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Workshop on linking CGE and TIMES models: lessons learned and next steps

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OCCASIONAL PAPER

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Workshop on linking CGE and TIMES models: lessons learned and next steps[1]

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1. Introduction and overview

The Centre for Energy Policy (CEP) and the Fraser of Allander Institute (FAI), at the University of Strathclyde organised a full day workshop (8th November 2016) dedicated to the topic of potential links between multi-sector computable general equilibrium (CGE) economic system model and The Integrated MARKAL-EFOM[2] System (TIMES) energy system models. The workshop brought together experts in energy system and economic modelling to explore the challenges and opportunities of linking these types of model more closely. The purpose of this document is to outline key outcomes of the workshop. These can be summarised as follows:

- **What is TIMES?** TIMES is an energy system model that identifies the most cost-effective way of delivering energy services given a set of constraints. This model is widely used by governments, such as the Scottish Government, the UK Government and the European Commission for the analysis of policy scenarios.
- **What is a CGE model?** A CGE model is an economic model that considers the interactions among different economic agents, such as firms, households and governments, within a certain economy, and identifies how these respond to a given disturbance to the economy. Some CGE models are tailored for the analysis of energy

[1] The workshop was funded as part of an EPSRC project (EPSRC Grant Ref. EP/M00760X/1) and also supported by ClimateXChange.
[2] MARKAL is the acronym of Market Allocation and EFOM is Energy Flow Optimisation Model.

and environmental policies. These models are again widely used by governments, such as the Scottish and UK governments, and the European Commission.

- **Why might we want to link CGE and TIMES models?** Economic system models such as CGE and energy system models such as TIMES have different characteristics and they look at energy policy related questions from different viewpoints. TIMES provides a better treatment of the technical characteristics of energy systems but typically takes economic variables such as GDP and energy service demand as given. CGE models provide a very detailed treatment of the economy but usually make simple assumptions about how energy suppliers behave. The notion behind linking the two is simply that economic information from the CGE could be used to inform TIMES. Similarly, energy systems constraints could improve the treatment of energy suppliers' behaviour in CGE models.
- **What type of links might be established?** There are two main types of links. A 'soft-link', where the results of each model are used to inform the other, essentially iterating the two models without modifying the structure of either. This could include for example informing TIMES with GDP or energy service demand information from a CGE model or using information on energy supply capacity decisions from TIMES to inform the CGE model. The other type is a 'hard-link', which means that the two models are integrated, essentially forming a new 'super-model' which includes the characteristics of both CGE and TIMES. However other types of hybrid links, where one model is augmented with elements of the other, are also possible.
- **What progress has been made so far?** There is limited experience in linking CGE and TIMES models. A number of research teams has attempted to soft-link very simple economic models and TIMES, including hard-linking high level macroeconomic (rather than multi-sectoral CGE) models and TIMES. Members of such teams shared their experience during the workshop. In Scotland, discussions over potentially linking the energy and economic system models have begun fairly recently, partly due to the quite recent adoption of the Scottish TIMES model.
- **What should the next steps be?** At present, the Scottish Government is keen to explore whether and how the Scottish TIMES model could be linked with the Scottish CGE model. The Centre for Energy Policy (CEP) along with the Fraser of Allander Institute (FAI) and the Department of Electronic and Electrical Engineering (EEE) at the University of Strathclyde have a key role in this process through two ClimateXChange fellowships that CEP/FAI/EEE members are working collaboratively on. However, before any linked CGE-TIMES framework is used as part of the decision making process it is necessary to consider the pros and cons of different linkage possibilities with the aim of informing discussion with the Scottish Government.

