradigm shift'.

I believe Fonseca and Zeidan are correct in their assessment of the likely evolution of the economics discipline. Economics is not like geology, biology or physics where the theories of plate tectonics, evolution by natural selection and general relativity overturned previous theories in a relatively short time. In economics, older theories and schools of thought linger for decades, and the profession is now so fragmented into specialised sub-fields that economists tend not to read outside their own speciality. Even a paper such as this, concerning different approaches to economic modelling, would be considered 'interdisciplinary' by some.

With such fragmented knowledge and expertise, I suspect that most economists tend to assume that while there may (or may not) be significant theoretical difficulties in their own sub-field, the foundations of the other sub-fields are quite solid. For these reasons I think a frontal assault on the foundations of orthodox economic theory is unlikely to get much of a hearing in the profession. Indeed, it has not. Many of the most devastating critiques, such as those cited earlier, have been published in top mainstream journals. My hunch is that most economists are either unaware of such papers, or assume that the problems they pose will have been 'dealt with' by someone and so they can be safely ignored.

7. CONCLUSIONS

In developing economic policy, there is much to be gained from a greater understanding of the strengths and weaknesses of different modelling approaches, and what domains are most appropriate for their use. The issue is not simply of academic interest. Economic policy recommendations have a profound effect on people's lives, particularly in developing countries where so people still many hover between life and death on a daily basis. As Paranuk *et al.* (1998, p. 1) remind us:

> [T]he duty of simulators ought to be first of all to the domain being simulated, not to a given simulation technology, and the choice of technology should be driven by its adequacy for the modelling task as well as its intrinsic interest to the modeler.

In other words, it is ethically questionable for economists to treat every problem like a nail just because all we have learned to use is a hammer. By exploring the strengths and weaknesses of CGE and ABM models and constructing interfaces between them, it is possible to draw on the strengths of each.

REFERENCES

Appel, K. and Haken, W., (1977) "Every Planar Map is Four Colorable Part I: Discharging", *Illinois Journal of Mathematics,* Vol. 21, pp. 429-490.

Appel, K., Haken, W. and Koch, J., (1977) "Every Planar Map is Four Colorable Part II: Reducibility", *Illinois Journal of Mathematics,* No. 21, pp. 491-567.

Amsden, A.H., (1989) *Asia's Next Giant: South Korea and Late Industrialization,* Oxford University Press, Oxford & New York, 379 pp.

Amsden, A.H., (1997) "Editorial: Bringing Production Back in - Understanding Government's Economic Role in Late Industrialisation", *World Development,* Vol. 25, No. 4, April, pp. 469-480.

Amsden, A.H., (2001) *The Rise of "The Rest": Challenges to the West from Late-Industrializing Economies,* Oxford University Press, Oxford & New York, 405 pp.

Annabi, N., Cissé, F., Cockburn, J. and Decaluwé, B., (2005) "Trade Liberalisation, Growth and Poverty in Senegal: A Dynamic Microsimulation CGE Model Analysis", CIRPÉE Working Paper 05-12, Montréal, Centre Interuniversitaire sur le Risque, les Politiques Économiques et l'Emploi, May, 30 pp. [http://132.203.59.36/CIRPEE/indexbase.htm (Accessed 18 May 2005)]

Batten, D.F., (2000) *Discovering Artificial Economics: How Agents Learn and Economies Evolve,* Westview Press, Boulder and Oxford, 314 pp.

Bourguignon, F., Robilliard, A.-S. and Robinson, S., (2003) "Representative Versus Real Households in the Macro-Economic Modelling of Inequality", Développement Institutions & Analyses de Long terme (DIAL), Document de Travail DT/2003-10, Paris, September, 29 pp. [http://www.dial.prd.fr/dial_publications/PDF/Doc_travail/2003-10.pdf (Accessed 30 May 2005)]

Bruun, C., (1999) "Agent-Based Keynesian Economics: Simulating a Monetary Production System Bottom-Up", Unpublished manuscript, Economic Research Group, Aalborg University, June, 26 pp. [http://www.socsci.auc.dk/~cbruun/cbresearch.htm (Accessed 14 Feb 2005)]

Bruun, C., (2003) "The Economy as an Agent-Based Whole - Simulating Schumpeterian Dynamics", *Industry and Innovation,* Vol. 10, No. 4, December, pp. 475-491.

