Economic Modelling 51 (2015) 38–52

Contents lists available at ScienceDirect

Economic Modelling

journal homepage: www.elsevier.com/locate/ecmod

The sensitivity of climate-economy CGE models to energy-related elasticity parameters: Implications for climate policy design

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ARTICLE INFO

Article history:
Accepted 21 July 2015
Available online xxxx

Keywords:
Sensitivity analysis
Dynamic CGE model
Elasticity of substitution
Climate policy
Energy sector

ABSTRACT

A dynamic climate-economy CGE model based on the GTAP framework is used to analyse how sensitive simulation results are to alternative values assumed by several types of elasticity of substitution in energy-related linkages. Input substitutability in the production function is also tested for the relationship between capital and energy in different manufacturing sectors. The simulation exercise reveals that the model produces highly differentiated results when different sets of elasticity parameters are adopted. As a general result, lower substitutability values correspond to a reduction in the flexibility of energy substitution possibilities, making carbon abatement efforts more expensive. Moreover, this restriction generates changes in the distribution of costs associated with abatement efforts across regions. This brings to severe implications on international competitiveness especially for energy-intensive industrial sectors. The direct implication derived from this work is that in order to use CGE models to assess the amount and distribution of mitigation costs and to inform the international community involved in discussing the feasibility of climate policies, the use of empirically estimated behavioural parameters at the highest possible disaggregation level is highly recommended.

1. Introduction

The impact of climate mitigation policies on economic activity is a longstanding controversial issue still highly debated by the international literature. Given the global scope of climate policies, a crucial aspect to carefully account for is the regional distribution of mitigation costs. This concern justifies the assessment of climate change costs by applying several model types which differ in purpose and perspective, such as, for instance, addressing a short or long term time horizon or focusing on a single country or a global analysis of unilateral or coordinated measures.

Computable General Equilibrium (CGE) models are particularly suitable for analysing the economic effects of low-carbon policies since they can capture differences between regulated and unregulated countries in terms of competitiveness through trade channels, but also through investment dynamics in the long term. However, these models need to be improved with detailed information on behavioural parameters representing the technology and energy sides in order to produce more reliable results. As far as CGE models are concerned, this kind of information is mainly represented by elasticity values that regulate the substitution processes in response to changes in relative prices.

Hence, a widely applied method to test the reliability of these numerical results is to conduct a sensitivity analysis investigating how the variation of outputs is connected with the variation in the input. However, the standard sensitivity investigation can only inform about the robustness of the results with respect to the variability in the model parameters in term of confidence intervals. Thus, further analysis is needed in order to understand how and to what extent the impacts of relevant parameters on the model results vary across countries and sectors, where the aggregation design needs to be coherent with the policy issues and the parameters under scrutiny. Therefore, sensitivity analysis for CGE models is crucial because it is a way to understand how the specific model works and help overcoming the critics to the CGE 'black box' (Fæhn, 2015).

Hence, the purpose of this paper is to analyse the sensitivity of a widely diffused CGE model framework as the GTAP (Global Trade Analysis Project) by testing different sets of energy-related elasticity parameters applied to the energy version of the model in its dynamic development (GDynE). GTAP-type models are increasingly used for assessing alternative climate policy options in terms of distribution of costs and benefits across regions and sectors with the final purpose of informing the debate on the optimal policy design in order to minimize the abatement costs while achieving an international agreement on the burden sharing. In order to provide more robust and reliable results, it is necessary to inform such models with realistic parameters. To the best of our knowledge, there are no empirical exercises focusing on the sensitivity of the GDynE model to changes in energy-related elasticity

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http://dx.doi.org/10.1016/j.econmod.2015.07.015
0264-9993/

parameters. More importantly, it seems that there are spare contributions trying to quantify to which extent CGE results might diverge when alternative values are tested. Finally, there are no attempts focusing specifically on sector-based empirically estimated elasticity values, which is in our opinion the most important value added of the present paper, since the attention to carbon leakage effects related to stringent climate abatement targets mainly addresses potential losses for energy-intensive manufacturing sectors.

The methodological strategy we adopt is to compare economic results derived by the same policy simulation scenarios where different elasticity sets are adopted. We assume that the best option is represented by elasticity values taken from existing contributions that have empirically estimated such substitution values based on historical data for a wide enough country sample. We than compare what we consider the most reliable model version with alternative subjectively adopted elasticity parameters, in order to highlight how and to which extent economic results suitable for climate policy impact assessment are diverging.

From a general point of view, we emphasize that more reliable assessment models allow better evaluating effective pay-offs matrices in the climate benefits and costs computation. These results might be hopefully used for reducing uncertainty over medium and long term economic impacts of climate mitigation actions, thus ensuring more robust analytical bases for the current climate negotiations. The adoption of empirically estimated parameters also allows better representing the real economic mechanisms in the absence of climate policies, in a business as usual situation. As emphasized by the IEA (2015), recent changes in the technological energy paradigm occurred in developed as well as in selected emerging economies as China have produced an impressive increase in the decoupling process between economic growth performance and carbon dioxide (CO_2) emission flows.

