MIT Joint Program on the Science and Policy of Global Change

Disaggregating Household Transport in the MIT-EPPA Model

Sergey Paltsev, Laurent Viguier, Mustafa Babiker, John Reilly and K.H. Tay

Technical Note No. 5
July 2004

The MIT Joint Program on the Science and Policy of Global Change is an organization for research, independent policy analysis, and public education in global environmental change. It seeks to provide leadership in understanding scientific, economic, and ecological aspects of this difficult issue, and combining them into policy assessments that serve the needs of ongoing national and international discussions. To this end, the Program brings together an interdisciplinary group from two established research centers at MIT: the Center for Global Change Science (CGCS) and the Center for Energy and Environmental Policy Research (CEEPR). These two centers bridge many key areas of the needed intellectual work, and additional essential areas are covered by other MIT departments, by collaboration with the Ecosystems Center of the Marine Biology Laboratory (MBL) at Woods Hole, and by short- and long-term visitors to the Program. The Program involves sponsorship and active participation by industry, government, and non-profit organizations.

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.

The Program's Technical Notes series is intended to document technical research details for our own use, and also for other researchers who may wish to recreate or update the work. Further information is available by request to the Program Office at the numbers listed below.

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
MIT E40-428
77 Massachusetts Avenue
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/

Printed on recycled paper

Disaggregating Household Transport in the MIT-EPPA Model

S. Paltsev[1], L. Viguier[2,3], M. Babiker[4], J. Reilly[1], and K.H. Tay[1]

[1] *MIT Joint Program on the Science and Policy of Global Change, USA*
[2] *Faculty of Economics and Social Sciences, University of Geneva, Switzerland*
[3] *Swiss Federal Institute of Technology, Lausanne, Switzerland*
[4] *Arab Planning Institute, Kuwait*

Abstract: The GTAP version 5 dataset has three transportation sectors. However, household transportation expenditures related to private automobiles are not represented explicitly in the data. We augment the existing GTAP data to separately disaggregate household transportation and explore the implications of this extension in the MIT Emissions Predictions and Policy Analysis (EPPA) model. Climate policy designed to limit carbon emissions affects the fuel cost. Thus, we calculate a change in welfare for a carbon policy scenario with and without a separate household transportation sector. Disaggregating transport into purchased and own-supplied increases the welfare costs of a carbon policy by around 5-20% in different regions. A sensitivity analysis with respect to different values of elasticities of substitution in household transportation is performed. The disaggregation allows us to make better use of the extensive work in the transportation sector to understand substitution possibilities.

1. Introduction

An explicit representation of household transportation is important for the quantitative analysis of energy and environmental policy. Household transportation is among the more rapidly growing energy uses, fuels in transportation are often taxed at much higher rates than in other sectors, policies directed toward energy use and environmental control generally treat the transportation and automobile energy efficiency differently than other uses, and substitution toward or away from automobile use in response to price and policy changes at the first level is likely to be toward purchased transportation. Aggregation of automobile fuel use with other fuels makes it impossible to study these factors explicitly. Many researchers use the GTAP dataset (Hertel, 1997), which accommodates detailed accounts of regional production and bilateral trade flows. The GTAP version 5 dataset (Dimaranan and McDougall, 2002) has three transportation sectors. However, household transportation expenditures related to private automobiles are not represented explicitly in the data. We augment the existing GTAP data to separately disaggregate household transportation and explore the implications of this in the MIT Emissions Predictions and Policy Analysis (EPPA) model.

The EPPA model is a recursive-dynamic multi-regional general equilibrium model of the world economy (Babiker *et al.*, 2001), which is built on the GTAP dataset and additional data for greenhouse gas (CO_2, CH4, 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). The EPPA model has been used in a wide variety of policy applications (e.g., Jacoby *et al.*, 1997; Jacoby and Sue Wing, 1999; Reilly *et al.*, 2002; Bernard *et al*., 2003; Paltsev *et al.*, 2003).

Transportation was disaggregated in EPPA3 for some special studies of sectoral policies in the USA (Babiker *et al.*, 2000b) and the European Union (Viguier *et al.*, 2003, Babiker *et al.*, 2003), and for a comparison with a more detailed sectoral model of transportation (Schafer and Jacoby, 2003). In that work, a methodology was developed to create a household supplied transportation sector (i.e., private automobiles) by augmenting the GTAP data with additional data on household transportation. We adopt an approach similar to that developed in this earlier work with EPPA, with an emphasis on identifying data to extend the analysis to all regions of the world and to accommodate the changes in the sectoral coverage of GTAP5. In identifying generally available data and a modeling approach, a goal is to make it possible for these data to become a regular component of GTAP.

The paper is organized in the following way. In the next section we briefly describe the modeling approach, data required, and the sources for household transportation data needed to augment the existing GTAP data. Presentation of the material in this section is general and not tied to any particular model. Section 3 discusses methodological issues regarding capital accounting in the personal transport sector. Section 4 presents the modified household transportation sector in the EPPA model, as we have disaggregated the sector into purchased and own-supplied transport. The corresponding adjustments to the household demand structure are also presented there. In Section 5 we report model simulation results to show the implications of these changes. In section 6, we conclude.

2. Data Requirements

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. Our strategy for modeling household transportation is to create a household production activity that combines goods purchased from industry to produce an 'own-supplied' transportation service that represents use of personal automobiles. Commercial transportation services purchased by the household from ATP, WTP, or OTP are already treated in the standard GTAP5 data, and this allows us to represent explicitly substitution possibilities between own-supplied transportation and purchased transport services. The missing component in GTAP, however, is the transportation service produced by household itself, i.e., that provided by private automobiles. 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 the own-supplied transportation activity but in other cases only a part of a sector final consumption is used in transportation. The data problem is to identify 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 accurately identify purchases of refined oil (gasoline and diesel fuel) used to fuel vehicles separately from that used for home heating and other household purposes.

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

$$OWNTRN_r = T\_ROIL_r + AC_r + \sum_i OC_{ir} \,, \qquad (1)$$

where $OWNTRN_r$ stands for household expenditures on own-supplied transport in a region *r*, and T_ROIL_r, AC_r, and OC_{ir} are, respectively, expenditures on refined oil used in household transportation (i.e., gasoline and diesel fuel), vehicles, and other operating costs such as maintenance and repairs, insurance, financing costs, and parking represented as usage of sectors *i*.

