Incorporating Domestic Margins into the GTAP-E Model: Implications for Energy Taxation

Everett B. Peterson
Dept. of Agricultural and Applied Economics
Virginia Tech

Huey-Lin Lee
Center for Global Trade Analysis (GTAP)
Purdue University

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**Abstract:**

In most applied general equilibrium (AGE) analyses, the transportation, wholesaling, and retailing activities required to facilitate the flow of goods from domestic producers (or imports) to domestic buyers are not tied to specific commodities. Because the margins on energy commodities can be substantial, ignoring these domestic margins has important consequences when analyzing the impacts of policies designed to limit greenhouse gas emissions. The objective of this paper is to incorporate the structure of the domestic trade and transport margins in the GTAP-M model into the GTAP-E model. The results for two different sets of experiments are compared for the GTAP-E model with and without domestic trade and transport margins. In experiments that varied a real tax on carbon emissions from $25 per ton to $100 to ton, the standard GTAP-E model over-estimated the reduction in carbon emissions, compared to the GTAP-ME model that includes domestic margins, by 34 to 80 million metric tons (10 to 15 percent). Similarly, experiments that compared the level of carbon taxes required to attain the country-specific abatement targets specified in the Kyoto Protocol, found that the standard GTAP-E model without domestic margins substantially under-estimated the required carbon tax compared to a model with domestic margins.

## *1. Introduction*

Concerns regarding the potential environmental consequences from the emissions of $CO_2$ and other greenhouse gases from energy use lead to the development of the GTAP-E model to help analyze the impacts of policies designed to limit greenhouse gas emissions. The GTAP-E model (Burniaux and Truong, 2001) extends the standard GTAP model by allowing substitution among energy types (e.g., coal, oil, gas, electricity and petroleum and coal products). In addition, the GTAP-E model incorporates carbon emissions from the combustion of fossil fuels and also allows for simulations of global emissions trading schemes.

As a descendant of the standard GTAP model, GTAP-E inherited the limitation of not including domestic trade and transport margins. These margins can be substantial, particularly for energy products purchased by private households. For example, in the United States, the value of domestic trade and transport margins for the GTAP commodity petroleum and coal products (p_c) sold to the private household is approximately 1.5 times the producer value at market prices. Without incorporating domestic margins, a tax increase results in the same percentage change in producer (seller) and retail (buyer) prices. In other words, the degree of price transmission is one. However, by including domestic margins, the percentage changes in producer and retail prices from the tax increase will likely differ.

Recently, Peterson (forthcoming 2005) has developed a new GTAP model and database (GTAP-M) that incorporates domestic trade and transport margins on domestic and imported goods going to final demand or used as intermediate inputs. For example, when re-examining the impacts of global technical change in the crops sector, Peterson found that only about only about fifty to eighty percent of the reduction in the crop price was passed through to consumers when domestic margins were incorporated into the model.

The objective of this paper is to incorporate the structure of the domestic trade and transport margins in the GTAP-M model into the GTAP-E model. We will then compare the results for two different scenarios on achieving the reductions in $CO_2$ emissions called for by the Kyoto Protocol for the GTAP-E model with and without domestic trade and transport margins. By comparing the simulation results from the two models, we attempt to illustrate the importance of including domestic marketing margins in models developed to analyze energy and environmental policies. For example, we expect to see higher marginal abatement costs under the same emissions reduction targets when domestic margins are accounted for in sectoral production. Domestic margins vary between countries and between commodities as well. Inclusion of domestic margins will affect marginal abatement costs incurred to conform with the Kyoto Protocol. Relative magnitudes of changes in marginal abatement costs will affect the cost-effective allocation of carbon abatement between countries. As marginal abatement cost is an important indicator in cost-effective emissions trading across countries, the incorporation of domestic margins helps to more accurately present the context of energy prices and the consequent responsiveness of energy users to global climate policies.

In section 2, we introduce the GTAP-ME model, which is built based on the GTAP-E model, with the inclusion of domestic margins. In Section 3, we introduce the data base and the sectoral and region aggregation for the experiments in this paper. We discuss the simulation results in section *4*. Section 5 concludes the paper.

