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Long-term economic modeling for climate change assessment

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ABSTRACT

A growing concern for using large scale applied general equilibrium models to analyze energy and environmental policies has been whether these models produce reliable projections. Based on the latest MIT Economic Projection and Policy Analysis model we developed, this study aims to tackle this question in several ways, including enriching the representation of consumer preferences to generate changes in consumption pattern consistent to those observed in different stages of economic development, comparing results of historical simulations against actual data, and conducting sensitivity analyses of future projections to key parameters under various policy scenarios. We find that: 1) as the economies grow, the empirically observed income elasticities of demand are better represented by our setting than by a pure Stone–Geary approach, 2) historical simulations in general perform better in developed regions than in developing regions, and 3) simulation results are more sensitive to GDP growth than energy and non-energy substitution elasticities and autonomous energy efficiency improvement.

1. Introduction

The MIT Economic Projection and Policy Analysis (EPPA) model is a computable general equilibrium (CGE) model of the global economy. It has been applied to the study of policy impacts on the economy and emissions, prospects for new technologies, agriculture and land use, and—in some versions—environmental feedbacks on the economy through human health and agricultural productivity. The model can be run in a standalone mode to, for example, investigate the implications of climate and energy policy (e.g. Jacoby and Chen, 2014), or it can be coupled with the MIT Earth System Model (MESM) to form the MIT Integrated Global System Modeling (IGSM) framework (e.g. Sokolov et al., 2009; Webster et al., 2012). The EPPA model is regularly updated as new global economic data become available. Previous EPPA versions are described in Babiker et al. (2001), Paltsev et al. (2005), and Paltsev et al. (2015).

EPPA has become a family of models, with different versions developed from the core model to examine in detail specific sectors or technologies such as, for example, private vehicle alternatives (Karplus et al., 2013a, b), the economics of producing jet fuel from biofuels (Winchester et al., 2013), the health and economic effects of air pollution (Nam et al., 2013) or land use change (Gurgel et al., 2007).[1] Incorporating such additional features often require substantial data development beyond the basic economic database. Our strategy for this update to EPPA was to first develop a core version of the model (EPPA version 6), with the goal of later adding in details as needed for special studies. In addition to updating the underlying economic database to a benchmark year of 2007, we revisit several key economic features, including the nature of economy-wide productivity growth, capital vintaging, and the relationship of final consumption goods to income growth. The new model provides a platform to develop economic projections to evaluate the implications of energy and climate policies; moreover, it also provides a robust platform for the ongoing model development, during which we plan to incorporate features of earlier versions of EPPA, and build additional features to study more detailed policy questions.

The current version of the model has been designed to allow focus on broader global change topics including land-use change, agriculture, water, energy, air pollution, transportation, population and development. Overall, we seek to understand the linkages of the economy to the broader earth system, the implications of earth system changes for global and regional economic growth, and the implications of economic policies meant to stabilize our relationship with the planet. We start from a theoretically grounded general equilibrium representation of the world economy, and add in the necessary physical detail on resources and environmental implications of their use. General equilibrium models are well-suited to the broader focus because they represent all sectors of the economy and interactions among sectors.

We have two main objectives of the paper. The first objective is to explain new developments in terms of model structure, data, and assumptions. For instance, we incorporate non-homothetic preferences in modeling final consumption to better capture the observed differences in income growth on regional consumption patterns of crops,

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[1] Publications on model variants and various applications are at: http://globalchange.mit.edu/research/publications.

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livestock, and food products. We develop a new vintaging structure for capital investment to better capture the observation that the lifetimes of some capital assets have been extended substantially beyond standard depreciation schedules. We also introduce the potential for exogenous improvements in capital productivity along with labor, land and energy productivity to allow for more balanced patterns of growth and factor prices under varying GDP growth assumptions. We update the main economic data—based on the Global Trade Analysis Project Version 8 (GTAP 8) database—with a benchmark year of 2007 (Narayanan et al., 2012). With the updated data we revise and update the regional business-as-usual (BAU) GDP projections.

The second major objective is to evaluate the reliability of the overall model with these new developments. While large scale applied general equilibrium models of the global economy have been used extensively in many areas, including energy and environmental policy analyses, for decades. A growing concern is whether these models produce reliable projections. We try to tackle that question in several ways. We compare the model's projections against historical data, and test if our revised representation of consumer preferences generates the type of structural changes we have observed in economies as they develop. Then, because we focus on energy, environment and natural resource use and are not experts in macro-economic forecasting, we seek reliability of the macro-economic projections by benchmarking to widely used and respected projections. Finally, we conduct conventional sensitivity analysis of policy results to key parameters. While sensitivity analysis shows model response, it does not tell us much about whether the response is realistic. Policy questions are often asking about new or potential policies and so it is generally not possible to find realistic historical analogues against which to compare model response to a policy shock. And, even if such analogues were to exist, model evaluation would require constructing a counter factual without the policy to test whether the model could reproduce what actually happened with the policy. Still sensitivity analysis can provide useful insight and help us to judge model response.

