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HOW USEFUL ARE COMPUTABLE GENERAL EQUILIBRIUM MODELS FOR SUSTAINABILITY IMPACT ASSESSMENT?[1]

Serban Scrieciu[2]

Institute for Development Policy and Management, University of Manchester, UK

Abstract

Computable general equilibrium (CGE) modelling represents a powerful tool for hypothesising possible sustainability outcomes that might be triggered with the implementation of trade-related policy proposals. Nevertheless, CGE modelling is based on several tight general equilibrium and neoclassical theoretical assumptions that make their application to the assessment of all three pillars of sustainability questionable. Although some over-simplistic assumptions have been relaxed in recent and more advanced CGE models, further research needs to be undertaken in order to bring model specifications closer to realistic behavioural relationships. CGE models also tend to focus on alternative equilibrium outcomes and rarely deal with the adjustment process or regulatory measures needed to realise the estimated potential benefits. Moreover, by design they face substantial limitations when dealing with environmental and social effects of trade-related policies. Nevertheless, some authors have argued that CGE modelling may provide a suitable backbone for all three dimensions of Sustainability Impact Assessment (SIA). The paper takes a critical stand and supports the view that though CGE models may provide some useful information on individual, particularly economic, impact aspects of policy reforms, it may be inappropriate, and in some cases misleading, to rely extensively on their use in SIAs.

Keywords: trade, sustainability impact assessment, computable general equilibrium modelling

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[2] Research Associate, PhD, Institute for Development Policy and Management, The University of Manchester; serban.scrieciu@manchester.ac.uk.

1. Introduction

The concept and practical implementation of sustainable development has become a key issue for policy agendas, research topics and even business plans. The Brundtland Report (or "Our Common Future") officially initiated the ongoing concern for sustainable development by defining it as a process that "seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future" (Bruntland, 1987). The need to provide a comprehensive and reliable analysis of the effects of major policy changes on sustainability outcomes has been increasingly recognised, and has led to the ongoing development of integrated methodological or conceptual frameworks for assessing the impact of policy on sustainable development.

The Sustainability Impact Assessment (SIA) methodology constitutes a response to this need.[3] It represents a relatively new conceptual approach for the ex-ante appraisal of the potential impacts of policy reform on sustainable development that has been particularly applied to trade negotiations and trade liberalisation measures.[4] The SIA methodology includes major improvements from previous traditional policy assessments in the sense that it adopts an integrated approach covering the economic, environmental and social impacts of policy reforms, it incorporates a consultation process with the active involvement of stakeholders in the assessment process, and, in addition to the identification of potential effects, it puts forward accompanying measures that would allow for both the enhancement of positive effects and the mitigation of negative impacts (George and Kirkpatrick, 2004a).[5]

SIA does not however recommend a particular tool or set of tools for quantitatively or qualitatively assessing potential economic, environmental and social effects, or trade-offs. It draws on a wide range of methodological approaches, tools and applications, largely depending

[3] The Sustainability Impact Assessment (SIA) methodology was originally developed at the Institute for Development Policy and Management, University of Manchester at the initiative of the European Commission (Kirkpatrick, Lee and Morrissey, 1999). *Ex-ante* assessment of policies has developed since the late 1990s, when the European Commission began to incorporate economic, environmental and social concerns into its policy formulation process (EC, 2004).

[4] SIA studies include assessments undertaken at multi-national and national level, such as those conducted by the European Commission for the appraisal of EU major policy proposals (also known as extended impact assessments, ExIA) (EC, 2005); the evaluation of the impact of greater trade and investment on sustainable development as part of the UK White Paper 2004 on trade and investment (Kirkpatrick, George and Scrieciu, 2004); the assessment of national sustainable development strategies in transition economies (Cherp, George and Kirkpatrick, 2004); and the sustainability impact assessment of WTO's Doha Development Agenda (Lee and Kirkpatrick, 2001, George and Kirkpatrick, 2004, Kirkpatrick, George and Scrieciu, 2006).