## *2. Incorporating Domestic Margins: the GTAP-ME model*

In most applied general equilibrium (AGE) analyses, the transportation, wholesaling, and retailing activities required to facilitate the flow of goods from domestic producers (or imports) to domestic private households, domestic firms, government demands, and foreign demand for exports are not tied to specific commodities. This is a reflection of usual treatment of margins in the underlying input-output (I-O) tables. The values in these I-O tables are computed to reflect producer prices. Thus, all of the marketing margins associated with the purchase of specific commodities are allocated to the appropriate margin activity and then treated as a direct purchase of that margin activity.

As discussed by Gohin (2001), marketing margins have been incorporated into AGE models in a variety of ways. In order to minimize the changes in the existing GTAP model (Hertel, 1997) structure, the specification of domestic marketing margins utilized in this paper follows the specification in the ORANI model (Dixon et al., 1982), Bradford and Gohin (2001), and Peterson (2005 forthcoming).[1] This approach specifies a nested CES structure shown in Figure 1. At the top of this structure is a composite commodity that is purchased by the private household, government household, or firms. Similar to the standard GTAP-E model (Burniaux and Truong, 2001), the composite commodity is a combination of the margin inclusive composite imported commodity and a margin inclusive domestic commodity (see Level 3 of Figure 1), where $\sigma_D$ is the elasticity of substitution between the composite import and the composite domestic commodity. Note that the composite commodities now include domestic trade and transportation margins. At Level 2, the composite imported commodity and the domestically produced commodity are combined with an composite marketing service. Based on the work of Holloway (1989) and Wohlgenant (1989), the potential for substitution between the composite commodity and composite marketing service is denoted as $\sigma_{pt}$. As shown in Level 1, the composite marketing service is itself a CES aggregate of all trade and transportation services

[1] Distinguishing domestic marketing margins is necessary because the standard GTAP model all ready identifies international trade and transport margins for all exported commodities.

needed to get the good from the producer to the purchaser. The constant elasticity of substitution $\sigma_{pm}$ governs the degree of substitutability between individual marketing services, such as land and air transport, as relative prices change.

The production structure of the GTAP-ME model is based on the GTAP-E model (Burniaux and Truong, 2001), which allows for substitution between capital and energy, and between various fuels in sectoral production. Figure 2 shows the nested production structure in the GTAP-E model. Sectors may substitute energy for capital when energy price rises more than capital rental does. The inter-fuel substitution comprises of three sub-nestings: (a) electricity v.s. non-electricity composite; (b) coal v.s. non-coal composite; and (c) between oil, gas, and petroleum products. For example, sectors may substitute coal for non-coal fuel (a composite of oil, gas and petroleum products) when coal is more expensive than non-coal fuels.

## *3. Data and Model Aggregation*

To implement an AGE model that incorporate domestic marketing margins requires that the values of these must be identified for all transactions in all regions. Peterson (2005 forthcoming) has recently developed a domestic margin inclusive version of the GTAP version 5.4 data base (GTAP-M data base). This data base contains information on trade and transportation margins for all intermediate transactions, purchases by consumers, and purchases by federal and state governments for all domestically produced and imported commodities. While information on domestic margins on exported commodities is available, these margins are not included in the current margin inclusive data base because to do so would require all the input-output tables in all regions to be rebalanced.[2]

[2] By construction, exports in the GTAP version 5.4 data base are valued at *fob* prices, which include all domestic trade and transport margins. Therefore, the value of production for an exported commodity is overstated by the

An eight region and ten commodity aggregation of the GTAP-M database is used in this paper (see Tables A1 and A2 for the specific regional and sectoral definitions). The eight regions are the United States (USA), the European Union (EU), Japan (JPN), Eastern Europe and the former Soviet Union (EEFSU), Rest of Annex 1 countries in the Kyoto protocol (ROA1), net energy exporters (EEX), China and India (CHIND), and the rest of the world (ROW). The ten commodities are agriculture (agr), coal (col), oil (oil), gas (gas), refined oil products (oil_pcts), electricity (ely), energy intensive industries (engy_int), trade (trd), transportation (trans), and other industries and services (other). With the exception of separating trade and transportation from all other services, the regional and commodity aggregations are the same as utilized by Burniaux and Truong (2001). This choice is made in order to be able to compare the results from the margin inclusive GTAP-ME model to the same from the GTAP-E model for the same set of experiments.