To this purpose, in this paper we demonstrate that the use of subjective elasticity values produces unrealistic results in climate mitigation options assessment for specific economic dimensions that are exactly under the lens of the climate debate, since also the starting point of each counterfactual exercise represented by a business as usual scenario results as not well calibrated with respect to current and real technological parameters. While the standard sensitivity analysis allows verifying the robustness of the results with respect to the input only in terms of confidence intervals, the current paper tries to make a step forward showing how the model results are non-uniformly affected by the same changes in energy elasticities. Our analysis discloses how relevant is to include in the model the most credible parameters as possible, given that they represent crucial technological aspects of the production processes and affect the distribution of climate change costs across regions and sectors, as measured by changes in GDP growth paths, sectoral output, carbon intensity and export competiveness.

The rest of the work is structured as follows. Section 2 provides a literature review of the relevance of sensitivity analysis in applied models to obtaining reliable results and the reasons why detailed behavioural parameters are crucial to the robustness of simulation results. Section 3 illustrates the GDynE model and describes simulation scenarios. Section 4 reports quantitative results and Section 5 outlines the main conclusions.

2. Literature review

The impact of policies on economic systems can be analysed by taking advantage of different applied models that can assess how the economy will react to any exogenous shock. Examples of shocks are the imposition or cutting of tariffs on imports, export subsidies, trade liberalisation and the impact of price rises of a particular good or changes in supply for strategic resources such as fossil fuels. There are many examples of simulation of economic scenarios through bottom-up, top-down or integrated assessment models, especially in the fields of international trade, agriculture and land use, and climate change policies. Whatever approach is selected, and depending on the issue under investigation, a particular aspect which must be taken into account is the role of the behavioural parameters that regulate the responsiveness of economic agents and, consequently, the effects of the modelled policy scenarios.

In particular, CGE models are an analytical representation of the interconnected exchanges that take place between all the economic agents, based on observed data. The advantages of this kind of analysis are that they can evaluate direct and indirect costs, spillovers and economic trade-off effects in a multi-region and inter-temporal perspective. A CGE model usually includes a detailed database, in the form of Input–Output (IO) matrices or Social Account Matrices (SAMs), and a set of equations linking variables through behavioural parameters (or elasticities). Different elasticity values strongly determine responses to a given shock, but there are often no empirically estimated values for these elasticities. This is a source of large criticism for CGE models. Moreover, given the computable nature of these models, the value assigned to the relevant parameters is of primary relevance because if not properly defined there is the risk that the model does not reach convergence or it provides results very distant from a 'real world'. Accordingly, model development needs also accurate estimations of crucial behavioural parameters.

For this purpose, the sensitivity of CGE models has been tested for instance with regard to the elasticity of substitution between goods and the Armington elasticity, which measures the degree of substitution between domestic and imported goods. Hertel et al. (2007) investigate how the elasticity of substitution across multiple foreign supply sources influences the economic impacts of free trade agreements. By using econometric estimations for behavioural parameters that are crucial to trade relationships, they conclude that there is great potential for improving the reliability of results when empirically estimated parameters are adopted. Németh et al. (2011) estimate Armington elasticities for seven sectors in the GEM-E3, which is a CGE model on the interactions between economy, energy and environment in Europe. They find significant differences in model results due to the different elasticity values between domestic and imported goods as well as between imported goods from different countries, both in the short and long term. More generally, Hillberry and Hummels (2013) state that the elasticity of substitution is one of the most important parameters in modern trade theory since it captures both the own-price elasticity of demand and the cross-price elasticity of demand by measuring how close goods are in the product space.

In climate change models used for policy modelling, there are two main classes of behavioural parameters: i) the elasticity of substitution between energy (E) and other inputs (I) in the production function, hereafter referred to as σ_{EI}; ii) the elasticity between different types of energy sources (inter-fuel substitution). As far as the former is concerned, it directly affects the costs associated with reduction target policies and represents one of the aspects characterising the technology embodied in the model (the others being, for example, the level of capital accumulation and the rate of technical change). It is crucial because changes in energy prices have a direct effect on supply and demand for energy, but also an indirect one on total output and welfare driven by changes in the intensity of other inputs, mediated through the magnitude of substitutability between inputs in the production function.

These behavioural parameters represent a component of technology information and regulate how the model responds to exogenous policy shocks. The value of σ_{EI}, in particular, is a measure of technological flexibility related to energy use. More precisely, a lower value for such elasticity corresponds, ceteris paribus, to a higher rigidity in the whole economy and, consequently, to higher abatement costs to be sustained for a given climate mitigation policy (Golub, 2013).

Empirical studies computing elasticity of substitution values in the production function generally take into account three or four inputs, thus distinguishing KLE and KLEM models (where K, L, E, M refer to capital, labour, energy and materials, respectively). The functional