Chen, S.-H., (2005) "Trends in Agent-Based Computational Modeling of Macroeconomics", *New Generation Computing,* Vol. 23, No. 1, pp. 3-11.

Chua, A., (1995) "The Privatization-Nationalization Cycle: The Link Between Markets and Ethnicity in Developing Countries", *Columbia Law Review,* Vol. 95, No. 2, March, pp. 223-303.

Chua, A., (1998) "Markets, Democracy and Ethnicity: Towards a New Paradigm for Law and Development", *Yale Law Journal,* Vol. 108, No. 1, October, pp. 1-107.

Chua, A., (2000) "The Paradox of Free Market Democracy: Rethinking Development Policy", *Harvard International Law Journal,* Vol. 41, No. 2, Spring, pp. 287-379.

Chua, A., (2003) *World on Fire: How Exporting Free market Democracy Breeds Ethnic Hatred and Global Instability,* William Heinemann, London, 346 pp.

Cockburn, J., (2001) "Trade Liberalisation and Poverty in Nepal: A Computable General Equilibrium Micro Simulation Analysis", CREFA Working Paper 01-18, Centre for the Study of African Economies

and Nuffield College (Oxford University) and CREFA, October, 28 pp.
[http://www.crefa.ecn.ulaval.ca/cahier/0118.pdf (Accessed 19 January 2005)]

Cogneau, D. and Robilliard, A.-S., (2000) "Growth, Distribution and Poverty in Madagascar: Learning from a Microsimulation Model in a General Equilibrium Framework", TMD Discussion Paper No. 61, Washington DC, Trade and Macroeconomics Division, International Food Policy Research Institute, November, 62 pp.

Cornforth, D., Green, D.G. and Newth, D., (2005) "Ordered Asynchronous Processes in Multi-Agent Systems", *Physica D,* Vol. 204, No. 1-2, 1 May, pp. 70-82.

Cororaton, C.B. and Cockburn, J., (2005) "Trade Reform and Poverty in the Philippines: A Computable General Equilibrium Microsimulation Analysis", CIRPÉE Working Paper 05-13, Montréal, Centre Interuniversitaire sur le Risque, les Politiques Économiques et l'Emploi, May, 26 pp.
[http://132.203.59.36/CIRPEE/indexbase.htm (Accessed 18 May 2005)]

Dawid, H., (2006) "Agent-Based Models of Innovation and Technological Change", In *Handbook of Computational Economics, Volume 2: Agent-Based Computational Economics* ed. Judd, K. and Tesfatsion, L.; North Holland, Amsterdam. For draft see:
http://www.wiwi.uni-bielefeld.de/~dawid/papers/ace_handbook_rev.pdf

Decaluwé, B., Patry, A., Savard, L. and Thorbecke, E., (1999) "Poverty Analysis Within a General Equilibrium Framework", Working Paper 9909, CRÉFA 99-06, Quebec, CRÉFA , Département d'économique Université Laval, June, 58 pp.

Deguchi, H., (2004) *Economics as an Agent-Based Complex System,* Springer-Verlag, Tokyo, Berlin, Heidelberg & New York, xiii+261 pp.

Devlin, K., (1999) *Mathematics: The New Golden Age,* Columbia University Press, New York, 320 pp.

Dibble, C. and Feldman, P.G., (2004) "The GeoGraph 3D Computational Laboratory: Network and Terrain Landscapes for RePast", *Journal of Artificial Societies and Social Simulation,* Vol. 7, No. 1, [http://jasss.soc.surrey.ac.uk/7/1/7.html (Accessed 7 December 2004)].