Tables 1 and 2 list the average share of the retail value accounted for by domestic trade and transport margins for purchases by the private household and for intermediate inputs.[3] These values illustrate that domestic margins vary substantially across commodities, regions, and uses. The domestic margins are larger for commodities purchased by the private household than for intermediate inputs purchased by firms. For energy related commodities purchased by the private household, coal (col), refined oil products (oil_pcts), and energy intensive industries (engy_int) have larger domestic margins than oil, gas, and electricity (ely). For electricity, the domestic margins are zero because it is provided directly to the private household. This is also

value of the domestic margins on exports. This also implies that the values of trade and transport services produced in the economy are being understated by the total value of the domestic margins on exports. To incorporate domestic margins on exports would then require changes in the composition of output from commodities to margin activities and necessitate that the I-O tables be rebalanced. Future versions of the GTAP-M data base will include domestic margins on exports.

[3] The averages in Tables 1 and 2 are over domestic and imported commodities. The national accounts in many countries do not distinguish between the domestic margins on imported versus domestic commodities. For these regions, the margins on domestic and imported commodities are assumed to be equal.

true for gas in regions like the US and Japan and with the exception of the EU, the domestic margin share for gas is very low for the remaining regions. In most industries, the domestic margins on coal (col), refined oil products (oil_pcts), and energy intensive industries (engy_int) are larger than the domestic margins on oil, gas, and electricity (ely). When comparing domestic margins across regions, the US tends to have larger margins that other Annex 1 countries, particularly for refined oil products purchased by the private household and by the trade and transport industries. At least for refined oil products purchased by the private household, the difference in the domestic margin share between the US and other countries is not entirely due to differences in transportation costs because trade services account for approximately 95 percent of the total domestic margin in all regions.

One impact of including domestic margins in an AGE model is that the degree of price transmission between producers and purchasers is no longer equal to one. Consider the case of refined oil products purchased by the US private household. If the market price of refined oil products increases by 5 percent, holding all other prices constant, then the retail price of refined oil products faced by the private household will increase by approximately two percent because only 40 percent of the retail value is attributed to the physical commodity (one minus the margin share in Table 1). Of course, an increase in the price of refined oil products will also lead to an increase in the cost of domestic trade and transport services, which comprise the domestic margin, implying that the composite price of the margin services will also increase. As long as the increase in the composite price of margin services is less than the increase in the refined oil products price, the consumer price will increase by less than the market price. However, if the composite price of margin services increases by more than the market price of refined oil products, the degree of price transmission will exceed one.

When analyzing the impact of taxation, a second impact of including domestic margins in the AGE model is to change the tax base used to compute the power of any energy tax increase. Because the tax is defined as the value of expenditures by firms, the private household, and the government household on domestic and imported coal, oil, gas, and oil_pcts at agents' prices less any own-use by firms, including domestic margins will increase the tax base. As shown in Table 3, the size of the increase in the tax base varies substantially across commodities and regions depending on the magnitudes of the domestic margins and the magnitudes of existing taxes on the use of these commodities. Consider the case of oil_pcts in the US. The tax base nearly doubles in the tax base in the margin inclusive model compared to the standard GTAP-E model. This is due to the relatively large domestic margins on oil_pcts purchased by the private household and by the transportation industry whose combined purchases account for nearly 40 percent of total US use of refined oil products. In both of these instance, the value of the domestic margins exceeds the commodity value at market prices. In contrast, the tax base for oil_pcts in the EU only increases by approximately 5 percent. This is due to the very large existing taxes on oil_pcts consumption in the EU, where the value of purchases at agents' price is several times larger than the value purchases at market prices. Because size of the domestic margins are determined relative to the commodity value at market prices, the size of these margins for oil_pcts in the EU are relatively small compared to commodity value at agents' prices. Therefore, the increase in the tax base of oil_pcts in the EU in the margins inclusive model is relatively small.

The effect of increasing the tax base in the margins inclusive model is to reduce the power of the carbon tax. To see this, recall the definition of the power of carbon tax:

$$cpower = \frac{NCTAX * CO_2}{Tax\ Base},$$

where *NCTAX* is the nominal carbon tax per ton of $CO_2$ emitted, $CO_2$ is the tons of $CO_2$ emitted, and *Tax Base* is the tax base of the commodity. Holding the nominal tax rate and the emission level constant, increasing the tax base effectively reduces the power of the carbon tax.