[5] Hence, the SIA methodology broadly addresses two complementary issues that feed into each other at various stages, namely an economic, environmental, and social assessment undertaken in a clear, scientific and objective manner, and a consultation and dissemination process among stakeholders (EC, 2004).

on the policy category to be assessed, the level of analysis and the typology of effects under investigation. However, recent studies have argued that potential trade-offs between the economic, social and environmental pillars of sustainability may be more adequately addressed through the greater use of numerical modelling techniques, particularly Computable General Equilibrium (CGE) models[6] (Böhringer and Löschel, 2006, Böhringer, 2004, Ferguson et al, 2005). These papers generally argue for the incorporation of sustainability indicators into numerical equilibrium modelling frameworks, and implicitly for the intensive use of these techniques to undertake sustainability impact assessments:

> "The quantification of tradeoffs requires the use of numerical model techniques. There is simply *no other way* to think systematically and rigorously about the interaction of the many forces that interact in the economy affecting potential indicators of Sustainable Development" (Böhringer, 2004: 10) (italics added)

This paper critically evaluates the proposition put forward in the literature, which advocates the use of Computable General Equilibrium models as the main analytical tool for effectively assessing sustainability outcomes of policy interventions. While acknowledging the usefulness of CGE modelling for some dimensions of policy analysis, the paper seeks to question the legitimacy of extensively, or even exclusively, relying on this particular modelling tool for the analysis of the multi-dimensional, inter-disciplinary, dynamic and complex concept of sustainability. It focuses particularly on the weaknesses and shortcomings emerging from the theoretical assumptions and model specification features underpinning CGE models.[7]

The paper is structured into five sections. The following section briefly discusses the concept of computable general equilibrium modelling. Section 3 evaluates to what extent the literature on CGE modelling has addressed sustainable development issues. Section 4 offers a critical appraisal of the appropriateness of using CGE models as a main tool or fundamental analytical framework for an effective SIA. Section 5 concludes.

[6] Computable general equilibrium models (CGEs) are also referred to in the literature as applied general equilibrium models (AGEs). Although the latter would represent a more appropriate name for these models (as their aim is to turn general equilibrium structures "from an abstract representation of an economy into realistic models of actual economies", Shoven and Whalley, 1984:1007), the former label is employed in this paper in order to conform to the common practice found in the modelling literature.

[7] However, other limitations of the methods may be further identified if one evaluates in detail the appropriateness of functional forms, closure rules, "dynamic" modelling elements and other aspects related to modelling performance (see, for example, Grassini, 2004, and McKitrick, 1998, for a more in-depth critical evaluation of CGE models).

2. CGE Modelling: Some Conceptual Issues

CGE models usually cover economy-wide impacts on relative prices, resource allocation and incomes (Kousnetzoff and Chauvin, 2004), and in addition, account for inter- and intra-industry foreign trade links. They represent a relatively recent category of modelling methods that convert Walrasian general equilibrium models from an abstract representation of an economy to a realistic representation of actual economies (Shoven and Whalley, 1984).[8] The theoretical underpinning of CGE models heavily draws on the neoclassical (micro-) economic theory of the optimisation behaviour of rational economic agents against the background of general equilibrium theoretical structures. Although the computer representation of the economy is complex enough to reflect its essential features, it may still retain the tractability characteristics of their analytical counterparts (Kehoe and Kehoe, 1994). In other words, the CGE methodology allows models of large dimensions to be quantitatively solved whilst retaining the basic general equilibrium structure of their theoretical counterparts (Glebe, 2003). This is because CGE models have emerged as the result of combined efforts of theorists that laid the foundations of general equilibrium theory, applied economists that looked at the real economy using the theoretical foundations, and mathematicians that have developed tools to bring about the feasibility of numerical computations (Grassini, 2004).

A more compact definition may thus present an CGE model as an analytical deterministic integrated system of non-linear equations derived from the economic theory of optimising behaviour of rational economic agents that describes the simultaneous linkages between markets, institutions and factor resources that renders an all-markets clearing equilibrium numerical solution. It could be compared to a scientific laboratory experiment where the modelled economy constitutes the subject of the experiment, the assumptions made are the necessary conditions for the experiment to work, and the exogenous policy changes are the shocks that are administered to the subject in order to investigate their potential effect. In other words, the aim of CGE modelling is "… to evaluate policy options by specifying production and demand parameters and incorporating data reflective of real economies" (Shoven and Whalley, 1984: 1007).

