

Bottom-up and top-down modelling approach

Abstract:

IntERACT model consist of top down general equilibrium model which is linked to a technical bottom-up partial equilibrium covering the energy system. The terms “top-down” and “bottom-up” used here can be seen as short hand for aggregate and disaggregated models. Models in the first category emphasize economy-wide features, while those in the second category focus on sectorial and technological details. Each model type has its comparative strengths and weaknesses, which will be discussed in closer detail in this working paper. The overall conclusion is that coupling the bottom-up and top-down model by means of soft-linking is seen as the best way to build on the strength of each modelling approach.

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Striking the right balance between top-down and bottom-up modelling approaches

The ideal situation for policy makers when designing energy policy is to have access to a model that can evaluate the effect of economy-wide policies working in concert with technology- and fuel-specific measures, and that incorporate regulations as well as market-based policies (Jaccard, 2009).

Such an ideal model would need to satisfy at least three criteria:

- i. Technological explicitness. A thorough representation of potential and realised technological changes,
- ii. Behavioural realism. A microeconomic foundation for accounting of how businesses and firms will decide among future technology options, given utility maximisation and profit maximisation, and
- iii. General equilibrium feedbacks. The accounting of macroeconomic feedbacks in reflecting how changes agent's choices impact economy wide.

Figure 1 below illustrates how the bottom-up approach and top-down approach perform against these three criteria. Conventional bottom-up models do well in terms of technological explicitness, but less well in terms of the other two attributes. Whereas conventional top-down models do well in terms of microeconomic realism and also in terms of macroeconomic feedbacks if they are general equilibrium models. However, they lack technological explicitness, making them ineffective for assessing the full range of policies that policy makers may wish to consider.

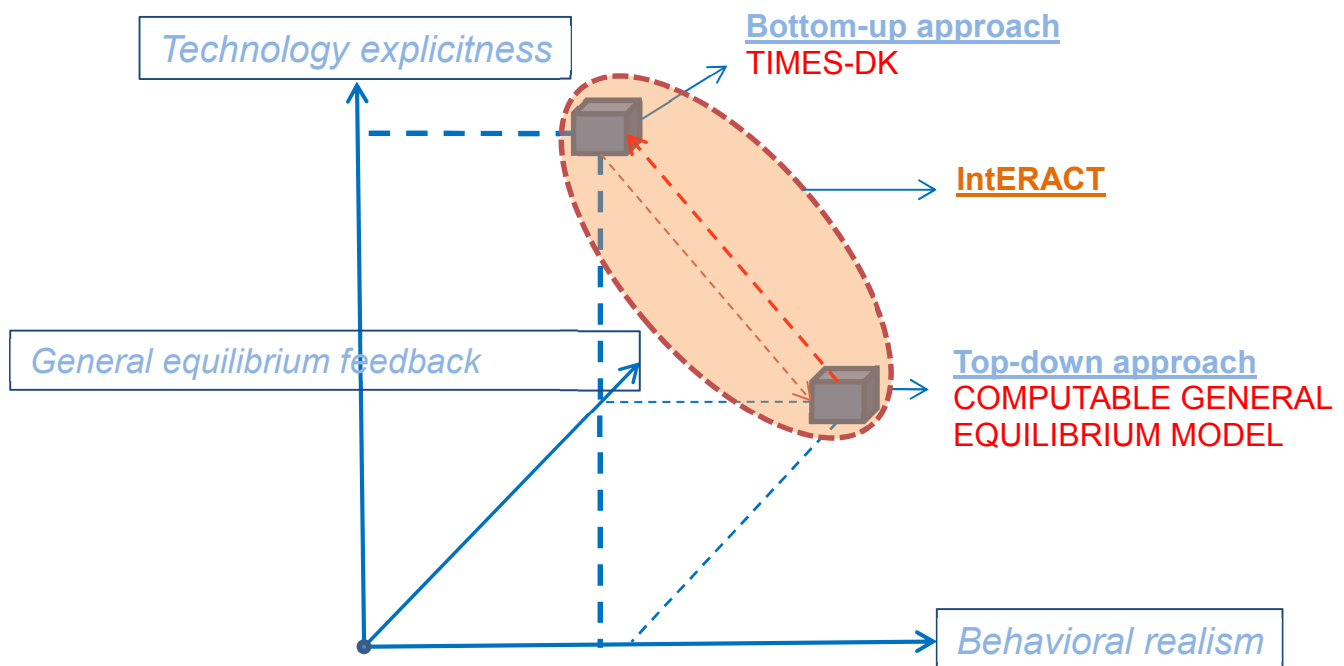


Figure 1 Criteria for comparing energy-economy models
Note: Adapted from Jaccard (2009).

This working paper elaborates on the comparative strengths and weaknesses of top-down and bottom-up models. Furthermore, a brief discussion is presented on the current international

efforts to link these two modelling approaches, in order to preserve the strengths while compensating for the weaknesses of each approach.