2. Motivation for the workshop

Recent academic and policy discussions commonly identify the need to increase the interaction between economic and energy systems models to provide better information to policy makers and practitioners (Fortes et al. 2014, Bye et al. 2016, Glynn et al. 2015a), also the IEA has run workshops exploring methodologies linking energy systems and economic models (IEA-ETSAP, 2014). Energy systems models such as TIMES consist of a very detailed treatment of the energy system, which is used to identify the cost-minimising combination of technologies that provides a set of energy services according to certain user defined constraints (e.g. GHG emission limits). However, they assume that some key economic variables such as final demand for energy, GDP and prices of imports are determined exogenously (i.e. outside the model, so that they are fixed therein). On the other hand CGE models provide a sophisticated treatment of economic systems and capture the economic impact of disturbances in different energy uses within the economy, including the response of energy suppliers to changing demand. However, they typically have limited capacity to treat specific technologies used to provide energy services.

For this reason a number of research projects have attempted (or are still in the process of) implementing some kind of link between frameworks, such as CGE and TIMES, and assessing the implications of such links (Arndt et al., 2016; Bye et al., 2016; Fortes et al., 2013, 2014; Glynn et al., 2015a, 2015b). These links are primarily of two types; soft-links and hard-links (Labriet et al., 2015).

A soft-link implies using outcomes from one model to inform the other, commonly in an iterative way. For instance an energy system model can inform the specifications of the energy supply curve in the economic model. In turn, a detailed economic model could update the exogenous variables (such as energy demands, wage and capital rates, changes in GDP pathways etc.) of the energy systems model.

A hard-link implies integrating the two types of models to solve them simultaneously or to create a third ‘super model’ including the main characteristics of both models. However, in this case, implementation of hard-links can be limited by technical difficulties (e.g. limited access to the model code) and computational limits (Labriet et al., 2015). Moreover, hard-linking increases the possibility that models behave as a ‘black box’ whose workings are very difficult to determine and whose results are difficult to explain.

In Scotland the conversation around potentially linking/interacting TIMES and CGE models is becoming increasingly important. In 2015, the devolved Scottish Government adopted a TIMES model for Scotland. At the same time, it has been using an economic CGE model based on

that developed by the University of Strathclyde (AMOS)[3], to inform policy decisions, and had developed an interest in using an energy-economy-environment variant of the CGE model (AMOSENVI), reflected in past ClimateXChange activities[4]. For this reason, from the point when the Scottish TIMES model has been commissioned, there has been an expressed interest to explore the potential to link, either via soft-link or full-integration, the CGE and TIMES models. The CEP, FAI and EEE of the University of Strathclyde are playing a key role in this process, particularly via the two ClimateXChange fellowships mentioned above.

3. The Workshop

3.1 Overview of the day

The workshop (held on 8th November 2016 at the Technology and Innovation Centre at the University of Strathclyde and sponsored by EPSRC and ClimateXChange) hosted academics and practitioners who have been actively engaged in projects exploring model linkages, and more generally those who are interested in how economic and energy systems interact. The aim of the workshop was for the participants to benefit from their accumulated experience in order to shed light on a number of issues associated with potentially linking CGE and TIMES models. The attendees came from different UK-based and international institutions such as Statistics Norway, the Scottish Government, Carbon Capture and Storage Association, the Parliamentary Office of Science and Technology, University College London, the University of Cork, in addition to the University of Strathclyde.

The workshop was organised in three parts. In the first part, Professor Karen Turner, Director of the Centre for Energy Policy, University of Strathclyde, Colin MacBean, Office Chief Economic Advisor of the Scottish Government, and Dr Grant Allan, Fraser of Allander Institute, introduced the topic and its policy context before offering their views on the current situation with economy-wide and energy system modelling in Scotland and the reasons why we may want to link more generally.

In three separate presentations in the second part of the workshop, Taran Fæhn from SSB Norway, Brian Ó Gallachóir from the University of Cork and Matt Winning from University College London (UCL), shared their experiences from working with TIMES and/or CGE, or other economic models, with the audience. The attendees had the opportunity to interact with the presenters, and to get a better insight into the practical and theoretical challenges of such projects.