It is useful to define household expenditures of own-supplied transport as a share, ES_r, of total household expenditure. Then we can derive $OWNTRN_r$ as:

$$OWNTRN_r = ES_r \times CONS_r \qquad (2)$$

with $CONS_r$, total household expenditure in a region *r*, available directly from the GTAP database.

It is also useful to define household expenditures on the refined oil products for own-supplied transportation as a share, OS_r, of total household expenditure on all refined oil products, and

TOS_r as total refined oil expenditure by the household. Often household expenditure data do not provide T_ROIL_r, but other energy surveys provide data on fuel expenditures. In that case T_ROIL_r can be derived as:

$$T\_ROIL_r = OS_r \times TOS_r \quad (3)$$

with TOS_r available directly from the GTAP database.

Based on equations (1-3), in order to disaggregate household transportation we need the data for AC_r, OC_{ir}, ES_r, and OS_r. National surveys report that household expenditures of own-supplied transport is on the order of 0.1 of total household expenditures for developed countries, and refined oil expenditures in household transportation is on the order of 0.9, 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); (3) transport services (air tickets, railway tickets, etc.). Items 1 and 2 sum to $OWNTRN_r$. As shown in table 1, these data were used for the US, Canada, the EU, and Mexico. For the European Union we use data from household budget surveys by Member States (Eurostat, 1999). This database provides estimates for ES_r in Europe by adding 3 items: (1) car purchase; (2) motor fuels (including greases, etc); (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 (UN, 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 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, 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 quantity (tons of oil equivalent) for OECD countries (IEA, 2000b) and non-OECD countries (IEA, 2000c), and 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. It means that the OS_r coefficients will tend to be overestimated. 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 on 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 moves of 93.7%. In the United States, the share of refined oil products for own-supplied transportation in total household expenditure is estimated to be 90% from the statistics of the U.S. Department of Commerce, 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 for 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 TRD sector (sales, maintenance, repair of motor vehicles, and trade margin on sales of automotive fuel are part of this sector), ISR sector (insurance), and OBS sector (which includes renting of transport equipment). As implemented in EPPA, however, GTAP sector data are aggregated, and we assume that OC_{ir} is supplied by a 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 while for other countries data are more limited and some further assumptions were 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.

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 a depreciation rate this implies the level of the capital stock. Own-supply from the household sector is not marketed and thus there is 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 or would be a basis for comparison, however, these may not be representative of the entire vehicle stock as new vehicles are typically leased for a 3-year period and then sold. Moreover, data on real leasing costs are not completely transparent as they depend on features of the lease such as limits on mileage, additional payments if mileage limits are exceeded, and the terms under which the vehicle can be purchased at the end of the lease.

At issue, nevertheless, 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. Getting relative cost shares correct is important because these affect the relationship between substitution elasticities and more frequently measured own-price elasticities of demand, and the share values can affect 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.

Regarding shares, available evidence suggests the fuel share we have calculated for the GTAP data from the above information is approximately consistent with that one gets by calculation of total annualized costs of vehicle ownership when conventional cost components are included. In the US, for example, the American Automobile Association (AAA) makes an estimate of the average annual cost of owning a vehicle accounting for depreciation.[1] Assuming 10,500 miles per year per vehicle,[2] 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 necessarily match exactly these estimates, 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 calculated fuel shares for other regions sometimes differ substantially. For the EU, for example, it is 24%, 3 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 match exactly our estimate based on GTAP data[3]. These calculations show that the tax-inclusive fuel price can 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.

Regarding the explicit treatment of capital vintaging in static and recursive-dynamic models, simulation results are often determined through a choice of the value of the elasticity of

---

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

[2] This is an average annual mileage per vehicle based on EPA data (EPA, 2002) on mileage by vehicle age class. Mileage of each vehicle age was weighted by the share of that age class in the US 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.

[3] 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).

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. Schafer and Jacoby (2003) compared the version of EPPA3 with transportation with a detailed transport model that treated explicitly vehicle stocks and found that initial EPPA elasticities over-estimated responses compared with the detailed model, especially in the nearer term. They thus lowered the elasticities in near term periods and raised them in more distant periods to correct for the lack of an explicit treatment of stock turnover in EPPA. The basic result of greater substitution potential in the longer run is compelling. A possible limit for the specific elasticities estimated by Schafer and Jacoby (2003), however, is that they focused on new vehicle technology and not in any great detail on substitution among existing models and features. For example, the option to purchase a vehicle with a smaller engine, smaller vehicles generally, or the potential ability of consumers with multiple vehicles to shift mileage toward the more efficient vehicle they already own if fuel prices rise were not represented in their detailed model. 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 *et al*., 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. However, Greene *et al.* (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*.

To relate 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 write (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.

In Jacoby and Schafer (2003), the estimation of the own-price elasticity of gasoline demand coming from the MARKAL model assumes implicitly that $\eta_{M,p} = 0$. The bottom-up MARKAL model computes $\eta_{F,p}$ by taking into account technology changes in response to fuel price changes. For example, an increase in fuel price will speed up the penetration of light-duty vehicles resulting in lower energy demand. This technology approach may underestimate the efficiency elasticity as it focuses mostly on technologies not currently offered in vehicles and does not consider the effects of a change in fuel price on the energy efficiency through (a) substitutions among existing car models/options (b) or through changes in drivers' behavior. For example, consumers switching to smaller cars or choosing smaller/more efficient engines when they purchase a new car are currently available options that could produce an efficiency response to a rise in the fuel price. They might also maintain the car to increase efficiency (e.g., tune-ups, maintenance of tire pressure, etc). According to Greene *et al* (1999), the US the long-run fuel price elasticity of vehicle miles travel ($\eta_{M,p}$) is estimated in the range of -0.2 to –0.3. Combining this with 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 does not consider all the possibilities for increasing efficiency this might be considered a low estimate.

Table 2 shows that the use of specific data or methodological approaches can create crucial differences in the magnitude of gasoline price elasticity. Nevertheless, the overwhelming evidence from this survey of econometric studies suggests that 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):

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

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 α_F is the cost share of fuels in the production function.

From household budget data described in section 2, α_r is about 0.08 percent 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[4].

