# *MIT Joint Program on the Science and Policy of Global Change*

# Modeling the Transport Sector:
## *The Role of Existing Fuel Taxes in Climate Policy*

*Sergey Paltsev, Henry D. Jacoby, John Reilly, Laurent Viguier and Mustafa Babiker*

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To inform processes of policy development and implementation, climate change research needs to focus on improving the prediction of those variables that are most relevant to economic, social, and environmental effects. In turn, the greenhouse gas and atmospheric aerosol assumptions underlying climate analysis need to be related to the economic, technological, and political forces that drive emissions, and to the results of international agreements and mitigation. Further, assessments of possible societal and ecosystem impacts, and analysis of mitigation strategies, need to be based on realistic evaluation of the uncertainties of climate science.

This report is one of a series intended to communicate research results and improve public understanding of climate issues, thereby contributing to informed debate about the climate issue, the uncertainties, and the economic and social implications of policy alternatives. Titles in the Report Series to date are listed on the inside back cover.

Henry D. Jacoby and Ronald G. Prinn,
*Program Co-Directors*

For more information, please contact the Joint Program Office

Postal Address: Joint Program on the Science and Policy of Global Change
77 Massachusetts Avenue
MIT E40-428
Cambridge MA 02139-4307 (USA)

Location: One Amherst Street, Cambridge
Building E40, Room 428
Massachusetts Institute of Technology

Access: Phone: (617) 253-7492
Fax: (617) 253-9845
E-mail: globalchange@mit.edu
Web site: http://MIT.EDU/globalchange/

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# Modeling the Transport Sector: *The Role of Existing Fuel Taxes in Climate Policy*

Sergey Paltsev[*], Henry D. Jacoby[*], John Reilly[*], Laurent Viguier[†] and Mustafa Babiker[‡]

## Abstract

*Existing fuel taxes play a major role in determining the welfare effects of exempting the transportation sector from measures to control greenhouse gases. To study this phenomenon we modify the MIT Emissions Prediction and Policy Analysis (EPPA) model to disaggregate the household transportation sector. This improvement requires an extension of the GTAP data set that underlies the model. The revised and extended facility is then used to compare economic costs of cap-and-trade systems differentiated by sector, focusing on two regions: the USA where the fuel taxes are low, and Europe where the fuel taxes are high. We find that the interplay between carbon policies and pre-existing taxes leads to different results in these regions: in the USA exemption of transport from such a system would increase the welfare cost of achieving a national emissions target, while in Europe such exemptions will correct pre-existing distortions and reduce the cost.*

## Contents

## 1. INTRODUCTION

An explicit representation of transportation is important for quantitative analysis of energy and environmental policy. This sector is among the more rapidly growing energy users, and fuel inputs are often taxed at much higher rates in transportation than in other areas of the economy. Also, policies directed toward energy use and environmental control generally give special treatment to the transportation sector (particularly the automobile). For example, transportation has been treated differently from other sectors in the design of cap-and-trade systems. The European Union excludes the transportation sector from the 2005-2007 trial period of its emission trading system (CEU, 2003), and the proposed US Climate Stewardship Act of 2003 (Paltsev *et al.*, 2003) would impose an upstream system for emissions from transportation fuels and a downstream system for those from other sectors.

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[*] MIT Joint Program on the Science and Policy of Global Change; corresponding author: paltsev@mit.edu.
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[†] Faculty of Economics and Social Sciences, University of Geneva, Switzerland; and Swiss Federal Institute of Technology, Lausanne, Switzerland.

[‡] Arab Planning Institute, Kuwait.

The goal of this paper is to study the welfare implications of a sector-specific cap-and-trade system that gives special treatment to industrial and household transportation. For analyzing climate policy many researchers use the GTAP dataset (Hertel, 1997), which incorporates detailed accounts of regional production and bilateral trade flows. Version 5 of this dataset (Dimaranan and McDougall, 2002) has three transportation sectors. However, household transportation expenditure on private automobiles are not represented explicitly in the data. The resulting aggregation of automobile fuel use with other transport fuels makes it impossible to study household transportation explicitly. To facilitate the needed analysis we have developed a method for augmenting the existing GTAP data to disaggregate household transportation (Paltsev *et al.*, 2004a), and here we apply this new data facility within the MIT Emissions Predictions and Policy Analysis (EPPA) model to explore the effects of exempting the transportation sector from a carbon policy. In general, exemption of some sectors implies increased carbon tax rates for others and higher costs for an economy as a whole. However, a carbon policy may interact with existing taxes and economic distortions to produce counterintuitive effects. We compare two regions: the US, which has low fuel taxes, and Europe, where fuel taxes are high.

Our presentation of the data development and analysis is organized in the following way. In the next section we describe the modeling approach, and the sources of the household transportation data used to augment the existing GTAP structure. The modified household transportation sector, disaggregated into purchased and own-supplied transport, is described. Corresponding adjustments to other aspects of the household demand structure are also presented. Section 3 discusses methodological issues regarding capital accounting in the personal transport sector. Section 4 reports the key results of an analysis of the welfare effects of exclusion of industrial and household transport from a carbon policy. In Section 5 we draw some conclusions about the importance of model and data improvements needed to adequately assess climate policies, taking account of the full complexity of their introduction into pre-existing policy environments.

## 2. DISAGGREGATING HOUSEHOLD TRANSPORT

The GTAP5 dataset represents production and trade flows for 66 regions and 57 sectors of the world economy (Dimaranan and McDougall, 2002). Among those sectors are three transportation sectors: air transport (ATP), water transport (WTP), and other transport (OTP). The OTP sector includes land transport, transport via pipelines, supporting and auxiliary transport activities, and activities of travel agencies. Commercial transportation services purchased by the household from ATP, WTP, or OTP are already treated in the standard GTAP5 data, and this feature allows us to represent explicitly the substitution possibilities between own-supplied transportation and purchased transport services.

The missing component in GTAP is the transportation service produced by the household itself, i.e., that provided by private automobiles. Our strategy for modeling household transportation is to create a household production activity that combines goods purchased from industry with fuel inputs to produce an "own-supplied" transportation service that represents the use of personal automobiles. Transport-related purchases of the household are, of course, already included in consumer final demands. In some cases we can assume that final consumption from a GTAP sector is used exclusively in own-supplied transportation, but in other cases only a part of a sector's contribution is used in transportation. The data problem is to identify the appropriate sectors and to estimate the share of final consumption from these sectors that goes to own-supplied transportation. For energy and environmental modeling purposes, for example, a critical data need is to separate purchases of refined oil (gasoline and diesel fuel) used to fuel vehicles from those fuels used for home heating and other household purposes.

The revised data set is then applied in the EPPA model, which is a recursive-dynamic multi-regional general equilibrium model of the world economy (Babiker *et al.*, 2001). Besides the GTAP data set, EPPA is built on additional data for greenhouse gas ($CO_2$, $CH_4$, $N_2O$, HFCs, PFCs, and $SF_6$) and urban gas emissions. The version of EPPA used here (EPPA4) has been updated in a number of ways from the model described in Babiker *et al*. (2001). Most of the updates are presented in Paltsev *et al*. (2003). For use in EPPA the GTAP dataset is aggregated into the 16 regions and 10 sectors shown in **Table 1**. The base year of the EPPA model is 1997. From 2000 onward it is solved recursively at 5-year intervals. Because of the focus on climate policy, the model further disaggregates the GTAP data for energy supply technologies and includes a number of "backstop" technologies—energy supply technologies that were not in widespread use in 1997 but could take market share in the future under changed energy price or climate policy conditions. This additional disaggregation and technology specification does not have a substantial direct effect on the transportation modeling we develop here. The EPPA model's production and consumption sectors are represented by nested Constant Elasticity of Substitution (CES) production functions (or the Cobb-Douglas and Leontief special cases of the CES). Capital applied in the industry production sectors is vintaged, but the capital implicitly embodied in the household vehicle stock is not—a topic to which we return in Section 3. The model is written in GAMS-MPSGE. It has been used in a wide variety of policy applications (e.g., Jacoby *et al.*, 1997; Jacoby and Sue Wing, 1999; Reilly *et al.*, 1999; Bernard *et al*., 2003; Paltsev *et al.*, 2003; Babiker, Reilly and Metcalf, 2003).

