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Vehicle technology under CO_2 constraint: a general equilibrium analysis

Andreas Schäfer[a,*], Henry D. Jacoby[b]

[a]Martin Centre for Architectural and Urban Studies, Department of Architecture, University of Cambridge, Cambridge CB2 2EB, UK
[b]Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology, 77 Massachusetts Avenue, E40-439, Cambridge, MA 02139, USA

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Abstract

A study is presented of the rates of penetration of different transport technologies under policy constraints on CO_2 emissions. The response of this sector is analyzed within an overall national level of restriction, with a focus on automobiles, light trucks, and heavy freight trucks. Using the US as an example, a linked set of three models is used to carry out the analysis: a multi-sector computable general equilibrium model of the economy, a MARKAL-type model of vehicle and fuel supply technology, and a model simulating the split of personal and freight transport among modes. Results highlight the importance of incremental improvements in conventional internal combustion engine technology, and, in the absence of policies to overcome observed consumer discount rates, the very long time horizons before radical alternatives like the internal combustion engine hybrid drive train vehicle are likely to take substantial market share.

Keywords: Climate policy; Transportation; Technology dynamics

1. Introduction

Given the strong coupling between economic growth, fossil energy use, and greenhouse gas emissions (GHG), large-scale introduction of advanced, fuel-efficient technology is an essential component of a comprehensive strategy for GHG emissions abatement. Already the single largest user of final energy and source of CO_2 emissions in the United States, the transport sector is steadily increasing its share of both. Partly in response to the threat of climate change, the motor vehicle industry is developing a number of fuel-saving technologies and beginning experimentation with their introduction into consumer markets. Several of these offer incremental improvements in fuel efficiency through reduced driving resistance (aerodynamic drag, rolling resistance, acceleration resistance) and improved mechanical drive train efficiency. Other developments aim at replacing the conventional mechanical drive train with a hybrid mechanical–electric one, and still more radical designs incorporate fuel cell technology (Weiss et al., 2003). Anticipating which of these vehicle types would likely move beyond niche markets to gain substantial economic market share is crucial for vehicle manufacturers in directing their R&D expenditures. It also is important for governments considering incentives to stimulate the introduction of more fuel-efficient systems.

In response to these needs, we examine the market penetration of these technologies under a CO_2 emissions constraint. Our analysis considers the role of automobiles, light personal trucks (minivans, sport utility vehicles, and pick-up trucks), and three classes of freight trucks—all within the context of an economy-wide, multi-sector emissions control effort. The study assumes an economically efficient GHG control policy, resulting

*Corresponding author. Tel.: +44 1223 331719; fax: +44 1223 331701.
E-mail addresses: as601@cam.ac.uk (A. Schäfer), hjacoby@mit.edu (H.D. Jacoby).

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in a common emissions price across sources. Thus the relative role of transport in relation to other economic sectors is endogenous to the analysis.

Questions of this kind are usefully addressed using a computable general equilibrium (CGE) analysis framework, which takes account of the interdependencies among economic sectors through price interactions, the sharing of intermediate inputs and outputs, and substitution in satisfying producer and consumer demands. Gaining advantages of the general equilibrium approach requires a simplified representation of production technology, however, making it difficult to represent specific vehicle designs. To incorporate the desired technology detail we couple a CGE model to an engineering-process model of energy systems and transport technology, linking the two by means of a model of the evolving split of total transport among different transport modes. The resulting model system is summarized in Section 2, along with a description of the vehicle technologies considered in the analysis.

Two of the issues that arise in such a study of transport technology merit some special discussion. They are the treatment of discount rates revealed in consumer behavior, and the long turnover rates of transportation infrastructure. These features of the analysis are discussed in Section 3. The results of the analysis, which covers a period to 2030, are shown in Section 4, with a focus on economic market penetration for an unconstrained reference case and for GHG control policies at two different levels of stringency. The implications of the results for greenhouse gas policy development are discussed in Section 5.

2. The analysis framework

The linked system of models used to carryout the analysis is shown in Fig. 1. It is detailed by Schäfer and Jacoby (in press), but is usefully summarized here to

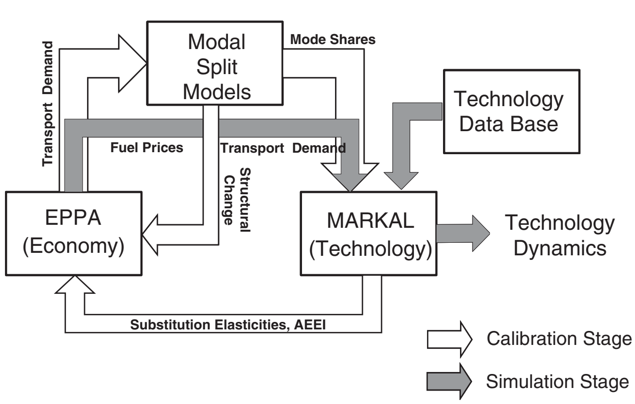

Fig. 1. Linked model system, consisting of the emission prediction and policy analysis (EPPA) model, the modal split models of passenger and freight transport, and the systems-engineering MARKAL model.

assist interpretation of the policy application. The MIT Emissions Prediction and Policy Analysis (EPPA) Model is used to project major characteristics of a multi-sector, multi-region economy, including technical change and emissions. EPPA's estimates of overall economic activity, the relative prices of fuel, and transportation demand are input into a MARKAL model of the transport sector, which simulates the introduction of particular technologies. To map from EPPA to the more detailed demand categories of the MARKAL model, aggregate transport demand from the aggregate model must be divided into the appropriate transport modes. For this intermediate step a third, Modal Splits model is applied. This third model also provides the basis for correcting EPPA parameters to reflect structural change that is present in the modal splits but below the EPPA level of aggregation (see Schäfer and Jacoby, in press).

The two representations of transport, energy use and greenhouse gas emissions—within the aggregate EPPA model and the technology representation in MARKAL—should be consistent with one another. The main criterion for model consistency is total energy use in the two transport sub-sectors defined within the EPPA model—i.e., personal transportation (own transport) and the aggregate of passenger transport by public modes and freight transport (purchased transport). To achieve convergence, we adjust the aggregate technology parameters in EPPA to be consistent with the more detailed specification in MARKAL. We also adjust the discount rate in MARKAL such that the base-year fuel cost shares are identical in the two models. The model system thus calibrated is used for both no-policy reference and policy cases without further parameter adjustment.

2.1. The EPPA model

The EPPA model is a recursive-dynamic, multi-regional general equilibrium model of the world economy (Babiker et al., 2000). It is built on the GTAP energy-economy data set (Hertel, 1997). In Version 3 of the EPPA model applied here the world is represented by 12 nations or multi-nation regions, and the production side of the economy is aggregated into nine sectors (four producing non-energy goods and services, including transportation, and five producing various forms of energy). The household sector includes the production of "own" transportation (from purchased equipment and fuel) as well as purchased transportation and other goods and services. The base year is 1995, and the model is solved in 5-year time steps. The analysis is limited to CO_2 emissions from fossil fuels, and national emissions reduction targets are assumed to apply to a 1990 baseline. In the calculations below, the model meets