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Sensitivity of modeling results to technological and regional details: The case of Italy's carbon mitigation policy

Gabriele Standardi [a,b,*], Yiyong Cai [c,d], Sonia Yeh [e]

[a] CMCC — EuroMediterranean Center on Climate Change, Isola di San Giorgio Maggiore n.8, Venice 30124, Italy
[b] FEEM — Fondazione Eni Enrico Mattei, Isola di San Giorgio Maggiore n.8, Venice 30124, Italy
[c] Oceans and Atmosphere Flagship, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Forestry House, Building 2, Wilf Crane Crescent, Yarralumla, ACT 2601, Australia
[d] Centre for Applied Macroeconomic Analysis, Crawford School of Public Policy, Australian National University, J.G. Crawford Building, Lennox Crossing, Acton, ACT 0200, Australia
[e] Department of Energy and Environment, Chalmers University of Technology, SE-412 96 Göteborg, Sweden

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ABSTRACT

Model differences in technological and geographical scales are common, but their contributions to uncertainties have not been systematically quantified in the climate policy literature. This paper carries out a systematic assessment on the sensitivity of Computable General Equilibrium models to technological and geographical scales in evaluating the economic impacts of carbon mitigation policies. In particular, we examine the impacts of sub-national details and technological details of power generation on the estimate of carbon price and economic cost. Taking Italy as an example, we find that the estimation for carbon price and the economic cost of a de-carbonization pathway by means of a model with technological and regional details can be lower than a model without such details by up to 40%. Additionally, the effect of representing regional details appears to be far more important than the effect of representing the details of electricity technology in both the estimated carbon prices and the estimated economic impacts. Our results for Italy highlight the importance of modeling uncertainties of these two key assumptions, which should be appropriately acknowledged when applying CGE models for policy impact assessment. Our conclusions can be generalized to different countries and policy scenarios not in terms of absolute numbers but in terms of economic explanations. In particular, intra-national trade and the sub-national sectoral/technological specialization are important variables for understanding the economic dynamics behind these outcomes.

1. Introduction

On account of human activity, the atmospheric concentration of greenhouse gases (GHG) has substantially increased since the Industrial Revolution. This is believed to be one of the key contributing factors of climate change (IPCC, 2014a). To mitigate the potential negative impacts of climate change, the European Union (EU) has put in place ambitious policies to control GHG emissions, develop renewable energies and improve energy efficiencies, with the aim of reducing emissions by 40% from the 1990 level by the end of 2030 (European Council, 2014). To achieve this, the existing reduction target of 1.74% per year for 2015–2020 will need to be scaled up to 2.2% per year from 2021 (European Council, 2014). Various studies suggest that significant reforms are needed to ensure the effectiveness of EU-internal abatement by 2030. This includes restoring a higher price path to the anticipated €30 or higher, as compared to the current level of around €5 per ton of CO_2-equivalent (CO_2e) since 2013 (Brink et al., 2014; Hu et al., 2015).

The European target is now part of the legally binding global agreement adopted at the Paris Conference (COP21) in December 2015 to limit global warming to well below 2 °C (FCCC, 2015; Latvian Presidency of the Council of the European Union, 2015). Since then, 197 countries representing 98% of global emission have made their Intended Nationally Determined Contribution (INDC) and 129 countries have ratified their NDCs. Among these countries are the most important economic players such as the United States, China, the European Union, Russia and India. The NDCs include both adaptation and mitigation actions. These actions will entail a reduction of GHG emissions, and at a certain point in time the transition toward green technologies and presumably some carbon pricing.

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* Corresponding author at: CMCC — EuroMediterranean Center on Climate Change, Isola di San Giorgio Maggiore n.8, Venice 30124, Italy.
E-mail address: gabriele.standardi@feem.it (G. Standardi).

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Legend

Piedmont	Northern regions
Aosta Valley	
Lombardy	
Trentino Alto Adige	
Veneto	
Friuli Venezia Giulia	
Liguria	
Emilia-Romagna	
Tuscany	Central regions
Umbria	
Marche	
Lazio	
Abruzzo	Southern regions
Molise	
Campania	
Apulia	
Basilicata	
Calabria	
Sicily	
Sardinia	

Fig. 1. Map of Italian regions.