### 2.1 Inter-Industry Transportation

Transport in the EPPA model is represented by two activities: an industry transportation sector (aggregating the modal splits in the base GTAP5 data) and a household transportation sector. Industry transportation (TRAN) supplies services (both passenger and freight) to other sectors of the economy and to households. The nesting structure of the industry transportation

**Table 1**. Countries, Regions, and Sectors in the EPPA Model

| Country or Region | Sectors |
|---|---|
| ***Annex B*** | ***Non-Energy*** |
| United States (USA) | Agriculture (AGRI) |
| Canada (CAN) | Services (SERV) |
| Japan (JPN) | Energy-Intensive Products (EIT) |
| European Union+[a] (EUR) | Other Industries Products (OTHR) |
| Australia & New Zealand (ANZ) | Transportation (TRAN) |
| Former Soviet Union[b] (FSU) | ***Energy*** |
| Eastern Europe (EET) | Coal (COAL) |
| ***Non-Annex B*** | Crude Oil (OIL) |
| India (IND) | Refined Oil (ROIL) |
| China (CHN) | Natural Gas (GAS) |
| Indonesia (IDZ) | Electric: Fossil (ELEC) |
| Higher Income East Asia[c] (ASI) | Electric: Hydro (HYDR) |
| Mexico (MEX) | Electric: Nuclear (NUCL) |
| Central & South America (LAM) | Electric: Solar and Wind (SOLW) |
| Middle East (MES) | Electric: Biomass (BIOM) |
| Africa (AFR) | Electric: Natural Gas Combined Cycle (NGCC) |
| Rest of World[d] (ROW) | Electric: NGCC with Sequestration (GGCAP) |
|  | Electric: Integrated Gasification with Combined Cycle and Sequestration (IGCAP) |
|  | Oil from Shale (SYNO) |
|  | Synthetic Gas (SYNG) |

[a] The European Union (EU-15) plus countries of the European Free Trade Area (Norway, Switzerland, Iceland).

[b] Russia and Ukraine, Latvia, Lithuania and Estonia (which are included in Annex B), andAzerbaijan, Armenia, Belarus, Georgia, Kyrgyzstan, Kazakhstan, Moldova, Tajikistan, Turkmenistan, and Uzbekistan, which are not. The total carbon-equivalent emissions of these excluded regions were about 20% of those of the FSU in 1995. At COP-7 Kazakhstan, which makes up 5-10% of the FSU total, joined Annex I and indicated its intention to assume an Annex B target.

[c] South Korea, Malaysia, Phillipines, Singapore, Taiwan, Thailand.

[d] All countries not included elsewhere: Turkey, and mostly Asian countries.

sector is depicted in **Figure 1**, which shows that its output is produced using energy, capital, labor, and intermediate inputs from different industries. The substitution elasticities for this sector, labeled as s1. . . s7, are provided in **Table 2**. At the top of the nest, intermediate inputs and the energy-labor-capital bundle are modeled as a Leontief composite. Both domestic and imported intermediate goods are used in the production activities, with elasticities of substitution between domestic and imported bundles, s2, and between imports from different regions, s3. The energy-labor-capital bundle is composed of separate energy and value-added nests. Energy inputs are nested into electricity and non-electric inputs, and value added (labor and capital). The data for modeling this sector come directly from ATP, WTP, and OTP sectors of the GTAP dataset.

### 2.2. Transportation in the Household Sector

Households consume both own-supplied (i.e., private cars) and purchased transport. Purchased transport (air travel, water travel, rail service, trucks, etc.) comes from the industry transportation sector described above. Own-supplied transportation services are provided using

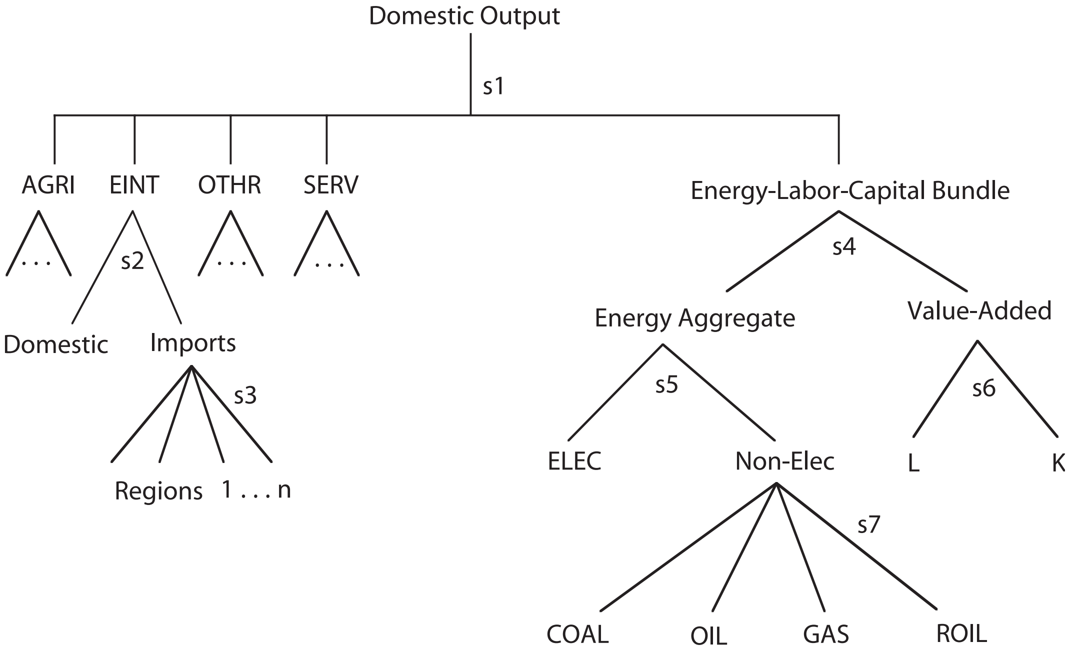

**Figure 1**. Structure of Production Sector for the Industry Transportation Sector

**Table 2**. Elasticity of Substitution Values for the Industry Transportation Sector

| Notation | Elasticity | Value |
|---|---|---|
| s1 | between Energy-Capital-Labor and Intermediate Goods | 0 |
| s2 | between Domestic and Imported Intermediates | 3 |
| s3 | between Imports from different regions | 5 |
| s4 | between Energy and Value-Added | 0.5 |
| s5 | between Electricity and Other Energy | 0.5 |
| s6 | between Capital and Labor | 1 |
| s7 | between Non-electric Energy inputs | 1 |

inputs from three sectors: Other Industries Products (purchases of vehicles), Services (maintenance, insurance, tires, oil change, etc.), and Refined Oil (fuel).

In order to model the household transportation sector, we make use of the following identity:

$$OWNTRN_r \equiv T\_ROIL_r + AC_r + \sum_i OC_{ir} \ , \tag{1}$$

where $OWNTRN_r$ stands for household expenditures on own-supplied transport in a region *r*, $T\_ROIL_r$ is expenditures on refined oil used in household transportation (i.e., gasoline and diesel fuel), $AC_r$ is vehicles, and $OC_{ir}$ aggregates operating costs such as maintenance and repairs, insurance, financing costs, and parking—the last drawing on several sectors *i*.

It is useful to define household expenditures on own-supplied transport as a share, $ES_r$, of total household expenditure,

$$OWNTRN_r = ES_r \times CONS_r \ , \tag{2}$$

where $CONS_r$, total household expenditure in a region *r*, is available directly from the GTAP database. Often household expenditure data do not provide $T\_ROIL_r$ , but other energy surveys provide data on fuel expenditures, so that household expenditures on refined oil products for own-supplied transportation is usefully stated as a share, $OS_r$ , of total household expenditure on all refined oil products, $TOS_r$ :

$$T\_ROIL_r = OS_r \times TOS_r , \tag{3}$$

with $TOS_r$ available directly from the GTAP database.