We note several caveats. First, the model is designed for mid- to long-term projections (over a decade to a century); as currently constructed, the model is not intended to generate or investigate annual or shorter fluctuations due to economic business cycles or shocks to oil or agricultural markets. Second, EPPA is designed as a simulation model to study "what if" questions regarding different underlying economic or policy assumptions. It is not designed to endogenously determine an optimal policy response, or otherwise simulate the behavior of political actors in the face of economic and environmental change. Environmental impacts of economic activities are "external" to private economic decision making, unless specific policies are implemented to price some or all of these externalities. The model incorporates economic distortions (such taxes, subsidies, controlled prices) that are present in the official economic data, but it does not capture unofficial economic transactions that might be substantial in certain parts of the world.

The remainder of the paper is organized as follows: Sections 2 and 3 introduce the theoretical framework and data, respectively; Section 4 presents model evaluation results based on a historical run, and analyzes simulation results for both the reference (BAU) and policy runs, and conducts sensitivity analyses with various model parameterizations and settings; and Section 5 provides conclusions and directions for future research.

2. Theoretical framework

CGE modeling has been widely used in various economy-wide analyses such as trade liberalization effects, interaction between FDI and trade, optimal taxation, modeling for roles of power sector technologies, and energy and environmental policies (Bovenberg and Goulder, 1996; Rutherford et al., 1997; Tapia-Ahumada et al., 2015; van der Mensbrugghe, 2010; Zhou and Latorre, 2014). The EPPA model is a classical computable general equilibrium model along the lines of these models, with the unique feature that it includes explicit advanced energy conversion technologies and accounting of both greenhouse gas and conventional pollutant emissions. It is a multi-region and multi-sector recursive dynamic model of the world economy solved at 5-year intervals from 2010 through 2100. The current version of the model includes 18 regions and 14 sectors, with labor, capital and multiple energy resources as primary factors. The model represents economic activities of three types of agents in each region: producers, consumers, and the government. Solving the model recursively means that production, consumption, savings and investment are determined by current period prices. Savings supply funds for investment, and investment plus capital remaining from previous periods forms the capital for the next period's production. The model is formulated in a series of mixed complementary problems (MCP), which may include both equations and inequalities (Ferris and Pang, 1997; Mathiesen, 1985; Rutherford, 1995). It is written and solved using the modeling languages of GAMS and MPSGE, and the latter is now a subsystem of the former (Rutherford, 1999).

Versions of the model have been solved as a fully dynamic model, implying forward looking behavior on the part of agents in the economy but to do so required simplification of some of the model features, for example, the explicit vintaging of capital. Babiker et al. (2009) compared similar versions solved either as a forward-looking or a recursive model and found similar results for policy simulations in terms of energy and technology use when the forward looking result that the carbon price rises at the discount rate was imposed on the recursive model. The overall policy costs were lower in the forward-looking model because of the additional flexibility of shifting consumption and investment over time. While forward-looking models are seen as conceptually superior, the implied perfect foresight is a strong assumption as future policies and other outcomes are rarely known with certainty.

2.1. The static model

In the recursive formulation, the model finds prices, quantities and incomes that represent an equilibrium in each period by solving an optimization problem for three types of agents in each region: the household, producers, and the government. The household owns primary factors including labor, capital, and natural resources, provides them to producers, receives income from the services it provides (wages, capital earnings and resource rents), pays taxes to the government and receives net transfers from it. In addition, representative regional household allocates income to consumption and savings.

Producers (production sectors) transform primary factors and intermediate inputs (outputs of other producers) into goods and services, sell them to other domestic or foreign producers, households, or governments, and receive payments in return. To maximize profit, each producer chooses its output level, and—under the given technology and market prices—hires a cost-minimizing input bundle. Production functions for each sector describe technical substitution possibilities and requirements. The government is treated as a passive entity, which collects taxes from household and producers to finance government consumption and transfers.

For a typical CGE model, the activities of different agents and their interactions can be described by three types of conditions: 1) zero-profit conditions; 2) market-clearing conditions; and 3) income-balance conditions. Zero-profit conditions represent cost-benefit analyses for economic activities. For the household, the economic activity is consumption that produces utility and for each producer, the activity is production, which results in output. A typical zero-profit condition expressed in MCP format is:

$$MC - MB \geq 0;\ Q \geq 0\ ;\ [MC - MB] \cdot Q = 0 \tag{1}$$

For instance, if a zero-profit condition is applied on a production activity, then if the equilibrium output $Q > 0$, the marginal cost MC must equal the marginal benefit MB, and if $MC > MB$ in equilibrium, the

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