The household production of a transportation service raises some other possibilities that we mention briefly here as directions for future investigation, and as caveats to use of our formulation. For this purpose, consider Figure 1 and what other factor inputs, the box labeled A, might appropriately enter household production. First, consistency of treatment of returns to

[4] 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.

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 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 does not account 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 (Jacoby and Schafer, 2003). To accurately model this process would likely require further disaggregation of purchased transportation and transportation demands. For example, in daily commuting to work automobiles may have a time advantage when competing with many forms of public transportation but for long-distance travel automobiles have a time disadvantage compared with air or rapid rail travel.

Adding these costs and income flows to households would expand the accounts beyond what are currently counted in the market economy as part of GDP, consumption, and income but 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. In the US fuel taxes largely support highway construction but we have not treated the public sector as explicitly providing this good to own-supplied transportation and so fuel taxes remain a pure distortionary tax. 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 would require more elaborate modifications and adjustments to GTAP.

4. Representation of the Transportation Sector in EPPA

The EPPA model aggregates the GTAP dataset into 16 regions and 10 sectors shown in Table 3 according to the mapping provided in Appendix 1. The base year for 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 is disaggregated further than the GTAP data for energy supply technologies and includes a number of 'backstop' technologies—energy supply technologies that were not in use in 1997 but could come into use in the future under some energy price or climate policy conditions. This additional disaggregation and technology specification does not have a substantial direct effect on the transportation modeling we developed here. EPPA models sectors and consumption using nested Constant Elasticity of Substitution (CES) production functions (or the Cobb-Douglas and Leontief special cases of the CES) and is written in GAMS-MPSGE.

4.1 Inter-Industry Transportation

Transport in the EPPA model is represented by two activities: industry transportation sector (aggregating the modal splits in the base GTAP5 data) and the household transportation sector discussed above. The industry transportation (TRAN) supplies transport services (both passenger and freight) to other sectors of the economy and to households. The nesting structure of the industry transportation sector is depicted in Figure 2.

The output of the TRAN sector is produced using energy, capital, labor, and intermediate inputs from different industries. The values for elasticities in the industry transportation sector, labeled as s1..s7, are provided in Table 4. At the top nest, intermediate inputs and the energy-labor-capital bundle are modeled as a Leontief composite. Both domestic and imported intermediates are used in the production activities, with elasticity of substitution between domestic and imported bundle, 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 the value-added into labor and capital. The data for the modeling of this sector come directly from the OTP (other transport), ATP (air transport), and WTP (water transport) sectors of the GTAP dataset.

4.2. Transportation in the Household Sector

Households consume both own-supplied (i.e., private cars) and purchased transport. Purchased transport comes from the industry transportation (air travel, water travel, rail service, trucks, etc.) sector described above. Own-supplied transportation services are provided using inputs from the other industries products (purchases of vehicles), services (maintenance, insurance, tires, oil change, etc.) and refined oil (fuel) sectors.

As noted earlier, the EPPA model uses a nested CES structure to describe preferences as well as production, as this specification is compatible with the MPSGE solver. Figure 3 shows the household sector as it existed in EPPA without disaggregation of own-supplied transportation. As illustrated, the nesting structure aggregates all Armington goods into a single consumption good, which is then aggregated together 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 5. The elasticity between non-energy inputs to 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. [5]

---

[5] This specification helps to capture the changing structure of consumption as development occurs that otherwise would not be captured by a CES function that is homogenous of degree 1, while allowing solution of the model using

Figure 4 illustrates the addition of the own-supplied transport nest. As described in section 2, 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 non-energy bundle in consumption. As shown in Figure 4, 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 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 6. A sensitivity analysis with respect to different values of elasticities is reported in the next section.

The allocation of shares of T_ROIL, T_SERV, and T_OTHR sectors, presented in Figure 4 for the household transportation is done in the following way:

- 1. Using the data described in Section 2 we determine the share of spending on own-transportation of a total household's expenditures (ES_r), and the share of refined oil used for private transport as a total consumption of refined oil by a household (OS_r). The results are presented in Table 7.

- 2. Using equation (2), we calculate the spending by a household in a region R on its own-supplied transport: $OWNTRN_r = ES_r \times CONS_r$, where $CONS_r$ is the total household consumption expenditure in EPPA. The data for $CONS_r$ come from the GTAP aggregate data. The resulting number represents the output of the household own-supplied transport sector.

- 3. Using equation (3), we compute a Refined Oil input to household transportation as: $T\_ROIL_r = OS_r \times TOS_r$, where TOS_r is total household refined oil consumption in EPPA. The data for TOS_r parameter come from the GTAP aggregate data.

- 4. The Other Industries sector input represents AC_r in equation (1). In EPPA we denote it as T_OTHR_r. The data for this input are taken from the GTAP data for the MVH sector, which represents a manufacture of motor vehicles.

- 5. To represent $\sum_i OC_{ir}$ in equation (1), the Services sector input is calculated as a residual: $T\_SERV_r = OWNTRN_r - T\_ROIL_r - T\_OTHR_r$.

- 6. We adjust the commodity accounts for $ROIL_r$, $OTHR_r$ and $SERV_r$ sectors within the household consumption block in EPPA.

the MPSGE algorithm, which was designed for the homogeneous CES family of production functions. For more details on estimated relationship and its effects on emissions, see Lahiri, *et al*., 2000.

- 7. We adjust the account for the industrial transport sector ($TRAN_r$) within the household consumption block in EPPA to get a household transport demand to a separate nest in a consumption function: $TOTTRN_r = OWNTRN_r + PURTRN_r$.

5. Illustrative Results

By introducing the change described above and specifying elasticities of substitution for energy and between own- and purchased transportation that are representative of the literature, we expect that differences, if they occur from the model without transport disaggregated, will show up in policy cases that increase fuel prices. Climate policy designed to limit carbon emissions affects the fuel cost. To consider what difference the addition of household transportation makes, we calculate a change in welfare for a carbon policy scenario with and without disaggregation of the household transportation sector. Here we consider a scenario where all countries of the world in 2010 return to their 2000 carbon emissions. There is no international emissions trading. We do not consider this scenario as a realistic policy, rather we want to consider the impact of adding household transportation for the whole world. Table 8 presents the results for a change in welfare due to a carbon policy for the EPPA model without a separate household transportation sector and a version of the model with disaggregated household transportation. We also show a percentage difference between the results from these two versions of the model.