Dixon, P.B. and Rimmer, M.T., (2003) *Dynamic General Equilibrium Modelling for Forecasting and Policy: A Practical Guide and Documentation of MONASH,* Series ed. Blundell, R., Caballero, R., Laffont, J.J. and Pearson, T.; Contributions to Economic Analysis; North-Holland, Amsterdam, Boston & London, Vol. 256, xiv+338 pp.

Epstein, J.M., (2002) "Modeling Civil Violence: An Agent-Based Computational Approach", *Proceedings of the National Academy of Sciences of the USA,* Vol. 99, Supplement 3, 14 May, pp. 7243-7250.

Evans, D., (2001) "Identifying Winners and Losers in Southern Africa from Global Trade Policy Reform: Integrating Findings from GTAP and Poverty Case Studies", Paper prepared for the 4th Annual Conference on Global Economic Analysis, Purdue University, 27-29 June 2001, GTAP Resource #675, 22 pp.

Felipe, J. and Fisher, F.M., (2003) "Aggregation in Production Functions: What Applied Economists Should Know", *Metroeconomica,* Vol. 54, No. 2-3, May-September, pp. 208-262.

Ferreira Filho, J.d.S.B. and Horridge, M., (2004) "Economic Integration, Poverty and Regional Inequality in Brazil", General Working Paper No. G-149, Centre of Policy Studies and the Impact Project Monash University, July, 39 pp.

Fonseca, M.G.D. and Zeidan, R.M., (2004) "Epistemological Considerations on Agent-Based Models in Evolutionary Consumer Choice Theory", *Emergence: Complexity & Organization,* Vol. 6, No. 3, pp. 4-8.

Gimblett, H.R. (Ed.) (2002) *Integrating Geographic Information Systems and Agent-based Modeling Techniques for Simulating Social and Ecological Processes,* Studies in the Sciences of Complexity; Oxford University Press for the Santa Fe Institute, Oxford & New York, 327 pp.

Greenwald, B.C. and Stiglitz, J.E., (1986) "Externalities in Economies with Imperfect Information and Incomplete Markets", *Quarterly Journal of Economics,* Vol. 101, No. 2, May, pp. 229-264.

Gross, D. and Roger, S., (2000) "Can Agent-Based Models Assist Decisions on Large-Scale Practical Problems? A Philosophical Analysis", *Complexity,* Vol. 5, No. 6, pp. 26-33.

Hertel, T.W., (1997) *Global Trade Analysis: Modeling and Applications,* Cambridge University Press, Cambridge, New York & Melbourne, 403 pp. See also: http://www.gtap.agecon.purdue.edu/

Hertel, T.W., Ivanic, M., Preckel, P.V. and Cranfield, J.A.L., (2003) "Trade Liberalization and the Structure of Poverty in Developing Countries", GTAP Working Paper No. 25, GTAP Resource # 1207, Purdue University, Global Trade Analysis Project, February, 23 pp.

Hertel, T.W., Hummels, D., Ivanic, M. and Keeney, R., (2004) "How Confident Can We Be in CGE-Based Assessments of Free Trade Agreements?" NBER Working Paper No. 10477, Cambridge, MA, National Bureau of Economic Research, Inc., May, 39 pp.

Holland, J.H. and Miller, J.H., (1991) "Artificial Adaptive Agents in Economic Theory", *American Economic Review,* Vol. 81, No. 2, May, pp. 365-371.

Horridge, M. and Ferreira-Filho, J.d.S.B., (2003) "Linking GTAP to National Models: Some Highlights and a Practical Approach", Paper presented at the 6th Annual Conference on Global Economic Analysis, The Hague, June 2003, GTAP Resource # 1262, Purdue University, Global Trade Analysis Project, 20 pp.

Horridge, M., Parmenter, B.R., Cameron, M., Joubert, R., Suleman, A. and de Jongh, D., (1995) "The Macroeconomic, Industrial, Distributional and Regional Effects of Government Spending Programs in South Africa", General Paper No. G-109, Centre of Policy Studies and the Impact Project Monash University, April, 38 pp.