In order to apply Equations (1) to (3) to the disaggregation of household transportation we need the data for $AC_r$, $OC_{ir}$, $ES_r$, and $OS_r$. National surveys report that, for developed countries, household expenditures on own-supplied transport as a fraction of total household expenditures is approximately 0.1, and refined oil expenditures within household transportation is around 0.9 as a fraction of household expenditures on oil products—that is, most of the refined oil products used by households are for transportation. The share of own-supplied transportation expenditure ($ES_r$) can be estimated from household expenditure surveys. In particular, the OECD produces statistical handbooks on final consumption expenditure of households by purpose: (1) purchase of vehicles, (2) operation of vehicles (including oil), and (3) transport services (air tickets, railway tickets, etc.). Items (1) and (2) sum to $OWNTRN_r$ . As shown in **Table 3**, these OECD data were used for the US, Canada, the EU, and Mexico. For the European Union we used data from household budget surveys by Member States (EUROSTAT, 1999). This database provides estimates for $ES_r$ in Europe by summing three items: (1) car purchase, (2) motor fuels (including greases, etc.), and (3) other services (including repairs, insurance, etc.). The results are consistent with the OECD national accounts. For the other countries and regions, we use statistical handbooks and the United Nations national accounts that provide useful data on personal transport equipment (United Nations, 2002).

Since the OECD data do not disaggregate fuel expenditures from other operation expenditures we use estimates of $OS_r$ to calculate $T\_ROIL_r$ from Equation (3). Conveniently, as noted, the

**Table 3**. Sources of Data for Own-Transport Expenditure and Own-Transport Refined Oil Shares

| Country or Region | Own-Transport Expenditure Shares | Own-Transport Refined Oil Shares |
|---|---|---|
| United States | OECD (1997) | BEA (Moulton & Moylan, 2003) |
| Canada | OECD (1997) | Statistics Canada (2002) |
| Japan | Adjusted OECD (1997) | IEA data |
| EU | Eurostat (1999) | Eurostat (1999) |
| Australia/New Zealand | Adjusted UN (2002) | IEA data |
| Eastern Europe | Adjusted UN (2002) | IEA data |
| Former Soviet Union | World Bank data | IEA data |
| India | National statistical handbook | Ministry of Statistics & Prog. Impl. (2001) |
| China | National statistical handbook | Nat'l Bureau of Statistics of China (2002) |
| Indonesia | Adjusted UN (2002) | IEA data |
| Dynamic Asia | Based on Korea (OECD, 1997) | IEA data |
| Mexico | OECD (1997) | IEA data |
| Central & South America | Based on Colombia (UN, 2002) | IEA data |
| Middle East | Based on Israel (UN, 2002) | IEA data |
| Africa | Based on S. Africa, World bank data | IEA data |

Eurostat database provides $T\_ROIL_r$ estimates directly for the EU countries. The surveys that provide a disaggregation for oil consumption are from the Bureau of Economic Analysis for the USA, Statistics Canada (2002), and national statistical handbooks for some developing countries (e.g., China and India). When expenditure data are not available, physical data on oil consumption shares for private transportation and other residential uses combined with fuel tax and price data provide another approach. The International Energy Agency (IEA/OECD) gives detailed energy balances in tons of oil equivalent (or toe) for OECD countries (IEA, 2000a) and non-OECD countries (IEA, 2000b), along with statistics on energy prices and taxes by fuel and by country in US dollars per toe (IEA, 2001). A problem with these data is that the ROAD sector defined in IEA energy balances includes trucks and commercial transport. This procedure leads to overestimation of the $OS_r$ coefficients. Canada gives detailed data on fuel consumption in transportation. There, households represent 77% of total expenditure in road fuels (93% of road gasoline and 28% of road diesel). Adjusting the IEA data for the road sector using these coefficients on road fuels for Canada suggests that the error introduced is relatively small. For example, the $OS_r$ coefficient from the country level data for Canada results in an $OS_r$ value of 92% compared with an estimate relying just on the IEA data of 93.7%. In the United States, the share of refined oil products for own-supplied transportation in total household expenditure is estimated from statistics of the US Department of Commerce to be 90%, compared to 94.8% with IEA data. These results indicate that IEA data may be considered as a relatively good proxy for $OS_r$. In cases where other additional data were not available we used the IEA data without adjustment.

The data for final purchases of vehicles ( $AC_r$ ) can be taken directly from the GTAP Motor Vehicle (MVH) sector sales to final consumption. From these data and GTAP final consumption we can derive the value of total consumption of own-supplied transportation for each country/region and expenditure on vehicles and fuels.

The other operating costs ( $OC_{ir}$ ) are derived as a residual of the total value of own-supplied transport less expenditure on vehicles and fuels. To disaggregate this quantity to the GTAP level a further identification of the supplying sectors of these other operating costs would be needed because the operating cost data are divided among the TRD sector (sales, maintenance, repair of motor vehicles, and trade margin on sales of automotive fuel are part of this sector), the ISR sector (insurance), and an OBS sector (which includes renting of transport equipment). As implemented in EPPA, however, these GTAP sectors are aggregated, and so we assume that $OC_{ir}$ is supplied by the service (SERV) sector.

As is evident from the above discussion, for some countries there are multiple sources of data that provide the ability to cross-check results, while for other countries data are more limited and further assumptions are needed. In general, we used household expenditure data directly when available, but often checked these with physical energy data or price-quantity data. We converted expenditure data to shares and applied these shares to the expenditure totals in GTAP to avoid inconsistencies in currency conversion and between the original data source and GTAP.

As noted earlier, the EPPA model uses a nested CES structure to describe consumer preferences as well as production, as this specification is compatible with the MPSGE solver. **Figure 2** shows the household sector as it existed in EPPA without disaggregation of own-supplied transportation. The nesting structure aggregates all Armington goods into a single consumption good, which is then aggregated with savings to determine the level of consumer utility. Savings enters directly into the utility function, which generates the demand for savings and makes the consumption-investment decision endogenous. The central values for elasticities in the household sector are provided in **Table 4**. The elasticity between non-energy inputs to