Imposing a higher carbon price will increase the overall cost of fossil-based energy technologies. As a result, producers will switch to less carbon-intensive technologies and practices such as energy conservation, while consumers will shift to goods and services with lower embodied emissions or reduce demand. The transition requires investments in new infrastructures, altered patterns of resource use, and shifts in labor markets. High transition costs can be associated with an ambitious de-carbonization target such as those committed by the EU. The debate on the costs of climate change mitigation implies very sensitive political considerations on distributional impacts among regions and industries (Gough, 2013; Barrett et al., 2015), and such discussions need to be based on rigorous quantitative analyses. In this context, Computable General Equilibrium (CGE) modeling has been a popular tool for analyzing the economic impacts of national carbon mitigation policies. The modeling approach captures the interactions between supply, demand, prices, labor, capital and trade; and it therefore provides a rigorous and consistent evaluation framework to quantify the socioeconomic impacts of government policies on energy production and consumption as well as other related economic activities. By identifying the winners and losers among affected regions, sectors, institutions and technologies, CGE models can help policy makers gain a broad view of the consequences of their decisions.

However, results from CGE models vary greatly, and they are sometimes contradictory, even for a common scenario. For instance, five recent studies suggest that for the EU27 countries to achieve a 20% emission reduction target by 2020 from the 1990 level, the carbon price can range from 19 €/tCO$_2$ to 70 €/tCO$_2$ (Bohringer et al., 2009; Durand-Lasserve et al., 2010; Peterson et al., 2011; Bosello et al., 2013; Orecchia and Parrado, 2013). These results indicate that there could be gross domestic product (GDP) gains of around 0.1% or losses of up to 2%. Similarly, Pearce (2012) finds that for Australia to achieve a 15% emission reduction target by 2020 from the 2000 level, the national carbon price is estimated to be from 25$ to 70$ per metric ton of CO$_2$, according to a meta-analysis of different CGE models, including G-Cubed (McKibbin et al., 2010), GTEM (Commonwealth of Australia, 2008, 2011), and the Tasman Global Model (ACIL Tasman, 2008). The consequential GDP losses are estimated to be 0.4% to 1.4% from the business-as-usual.

Great variations in modeling results are not surprising, and numerous modeling comparison efforts have been conducted since the 1970s to explore the underlying factors contributing to the differences and to gain insights (e.g. some more recent efforts include Luderer et al. (2012), IPCC (2014b), and Fawcett et al. (2014)). Most of the differences in modeling results can be attributed to differences in (1) modeling mechanisms (e.g. macroeconomic "top-down" model vs. "bottom-up" technology-detailed optimization model (Bohringer, 1998; McFarland et al., 2004; Sue Wing, 2006), (2) the scale and scope of the model (e.g. the boundary and resolution of the analysis), (3) assumptions about baseline scenarios, and (4) assumptions on policy constraints (Pearce, 2012), and market responses (Carraro et al., 2012).

Among these factors, the model differences in technological and geographical details are particularly noticeable. For example, studies examining the 20% emission reduction target by 2020 in EU27 show different levels of sophistication in representing the electrical sector and country-level details. The ICES model (Bosello et al., 2013; Orecchia and Parrado, 2013) has four electricity technologies, including hydro, solar, wind and others, whereas the models used in other studies have only one electricity sector without further technological details. Peterson et al. (2011) considers EU27 as a single economic unit, while the models in other studies account for each major country separately. In the Australian case study referenced above, while the GTEM model (Commonwealth of Australia, 2008, 2011) and the Tasman Global model (ACIL Tasman, 2008) disaggregate the electricity sector into a menu of technologies with different cost structures and carbon intensities, the G-Cubed model (McKibbin et al., 2010) represents the production of electricity as a single technology. Similarly, the Tasman Global model considers each Australian state and territory as a single economic unit, whereas G-Cubed and GTEM do not account for the sub-national differences.

Given the great differences in the cost and emission profiles of electricity generation technologies, there will be variations in the represented electricity sector responses to shocks such as policy changes. For example, the average levelized cost of electricity (LCOE) for a conventional coal power plant is much lower than that of a solar unit (EIA, 2014). Furthermore, nations with politico-economic union or administrative units within a nation are heterogeneous in their