Ianchovichina, E. and McDougall, R., (2000) "Theoretical Structure of Dynamic GTAP", GTAP Technical Paper No. 17, Purdue University, Global Trade Analysis Project, December, 68 pp.

Izumi, K., Nakamura, S. and Ueda, K., (2005) "Development of an Artificial Market Model Based on a Field Study", *Information Sciences,* Vol. 170, No. 1, February, pp. 35-63.

Kirman, A., (1989) "The Intrinsic Limits of Modern Economic Theory: The Emperor Has No Clothes", *Economic Journal,* Vol. 99, No. 395, Supplement, pp. 126-139.

Kirman, A.P., (1992) "Whom or What Does the Representative Individual Represent?" *Journal of Economic Perspectives,* Vol. 6, No. 2, Spring, pp. 117-136.

Kuhn, T.S., (1996) *The Structure of Scientific Revolutions,* 3rd Edition; University of Chicago Press, Chicago & London, xiv+212 pp.

Lall, S. (Ed.) (1996) *Learning from the Asian Tigers: Studies in Technology and Industrial Policy,* MacMillan Press & St Martin's Press, London & New York, 235 pp.

Lawson, T., (1997) *Economics and Reality,* Routledge, London, xx+364 pp.

Malerba, F., Nelson, R., Orsenigo, L. and Winter, S., (2001) "History-Friendly models: An overview of the case of the Computer Industry", *Journal of Artificial Societies and Social Simulation,* Vol. 4, No. 3, June, [http://www.soc.surrey.ac.uk/JASSS/4/3/6.html (Accessed 26 May 2005)].

Marietto, M.B., David, N., Sichman, J.S. and Coelho, H., (2003) "A Classification of Paradigmatic Models for Agent-Based Social Simulation", In *Multi-Agent Based Simulation III, Revised papers from the 4th International Workshop (MABS 2003), Melbourne, Australia, July 14, 2003, Lecture Notes in Computer Science Vol. 2927* ed. Hales, D., Edmonds, B. and Norling, E.; Springer-Verlag, Berlin, pp. 193-208.

McCauley, J.L., (2000) "The Futility of Utility: How Market Dynamics Marginalize Adam Smith", *Physica A,* Vol. 285, No. 3-4, 1 October, pp. 506-538.

McFadzean, D., Stewart, D. and Tesfatsion, L., (2001) "A Computational Laboratory for Evolutionary Trade Networks", *IIEE Transactions on Evolutionary Computation,* Vol. 5, No. 5, October, pp. 546-560.
Parunak, H.V., Savit, R. and Riolo, R.L., (1998) "Agent-Based Modeling vs. Equation-Based Modeling: A Case Study and Users' Guide", *Proceedings of Multi-Agent Systems and Agent-Based Simulation (MABS '98), Lecture Notes in Artificial Intelligence,* Vol. 1534, pp. 10-25.

Popper, K., (1980) *The Logic of Scientific Discovery,* 4th Edition; Hutchinson, London, 479 pp.

Pyka, A. and Fagiolo, G., (2005) "Agent-Based Modelling: A Methodology for Neo-Schumpeterian Economics", Working Paper No. 272, University of Augsburg, February, 26 pp. [http://www.wiwi.uni-augsburg.de/vwl/institut/paper/272.pdf (Accessed 25 May 2005)]

Radner, R., (1968) "Competitive Equilibrium Under Uncertainty", *Econometrica,* Vol. 36, No. 1, January, pp. 31-58.

Radner, R., (1970) "Problems in the Theory of Markets under Uncertainty", *American Economic Review,* Vol. 60, No. 2, May, pp. 454-460.