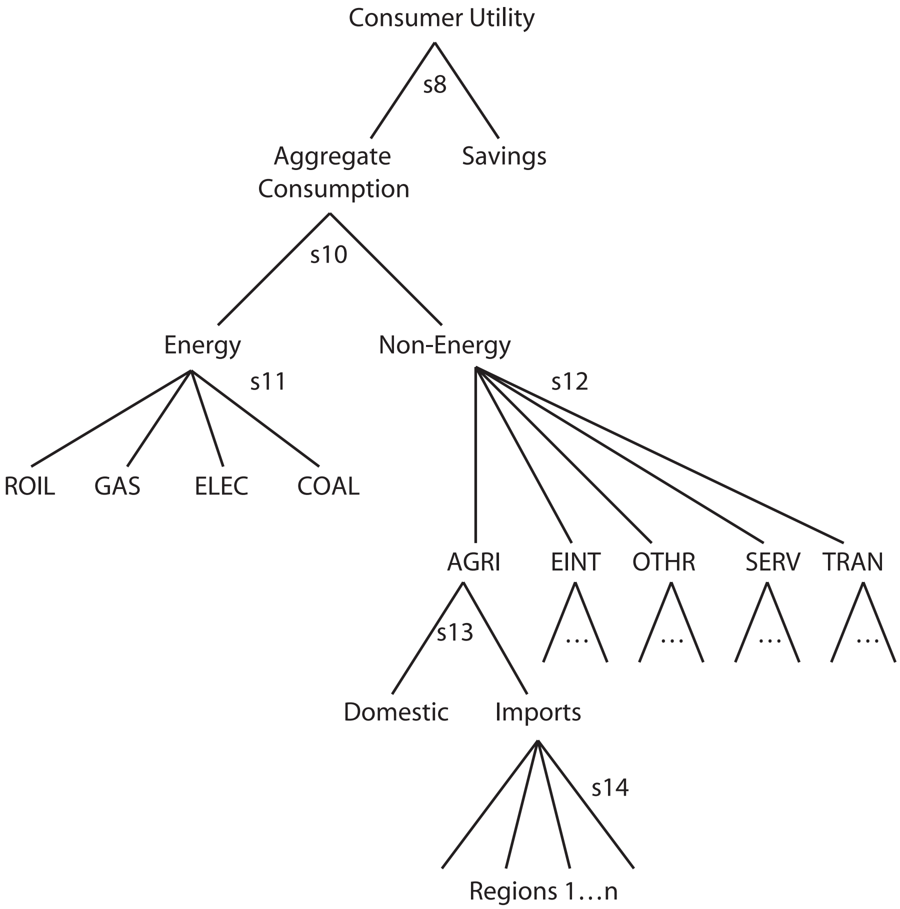

**Figure 2**. Structure of the Household Sector without Transportation

**Table 4.** Elasticity of Substitution Values for the Household Sector

| Notation | Elasticity | Value |
|---|---|---|
| s8 | between Aggregate Consumption and Savings | 1 |
| s10 | between Energy and Non-Energy Consumption | 0.25 |
| s11 | between Energy Inputs to Consumption | 0.4 |
| s12 | between Non-Energy Inputs to Consumption | 0.25–0.65 |
| s13 | between Domestic Goods and Imports | 3 |
| s14 | between Imports from different regions | 5 |

consumption is a function of per capita income and thus varies by region and time period. Consumption shares also are function of per capita income.[1]

**Figure 3** illustrates the addition of the own-supplied transport nest. As described above, we reallocate a portion of other industries (OTHR), services (SERV), and refined oil (ROIL) consumption to own-supplied transportation. The TRAN sector, which represents purchased transportation, is separated from the non-energy bundle in consumption. As shown in Figure 3, we rename purchased transportation as PURTRN sector and move it to the nest that represents a trade-off between purchased and own-supplied transportation (OWNTRN). The own-supplied

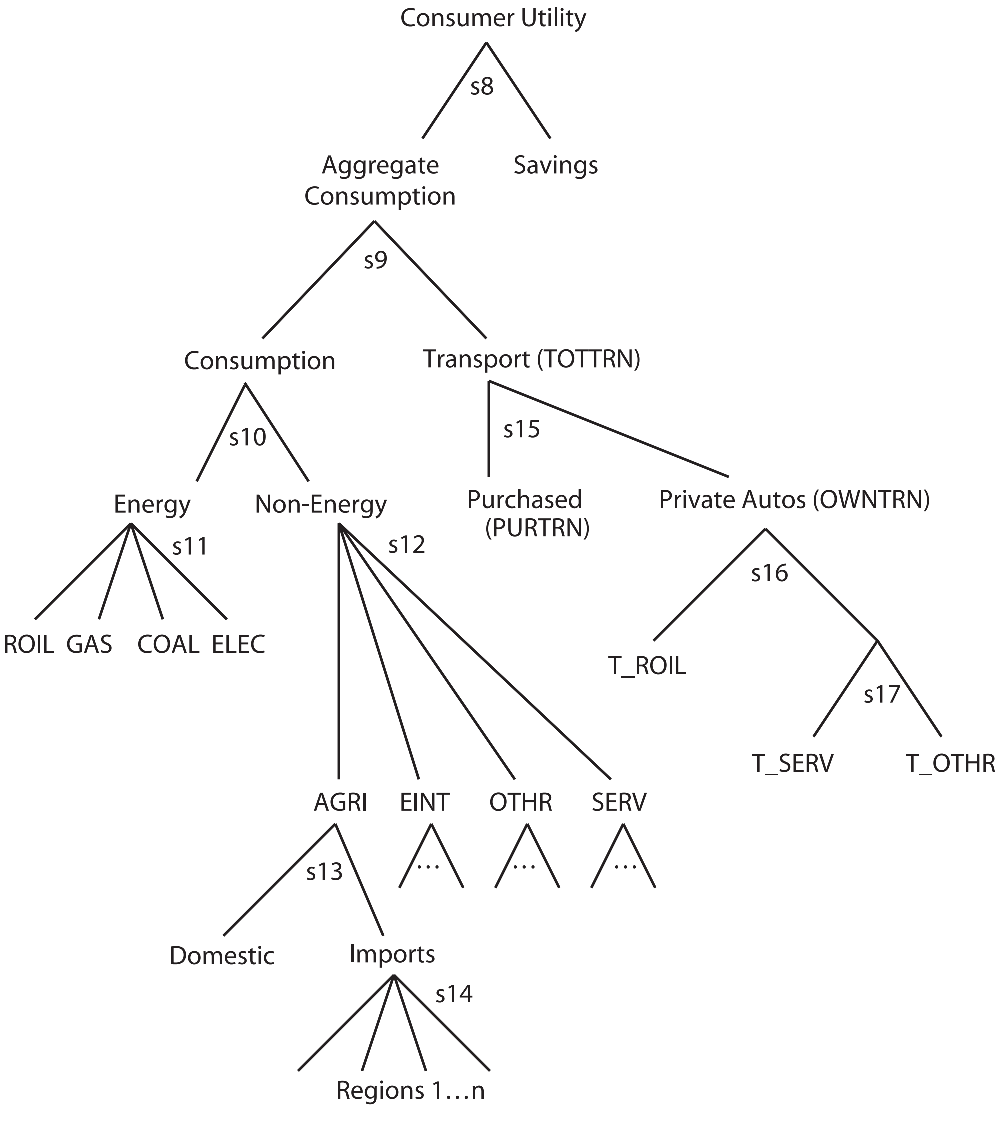

**Figure 3**. Structure of the Household Sector with Transportation

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[1] This specification allows use of the MPSGE algorithm, which was designed for the homogeneous CES family of production functions (homogenous of degree 1) while still capturing the changing structure of consumption with economic development that could not otherwise be represented using this functional form. For more details on the estimated relationship and its effects on emissions, see Lahiri, Babiker and Eckaus (2000).

transportation is aggregated from the consumption of other industries (T_OTHR), services (T_SERV), and refined oil (T_ROIL) directly related to private cars. The values for elasticities of substitution in the household transportation sector are provided in **Table 5**.

A sensitivity analysis of these elasticities is reported in Paltsev *et al.* (2004a). It is shown there that the results are insensitive to the elasticity of substitution between services and other inputs (s17), and modestly sensitive to the elasticity of substitution between transport consumption and other consumption (s9) and between purchased and own-supplied transport (s15). But results are very sensitive to the elasticity between fuel and other inputs to own-supplied transport (s16). The insensitivity of results to the own- and purchased-transportation elasticity was unexpected, but is easily explained. An economy-wide climate policy affects energy costs in both the purchased and own-supplied transport sectors, and upon inspection we found that the fuel shares of purchased and own-supplied transport were not very different. Thus, the policy created very little change in the relative prices of purchased and own-supplied transportation, so the elasticity of substitution was largely irrelevant. Other policy designs that differentially focused on automobiles and other transport modes could show greater sensitivity to this elasticity.