### 3.1 Model Parameters

The production, margin, and trade elasticities of substitution utilized in the both the margin inclusive GTAP-E model and the standard GTAP-E model are listed in Table 5. All production and trade elasticities are set equal to values used in the standard GTAP-E model (see Burniaux and Truong (2001)). There is no substitution between non-energy intermediate inputs and value-added ($\sigma_T$). Unlike the standard GTAP model, the elasticity of substitution among the components of value-added ($\sigma_{VA}$) is allowed to vary across regions. This occurs for the agriculture (agr) and gas sectors. There is no substitution allowed between energy and capital ($\sigma_{KE}$), electricity and non-electricity ($\sigma_{ELY}$), and coal and non-coal ($\sigma_{COAL}$), and between non-coal energy intermediate inputs ($\sigma_{FU}$) for the coal (col), oil, gas, and oil_pcts sectors. All other sectors have limited substitution possibilities. All experiments using the margin inclusive version of the GTAP-E model assumes fixed domestic margins, implying that $\sigma_{pt}$ and $\sigma_{pm}$ equal zero. Finally, the elasticities of substitution between domestic and the composite imported commodity ($\sigma_D$) and between imported commodities ($\sigma_M$) are equal to the standard values in the GTAP v5.4 data base with the exception of oil, where the trade elasticities are set equal to 30, reflecting the belief that crude oil is a more homogeneous commodity.

The demand parameters from the GTAP v5.4 data base are utilized in both models. Because the budget shares differ between the margin inclusive and standard GTAP-E models, there are slight differences in the uncompensated price and income elasticities between the two models. These differences are generally less than 0.02 for both the price and income elasticities.

The largest absolute differences for the price and income elasticities are 0.08 for trd in CHIND and 0.05 for oil_pcts in CHIND.

Because the cost shares for intermediate inputs will differ between the two models, using the same elasticities of substitution leads to slight differences in the compensated input demand elasticities. These differences are very small.

### 3.2 Initial $CO_2$ Emissions

The levels of initial $CO_2$ emissions for each region by energy-related commodity are obtained from the GTAP version 5.4 energy data base and are given in Table 4. Overall, the US is the largest emitter of $CO_2$ followed by China and India, the EU, and Eastern Europe and the former Soviet Union. For the US, the largest source of $CO_2$ emissions is refined oil products followed by coal and the gas. For China and India (CHIND), by far the largest source of $CO_2$ emissions comes from coal. Note that very little of $CO_2$ emissions are attributed directly to (crude) oil because most of its use is in refined oil products.

## 4. *Simulations and Results*

Two different sets of experiments are considered: the first set considers exogenous increases in the real carbon tax in the US, EU, Japan, and the rest of the annex 1 countries (ROA1) with the exception of Eastern Europe and the former Soviet Union; and the second set analyzes the impact of implementing the Kyoto protocol abatement targets under various assumptions of emission trading regimes: (a) no emissions trading, (b) emissions trading between Annex I countries, and (c) world-wide participation of emissions trading. In both sets of experiments, comparisons are made between the results of the standard GTAP-E model (i.e., the no domestic margins model) and the GTAP-ME model that includes domestic margins. The purpose of the first set of experiments is to compare the differences between the two models holding the level of the carbon tax constant. The purpose of the last set of experiments is to replicate the experiments reported in Burniaux and Truong (2001) and compare the carbon taxes—incurred in the GTAP-ME and the GTAP-E models—required to attain the country-specific abatement targets to abide by the Kyoto Protocol.

### 4.1 Exogenous Change in Real Carbon Tax

Four different levels of real carbon taxes are consider in the first set of experiments: \$25 per ton, \$50 per ton, \$75 per ton, and \$100 per ton of $CO_2$ emissions are placed on coal, oil, gas, and oil_pcts. Table 6 reports the results from these experiments. In all experiments and in both models, $CO_2$ emissions decreased in the US, EU, Japan, ROA1, and CHIND, while $CO_2$ emissions increased in EEFSU, EEX, and ROW. The reduction of $CO_2$ emissions for the US is 16 to 18 percent smaller when domestic margins are incorporated in the GTAP-E model and 7 to 10 percent smaller for Japan. Smaller differences in $CO_2$ emissions, less than 5 percent, occurred for the EU and ROA1. For most regions, the percent different in $CO_2$ emissions between the two models is fairly constant regardless of the size of the real carbon tax. The largest change across the different tax rates is 25 percent in CHIND. This large percentage change is due to relatively small reductions in $CO_2$ emissions for CHIND (between 0.5 and 0.8 percent) using the standard GTAP-E model, which serves base.