[8] The Walrasian general equilibrium theory states that in an economy where consumers are endowed with factors and demand produced goods, and firms demand factors and produce goods with a fixed coefficients production technology (or more generally, a constant returns to scale production function), both output and factor markets clear, whilst perfect competition assures that producer prices equal the costs of production for every operating activity.

Numerical CGE models are based on classical analytical equilibrium models (formalised by Arrow and Debreu in the 1950s), according to which a unique (optimal) general equilibrium solution in competitive markets may arise if three equilibrium conditions are simultaneously satisfied (Mathiesen, 1985, Paltsev, 2004): (i) the "zero profit condition" requiring that any activity that is functioning and operating must earn zero profit; (ii) the "market clearance condition" requiring that supply and demand for any good and factor of production must balance; and (iii) the "income balance condition" requiring that for each economic agent the value of income must equal the value of factor endowments. However, CGE models represent an extension to classical equilibrium analytical models in the sense that they are mostly policy driven and aim to provide numerical solutions to large multi-sectoral models.[9] Their main task is to simultaneously find equilibrium prices, quantities, and incomes of an economy where all economic flows are accounted for. In other words, they ensure that there is a "sink" for every "source" (Paltsev, 2004). Furthermore, they are capable of illustrating the respective economic flows in much more detail and complexity than analytical models, which can only afford to work in small dimensions.[10]

CGE modelling hence represents a flexible analytical and simulation device for distinguishing between the multiple effects that might be brought about by the implementation of a set of combined policy issues (FAO, 2003). It also has the main advantage of addressing the workings of an economy in an integrated manner and considering the complex inter-linkages, feedback and spill-over effects between all the sectors and economic agents operating in the modelled economy, whether at a national, regional or global level. Nevertheless, CGE models are, in a nutshell, quantitative expressions of neoclassical economic theory, which tends to impose a number of strict assumptions on the modelling (Barker, 2004). In other words, specific functional forms or restrictions need to be employed in order to ensure a unique and stable equilibrium, though the economic realism of these restrictions has often been overlooked (Ackerman, 2002). This typically renders the CGE simulation approach often too stylised and rigid for sustainability impact analysis.

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[9] General equilibrium problems have been approached in the last three decades more from a computational and practical perspective due to the pioneering work undertaken in the 1950s, 1960s and 1970s notably by James Meade, Harry G. Johnson, Arnold Harberger, H. Scarf, John Shoven and John Whalley.

[10] Because CGE models usually work at a level of detail halfway between micro and macro variables, some authors have labelled their level of detail as being "meso", namely the level at which policy makers are interested in (Grassini, 2004).

3. CGE Modelling and Sustainability Impact Assessment

The modelling literature dealing simultaneously with interactions between all three -economic, social and environmental - components of sustainable development is extremely sparse. This is because both the SIA concept and CGE economic modelling techniques to incorporate sustainability issues have only recently emerged. However, there are several studies that model the impact of policy changes on individual relationships/aspects of the sustainability process, for example issues pertaining to economic and environmental development or between economic and social aspects.

On the one hand, an increasing number of studies address the relationship between economic policy reforms and environmental performance or environmental policies. For instance, a large number, of this type of studies, investigate the interactions between trade policy reforms or greater trade liberalisation and the environment. These are performed at various aggregation levels, from a global perspective (Perroni and Wiggle, 1994, Cole and Rayner, 2000, Copeland and Taylor, 2004, and Nijkamp, Wang and Kremers, 2005), on a regional scale (Brown, Deardoff and Stern, 1992 and Anderson, 2001, for NAFTA, Löschel and Mraz, 2001, and Zhu and van Ierland, 2006, for an extended EU), or at a country level (Anderson and Strutt, 1998, for Indonesia, Townsend and Ratnayake, 2000, for New Zealand, Dean, 2000, for China). The modelling approach generally attaches an environmental module to production or consumption functions often under the form of technical coefficients of emissions (for example, Nijkamp, Wang and Kremers, 2005, add an explicit capital-energy composite input into the production structure).