**Table 5**. Elasticity of Substitution Values for Household Transportation

| Notation | Elasticity | Value |
|---|---|---|
| s9 | between Aggregate Consumption and Transport | 0.5 |
| s15 | between Own-Transport and Purchased-Transport | 0.2 |
| s16 | between Gas and Other Inputs to Own-Transport | 0.3–0.7 |
| s17 | between Services and Other Inputs to Own-Transport | 0.5 |

## 3. FLOW AND STOCK ACCOUNTING OF VEHICLES

The approach so far outlined is consistent with National Income and Product Account practices that treat most household purchases of durables, and vehicles in particular, as a flow of current consumption. In reality, of course, vehicles are capital goods that depreciate over time and provide a service flow over their lifetime. To reconstruct the data in this way would require further estimation of annual service flow, depreciation rates, and treatment of vehicle purchase as an investment. In industrial sectors, the residual of the value of sales less intermediate input and labor costs is an estimate of payments to capital, and under the assumption of a normal rate of return and depreciation rate these quantities imply a level of the capital stock. Own-supply from the household sector is not marketed, however, and thus there are no comparable sales data on gross value of the service from which intermediate input costs can be subtracted. An implicit rental value for the vehicle service could be constructed with historical data on vehicle sales, assumed depreciation rates, and an assumed rate of return following a Jorgenson (1987) type cost of capital accounting. Long-term car leasing rates could also be used as a basis for comparison, although these data may not be representative of the entire vehicle stock when new vehicles are typically leased for a 3-year period and then sold. Moreover, data on real leasing costs are not completely transparent because they depend on features of the lease—such as limits on mileage, additional payments if mileage limits are exceeded, and the purchase terms at the end of the lease.

At issue, given these more or less problematic approaches to estimation, is whether a significant effort to correctly account for the stock nature of vehicles would have a large effect on the results. Two issues arise. One is whether this re-accounting of the service flow would result in a large change in the fuel and vehicle cost shares. Estimating the correct relative cost shares is important because they affect the relationship between substitution elasticities and more-frequently-estimated own-price elasticities of demand, and the share values can affect the response to policies or fuel prices. A change that resulted in a much higher (lower) relative fuel share would mean that a given change in the fuel price, due to a carbon charge for example, would create a larger (smaller) percentage increase in the service cost, and thus make results more (less) sensitive to the ability to substitute away from own-supplied transportation toward purchased transportation or other goods. A second issue is the explicit treatment of irreversibility of investment in a dynamic model and how it might limit substitution away from fuels in the short-run.

### 3.1 The Cost Shares

Regarding shares, available evidence suggests the fuel share we have calculated for the GTAP dataset, based on the above information, is approximately consistent with estimates derived from of total annualized costs of vehicle ownership with conventional cost components included. In the US, for example, the American Automobile Association (AAA) estimates the average annual cost of owning a vehicle including depreciation.[2] Assuming 10,500 miles per year per vehicle,[3] and using the AAA per mile estimate, would mean that fuel and oil costs were about 10% of total annual costs of owning and operating a car in 1998. Fuel alone at 10,500 miles per year, 23 mpg, and $1.20/gal would be 8.5% of total costs. While we do not expect to match these estimates exactly, they are comparable to the 8% fuel share we have estimated from the above procedure in our augmented GTAP data for the US.

We do not have comparable estimates for other regions, but our calculation of their fuel shares sometimes differs substantially. For the EU, for example, it is 24%, three times the US share. The big difference is that high fuel taxes raise the price of fuel in the EU. Using the AAA data and assuming 10,500 miles per year and 23 mpg, the fuel share rises to 24% with fuel at $4.00/gal, a price representative of fuel costs inclusive of taxes in Europe, and matches exactly our estimate based on GTAP data[4]. These calculations show that the tax-inclusive fuel price can

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[2] See, http://www.hfcu.org/whatsnew/hff/june98_1.htm.

[3] This is an average annual mileage per vehicle based on EPA data on mileage by vehicle age class (EPA, 2002). Mileage of each vehicle age was weighted by the share of that age class in the U.S. total vehicle fleet (e.g., the annual mileage of cars falls as they age but older cars account for a much smaller share of the fleet as more and more of the age class is retired). We focused on light duty gasoline vehicles for the average mileage estimate, but the average for other classes would be very similar.

[4] In France, the share of fuel costs has decreased from 28% in 1985 to 21% in 1998; In 2000, the fuel share was 20% with cars estimated to consume 7.4 liter per 100 km, or 32 mpg, and to travel 8625 miles per year (Baron, 2002).

explain the very different fuel cost shares in the EU and the US, and suggests that our approach for augmenting the data produces reasonable estimates. Of course, other costs and assumptions such as annual mileage or miles per gallon likely vary somewhat. One thing to note is that the AAA ownership costs include an estimate of financing costs based on 20% down payment. Inclusion of financing costs is consistent with market data in GTAP and survey data on household expenditure that we used.

### 3.2 Capital Accounting

Next is the issue of the treatment of capital vintaging in static and recursive-dynamic models. Note that, with no explicit stock of consumer vehicle capital it is not possible to incorporate the vintaging that is imposed in EPPA in the industry production sectors. When vintaging is not represented, simulation results often approximate the influence of fixity of capital through the choice of the value of the elasticity of substitution, using lower elasticities to estimate short-run effects of price changes, and raising the elasticity if one is interested in results closer to a long-run equilibrium result after the capital stock has had time to adjust. Schäfer and Jacoby (2003) compared the representation of transport in an earlier EPPA version (EPPA3) with the results of a detailed MARKAL-based transport model that treated vehicle stocks explicitly. They found that reference EPPA elasticities over-estimated responses compared with the detailed model, especially in the near term. To correct for the lack of an explicit treatment of personal transport, they lowered the elasticities in near term periods and raised them in more distant periods.

The logic behind this application of greater substitution potential in the longer run is compelling. A possible limit for the specific elasticities estimated by Schäfer and Jacoby (2003), however, is that they focused on new vehicle technology and not in any detail on substitution among existing models and features. For example, their method misses the option to purchase a smaller vehicle or the same vehicle with a smaller engine, and omits the potential ability of consumers with multiple vehicles to shift their driving toward the more efficient ones. Many econometric studies of gasoline demand and vehicle travel have been conducted over the years (e.g., Archibald and Gillingham, 1981; Dahl and Sterner, 1991; Haughton and Sarker, 1996; Greene, Kahn and Gibson, 1999). In these studies the estimated response to price usually includes both a technical efficiency effect and a behavioral response in terms of miles driven.

To relate these different approaches to one another, and to pure technology studies, it is useful to observe that gasoline demand, denoted $F(p)$, can be defined as energy efficiency, $e$, times the number of miles traveled, $M$:

$$F(p) = e(p)M(p), \tag{4}$$

where both $e$ and $M$ are a function of fuel price $p$. Logarithmic differentiation of (4) with respect to the price of gasoline yields:

$$\frac{\partial \ln F}{\partial \ln p} = \frac{p}{e}\frac{\partial e}{\partial p} + \frac{p}{M}\frac{\partial M}{\partial p}. \tag{5}$$

And recognizing the expressions for elasticities, we can rewrite (5) as:

$$\eta_{F,p} = \eta_{e,p} + \eta_{M,p}, \tag{6}$$

where $\eta_{F,p}$ is the elasticity of gasoline demand to a change in fuel price, $\eta_{e,p}$ is the elasticity of energy efficiency (e.g., miles per gallon) with respect to a change in *p*, and $\eta_{M,p}$ is the elasticity of vehicle miles with respect to a change in *p*.

The version of the bottom-up MARKAL model applied by Schäfer and Jacoby (2003) assumes implicitly that $\eta_{M,p} = 0$. Also, their computation of $\eta_{F,p}$ takes into account the effect of fuel price change only on vehicle technology—capturing the fact that an increase in fuel price will speed up the penetration of vehicles of more efficient design, resulting in lower energy demand. This focus on technology shift likely underestimates the efficiency elasticity, as it does not consider the effects of a change in fuel price by means of substitutions among existing car models/options and/or through changes in driver behavior. For example, new car consumers face choices among vehicle sizes and engine power even within a particular technology class. At higher fuel prices owners might also perform better maintenance on their cars to increase efficiency (e.g., tune-ups, maintenance of tire pressure, etc.).[5]

Greene, Kahn and Gibson (1999) estimated a pure behavioral response in terms of miles driven, treating any change in energy efficiency (defined as gallons of fuel per mile) as *exogenous* and estimated the US the long-run fuel price elasticity of vehicle miles travel ($\eta_{M,p}$) to be in the range of –0.2 to –0.3. Combining this result with an efficiency elasticity ($\eta_{e,p}$) of –0.126 estimated from the MARKAL model suggests an own-price elasticity of gasoline demand ($\eta_{F,p}$) of between –0.3 to –0.4. Because the MARKAL model used by Schäfer and Jacoby (2003) does not consider all the possibilities for increasing efficiency this might be considered a low estimate. **Table 6** shows that the use of different data and/or methods can create crucial differences in the magnitude of gasoline price elasticity. Nevertheless, the overwhelming evidence from this survey of econometric studies suggests that the short run price elasticity typically falls between –0.2 to –0.5, and long run price elasticities will typically tend to fall in the –0.6 to –0.8 range (see Graham and Glaister, 2002).