As can be seen, disaggregating transport into purchased and own-supplied increases the welfare costs of a carbon policy in almost all regions, but the increase varies from very little increase, to around 10% in many regions, to as much as 28% in Europe. The result follows from the fact that the substitution elasticity between fuel and non-fuel inputs was somewhat lower in the transport sectors than between energy and non-energy goods. However, the energy-non-energy substitution elasticity is not the only relevant parameter. In making this change, there is no longer direct substitution between refined oil used in transport and other fuels, but there are additional substitution possibilities between purchased and own-supplied transportation.

To examine which of the elasticities are most important we separately vary the potentially important elasticities. These elasticities are not known with certainty in any case and so it is useful to see how sensitive results are to different specifications. We show results for 6 regions (Tables 9-12) that are generally representative of the regions in the model.

As tables 9-12 show, the results are insensitive to elasticity of substitution between services and other inputs (s17), modestly sensitive to elasticity of substitution between transport consumption and other consumption (s9) and between purchased and own-supplied transport (s15), and very sensitive to elasticity between fuel and other inputs to own-supplied transport (s16). In fact, a choice of s16=0.8 produces welfare results very close to those without a separate household transportation sector. The somewhat surprising result was the insensitivity of results to the own- and purchased transportation elasticity. However, this insensitivity can be easily explained. The 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 price of purchased and own-supplied transportation and 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.

6. Conclusion

In order to model the household transportation sector explicitly, we have created a methodology based on the use of GTAP data and additional data on a household expenditure share of own-supplied transport and a refined oil expenditure share for transport of the total household expenditure on refined oil in different regions. The surveys report that household expenditures of own-supplied transports are about 10 percent of total household expenditures, and refined oil expenditures in household transportation is on the order 90 percent, that is most of the refined oil products used by households is for transportation. Based on the developed methodology, we have modified household transportation sector in the EPPA model. Illustrative simulations show that disaggregating transport into purchased and own-supplied increases the welfare costs of a carbon policy by around 5-20% in different regions.

By disaggregating the transport sector and being able to select elasticities that more accurately characterized substitution possibilities there we have, we hope, more accurately characterized the economic costs of climate change policy. Of course, we can approximate the results of the non-disaggregated transport sector for some purposes through selection of the elasticity value, or perhaps more to the point we can now understand what value we were implicitly choosing for the transport elasticity by our choice of elasticities in the non-disaggregated model. The disaggregation allows us to make better use of the extensive work in the transportation sector to understand substitution possibilities.

The degree of data disaggregation used in the modeling is an important factor for studying particular sector-specific effects. A modeler should be careful with adjusting elasticities with a change to a more disaggregated model. Our disaggregation allows us to make better use of the extensive work in the transportation sector to understand substitution possibilities.

7. References

Agras, J., and D. Chapman, 1999. "The Kyoto Protocol, CAFÉ Standards, and Gasoline Taxes," *Contemporary Economic Policy*, 17(3): 296-308.

Babiker M., J. Reilly, and D. Ellerman, 2000a. "Japanese Nuclear Power and the Kyoto Agreement," *Journal of Japanese and International Economies*, 14(3), 169-188.

Babiker M., M. Bautista, H. Jacoby, and J. Reilly, 2000b. Effects of Differentiating Climate Policy by Sector: A U.S. Example. MIT Joint Program on the Science and Policy of Global Change, Cambridge, MA, Report 61.

Babiker M., . Criqui P., Ellerman D., Reilly J., and L. Viguier, 2003. "Assessing the Impact of Carbon Tax Differentiation in the European Union," *Environmental Modeling & Assessment*, 8(3): 187-197.

Babiker M., J. Reilly, and H. Jacoby, 2000c. "The Kyoto Protocol and Developing Countries," *Energy Policy*, 28, 525-536.

Babiker, M., J. Reilly, M. Mayer, R. Eckaus, I. Sue Wing, and R. Hyman, 2001. The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparison of Results, MIT Joint Program on the Science and Policy of Global Change, Cambridge, MA, Report 71.

Babiker M., and R. Eckaus, 2002. "Rethinking the Kyoto Emissions Targets," *Climatic Change*, 54(4), 339-414.

Babiker M., H. Jacoby, J. Reilly, and D. Reiner, 2002. "The Evolution of a Climate Regime: Kyoto to Marrakech and Beyond," *Environmental Science and Policy*, 5(3), 192-206.

Baron J.-F., 2002. « La consommation automobile depuis quarante ans », *INSEE Première*, INSEE, n° 844, Mai.

Bernard, A., S. Paltsev, J. Reilly, M. Vielle, and L. Viguier, 2003, Russia's Role in the Kyoto Protocol, MIT Joint Program on the Science and Policy of Global Change, Cambridge, MA, Report 98.

Dahl, C.A., and T. Sterner, 1991. "Analyzing Gasoline Demand Elasticities: A Survey," *Energy Economics*, 13(3): 203-210

Dimaranan B. and R. McDougall, 2002. Global Trade, Assistance, and Production: The GTAP 5 Data Base. Center for Global Trade Analysis, Purdue University, West Lafayette, Indiana.

Ellerman A.D., and I. Sue Wing, 2000. "Supplementarity: An Invitation to Monopsony?" *The Energy Journal*, 21(4), 29-59.

EUROSTAT, 1999. Household Budget Survey of 1999, Luxembourg.

Graham, D.J., and S. Glaister, 2002. The Demand for Automobile Fuel: A Survey of Elasticities, forthcoming in *Journal of Transport Economics and Policy*, 36(1): 1-25.

Greene, D.L:, J.R. Kahn, and R.C. Gibson, 1999. "Fuel Economy Rebound Effect for US Household Vehicle," *The Energy Journal*, 20(3): 1-31.

Hagler Bailly, 1999. Potential for Fuel Taxes to Reduce Greenhouse Gas Emissions from Transport, Transportation Table of the Canadian National Climate Change Process, Hagler Bailly Inc, Arlington, VA.

Haugton, J., and S. Sarkar, 1996. "Gasoline Tax as a Corrective Tax: Estimates for the United States, 1970-1991," *The Energy Journal*, 17(2): 103-126.

Hertel, T., 1997. Global Trade Analysis: Modeling and Applications. Cambridge University Press, Cambridge, UK.