[3] AMOS is the acronym of A Model Of Scotland (Harrigan et al., 1991). AMOSENVI is a variant of the model that incorporates considerable detail and the energy system and includes environmental impacts.
[4] See e.g. Allan et al (2014) for an analysis of a Scottish-specific carbon tax.

The third and final part was organised in three different discussion groups. Each group had a specific topic assigned, along with key topics/questions to be discussed. The aim was to generate useful debates, concerning linking CGE and TIMES models, with potentially wider transferability to similar model linking work. The discussion groups addressed the following questions:

- Group 1: "What are the common objectives in linking CGE and TIMES?"
- Group 2: "Current experience of linking CGE and TIMES – What are the recommendations on approach and timing/sequencing of changes?"
- Group 3: "Practical example: can the interaction between CGE and TIMES inform the analysis of Carbon Capture and Storage (CCS) technologies?"

The central themes arising from the different topic groups are summarised below.

3.2 The breakout sessions

3.2.1 What are the objectives of establishing links between CGE and TIMES models?

Links between CGE and TIMES models can be implemented to serve different objectives, and vary from user to user. For instance, one of the current goals of the Scottish Government is to explore the possibility of linking the two models in order to consider how changes in the economy may impact actions in the energy system and vice versa. In this respect the Centre for Energy Policy and its partners at the Fraser of Allander Institute and the department of Electronic and Electrical Engineering at the University of Strathclyde play a key role through two ClimateXChange fellows who are investigating whether and how this would be beneficial for the climate change/energy policy making process. The objective of the Scottish Government is purely exploratory and there is no guarantee that any link between the two models will be featured in the decision making process.

During the discussion, **two main points** were underlined. The **first point** is **what type of policy each of these models can inform**. In general, it is recognised that CGE and TIMES address different questions. This is not surprising, as the two models are designed with two distinct objectives in mind. However, the real challenge is to identify which areas of a policy question are better informed with one model or the other, and the additional insight that may be gained by looking at both and/or having them interact with one another. That is, when links between the two models are created, it is fundamental to demonstrate the added benefits of obtaining information from the linked models.

The **second point** is to understand **how these models can help to inform the analysis of wider policy objectives that are not purely energy related,** for example, economic growth and the distribution of income. By their very nature, CGE models are able to capture a wider set of economic interactions and ramifications of a given energy policy or market development.

However, the use of bottom-up information from TIMES models could enhance the quality of the CGE analysis of economy-wide implications of energy policy by introducing more detailed and realistic treatment of energy systems.

In general, given the recognised interdependence of energy-economy-environment issues, the role of energy policy should be analysed in the context of the wider set of policy aims, objectives and instruments of a given region or country. There was consensus amongst the participants of Breakout session 1 that a holistic approach to energy policy analysis is preferred and that it is not really desirable to look at energy policy issues in complete isolation, since this can generate misleading implications for policy. For example, if the interdependences of the energy and economic subsystems are not captured, "rebound effects" reflected in a less than proportional change in energy demands, are simply precluded by assumption.

However, the complexity of the policies, and therefore the questions asked, could act as a barrier to the implementation of relevant analysis using these models. This is due to the fact that policy constraints can be difficult to include in the models. For instance, the lack of a government sector in TIMES makes it especially hard to take account of taxation issues. With that in mind it is probably not realistic to expect that a single model could be the tool to answer all the energy policy questions.

Different scenarios would need to be considered using different models, and a range of other analytical techniques (i.e. not limited to CGE and TIMES) should be considered, essentially forming a diversified portfolio of available policy analysis tools that serve complex informational requirements.

3.2.2 What current experience do participants have of linking CGE and TIMES models?

In these sessions three main issues were explored. These are benefits of linking CGE and TIMES; linking techniques and limitations; and data issues.

Benefits of linking CGE and TIMES models

Two main benefits of linking CGE with TIMES emerged from the breakout discussions. The **first benefit** is **the ability to assess the technical feasibility of the outcomes generated by CGE simulations using TIMES** and, vice versa, **to verify the economic feasibility of the TIMES simulations using CGE**.