On the other hand, a growing body of CGE modelling literature investigates the impact of policy proposals or policy changes not only on economic growth but also on social welfare, poverty and equity. For example, Mbabazi (2002) analyses short-run welfare impacts of trade liberalisation in Uganda, Humphreys (2000) evaluates within a CGE modelling framework, poverty and distributional impacts of trade liberalisation in South Africa, and Coady and Harris (2004) adopt an augmented CGE approach[11] that addresses the welfare impact of cash transfers targeted at rural areas in Mexico.

[11] These represent latest developments in CGE modelling techniques that attempt to link a computable general equilibrium model with a micro-simulation model based on household survey data, allowing the researcher to evaluate welfare and poverty impacts consistent with the macroeconomic policies captured in the general equilibrium model (World Bank, 2003).

This paper does not go into more detail pertaining to the above-mentioned literature because the present analysis deals with issues of measuring the impacts of policy initiatives on all three pillars of sustainable development from an integrative and not separated standpoint. The paper hence focuses on studies that have attempted to use CGE modelling as a tool for providing an integrative assessment of the sustainability dimension. The particular suitability of computable general equilibrium models for measuring all three pillars of sustainable development has been particularly advocated, for example, in Böhringer and Löschel (2006) and Böhringer (2004), for which a critical discussion is presented in the remainder of this paper.[12]

Böhringer and Löschel (2006) presents the case for the use of Computable General Equilibrium modelling as a flexible backbone tool for quantifying the impacts of policy changes or proposals on the three pillars (economic, environment and social) of sustainable development. The authors assert that CGE modelling may represent a good fit of the requirements for a comprehensive Sustainability Impact Assessment (SIA):[13]

> "We argue that CGE models can incorporate several key sustainability (meta-) indicators in a single micro-consistent framework, thereby allowing for a systematic quantitative trade-off analysis between environmental quality, economic performance and income distribution" (Böhringer and Löschel, 2006)

The authors start their arguments by displaying two lists of policy-relevant systems of sustainable indicators that may be partially addressed within a CGE modelling framework. These refer to the list of *Indicators of Sustainable Development* developed by the United Nations Commission on Sustainable Development (CSD) and a list compiled by the European Commission with the aim of evaluating the progress of the EU towards sustainable development. Both sets of indicators of sustainable development are constructed for use at a national level.[14] A large number of these sustainability indicators can be included within a CGE modelling framework according to

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12 Although, Ferguson et al (2005) mention in their title "incorporating sustainability indicators into a Computable General Equilibrium model", their study addresses only the economic-environment relationship, and within this relationship only environmental aspects pertaining to output emissions and global warming.

13 In this regard, Böhringer and Löschel (2006) and Böhringer (2004) acknowledge that their exclusive focus on quantitative CGE-based analysis should not downplay the role that other numerical modelling approaches may play in sustainability impact assessment studies. However, note that the authors do argue for the exclusive use of numerical modelling techniques, which in turn is largely dominated by CGE modelling techniques.

14 The list compiled by the United Nations CSD contains a set of 58 "core indicators" that are grouped within 15 themes and 38 sub-themes, covering the three main pillars of sustainable development (economic, social and environmental) plus an institutional component reflecting the framework and capacity of each country to implement corresponding sustainability measures. The list forwarded by the European Commission encompasses only fourteen structural indicators that facilitate the process of evaluating the progress made by EU member states towards sustainable development.

Böhringer and Löschel (2006). This would provide a quantitative approach to SIA and lead to better-informed policy decision-making (Böhringer, 2004).

The authors develop a generic ("core") CGE model to which they propose several extensions that would increase the policy relevance and would cover a wider range of indicators for SIA. The generic model represents a standard comparative-static multi-sector and multi-region model of trade and environmental or energy policies that employs three primary factors of production (labour, capital and resource of fossil fuels) and non-energy intermediate inputs. The assumptions of no change in the employment of resources, constant returns to scale and perfect competition are generally associated with standard/generic CGE models.[15] However, the Böhringer and Löschel (2006) core model has limited application for SIA purposes in the sense that besides the fact that it addresses only a limited number of economic and environmental indicators for sustainable development,[16] when it comes to the latter it provides only a quantitative assessment in terms of emissions from fossil fuel combustion (namely, CO_2) and may simulate only a very narrow spectrum of environmental policy responses, such as the application of a carbon tax.