Hyman, R.C., J.M. Reilly, M.H. Babiker, A. de Masin, and H.D. Jacoby, 1997. "Modeling Non-CO_2 Greenhouse Gas Abatement, *Environmental Modeling and Assessment*, 8(3): 175-186.

IEA, 2000a. Energy Balances of OECD Countries 1997-1998, Paris, France.

IEA, 2000b, Energy Statistics of OECD Countries, 1997-1998, Paris, France.

IEA, 2000c, Energy Statistics of non-OECD Countries, 1997-1998, Paris, France.

IEA, 2001, Energy Prices and taxes, 1999, Paris, France.

Jacoby, H., R. Eckaus, A.D. Ellermann, R. Prinn, D. Reiner, and Z. Yang, 1997. "CO_2 Emissions Limits: Economic Adjustments and the Distribution of Burdens," *The Energy Journal*, 18, 31-58.

Jacoby, H. and I. Sue Wing, 1999. "Adjustment Time, Capital Malleability, and Policy Cost," *The Energy Journal*, Special Issue, The Costs of the Kyoto Protocol: A Multi-Model Evaluation, 73-92.

Jorgenson, D. W., F.M. Gollop, and B.M. Fraumeni, 1987. Productivity and US Economic Growth, Cambridge, MA: Harvard University Press.

Lahiri, S., M. Babiker, and R.S. Eckaus, 2000. The Effects of Changing Consumption Patterns on the Costs of Emission Restrictions, MIT Joint Program on the Science and Policy of Global Change, Cambridge, MA, Report 64.

McFarland, J., J. Reilly, and H. Herzog, 2003. "Representing Energy Technologies In Top-Down Economic Models Using Bottom-Up Information," Energy Economics, forthcoming (also available as the MIT Joint Program on the Science and Policy of Global Change, Cambridge, MA, Report 89).

Ministry of Statistics and Programme Implementation, 2001. Statistical Abstract of India 2001, Central Statistical Organisation, New Dehli.

Moulton B., and C. Moylan, 2003. Comprehensive Revision of the National Income and Product Accounts 1929 Through Second Quarter 2003, Bureau of Economic Analysis, BEA News, BEA 03-48, December.

National Bureau of Statistics of China, 2002. China Statistical Yearbook 2002, China Statistics Press.

Nivola, P. S., and R. W. Crandall, 1995. The Extra Mile: Rethinking Energy Policy for Automobile Transportation, The Brookings Institution, Washington D.C.

OECD (1997), National Accounts of OECD Countries, 1997, OECD, Paris.

Paltsev S., J. Reilly, H. Jacoby, A.D. Ellerman, and K.H. Tay, 2003. Emissions Trading to Reduce Greenhouse Gas Emissions in the United States: The McCain-Lieberman Proposal. MIT Joint Program on the Science and Policy of Global Change, Cambridge, MA, Report 97.

Reilly J., R. Prinn, J. Harnisch, J. Fitzmaurice, H. Jacoby, D. Kicklighter, J. Melillo, P. Stone, A. Sokolov, and C. Wang, 1999. "Multi-gas Assessment of the Kyoto Protocol," *Nature*, 401, 549-555.

Reilly J., M. Mayer, and J. Harnisch, 2002. "The Kyoto Protocol and Non-CO_2 Greenhouse Gases and Carbon Sinks," *Environmental Modeling and Assessment*, 7(4), 217-229.

Schafer, A. and H. Jacoby, 2003. Technology Detail in a Multi-Sector CGE Model: Transport Under Climate Policy, MIT Joint Program on the Science and Policy of Global Change, Cambridge, MA, Report 101.

Statistics Canada, 2002. Survey of Household Spending 2002, Ottawa.

United Nations, 2002. National Accounts Statistics: Main Aggregates and Detailed Tables, 1999, Department of Economic and Social Affairs, New York.

Viguier L., Babiker M., and J. Reilly, 2003. The costs of the Kyoto Protocol in the European Union", *Energy Policy*, 31 (5), 2003, 393-483.

Webster, M., M. Babiker, M. Mayer, J. Reilly, J. Harnisch, R. Hyman, M. Sarofim, and C. Wang, 2002. "Uncertainty in Emissions Projections for Climate Models," *Atmospheric Environment*, 36(22), 3659-3670.

Table 1. Sources of Data for Own-Transport Expenditure (ES) and Own-Transport Refined Oil (OS) Shares

Country or Region	ES	OS
United States	OECD (1997)	BEA (Moulton and C. 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 & Programme Implementation (2001)
China	National statistical handbook	National 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 South Africa, World bank data	IEA data

Table 2. Survey of Econometric Studies on Gasoline Price Elasticity

Authors	*Country or 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, 1969-1988*
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. 1982-1995*
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).

Table 3. 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 (EINT)
European Union+[a] (EUR)	Other Industries products (OTHR)
Australia/New Zealand (ANZ)	Transportation (TRAN)
Former Soviet Union[b] (FSU)	**Energy**
Eastern Europe[c] (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[d] (ASI)	Electric: Hydro (HYDR)
Mexico (MEX)	Electric: Nuclear (NUCL)
Central and 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[e] (ROW)	Electric: NGCC with Carbon Capture (NGCAP)
	Electric: Integrated Gas Combined Cycle with Carbon Capture (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) and Azerbaijan, 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] Hungary, Poland, Bulgaria, Czech Republic, Romania, Slovakia, Slovenia.
[d]South Korea, Malaysia, Phillipines, Singapore, Taiwan, Thailand.
[e]All countries not included elsewhere.

Table 4. Elasticity 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

Table 5. Elasticity 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

Table 6. Elasticity 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

Table 7. Own-Transport Expenditure (ES_r) and Own-Transport Refined Oil (OS_r) Shares

Region	ES	OS
USA	0.104	0.899
CAN	0.129	0.921
MEX	0.070	0.862
JPN	0.070	0.829
ANZ	0.104	0.992
EUR	0.134	0.855
EET	0.085	0.902
FSU	0.087	0.904
ASI	0.058	0.937
CHN	0.042	0.995
IND	0.054	0.957
IDZ	0.058	0.937
AFR	0.053	0.875
MES	0.060	0.884
LAM	0.060	0.854
ROW	0.060	0.900

Table 8. Change in Welfare (%). Scenario: Return to 2000 carbon emissions in 2010.