For the Danish case, the modelling approach taken in the IntERACT project is to “soft link” a bottom-up model of the Danish energy system – TIMES-DK - with a general equilibrium model describing the Danish economy, thus bridging the gap between the two fundamental different modelling approaches.

Strengths and weaknesses of top-down and bottom-up approach

According to Sue Wing (2008):

"The disparities in the structure and scope of bottom-up and top-down models imply that each has a comparative advantage in addressing complementary subsets of the research questions which arise in energy and climate policy analysis".

For Bottom-up models the comparative strength lies in their ability to investigate the impacts of energy policy on the portfolio of technologies that make up the supply and demand components of the energy system, in order to identify low-cost opportunities or design technology-based taxes, subsidies or standards. The comparative strength of the top-down model is its ability to assess the macroeconomic costs of a policy shock and its economy-wide feedbacks on prices, commodity and factor substitution, income and economic welfare.

The strength of each modelling approach is also reflected as a mirror image of their respective weaknesses. The incapacity of the typical CGE models to cope with a detailed energy sector structure is often cited as the main drawback of this type of model (Frei et al., 2003). If capital stocks are implemented as a homogenous factor of production, i.e. without specification according to technologies, the CGE model will not be able to represent energy supply or end-use technologies explicitly. Different technologies within a sector may be represented as competing subsectors, but structural change, or the “natural” emerging and phasing out of technologies, is incompatible with the neoclassical concept of smooth (i.e. differentiable) substitution. The complete phasing out of a technology or the complete replacement of an old technology by emerging new technologies correspond to singularities in the sector aggregate production function and are therefore in contradiction with smooth substitution. Nevertheless, in reality and on a long-term scale, old technologies prove to be too expensive to continue to be operated and are abandoned while new technologies become competitive and gain market shares. A further, related, criticism about the CGE approach is the lack of empirical evidence on elasticities determining technological evolution under energy policy constraints. The pertinence of this criticism is illustrated by the sensitivity of empirical assessment of quantitative effects on key elasticities. It is these weaknesses of CGE models that bottom-up models are much better equipped to deal with. Bottom-up or partial (equilibrium) activity analysis models replace the need for these elasticities and technological choices by an accurate description of the technological system and its functioning (Frei et al., 2003).

In same vein technical bottom-up models, by reason of scope and structure, are criticized for excluding many economic costs and behavioural effects. At a general level, technologies, markets and policies interact, but the typical bottom-up model does not take into account the

simultaneity and scale of issues involved. Bottom-up analyses typically ignore the costs of taxes and other policies, i.e. economic wide distortionary effects. They may also have a tendency to ignore differences in financing costs which may differ quite substantially across households, firms and government. Then, and partly related, there is an ongoing discussion of using appropriate discount rates in the bottom-up models. Private discount rates are often much higher than societal discount rates applied in bottom-up models. Furthermore, the bottom-up approach is often based on case studies of small-scale implementations of a set of technologies. It is quite another issue than large-scale deployment or adaptation of new technologies. For example, the large-scale deployment of technologies is likely to affect emissions intensities, energy prices, etc. These are typically assumed to be constant in bottom-up studies but should be part of the analysis. Finally, bottom-up models rarely have economic resource constraints on the use of labour, capital and other intermediate inputs, whereas accounting of resource use within the bottom-up model's paradigm is usually done (i.e. availability of gas and oil). These weaknesses the modelling of deployment and choice of technologies are often covered through the smooth substitution in CGE models and the resource use questions are fully accounted for by the very nature of general equilibrium.

Linking top-down and bottom-up models

A number of researchers are developing “hybrid” models that aim at combining the technological explicitness of bottom-up models with the economic richness of top-down models, thereby seeking to compensate for the limitations of one approach or the other. To simplify, hybrid models can be based on either a soft-linking or a hard-linking approach.

Soft-linking attempts to align top-down and bottom-up models in order to keep their respective strengths. Soft-linking signifies that the macroeconomic top-down model and the energy system bottom-up models are linking through an iterative process, where convergence of central parameters are satisfied (e.g. price and quantity parameters) (Kumbaroğlu & Madlener, 2003).

Hard-linking on the other hand implies that the properties of the bottom-up and top-down models are integrated into a single model that is solved in a simultaneous optimization. This often implies a simplified description of either bottom-up or top-down aspect in the integrated the model.

Böhringer and Rutherford (2009) classify hybrid modelling according to the following categories:

- i. Coupling of existing large-scale bottom-up and top-down models
- ii. Combining one model type with a “reduced form” representation of the other.
- iii. Combining bottom-up and top-down characteristics directly through the specification of market equilibrium models as mixed complementarity problems

Where Böhringer and Rutherford (2009) emphasise that each approach have significant drawbacks: When soft-linking across bottom-up and top-down models the differences in model setup and accounting methods could potentially cause problems in convergence when trying to align them using iterative procedures. The reduced form approach simplifies one model too badly. While, the integrated mixed complimentary approach may also suffer from

complexity and dimensionality issues thus imposing significant limitations on its practical application.