A state-of-the-art in the use of energy-economy-environment (E3) CGE models for SIA is further assessed in Böhringer and Löschel (2006). The authors acknowledge that although this type of CGE models displays a good coverage of key economic indicators, environmental indicators are only partly covered (with an emphasis on energy-related emissions and, hardly, no assessment of more complex ecological processes such as biodiversity loss or water stress), whereas social indicators stand out for their very weak coverage, due to difficulties in defining and measuring the social dimensions of development. However, despite these deficiencies of CGE models to cover key sustainability indicators, the authors advocate a so-called "hard link" approach that makes use of a single integrated modelling framework, implying that the "data and functional relationships from other models must be condensed and synthesised in a way compatible to the structure of the core [CGE] model" Böhringer and Löschel (2006). In other words, the authors argue for the supremacy of the CGE modelling tool over other methods in

15 In a standard model output is derived from a Leontief combination (namely zero elasticity of substitution) of intermediate inputs and aggregate value added, the latter consisting of nested constant elasticity of substitution cost functions. The Armington assumption is also employed to differentiate domestically produced goods from imported commodities.

16 The core model includes in its framework only six (GDP per capita, balance of trade in goods and services, intensity of material use, annual energy consumption per capita, intensity of energy use and emission of greenhouse gases) out of fifty-eight indicators on the United Nations CSD list and four (GDP per capita, labour productivity, greenhouse gas emissions and energy intensity of the economy) out of the fourteen structural indicators on the European Commission's list.

assessing sustainability impacts. This may pose a serious danger to sound policy making, particularly if this simulation device fundamentally mis-represents (as argued in this paper) the complexity of the development process and sustainability systems.

Furthermore, several extensions are discussed in Böhringer and Löschel (2006) that may develop the core model towards a better assessment of potential interactions and trade-offs between various sustainability indicators. These refer to the inclusion of non-CO_2 greenhouse gases, accounting for market distortions such as taxes or subsidies, involuntary unemployment and imperfect competition, adding dynamic specifications and endogenous technological change. The disaggregation of the representative agent into heterogeneous households would allow for the analysis of equity issues, as well as linking models to ensure a more comprehensive coverage of SIA requirements. However, the authors merely present how each of the proposed extensions may be capable of widening the policy relevance for SIA, but do not provide greater detail on their practical implementation and the appropriateness of their incorporation into a CGE modelling framework.

A more detailed explanation of possible CGE methodological extensions and their relevance for SIA is put forward in Böhringer (2004). The author acknowledges that one of the main weaknesses of CGE numerical modelling is that it is very difficult to distinguish between the numerous general equilibrium effects that are at work and that drive the simulation results, i.e. the black box critique.[17] The study then presents in more depth two alternative decomposition techniques that would identify the economic channels through which international trade may transmit policy impacts. Further extensions to the core CGE model are represented in terms of specifying and solving optimal policy problems, or undertaking systematic sensitivity analysis for key elasticities. Nonetheless, although the proposed extensions to the core model are important for a more reliable CGE analysis, they once again do not particularly address sustainability issues. This is because, despite the fact that such proposals to model development are welcome in the modelling literature, they tend to address CGE modelling limitations in general, and do not necessarily provide satisfactory answers to a range of questions particularly pertaining to the dynamics of sustainable development. In other words, the major assumptions that underpin CGE models and their associated limitations raise the question of how useful are these models in providing an effective and reliable assessment of the sustainability impacts of policy changes.

[17] The sheer size of CGE models and the difficulty in pinpointing the precise source of a particular result often render these as "black boxes".

4. The Inherent Limitations and Drawbacks of CGE Modelling for an Effective SIA

At first glance, CGE modelling, as suggested in the Böhringer and Löschel (2006) and Böhringer (2004) studies, appears to provide the much-needed single consistent framework necessary to quantitatively perform Sustainability Impact Assessments. Nonetheless, when one looks into the detail of the workings, underpinnings and assumptions of computable general equilibrium modelling, one starts to question their ability to deliver plausible assessments of crucial aspects linked to the complex process of sustainability, particularly when referring to environmental and social dimensions. The following sections discuss the inherent limitations and drawbacks of CGE modelling for an effective SIA.