The **second benefit** is to **overcome some of the identified limitations of each of the models**. For example, the model structure of TIMES includes 'exports' as an exogenous variable (i.e. determined outside the model). Hence, it is not possible to estimate through TIMES alone the impact on exports which may result from the introduction and decommissioning of different energy technologies. However, exports are known to be driven

by changes in prices and strongly correlated to GDP and, thus, to important socio-economic figures such as the unemployment rate.

To overcome these limitations, the use of an economic model is necessary to consider how prices and export demand may be affected by changes in the energy system and how this, in time, may feed back to affect the functioning of the energy system. On the other hand, a key assumption that is generally made when using an economic model such as CGE is that capital and investment are adjusting smoothly over time in responses to changes in economic circumstances and how these feed back on profitability and returns to capital. Using TIMES, it may be possible to obtain a supply curve for energy sectors that would be more realistic in terms of the adjustment of capital and investments over time.

Linking techniques and limitations

A number of research teams have attempted different types of links between economic models (not limited to CGE) and TIMES models (Arndt et al., 2016; Bye et al., 2016; Fortes et al., 2013, 2014; Glynn et al., 2015a, 2015b). This typically involves soft-links where the simulation results of one are used to inform the other. At the present time experiences of hard-links include the TIMES MACRO plus developed at UCL, which links TIMES with a traditional macroeconomic growth model, rather than (and lacking the sectoral and individual market detail of) a CGE model.[5] This experience was shared with the attendees of the workshop highlighting ways in which the models can be linked, as well as data and software requirements and potential confidentiality issues.

In general the most straightforward way proposed to link the two models was to share information between them and iterate until the outcomes converge (i.e. a form of soft-linking). This was also recognised as a first step towards establishing links between CGE and TIMES more generally. When using this approach it is important that the convergence is achieved without sacrificing too much of the specialisation of either model.

The other proposed approach was to include the outputs of one model into the other as a new feature, essentially augmenting each model. However, some scepticism was expressed by the participants of this breakout session as to whether an augmentation approach would be possible for all cases/technologies. For instance, CGE models consider user choice better than TIMES. That is, end-user choice in TIMES is based solely on the economic costs of energy options, while other elements, such as the price of other non-energy goods and services, the impact of changing economic circumstances on wages etc., are overlooked. Relying solely on the TIMES approach can therefore produce dramatic technology changes, which might seem unrealistic. Typically this is avoided in TIMES modelling through the addition of artificial constraints (limiting technology adoption). While this may be interpreted as an attempt to better

[5] For details see https://www.ucl.ac.uk/energy-models/models/times-macro-plus

represent consumer choice, they are imposed by the model user and reflect his/her judgements about feasible technology changes. These constraints may be based on assumptions that might bias the model outcomes. Accordingly, interpretation of the model simulation results may become problematic.

In considering an augmentation approach, there is also a practical **limitation** in terms of the solution procedure. Any link between CGE and TIMES would be implemented through the use of relevant software. In the case of CGE, the Generic Algebraic Modelling System (GAMS) is the most commonly used software package, whereas for TIMES the Versatile Data Analyst (VEDA) is primarily used as user interface linked to GAMS. However, TIMES source codes are typically not available to the user and this limits the extent to which hard-links can be created.

Data issues

A major limitation when working with CGE and TIMES is the huge amount of data required. **Three main data related issues** were identified.

The first is compatibility of data. Due to the different nature of the two models they utilise different datasets, both in terms of aggregation and means of reporting the information. CGE for instance is calibrated using a Social Accounting Matrix (SAM) which is derived from, but augments, national or regional Input-Output (IO) tables. This involves data reported in monetary units, with some degree of industry aggregation over energy supply and use (given that IO data are designed to focus on the economic system more generally). On the other hand, the TIMES calibration dataset for the energy system is usually disaggregated by technology and the data are reported in physical units of energy. It can be seen then that the calibration datasets have significant differences and there is some uncertainty on whether a clear mapping between the two dataset is achievable.