We can approximately translate own-price elasticities of gasoline demand to the substitution elasticity of the CES production function via the formula (Hyman *et al.*, 2003):

$$\sigma_{F,p} = -\frac{\eta_{F,p}}{1-\alpha_F}, \tag{7}$$

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[5] Other versions of MARKAL can explore the effect of differential maintenance and choice of auto size for given technology, but other than sensitivity testing of the effect of alternative assumptions about the share of cars and light trucks (i.e., pickups, vans, SUVs) these features were not included in the analysis by Schäfer and Jacoby.

**Table 6**. Survey of Econometric Studies on Gasoline Price Elasticity

| Authors | Country/region | Gasoline price elasticity | | Type of data |
|---|---|---|---|---|
| | | SR | LR | |
| Drollas (1984) | UK | –0.26 | –0.6 | Country data, 1950-1980 |
| | West Germany | –0.41 to –0.53 | –0.8 to –1.2 | |
| | France | –0.44 | –0.6 | |
| | Austria | –0.34 to –0.42 | –0.8 to –0.9 | |
| Sterner et al (1992) | Canada | –0.25 | –1.07 | Country data, 1960-1985 |
| | US | –0.18 | –1 | |
| | Austria | –0.25 | –0.59 | |
| | Belgium | –0.36 | –0.71 | |
| | Denmark | –0.37 | –0.61 | |
| | Finland | –0.34 | –1.1 | |
| | France | –0.36 | –0.7 | |
| | Germany | –0.05 | –0.56 | |
| | Greece | –0.23 | –1.12 | |
| | Ireland | –0.21 | –1.62 | |
| | Italy | –0.37 | –1.16 | |
| | Netherlands | –0.57 | –2.29 | |
| | Norway | –0.43 | –0.9 | |
| | Portugal | –0.13 | –0.67 | |
| | Spain | –0.14 | –0.3 | |
| | Sweden | –0.3 | –0.37 | |
| | Switzerland | 0.05 | 0.09 | |
| | UK | –0.11 | –0.45 | |
| | Australia | –0.05 | –0.18 | |
| | Japan | –0.15 | –0.76 | |
| | Turkey | –0.31 | –0.61 | |
| | Mean | –0.24 | –0.79 | |
| Dahl & Sterner (1992) | OECD | –0.26 | –0.86 | Country data, 1960-1985 |
| Eltony (1993) | Canada | –0.31 | –1.0073 | Micro-level data, 1969-88 |
| Goodwin (1992) | | –0.27 | –0.71 | Time-series |
| | | –0.28 | –0.84 | Cross-section |
| Johansson & Schipper (1997) | 12 OECD | | –0.7 | 1973-1992 |
| Puller & Greening (1999) | US | –0.35 | –0.8 | US household data |
| Agras & Chapman (1999) | US | –0.25 | –0.92 | Annual US data, 1982-95 |
| Haugton & Sarkar (1996) | US | –0.09 to –0.16 | –0.22 | Annual US States data |
| Nivola & Crandall (1995) | US | –0.1 to –0.4 | –0.6 to –1.1 | US data |
| Graham & Glaister (2002) | US | –0.2 to –0.5 | –0.23 to –0.8 | |
| | OECD | –0.2 to –0.5 | –0.75 to –1.35 | |
| Hagler Bailly (1999) | Canada | –0.1 to –0.2 | –0.4 to –0.8 | |

Sources: based on Graham & Graister (2002); Nivola & Crandall (1995); Haugton & Sarkar (1996); Agras & Chapman (1999); Hagler Bailly (1999).

where $\sigma_{F,p}$ represents the constant elasticity of substitution between energy and other inputs, $\eta_{F,p}$ stands for the own-price elasticity of fuel demand, and $\alpha_F$ is the cost share of fuels in the production function. From household budget data described in section 2, $\alpha_r$ is about 0.08% in the US. Using Equation (7), based on the own-price elasticity range in Table 2, the short run substitution elasticity is between 0.22 to 0.54 and the long run substitution elasticity is 0.65 to 0.87 in the US.[6]

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[6] In the EPPA model, we gradually increase elasticity of substitution between fuel and non-fuel inputs in the household transportation sector from 0.3 to 0.7 over a century.

### 3.3 Other Issues

Modeling the household production of transportation service raises other issues that we mention briefly here as directions for future investigation, and as caveats to the use of our formulation. For example, consider **Figure 4** and what other factor inputs, represented by the box labeled A, might appropriately enter household production. First, consistency of treatment of returns to capital in the household sector would attach an opportunity cost of funds invested in automobiles as a payment to the capital “lent to” production of own-supplied transport services. Only financing costs paid to lending firms are currently included as a flow to the services sector. The value of any cash payments for vehicles, or the value of the vehicle once loans are paid off, incurs no such cost in the model when in reality there is an opportunity cost of the capital in lost investment income or continued interest charges on other loans. Similarly, market data do not account for any household supplied parking and vehicle storage costs (e.g., garage, driveway, parking areas owned by the household). A full-cost accounting of automobile ownership and use would apply a rental cost to the own-supply of transportation services and a corresponding payment to the household for the capital. Where the household rents a dwelling, some part of that rental may be correctly attributed to the own-supply of transportation services if garage/parking areas are provided along with the housing rental.

One might also consider including a labor cost both in own-supply and purchased transportation to account for travel time. Such a fuller accounting of household labor input could be important in explaining and projecting modal shifts as wages or fuel prices change. Detailed transportation surveys suggest travel time as an important explanatory variable for travel mode choice (Schäfer and Jacoby, 2003). To accurately model this process would likely require further disaggregation of purchased transportation and transportation demands. For example, for the daily work trip automobiles may have a time advantage in competition with public transportation, but for long-distance travel automobiles have a time disadvantage compared with air or rapid rail travel.

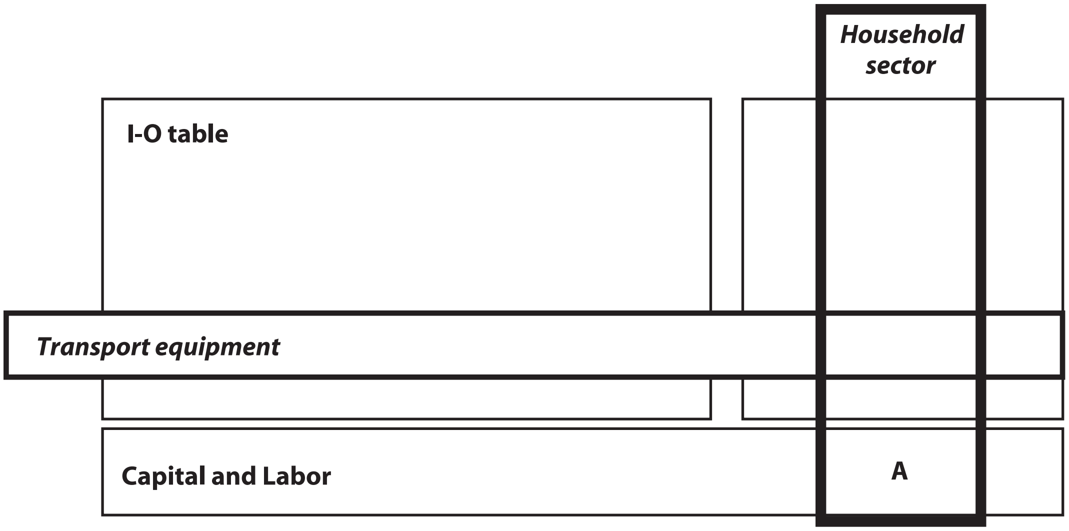

**Figure 4**. Household Production of Transportation, Broader Considerations

Adding these costs and income flows to households would expand the accounts beyond what is currently included in the market economy as part of GDP, consumption, and income, but such a change would more fully consider the full cost of vehicle ownership and real differences between own-supplied and purchased transportation services. Public supply of highway infrastructure and maintenance of it ought also to be accounted for. In the US, fuel taxes largely support highway construction. We have included them as part of the price of fuel. They thus have no distortionary effect but we have not treated the public sector as explicitly providing this good to own-supplied transportation. Additionally, one might be concerned about other non-market costs of transportation such as contribution to air pollution. We mention these issues as possibilities for further research and data development but have not pursued their potential importance beyond the brief discussion here. To implement them would require considerable effort to estimate or approximate these additional costs, for which data are not readily available, and which would require more elaborate modifications and adjustments to GTAP.

