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The synthesis of bottom-up and top-down approaches to climate policy modeling: Electric power technology detail in a social accounting framework ☆

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Abstract

“Hybrid” climate policy simulations have sought to bridge the gap between “bottom-up” engineering and “top-down” macroeconomic models by integrating the former’s energy technology detail into the latter’s macroeconomic framework. Construction of hybrid models is complicated by the need to numerically calibrate them to multiple, incommensurate sources of economic and engineering data. I develop a solution to this problem following Howitt’s [Howitt, R.E., 1995. Positive Mathematical Programming, American Journal of Agricultural Economics 77: 329-342] positive mathematical programming approach. Using data for the U.S., I illustrate how the inputs to the electricity sector in a social accounting matrix may be allocated among discrete types of generation so as to be consistent with both technologies’ input shares from engineering cost estimates, and the zero profit and market clearance conditions of the sector’s macroeconomic production structure.

JEL classification: C680; Q400; Q540

Keywords: Energy modeling; Top-down; Bottom-up; Computable general equilibrium models; Electric power technologies

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1. Introduction

A crucial factor in mitigating future climate change is the expansion of energy supply technologies that have low or zero carbon dioxide (CO_2) emissions (IPCC, 2001). Computational policy models used to assess the climate implications of economic growth, energy use and GHG emissions represent these technologies in different ways, which has resulted in divergent predictions of the contributions of new energy sources – particularly renewables – to the future global energy supply. The main divide is between "bottom-up" engineering models, which simulate the interactions among the numerous individual energy technologies that make up the energy system of an economy, and "top-down" macroeconomic models, which simulate the effect on prices of the supply–demand interactions across the markets for all commodities, energy and non-energy alike.[1]

Attempts to reconcile these two approaches have focused on creating hybrid models which incorporate bottom-up technology detail within a top-down macroeconomic framework. The aim of this paper is to further this line of inquiry by developing a method for transparently integrating engineering data on technology detail into the macroeconomic accounts on which top-down models are empirically calibrated. I apply Howitt's (1995) positive mathematical programming (PMP) approach to data for the U.S. electric power sector to estimate the allocation of capital, labor, energy and material inputs among discrete activities and technologies in a way that is consistent with both the input shares implied by engineering cost data, and the conditions of zero profit and market clearance which define the sector's production structure from a macroeconomic perspective. The results demonstrate how the inconsistencies between engineering and macroeconomic data may be reconciled in a manner that is both transparent and portable among a variety of modeling applications.

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. Top-down models are a standard tool for assessing the macroeconomic costs of CO_2 abatement and its economy-wide feedbacks on prices, commodity and factor substitution, income and economic welfare. Bottom-up models are used to investigate the impacts of CO_2 emissions constraints on the portfolio of technologies that make up the supply and demand components of the energy system, in order to identify low-cost abatement opportunities or design technology-based subsidies or emission standards.

However, the results of these two approaches have tended to diverge, with top-down models typically indicating larger macroeconomic costs as the consequence of a given mitigation policy (NAS, 1991: 62; Grubb et al., 1993; Wilson and Swisher, 1993; IPCC, 2001). The origins of this

[1] Bottom-up models (e.g., MARKAL — Kypreos, 1998) are primal activity analysis simulations which solve for the levels of capacity of energy transformation and conversion technologies that minimize the cost of fulfilling demands for energy services. Energy demands are either specified exogenously or derived from simple aggregate macroeconomic models (e.g. Manne et al., 1995). Energy supplies emanate from a detailed model of the energy system which represents the capacities of and linkages among of a large set of discrete processes which transform primary energy resources into energy carriers, and convert these commodities into energy services that satisfy final demands. Top-down macroeconomic models come in two flavors: primal simulations of an aggregate Ramsey growth model with an environmental sector (e.g., DICE and RICE — Nordhaus and Boyer, 1999), and, more relevant to the subject matter of the present paper, primal–dual computable general equilibrium (CGE) simulations (e.g., EPPA — Paltsev et al., 2005). The latter solves for the set of commodity and factor prices and levels of industry activity and household income which clear all markets in the economy, given factor endowments, households' consumption technologies (specified by their utility functions) and industries' transformation technologies (specified by their production functions).