The second is the regular availability of data. It is a known issue that economic IO tables in particular require significant amount of time to be compiled and published, so that there is usually a time lag of a few years in reporting. This is a factor that could influence how often the two models could be updated. However, in the case of Scotland, updated data are published more regularly than is the case in many regions/countries. This means that it is possible to calibrate the Scottish CGE and TIMES models frequently. Nonetheless, these uncertainties on the data front reinforce the opinion that it may be preferable to run the models in a parallel fashion, using the appropriate datasets for each one, before attempting a closer integration.

The third is data confidentiality. Teams working on integrating CGE and TIMES models may be based on different institutions (or different departments of the same institution) and the communication between the teams can create the possibility of confidentiality breaches. On the other hand, progress cannot be made if researchers are denied access to the data. Thus, it is necessary to identify ways in which the researchers involved in developing the link between

CGE and TIMES can have access to all the required data to conduct their research, while at the same time minimising the risk for confidentiality breaches.

The introduction of strict protocols that would help avoid such breaches, and making sure that all involved parties adhere to them, is thus crucially important. Moreover, during the breakout discussions it was proposed that internships could be used as a tool to efficiently diminish the potential of sensitive data being revealed. The idea is that in this way the data do not "leave the building". So the intern uses the data/models for the research on the other institute, without openly sharing the model/data with the other institute.

3.2.3 Introducing a new technology: A practical CCS example

Part of the challenge faced when considering future energy policies/strategy is the need to be able to properly include both the costs and benefits of activities and technologies that are currently under development and to do so at both micro/private and macro/societal level. This aspect creates uncertainties, especially when the new technologies lead to the creation of new markets where, by definition, there is no prior experience/expertise on how these markets might operate. Carbon Capture and Storage (CCS), alongside the necessary CCS transport infrastructure, is one such technology. "Atmospheric cleaning" is essentially a new market that bears little resemblance to any existing pollution cleaning market (where there are, in any case, few if any examples of perfectly functioning markets) and CCS is a major technology in both this market and the wider economy. At the same time, the ambitious carbon emissions targets set by both the UK and Scotland alike mean that it is essential for CCS technologies to be developed and deployed in the near future. Thus, for the technology to be deployed it is likely to be crucial that government support is granted in this pre-market state: for this to be the case it is necessary to be in a position to determine the 'value' of CCS against other competing technologies and/or policies.

The breakout discussions considered whether it would also be useful to identify any potential comparative advantages of deploying CCS in Scotland (or the UK as a whole) first, rather than allowing for the technology to advance and be fully commercialised elsewhere in the world first. Unfortunately, as highlighted by the National Audit Report[6], the commercialisation competition that took place in the UK aimed to deliver CCS before it was absolutely necessary to meet UK's climate change targets. HM Treasury considered the introduction of CCS at this point as not being cost-effective, raising "concerns about the merits of the carbon capture and storage competition given fiscal constrains", hence leading to the cancellation of the competition.

[6] The HM Treasury concerns were first reflected in the 'Sustainability in the spending review' published on July 2016 and can be found here: https://www.nao.org.uk/wp-content/uploads/2016/07/Sustainability-in-the-Spending-Review.pdf

Thus, the question that was raised during the wider workshop and this breakout session was whether linked CGE and TIMES models may bring advantages to the process of estimating the value of CCS, as well as the economic 'service' values of the necessary transport and storage infrastructure which form a core part of CCS, alongside the required capture at industry/power sector level.

The group discussed how it is possible to use CGE and TIMES to look at the same questions from different perspectives. However, to have a linked model, the inputs to and the conclusions drawn by each of the models need to be compatible. At this point in time, the differences and similarities of the simulation results obtained by both models are quite complex in nature, requiring expert modellers to be able to decipher the lessons that can be learned by those results. Furthermore, as discussed above there are data issues/inconsistencies that present significant barriers to the fuller integration of CGE and TIMES.