## 4. EXEMPTING TRANSPORTATION FROM GREENHOUSE GAS CONTROL MEASURES

To study the effect of exempting transport from a carbon policy we focus on two regions which represent a wide range of pre-existing fuel taxes. **Table 7** provides the GTAP tax rate structure for refined oil use by households and industrial transport in several regions. USA tax rates are reported as zero here because we assume the existing transport fuel tax ($0.184 per gallon) is a user charge covering highway construction. The tax revenues are designated for highway repair and construction through the Federal Highway Trust Fund. The European tax rates for fuel used in transportation are the highest in the world. The revenues from these taxes have no specific designation, but instead are part of general revenue. They may correct in part for non-climate-related external effects of fuel use—such as air and noise pollution, congestion, or other spillovers—but there is scant evidence that this purpose reflects a substantial fraction of prevailing tax levels (Babiker, Reilly and Viguier, 2004; Newbery, 1992). We thus treat them as tax distortions rather than as a user charge. The actual rates vary somewhat among EU countries, fuels, and sectors but were generally in the range of $2.80 to $3.80 per gallon for gasoline (OECD/IEA, 2004).

In terms of the shares of carbon emissions from transportation, the USA and Europe are about the same. From **Table 8**, industrial and household transportation emissions add up to 25.1% of total emissions in USA and 26.4% in Europe. The similar if somewhat larger share of transport emissions in Europe is at first surprising, because the high fuel taxes in Europe should lead to less vehicle use and more efficient vehicles, as suggested by our elasticity estimates. In fact, the

**Table 7**. Fuel Tax Rates

| | USA | EUR | CAN | JPN | ASI | AFR |
|---|---|---|---|---|---|---|
| Tax Rate on Household Demand for ROIL | 0 | 4.7 | 1.3 | 2.7 | 0.3 | 0.4 |
| Tax Rate on Industrial Transport Demand for ROIL | 0 | 2.5 | 0.7 | 0.9 | 0.07 | 0.2 |

**Table 8**. Sectoral $CO_2$ Emissions Share (%)

| | **USA** | **EUR** |
|---|---|---|
| AGRI | 2.9 | 1.8 |
| ROIL | 2.7 | 3.3 |
| ELEC | 40.8 | 28.6 |
| EINT | 12.3 | 16.4 |
| OTHR | 3.0 | 4.0 |
| SERV | 9.5 | 11.5 |
| Industrial TRAN | 12.7 | 12.3 |
| Household TRAN | 12.4 | 14.1 |
| Household | 3.8 | 7.9 |

similar share in the USA and Europe is not inconsistent with greater vehicle efficiency and less vehicle use. The reason for the similar emission shares is that the US is more carbon intensive across the economy, primarily because of the heavy reliance on coal in electric utilities. With emissions comparatively higher in the rest of the economy, the heavy use of vehicles and relatively inefficient fleet still leads to no greater share of economy-wide emissions in the US than in Europe. The fact that the shares are similar between the regions means that, in both regions, the exemption of transportation from an emission cap will impose a large (and similar) additional reduction burden on the sectors that remain capped.

To estimate the welfare costs of exempting industrial and household transportation sectors from a carbon policy, we consider a scenario where, starting in 2010, a region limits its carbon emissions to 25% below the 2010 non-policy level, and holds that absolute constraint to 2025. We construct the following cases, imposing this restriction individually on the US and on Europe.

| | |
|---|---|
| Ref: | Reference case with no carbon policy |
| Case 1: | 25% reduction, with economy-wide emissions trading |
| Case 2: | 25% reduction, with no emissions trading among sectors |
| Case 3: | As in Case 1, with industrial transport excluded from the restriction |
| Case 4: | As in Case 1, with household transport excluded from the restriction |
| Case 5: | As in Case 1, with both industrial and household transport sectors excluded |

No international trade in emissions is allowed. There is some policy effect on goods trade, which is included in the model, but its influence on the results shown here is insignificant.

The reference case serves as a basis of comparison, to allow estimation of the welfare cost of the policy cases. In Case 1 all sectors within each economy are allowed to trade their carbon emissions. In Case 2 all sectors take an equal share of the emissions reduction without any possibility of emission trading with other sectors. In Cases 3 to 5 non-excluded sectors participate in emission trading, while excluded sectors have no limit on their carbon emissions. In Cases 3 to 5 we require that the economy continue to meet the overall target reduction. Exclusion of one or more sectors thus means that the remaining sectors must further reduce their emissions to make up for in the excluded sectors.

**Table 9** reports the results for the US, and **Table 10** contains results for Europe. In both regions, the policy including economy-wide emissions trading (Case 1) is less expensive for all years than the imposition of independent sectoral caps (Case 2). Differential growth in emissions among sectors, and differential opportunities to reduce emissions, mean there is some benefit from emissions trading. The specific benefit of trading depends, of course, on the sectoral allocation. In some allocation schemes there is an attempt to consider projections of growth for sectors, or opportunities to abate emissions. If projected exactly, sectoral caps could achieve the emissions trading result, and there would be no benefit from trading. The presumed superiority of emissions trading in terms of economic efficiency, however, is that trading can correct for our inability to project emissions with accuracy. With trading, such errors in projection do not lead to loss of economic efficiency. More generally, the simple case for trading is that economic efficiency is separated from the problem of how to allocate emissions, leaving that decision to be made on other grounds.[7] It is noteworthy that the percentage welfare loss in Europe is considerably greater than in the US, a result to which we will return.

For the US, Cases 3-5 (which exempt the transportation sectors) lead to increased carbon tax rates for remaining sectors and higher welfare costs for the economy as a whole. Case 5 is the most costly, exempting sectors that account for 25% of emissions, and thereby requiring proportionally greater reductions in the other sectors. This exemption roughly doubles the economy-wide welfare loss over the period 2010 to 2025. Even though industrial and household transportation contribute a similar share of emissions for the US, we find that the industrial transportation exemption increases the policy cost slightly more than the household transportation exemption.

**Table 9**. Change in Welfare in USA (%), Economy–Wide Emissions Held 25% Below 2010 Baseline Level

| | **Case 1**<br>*Economy–wide trading* | **Case 2**<br>*Sectoral targets, no trading* | **Case 3**<br>*Industrial transport exempt* | **Case 4**<br>*Household transport exempt* | **Case 5**<br>*All transport exempt* |
|---|---|---|---|---|---|
| 2010 | – 0.23 | – 0.26 | – 0.31 | – 0.30 | – 0.41 |
| 2015 | – 0.38 | – 0.45 | – 0.52 | – 0.49 | – 0.67 |
| 2020 | – 0.53 | – 0.69 | – 0.72 | – 0.68 | – 0.94 |
| 2025 | – 0.71 | – 1.02 | – 0.98 | – 0.91 | – 1.27 |

**Table 10**. Change in Welfare in Europe (%), Economy–Wide Emissions Held 25% Below 2010 Baseline

| | **Case 1** | **Case 2** | **Case 3** | **Case 4** | **Case 5** |
|---|---|---|---|---|---|
| 2010 | – 1.33 | – 1.83 | – 1.36 | – 1.01 | – 0.99 |
| 2015 | – 1.75 | – 2.62 | – 1.79 | – 1.37 | – 1.35 |
| 2020 | – 2.30 | – 3.59 | – 2.36 | – 1.81 | – 1.76 |
| 2025 | – 2.81 | – 4.78 | – 2.90 | – 2.23 | – 2.19 |

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[7] The more complex case of allocating permits versus selling and using the revenue to offset existing distortionary taxes is one well-recognized caveat to this simple result. See, e.g., Babiker, Metcalf, and Reilly (2003).