The problem of quantifying sustainability

The first argument pertains to the capacity of quantitative methods in general (and CGE models as a sub-category of these) relative to qualitative approaches in providing a meaningful assessment of sustainability impacts. Although the need to deliver robust and rigorous quantitative SIAs is widely acknowledged, at the same time it is also increasingly acknowledged that many environmental, social and even economic aspects of sustainable development are very difficult to estimate quantitatively (and in some cases, it may not even be desirable).[18] For example, in a multitude of cases the natural capital may have an intrinsic value (not quantifiable in monetary terms) and integrating it within a pricing system based on individual preferences may actually be in conflict with ecological concerns.[19] The difficulty of mathematically formulating and quantifying interactions between economic activities and the environment becomes more pronounced for example in the case of agriculture, which plays a multifunctional role and provides, in addition to corresponding private commodities, a series of rural amenities and public goods. Besides the fact that major aspects of the agriculture-environment nexus are not suited for modelling (e.g. biodiversity and landscape), those elements of the relationship that may be modelled continue to be the focus of intense discussions amongst modellers.[20]

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[18] However, a more in-depth discussion of the pros and cons of quantitative versus qualitative analysis for sustainability impact assessment is not pursued here.

[19] This view corresponds in fact to the "strong sustainability" approach to sustainable development that argues that the full contribution of component species and processes to life-support capacity is not fully measurable in (economic) value terms at all (Turner, 2002).

[20] However, in the last few years there tends to be a convergence in the CGE modelling approach for example in response to EU's future shift towards a multifunctional agriculture, namely as a joint production of a pure public good (induced by the government through decoupled direct payments) and an agricultural private good (Cretegny, 2002). The author argues for the importance in considering the multifunctionality of agriculture when analysing the policy impacts on consumer welfare, as it might even lead to opposite conclusions if it is ignored.

Limitations of the economic theory underpinning CGE models

The CGE theoretical framework draws on a combination of general equilibrium theory, neo-classical micro-economic optimisation behaviour of rational economic agents, and some macro-economic elements that attempt to explain economic, and recently, also social and environmental phenomena. In other words, to many economists, the conventional neoclassical approach that extends well-known established liberal concepts, such as supply and demand forces, market equilibrium, profit maximisation, utility maximisation, prices, and monetary valuation to address ecological challenges represents a viable solution in tackling environmental problems. Nevertheless, as Söderbaum (2000) also argues, this encompasses a mechanistic, monetary reductionist approach that places a strong emphasis on the market as the solution to all kind of problems (including environmental and social issues) and fails to appropriately account for the institutional arrangements, ethical issues and the developmental needs of a society within an interdisciplinary, pluralistic, holistic, and dynamic approach. When economic and environmental linkages are assessed within an CGE modelling framework, their complexity tends to be narrowed down for example to the attachment of an environmental module to production or consumption functions often under the form of technical coefficients of emissions. Moreover, the elegance of the theory underlining CGE models and its apparent ability to explain the world relies on a truism, as these models, which are typically based on one year's data, are inherently not falsifiable and fit the data perfectly (Barker, 2004).

Conventional neoclassical theory also assumes that individual behaviour reflects the rational pursuit of self-interest, and consequently, the optimal policy is one that best allows individuals to maximise their personal utility and meet their preferences. However, individual preferences or personal welfare concerns play only a limited role in human behaviour, as persons generally base their choices on a much more complex set of values. For instance, they may display altruistic or sympathetic preferences or may have goals that transcend maximising utility objectives, such as moral values or socially valuable choices.[21]

Hence, the theory of optimisation behaviour represents a very specific view of human beings, society and nature. Other theoretical perspectives in both economics and other social and physical sciences, hence, tend to be marginalised or even excluded. Furthermore, neoclassical economists tend to over-emphasise people's autonomy and self-interest, and downplay the influence of others on individual preferences and decision-making, thus ignoring the social

[21] These are labelled by Amartya Sen as meta-preferences or second-order preferences, as opposed to first-order preferences derived from the standard "rational" economic behaviour.

networks, interactions and context within which people are generally embedded (Surowiecki, 2005). This raises important questions related to the effectiveness of CGE models based on neoclassical theoretical underpinnings to investigate those social impacts that are significantly determined by social interactions and processes (e.g. education, empowerment, health, intra-household income distribution). In other words, following the path of objectivity (namely a mechanistic observation of regularities) and value neutrality, neoclassical economists claim to provide "optimal solutions" from a societal point of view to environmental and development problems. But, in relation to these latter problems there is no value-free science, as environmental and development issues go much further beyond the limited monistic view of a single discipline (Söderbaum, 2000).