Region	no separate Household Transport	separate Household Transport	% difference
USA	-0.110	-0.114	3.4
CAN	-0.961	-1.069	11.3
MEX	-0.464	-0.534	15.0
JPN	-0.134	-0.150	12.0
ANZ	-0.702	-0.771	9.9
EUR	-0.251	-0.322	28.1
EET	-0.058	-0.059	0.4
FSU	-1.119	-1.198	7.0
ASI	-0.438	-0.446	1.7
CHN	-1.152	-1.206	4.7
IND	-0.897	-1.019	13.6
IDZ	-1.053	-1.152	9.3
AFR	-1.536	-1.719	11.9
MES	-3.603	-4.046	12.3
LAM	-0.457	-0.531	16.3
ROW	-0.553	-0.588	6.3

Table 9. Change in Welfare (%). Different elasticity of substitution between transport consumption and other consumption (s9).

	0	0.25	0.5	0.75	1
USA	-0.12	-0.11	-0.11	-0.11	-0.11
EUR	-0.33	-0.33	-0.32	-0.31	-0.31
JPN	-0.16	-0.16	-0.15	-0.15	-0.15
FSU	-1.19	-1.20	-1.20	-1.20	-1.20
CHN	-1.23	-1.22	-1.21	-1.19	-1.18
MES	-4.11	-4.07	-4.05	-4.02	-4.00

Default: s9 = 0.5

Table 10. Change in Welfare (%). Different elasticity of substitution between purchased and own-supplied transport (s15).

	0	0.2	0.4	0.6	0.8
USA	-0.11	-0.11	-0.11	-0.11	-0.11
EUR	-0.32	-0.32	-0.32	-0.32	-0.33
JPN	-0.16	-0.15	-0.15	-0.16	-0.15
FSU	-1.20	-1.20	-1.20	-1.19	-1.20
CHN	-1.21	-1.21	-1.20	-1.20	-1.19
MES	-4.08	-4.05	-4.01	-3.99	-3.95

Default: s15 = 0.2

Table 11. Change in Welfare (%). Different elasticity of substitution between fuel and other inputs to own-supplied transport (s16).

	0	0.2	0.4	0.6	0.8
USA	-0.20	-0.15	-0.11	-0.09	-0.07
EUR	-0.38	-0.35	-0.32	-0.30	-0.27
JPN	-0.20	-0.17	-0.15	-0.14	-0.13
FSU	-1.24	-1.22	-1.20	-1.18	-1.16
CHN	-1.33	-1.26	-1.21	-1.16	-1.12
MES	-4.14	-4.10	-4.05	-3.97	-3.89

Default: s16 = 0.4

Table 12. Change in Welfare (%). Different elasticity of substitution between services and other inputs to own-supplied transport (s17).

	0	0.25	0.5	0.75	1
USA	-0.11	-0.11	-0.11	-0.11	-0.11
EUR	-0.32	-0.32	-0.32	-0.32	-0.32
JPN	-0.15	-0.15	-0.15	-0.15	-0.15
FSU	-1.20	-1.20	-1.20	-1.20	-1.20
CHN	-1.21	-1.21	-1.21	-1.21	-1.21
MES	-4.05	-4.05	-4.05	-4.05	-4.05