The European results for Cases 3-5 (Table 10) show that exempting the transportation sectors, or even just the household transport sector alone, serves to *reduce* the economy-wide cost of the restriction. The result is counter-intuitive: limiting flexibility and forcing greater reductions on a narrower part of the economy should under most circumstances increase cost. In fact, we do find that the carbon prices rise in the exemption cases compared with Case 1. But costs measured in terms of lost economic welfare fall if household transport is exempted. This result occurs because climate policy designed to limit carbon emissions affects fuel cost, and fuels in Europe (and most particularly the gasoline that dominates household use) are already taxed at a high rate. There is thus a two-part effect: a direct cost of the emissions restriction and a distortion cost caused by the interaction of that restriction with existing fuel taxes (and this distortion cost is removed or decreased in the exemption cases). Paltsev *et al.* (2004b) describe in more detail how the general equilibrium economic effects of a policy can differ from a simple marginal abatement curve analysis. Comparing the USA, where exemptions of transportation increased the cost of restriction, to the European results where exemptions can actually reduce the cost, we can infer that the tax interaction effect is a significant cost.

An initial reaction to these results is surprise that the tax distortion effects are so large that avoiding them reduces cost, even when far deeper cuts must be made in the sectors that remain under the cap. **Figure 5** illustrates how the distortion costs can be so large. We show a demand for fuel, assuming a supply at constant marginal cost supply yielding a price of fuel ($p_f$). The existing fuel tax (t) results in the tax-inclusive price of fuel of $p_f + t$. The economic cost of fuel tax policy is the triangle labeled *a*. A carbon cap results in a carbon price labeled $P_C$. The fuel price (tax and carbon price inclusive) is thus $p_f + t + P_C$. As shown by Paltsev *et al.* (2004b) a

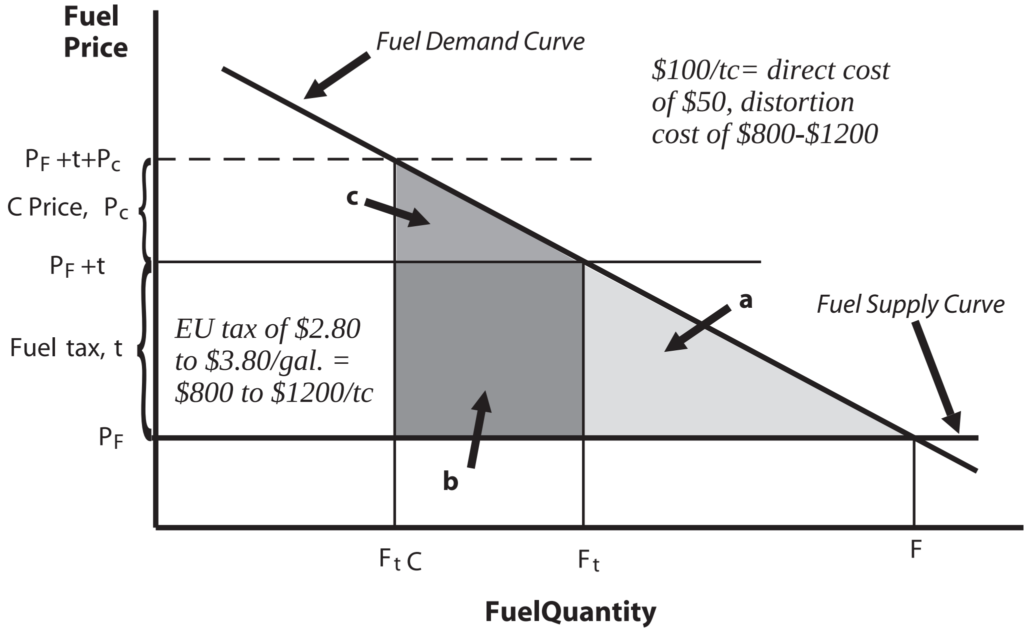

**Figure 5**. Effects of Tax and Carbon Policy Interactions on Carbon Policy Costs

marginal abatement curve cost approach evaluates the carbon policy cost as the triangle labeled *c*. But, the full cost of the policy includes the tax interaction loss represented by the rectangle labeled *b*. Fuel taxes in Europe which for gasoline are on the order of \$2.80 to \$3.80 per gallon. Given the carbon content of gasoline this equates to a carbon tax equivalent of \$800 to \$1200 per ton C. Considering a carbon policy that resulted in a carbon price of \$100 per ton C, which is the approximate level of carbon tax we obtain in these simulations, the direct cost per ton is the triangular area, $^1/_2 \times \$100 = \$50$. But the tax interaction effect is a rectangle. For one ton this is $1 \times \$800$ (or up to \$1200). Thus, in the transport sector the distortion cost in Europe is on the order of 16 to 24 times greater than the direct carbon cost. Thus, it is not hard to see how avoiding the tax distortion cost by exempting transportation saves more than the increased cost on other sectors because they must reduce emissions further.

The results presented in Tables 9 and 10 show how the interplay between carbon policies and pre-existing taxes can differ across countries. It is important to represent these tax distortions, and other ways in which real economies differ from the idealized textbook economy. In this case, distortions increase the cost, and exempting sectors in Europe avoided these added tax interaction effects. In general, the interaction of policies with taxes or other economic distortions can either increase or decrease the policy cost. As this comparison between the US and Europe shows, one must be cautious in extrapolating the results from a country specific analysis to other countries.

## 5. CONCLUSIONS

In order to model the household transportation sector explicitly, we have created a methodology based on the use of the GTAP system and additional data for household expenditures on own-supplied transport by region. The surveys report that household expenditures of own-supplied transport are about 10% of total household expenditures, and refined oil expenditures in household transportation are on the order of 90% of total household oil use. Based on the developed methodology, we have modified the household transportation sector in the EPPA model. As shown in Paltsev *et al*. (2004a) and Schaefer and Jacoby (2003) it is possible to capture the broad behavior of a disaggregated model with a more highly aggregated model if one adjusts the elasticity parameters to match the disaggregated model. But, it is hard to know what the correct parameters for the aggregate model unless one can extensively compare performance of the aggregate model with the detailed models or directly to relevant econometric results. That alone makes a case for disaggregating key sectors of the economy.

Here we explored another important reason for greater disaggregation. Tax interaction effects can be important, and with differential tax rates across sectors it is necessary to maintain sufficient disaggregation to represent this variation. The magnitude of the possible effects is demonstrated for a set of cases that exclude industrial and household transport from a carbon policy. In the absence of pre-existing distortions, as is the case in the US, exemption of transportation sectors implies increased carbon tax rates for other sectors and higher costs for an economy as a whole. With existing distortions, as with high transport fuel taxes in Europe, the policy interaction effects are important in estimating costs. We showed that exemption of the already highly taxed transport sector actually decreases the estimated cost of meeting a carbon constraint, even when the capped sectors are required to cut further to make up for the sector exemptions. The disaggregation of household transportation sector thus allows better use to be made of the extensive work done on transportation sector and the substitution possibilities it offers. By disaggregating the transport sector and being able to select elasticities that more accurately characterize substitution possibilities there we have been able to more accurately characterize the economic costs of a sample policy for greenhouse gas reduction.

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