Especially in the case of Scotland and a technology like CCS it is crucial to define the regional boundaries for both models so that it is possible to identify among others the regional capacity in terms of the potential to capture carbon and to transport and store it. Moreover, given the role of CCS as a technology in the TIMES system, it is important properly to define resources and energy vectors so that their differences are clear. These definitions will then aid in clarifying how to incorporate the different elements of CCS within the economic system, including but not limited to, modelling the supply chains of energy sectors.

Both CGE and TIMES models have a significant contribution to make in studying CCS as a new low carbon solution. CGE has a specific role to play in enabling the study of how newly introduced CCS market(s) might behave. On the other hand, TIMES helps to understand CCS as new technology and how it interacts with existing technologies operating in the sector. However, there was consensus that, at the moment, a linked CGE-TIMES model would probably complicate matters rather than provide clarity due to the many differences between the two modelling approaches. Existing uncertainties regarding the convergence of results obtained by each model and data related issues, indicate that there are more steps to be taken before the two models can be used together. Therefore, it was agreed that linked CGE-TIMES modelling would not be the preferable first step in studying CCS. For a new technology like this it is crucial to explore incentives and policies that would boost the uptake of CCS by industries and study the economic implications of extending national accounts to include CCS. With these in mind, a CGE approach, which incorporates markets, might be preferable. However, the point of using CCS is ultimately to reduce CO_2 emissions. This evaluation can be better captured using TIMES which is specifically designed to capture operation outcomes of specific technologies.

4. General conclusions and ways forward

Some overarching conclusions emerged from the three breakout groups. All the participants, in one way or another, have raised the issue that in order to attempt a link between CGE and TIMES it is necessary, beforehand, to be in a position to get compatible and comparable answers to the same questions from each model. Currently, there is some degree of uncertainty on whether this is possible, while ensuring that we make the least amount of compromises possible. Especially in the cases where the objective is a full integration, a hard-link, between the two models, it might be necessary for the two models to be fitted/trained to work with the same data and this task alone will require solving some already identified data issues, even though in the case of Scotland data availability is considered to be quite good.

A recurring point during the workshop was the added value that may be gained by linking CGE and TIMES. There was consensus amongst the attendees that a link between the two models would enhance the quality of the simulation results obtained by both. As has been pointed out earlier in this paper, two members of the Centre for Energy Policy (working with the Fraser of Allander Institute and the department of Electronic and Electrical Engineering at the University of Strathclyde) are exploring the possibility and the added benefits of a link between the Scottish CGE and TIMES models through two ClimateXChange fellowships. This was identified as an important step for the Scottish Government to decide on whether a linked Scottish CGE-TIMES would be used to inform future energy policy.

However, as discussed in the example of the introduction of CCS, the TIMES model, by itself, can be successfully used to conduct meaningful analysis, and a linked CGE-TIMES model might not be necessary for all cases, especially when the use of a linked model might actually complicate rather than add clarity to the topic under study (due to the added complexity of managing two models). Still a well-designed soft-link between CGE and TIMES, where the answers of the two models to similar questions are compatible, has the potential to provide additional insight (which could not be possible by solely using one model) on how newly introduced technologies or policy changes might affect the activity of the already established actors in the energy system.

It is very important to highlight though that no single model, or any link of models, can provide the basis for gaining definitive answers to all our policy questions. A range of appropriate modelling and other analytical techniques are required, each focusing and specialising on different aspects/viewpoints relevant to the energy and/or other policy under consideration.

In practice, even using the two models separately is already a very challenging task, and time and resources should be used to improve the quality of each model as well as the understanding of the models' results and policy implications. Those remarks by no means indicate that a link between CGE and TIMES should be discouraged. After all, as already indicated the attendees

of the workshop could see the merits of such a link. A soft-link had been suggested as an appropriate first step in linking economic and energy systems models. Then, driven by the lessons learned through a soft-link, we will be in a position to consider, with a higher degree of confidence, whether a hard-link between the models would be something that merits the investment in.

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