Default: s17 = 0.5

Figure 1. Household Production of Transportation, Broader Considerations

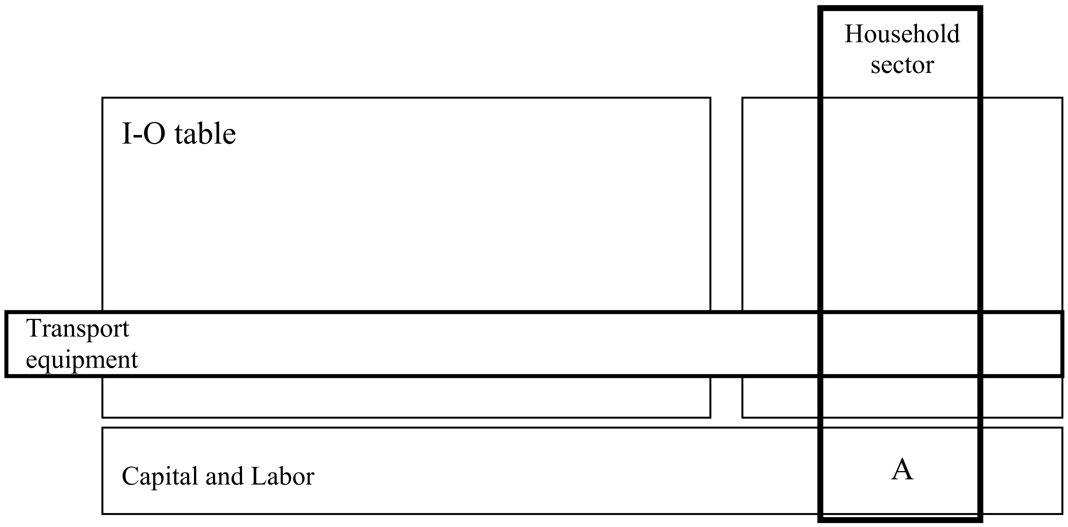


Figure 2. Structure of Production Sector for the Industry Transportation Sector

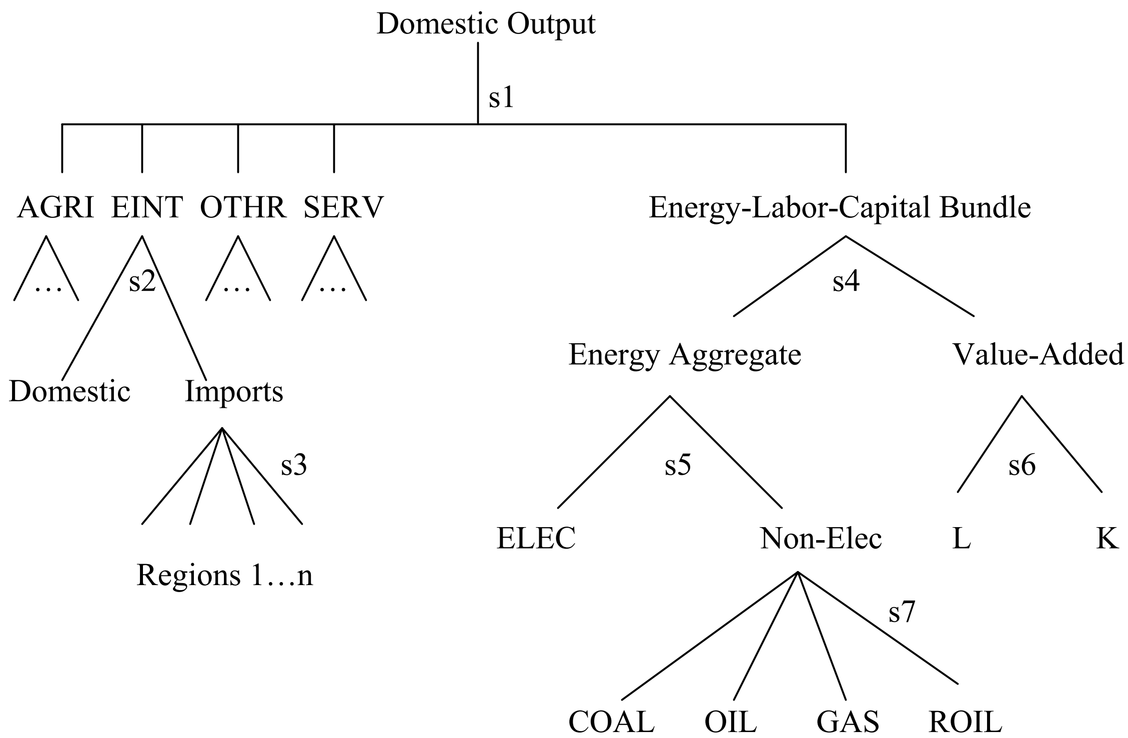


Figure 3. Structure of the Household Sector without Transportation

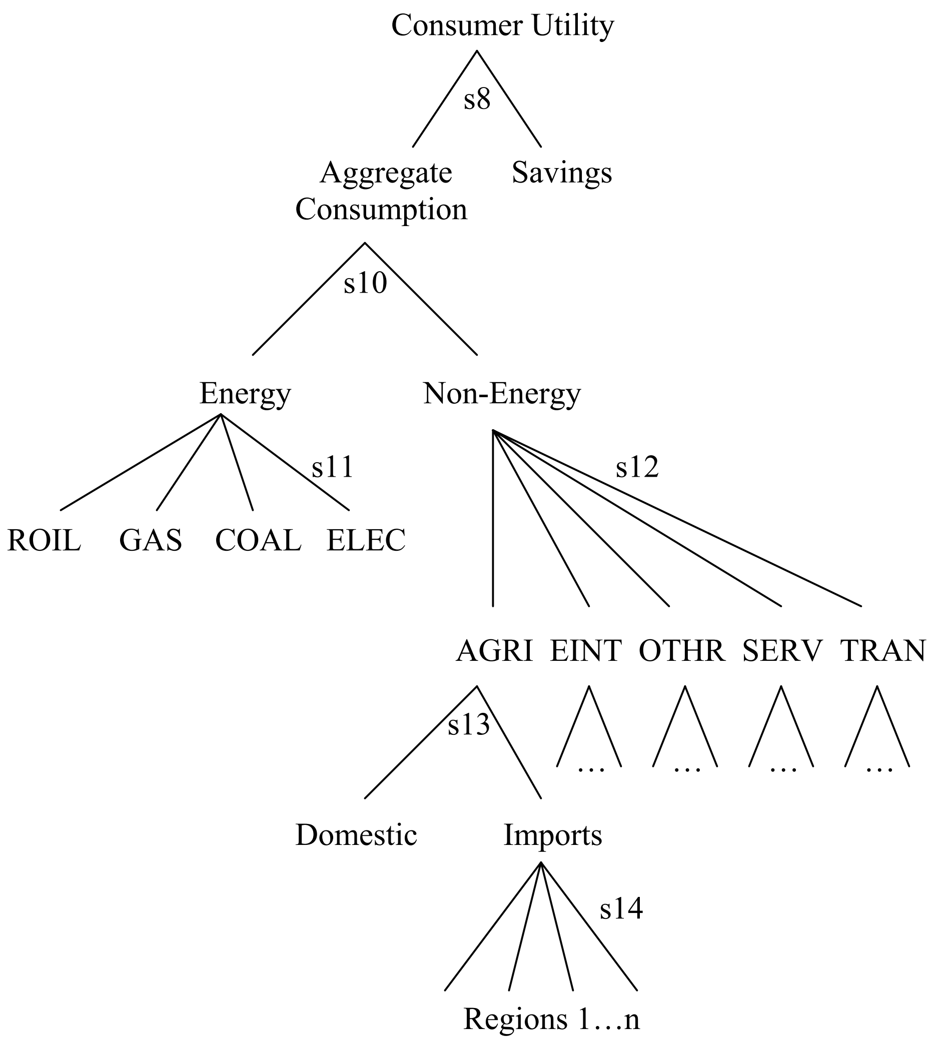
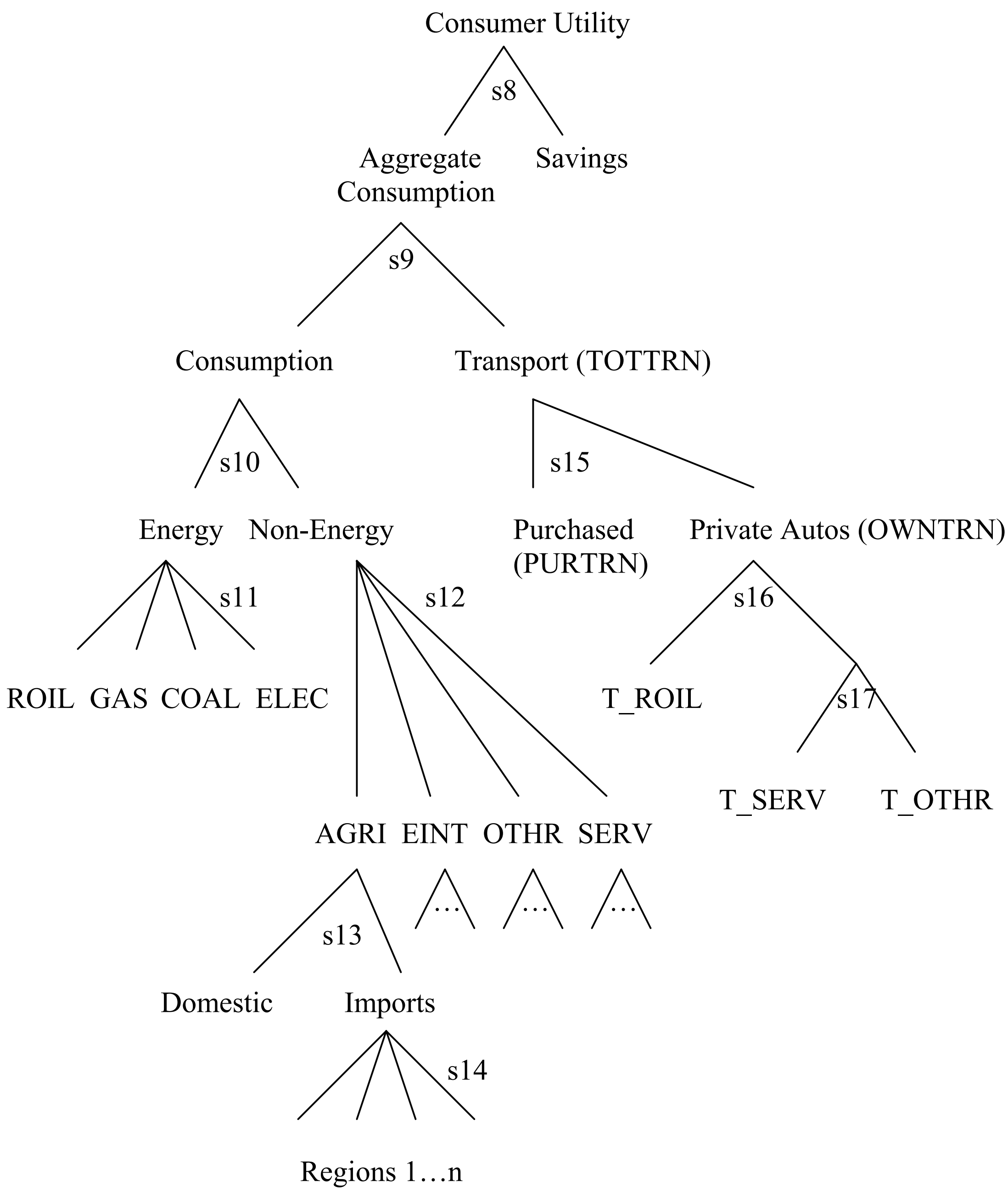