The approach in the IntERACT model is coupling of large scale models using soft-linking, but with the important caveat that both models are developed from scratch. This allows for the development to take into account appropriate considerations of limitation and requirements of each model. In addition, the Swedish experience of linking the TIMES setup with a static CGE model shows that convergence can be reached by few iterations when linking these specific types of models (CGE and TIMES) (cf. Berg et al. 2012).

Further on the IntERACT model setup

Macroeconomic models often use energy goods directly in the modelling of energy use, e.g. using specification of specific goods such as oil, gas or electricity. This applies to models such as the EMMA model and the international GTAP model. The approach is useful when considering incremental or marginal changes to the economy or small changes to the energy system. However, such an approach is not well suited when analysing large scale technological changes such as the case of a complete green transition or phase-out of fossil fuels.

The concept of energy services offers a solution in this situation. Energy services are the actual service that the use of energy leads to. The burning of gasoline in a car is used for moving the car from point A to B. The energy service is the transportation of the vehicle. Similarly, a firm may use gas for heating water to high temperatures. It is the heated water that is the service. Significantly, these services do not explicitly require the burning of gasoline or gas, but could be supplied by other technologies that use other energy types. For example by using an electric vehicle or burning biomass to heat water. But the relevant economic issue is what the service costs (all included, i.e. investment and running costs). In the case of a large technological transition, the concept of energy services is more robust for the economic modelling. The demands for comfortable room temperature, lightning, transport services and process energy are basic needs of the economy, and it is the impact of the relative costs of these that have significant influence on economic behaviour.

Energy services as the main energy abstraction in the economic top-down model

The premise in the IntERACT model is that agents make economic decision based on the (relative) prices of energy services, while the specific fuel use and the specific technology applied in order to obtain the energy service is secondary. I.e. economic utility or revenue is not derived from the amount of PJ of fuel consumed, but rather from the energy services the fuel actual delivers. To be precise, agents maximise profit and utility using the costs of the energy service (relative prices as usual).

So, for the top-down model in IntERACT, demand for energy is a derived demand. In the production of goods and services as well as in the composition of utility, energy is an input to provide a set of energy services, such as heating, cooking, lighting, transportation. For firms energy services could be melting, casting or pumping.

By using energy services like this, the economic top-down model creates an abstraction of energy and in a sense reduces the role of exact technologies. Indeed the top-down model does

not make any technological choices to obtain a given amount of energy services; it is the bottom-up model that deals with technology. I.e. for the economic agent's point of view: it does not matter how a room is heated, but it matters how much it costs relative to inputs in production or goods in the utility bundle.

Energy services are the crux of linking bottom-up and top-down

In order for the economic top-down model to base the optimisation on energy services, the bottom-up model is used to describe how energy services are constructed. In the bottom-up model (TIMES-DK) all energy supplies and demands for energy services are depicted, and these are matched to energy service demands on the basis of technology costs and technical characteristics. Technologies are selected by comparison of life-cycle costs of alternative investments.

It is TIMES-DK – the technical model – that optimizes how the energy and technologies should be chosen in order to satisfy demands for energy service given from the top-down model. At a given demand for an energy service, TIMES-DK finds the most cost efficient way of delivering these services. The composition of the energy system is basically optimized from three types of information: prices of fuels, data for technology and a range of other restrictions, e.g. regulation slow uptake in technology or policy targets. The output from TIMES-DK consists of a vector of prices for energy services, but also includes forecasts on investment requirements in the energy system at that given supply of energy. The investment costs are based on available technology catalogues from national and international sources.

It should be stressed the TIMES-DK in IntERACT will have imposed constraints in technological change or deployment of new technologies. This includes transition costs as well as slowdown in adaption of new technology (even though it can be least cost from a technological point of view, real world adaptation might be slower). This is also done in order not to have bang-bang changes in the use of technology, e.g. a complete change of all vehicles to electrical vehicles in the transport sector.

The information on changes in prices and quantities of energy services, fuel mix and investment profiles are fed to the top-down CGE model. And given these, the CGE model can determine new optimum of utility maximization and profit maximization under general equilibrium.

In turn, the CGE model may find that at the given prices of energy service demand might change, thus it sends information back to the TIMES-DK model on the revised demands. This process continues iteratively until a satisfactory convergence is achieved.

Beside energy services a number of other data needs to be exchanged between the top down model and the bottom-up model, e.g. use of other intermediates, labour, capital and capital costs. These will be discussed in closer detail in later working papers.

For a further discussion and example of soft and hard-linking, there has been work carried out on linking the TIMES-Sweden model with the CGE model EMEC.¹ (Berg et al. 2012). The main findings from the linking of the models show the following:

- Provides a consistent picture of the economy and energy system.
- The theoretical basis for the macroeconomic structure and economic behaviour is almost the same.
- The technical level of detail remains.
- Technology development is described better in comparison with a general equilibrium model.
- Provides a transparent process in general and specifically on assumptions about demand for energy services
- Opens up new and improved opportunities to study the policy package current regulation and taxes.

¹Available in Swedish here: http://www.konj.se/download/18.11e05f6313b817f634f561/Specialstudie_32.pdf

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