The general equilibrium assumption that is inherent to CGE models is also fragile and over-simplistic. A steady-state equilibrium may never be reached, as the society tends to always find itself in a never-ending process of change and disequilibrium. The general equilibrium assumption on which CGE models lay their foundations hence suddenly seems very unstable, as there is no theory to explain what may happen out of equilibrium and there is no reason to believe that equilibrium is achieved in the real world (Grassini, 2004).

Classical GE assumptions typically include perfect competition, full employment of resources and perfectly mobile factors of production. In addition, the general equilibrium theory behind CGE models assumes that there is complete information about all prices now and in the future, and that economic agents implicitly have unlimited computational abilities. Although some of these assumptions have been relaxed in recent and more advanced CGE models, further research needs to be undertaken in order to bring model specifications closer to realistic behavioural relationships, for example, those characterising transitional or developing economies Moreover, market clearing conditions and the GE rule that every source needs to find a sink (a factor cannot be employed in two different places, households cannot spend more than they earn, the society is a waste-free economy) represents a relatively strong reductionist view on the workings of the real economy. The CGE model builder tends to be satisfied with the choice of some specific functional forms and closure rules, and modifies the available representation of the real world instead of rejecting the model (Grassini, 2004).[22] In other words, specific functional forms or restrictions need to be employed in order to ensure a unique and stable

[22] CGE modelling studies have been criticised for their recourse to models characterised by internally inconsistent assumptions, and their choice of model structure, parameter values and functional forms that best serve their purpose (Panagariya and Duttagupta, 2001).

equilibrium, though the economic realism of these restrictions has often been overlooked (Ackerman, 2002). In addition, on the environmental side there is considerable research showing that ecological systems rarely exhibit equilibrium behaviour, which questions the general equilibrium idea and the hegemony of the neoclassical model of ecological price determination (Patterson et al, 2006).[23] This typically renders the CGE simulation approach often too stylised and rigid for sustainability impact analysis.

The problem of dynamic representation

CGE modelling often produces a static equilibrium, whereas an open society is grounded in instability and subject to dynamic disequilibrium forces (Soros, 2003). The assumption of a steady-state equilibrium becomes even more uncertain in the case of developing or transition economies that continue to undergo rapid and substantial changes (the so-called "transition" handicap outlined in Piazolo, 2001). CGE models focus on equilibrium positions, and are, consequently, unsuited to adequately investigate transitional adjustment paths (Barker, 2004).

Furthermore, though more recent developments in CGE modelling allow for the insertion of "dynamic" elements, these are limited in scope and provide an unsatisfactory description of dynamism within an economy. For instance, CGE models may account for capital accumulation effects but remain silent with respect to regulatory and institutional changes that an economy may need to undergo in order to be on the modelled or "desired" adjustment path. The dynamic representation in some CGE models that do incorporate pseudo-dynamic features is over-simplistic and merely extends the usual CGE snapshots of comparative statics to a series of annual snapshots based on artificially perfect macroeconomic stability (Ackerman, 2005). In other words, CGE models fail to adequately explain adjustment paths and what may happen during disequilibrium.

Other shortcomings

Other disadvantages that are particularly associated with the workings of CGE modelling in general include: the use of very complicated models and the simultaneous running of several policy scenarios that makes it difficult to identify the triggering factors and mechanisms leading to final outcomes; the borrowing of parameter estimates from other sources and hence difficult

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[23] Patterson et al (2006) argue against the general equilibrium assumptions of neoclassical ecological pricing methods and outline a new method for determining ecological prices in complex ecology-economy systems where non-equilibrium prices are more likely to prevail.

to validate or falsify in the traditional sense (econometric critique);[24] and a limited macro side that is based upon the money neutrality assumption and that typically fails to address monetary policies and the role of nominal variables (inflation, interest rates) in influencing economic outcomes.[25] Furthermore, several crucial limitations related to the appropriateness of CGE models to simulate policy reform and sustainable development issues, particularly pertaining to climate change, and the interactions between energy and output have been highlighted in Barker, Köhler and Villena (2002). These refer to: limited disaggregation of productive sectors and factors of production, high uncertainty of the assumed values of substitution elasticities between factors of production, and especially the very limited representation of technical progress.