Figure 4. Structure of the Household Sector with Transportation



Appendix 1: Mapping of GTAP data to EPPA format

```
set mapi  Mapping for sectors and goods /
PDR.agri paddy rice
WHT.agri wheat
GRO.agri cereal grains nec
V_F.agri vegetables - fruit - nuts
OSD.agri oil seeds
C_B.agri sugar cane - sugar beet
PFB.agri plant-based fibers
OCR.agri crops nec
CTL.agri bo horses
OAP.agri animal products nec
RMK.agri raw milk
WOL.agri wool - silk-worm cocoons
FRS.agri forestry
FSH.agri fishing
COL.coal coal
OIL.oil oil
GAS.gas gas
OMN.othr minerals nec
CMT.othr bo meat products
OMT.othr meat products
VOL.othr vegetable oils and fats
MIL.othr dairy products
PCR.othr processed rice
SGR.othr sugar
OFD.othr food products nec
B_T.othr beverages and tobacco products
TEX.othr textiles
WAP.othr wearing apparel
LEA.othr leather products
LUM.othr wood products
PPP.eint paper products - publishing
P_C.roil petroleum - coal products
CRP.eint chemical - rubber - plastic products
NMM.eint mineral products nec
I_S.eint ferrous metals
NFM.eint metals nec
FMP.eint metal products
MVH.othr motor vehicles and parts
OTN.othr transport equipment nec
ELE.othr electronic equipment
OME.othr machinery and equipment nec
OMF.othr manufactures nec
ELY.elec electricity
GDT.gas gas manufacture - distribution
WTR.othr water
CNS.othr construction
TRD.serv trade
OTP.tran transport nec
WTP.tran water transport
ATP.tran air transport
CMN.serv communication
OFI.serv financial services nec
ISR.serv insurance
OBS.serv business services nec
ROS.serv recreational and other services
OSG.serv public admin - and defence - education - health
DWE.othr ownership of dwellings
CGD.cgd     Savings good /;
```

```
SET MAPR  mapping GTAP regions /
AUS.anz Australia
NZL.anz New Zealand
CHN.chn China
HKG.chn Hong Kong
JPN.jpn Japan
KOR.asi Korea - Republic of
TWN.asi Taiwan - Province of China
IDN.idz Indonesia
MYS.asi Malaysia
PHL.asi Philippines
SGP.asi Singapore
THA.asi Thailand
VNM.row Viet Nam
BGD.row Bangladesh
IND.ind India
LKA.row Sri Lanka
XSA.row rest of South Asia
CAN.can Canada
USA.usa United States
MEX.mex Mexico
XCM.lam Central America and Caribbean
COL.lam Colombia
PER.lam Peru
VEN.lam Venezuela
XAP.lam rest of Andean Pact
ARG.lam Argentina
BRA.lam Brazil
CHL.lam Chile
URY.lam Uruguay
XSM.lam rest of South America
AUT.eur Austria
DNK.eur Denmark
FIN.eur Finland
FRA.eur France
DEU.eur Germany
GBR.eur United Kingdom
GRC.eur Greece
IRL.eur Ireland
ITA.eur Italy
NLD.eur Netherlands
PRT.eur Portugal
ESP.eur Spain
SWE.eur Sweden
BEL.eur Belgium
LUX.eur Luxembourg
CHE.eur Switzerland
XEF.eur rest of EFTA
HUN.eet Hungary
POL.eet Poland
XCE.eet rest of Central European associates
XSU.fsu former Soviet Union
TUR.row Turkey
XME.mes rest of Middle East
MAR.afr Morocco
XNF.afr rest of North Africa
BWA.afr Botswana
XSC.afr rest of SACU
MWI.afr Malawi
MOZ.afr Mozambique
TZA.afr Tanzania - United Republic of
ZMB.afr Zambia
```

```
ZWE.afr Zimbabwe
XSF.afr rest of southern Africa
UGA.afr Uganda
XSS.afr rest of sub-Saharan Africa
XRW.row rest of world    /;
```