RePast (2004) *RePast: Recursive Porous Agent Simulation Toolkit*, version 3.0, RePast Organization for Architecture and Development, http://repast.sourceforge.net/

Riechmann, T., (2000) "A Model of Boundedly Rational Consumer Choice - An Agent Based Approach", Diskussionspapier Nr. 232, University of Hannover, Department of Economics, May, 27 pp. [http://www.econometricsociety.org/meetings/wc00/pdf/0715.pdf (Accessed 31 May 2005)]

Rutherford, T.F., Shepotylo, O. and Tarr, D.G., (2005) "Poverty Effects of Russia's WTO Accession: Modeling "Real" Households and Endogenous Productivity Effects", Policy Research Working Paper No. 3473, Washington DC, World Bank, January, 64 pp.

Saari, D.G., (1995) "Mathematical Complexity of Simple Economics", *Notices of the AMS,* Vol. 42, No. 2, February, pp. 222-230.

Savard, L., (2003) "Poverty and Income Distribution in a CGE-Household Micro-Simulation Model: Top-Down/Bottom Up Approach", CIRPÉE Working Paper 03-43, Montréal, Centre Interuniversitaire sur le Risque, les Politiques Économiques et l'Emploi, October, 40 pp. [http://132.203.59.36/CIRPEE/indexbase.htm (Accessed 18 May 2005)]

Savard, L., (2004) "Poverty and Inequality Analysis within a CGE Framework: A Comparative Analysis of the Representative Agent and Micro-Simulation Approaches", CIRPÉE Working Paper 04-12, Montréal, Centre Interuniversitaire sur le Risque, les Politiques Économiques et l'Emploi, May, 19 pp. [http://132.203.59.36/CIRPEE/indexbase.htm (Accessed 18 May 2005)]

Shin, J.-S., (1996) *The Economics of the Latecomers: Catching-up, Technology Transfer and Institutions in Germany, Japan and South Korea,* Routledge Studies in the Growth Economies of Asia; Routledge, London & New York, 214 pp.

Simon, H.A., (1986) "The Failure of Armchair Economics", *Challenge,* Vol. 29, No. 5, November - December, pp. 18-25.

Stiglitz, J.E., (1989) "Markets, Market Failures, and Development", *American Economic Review,* Vol. 79, No. 2, May, pp. 197-203.

Stiglitz, J.E., (1996) "Some Lessons from the East Asian Miracle", *World Bank Research Observer,* Vol. 11, No. 2, August, pp. 151-177.

Taylor, L. (Ed.) (1990) *Socially Relevant Policy Analysis: Structuralist Computable General Equilibrium Models for the Developing World,* MIT Press, Cambridge, MA & London, x+379 pp.

Temple, J., (1997) "St Adam and the Dragons: Neo-classical Economics and the East Asian Miracle", *Oxford Development Studies,* Vol. 25, No. 3, pp. 279-300.

Tesfatsion, L., (1997) "How Economists Can Get ALife", In *The Economy as an Evolving Complex System II, Santa Fe Institute Studies in the Sciences of Complexity, Vol. XXVII* ed. Arthur, W.B., Durlauf, S.N. and Lane, D.; Addison-Wesley, Reading, MA, pp. 533-564.

Tesfatsion, L., (2003) "Agent-Based Computational Economics", ISU Working Paper No. 1, Revised August 24, 2003, Iowa State University, 30 pp. [http://www.econ.iastate.edu/tesfatsi/]

Tobias, R. and Hofmann, C., (2004) "Evaluation of Free Java-Libraries for Social-Scientific Agent Based Simulation", *Journal of Artificial Societies and Social Simulation,* Vol. 7, No. 1, January, pp. 29. [http://jasss.soc.surrey.ac.uk/7/1/6.html (Accessed 7 August 2004)].

Wade, R., (1990) *Governing the Market: Economic Theory and the Role of Government in East Asian Industrialization,* Princeton University Press, Princeton, N.J, 438 pp.

Werker, C. and Brenner, T., (2004) "Empirical Calibration of Simulation Models", Max Planck Institute for Research into Economic Systems, Jena, Papers on Economics and Evolution No. 0410, 13 May, 15 pp. [https://papers.mpiew-jena.mpg.de/evo/discussionpapers/2004-10.pdf (Accessed 26 May 2005)]