The nature of CGE modelling and the underlying assumptions that it employs pose the risk of generalising and homogenising completely different economies and societies, thus failing to account for key country- and context-specific differences. For instance, with regard to the economic background of a nation, CGE modelling is weak in dealing with structural details and often starts from the assumption that economic agents are fully capable of responding to the incentives provided under the new policy change and hence act accordingly. Nonetheless, there may be a multitude of structural barriers and institutional impediments that constrain supply responsiveness, particularly in countries that continue to face important market dysfunctions.

Finally, with regard to the assessment of the social dimension of sustainable development, CGE models perform poorly, as also acknowledged in the Böhringer and Löschel (2006) study. Those that do evaluate social implications tend to focus on poverty impacts, usually employing simplistic poverty measurements (headcount index or the number of poor lifted out of poverty), and, to a lesser extent, on distributional concerns, without consideration for other major social issues such as education, health or justice. Moreover, CGE modelling typically works at high levels of aggregation and focus on representative agents, without special consideration to household heterogeneity and inter- or intra-household distributional concerns. Complementing general equilibrium work with detailed household modules, though still in its emerging phase, may provide valuable insights into spelling out micro-macro links and assessing distributional impacts. However, at the very least, the use of other techniques should be considered in

[24] CGE models derive the values for various crucial model parameters from mathematical manipulation (calibration), and typically on the basis of on one year's data, or are questionably borrowed from the literature, and, hence, are not estimated from statistical fittings of empirical data. They generally ignore the availability of rich sources of time series data and "do not model observations on the long-term processes of income growth, adjustment to price changes (such as responses to oil price shocks) or technological change" (Barker, 2004: 3).

[25] The zero homogeneity of demand functions coupled with the linear homogeneity of profits in prices implies that only relative prices affect consumer and producer behaviour, and that the absolute level of prices has no effect on equilibrium outcome (Shoven and Whalley, 1984).

conjunction or in parallel with CGE modelling tools, and the latter should not be seen as holding supremacy over other assessment methods, particularly when informing policy decision makers on the potential sustainability impacts.

5. Conclusions

The paper critically assessed the appropriateness of computable general equilibrium models to effectively provide consistent insights into the sustainability impacts of policy proposals. Though CGE models may render useful information on some individual, particularly economic aspects of policy appraisal and SIA studies, by design they are unlikely to perform well when it comes to integrated sustainability impact assessment, and particularly when assessing the environmental and social dimensions of sustainable development. The use of this approach as a main or "backbone" tool for assessing sustainability outcomes may result in inappropriate or even misleading results and policy suggestions. This is largely because of the often over-simplistic and unrealistic assumptions underlining general equilibrium theory, and the inherent nature of CGE models that allows only for a limited, often static (or at the most pseudo-dynamic) and mostly mis-represented view of the complex process of sustainable development.

Using CGE modelling as a "backbone" tool for integrated SIA may lead to the domination of an exclusively quantitative technique that heavily draws on a rather narrow view of economic realities, human behaviour and the interactions between economic, social and environmental dimensions of development. This may seriously infringe upon the basic values promoted by the SIA methodology, namely heterogeneity and the reliance of assessment work on both quantitative and qualitative approaches. It is important hence to understand the weaknesses of evaluating indicators of sustainability using CGE models. In other words, whilst acknowledging the strengths, advantages and potential of employing general equilibrium modelling techniques in evaluating certain aspects of sustainability, a certain degree of variety and "competing" assessment tools would be essential in rendering useful and integrated SIAs. CGE models may be useful particularly in the context for which they have been initially developed (e.g. the potential impact of fiscal or trade policy on factor allocation and sectoral outputs). However, the range of questions that they can answer pertaining to sustainable development and potential mitigating and enhancing policy measures is greatly limited.

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