In results not shown in Table 6, the quantity reduction in $CO_2$ emissions for the US were 34 million metric tons lower for a \$25 real carbon tax when domestic margins are included in the model to 85 million metric tons lower for a \$100 real carbon tax. Overall, when domestic margins are included in the GTAP-E model the global reductions in $CO_2$ emissions ranged from

34 million metric tons lower for a $25 real carbon tax to 80 million metric tons lower for a $100 real carbon tax.

One major driving force behind the smaller reductions in $CO_2$ emissions is the smaller increases in the power of the carbon tax in the US, EU, Japan, and ROA1. For all taxed commodities in all regions, the power of the carbon tax is lower, in some instances much lower, when domestic margins are incorporated into the model. The degree of difference in the power of the carbon tax is related to inverse of the ratios of the energy tax bases at the bottom of Table 3. The largest reduction in the power of the carbon tax is a 46 percent reduction for oil_pcts in the US and the smallest is a 1 percent reduction for oil in the EU. All else equal, a smaller increase in the power of the carbon tax leads to a smaller increase in the price paid for the taxed commodity by firms and consumers, leading to a smaller decrease in demand in for that commodity, and therefore a smaller decrease in $CO_2$ emissions.

However, the difference in the power of the carbon tax is only part of the story. Because the degree of price transmission may be less than one in margin inclusive model, some or all of the effect of a smaller increase in the power of the carbon tax may be offset. This is because any tax increase will reduce consumption and therefore the market price of that commodity. However, if the degree of price transmission is less than one, then less than the full price decrease will be passed on to firms and consumers. Therefore, even though the power of the carbon tax may be smaller, if very little of the price market price decrease gets passed onto buyers then the net effect could be for the carbon tax inclusive price to be higher when domestic margins are included in the model.

To illustrate this possibility, consider the case of the price of oil_pcts purchased by the private household in the EU when a $25 real carbon tax is applied. In the margin inclusive model (GTAP-ME) results, the market price of oil_pcts in the EU decreases by 0.9 percent. Because the carbon tax increases the cost of providing trade and transportation services, the composite "margin price" increases by 0.2 percent. The margin inclusive price for domestically produced oil_pcts is the margin share times the change in the composite margin price times one minus the margin share times the change in the market price: 0.28*0.2 + 0.72*(-0.9) = -0.6. Similarly, the composite import price of oil_pcts decreases by 0.8 percent but the margin inclusive price decreases by only 0.5 percent. The change in the before (carbon) tax composite price of oil_pcts purchased by the private household in the EU is the import share weighted price change in the margin inclusive domestic and imported price, yielding a 0.6 percent price decrease. For the case of no domestic margins, all of the change in the market price of the domestic and imported product is passed through to the private household, yielding a 1.3 percent decrease in the before tax composite price. Thus, the before tax price decrease is 0.7 percentage points smaller when domestic margins are included in the model. Because of the relatively small differences in the refined oil product tax base between the GTAP-ME and GTAP-E models, the power of the carbon tax for oil_pcts is only slightly smaller in the GTAP-ME model versus the GTAP-E model: 3.2 percent versus 3.3 percent. Thus, the smaller before tax price decrease more than offsets the smaller power of the carbon tax such that after tax price increase for the GTAP-ME model is larger than for the GTAP-E model (2.6 percent versus 2.0 percent).

For the private household in Japan, the smaller decrease in the before tax composite price of oil_pcts in the margin inclusive model exactly offsets the smaller increase in the power of the carbon tax for oil_pcts. Thus, the change in the price paid by the Japanese private household is the same in both models. However, for the US private household, the smaller decrease in the composite price in the GTAP-ME model is not enough to entirely offset the smaller increase in the power of the carbon tax. Thus, price increase for oil_pcts purchased by the US private household is about 40 percent smaller in the GTAP-ME model compared to the GTAP-E model.[4]

The interaction of domestic margins and the carbon tax is different for the remaining energy-related commodities, gas, electricity (ely), and energy-intensive (engy_int).[5] For gas, the domestic margins are either zero or very small for private households across regions. Thus, the difference in the price paid by the private household for gas between the GTAP-ME and GTAP-E models are due to differences in the power of the carbon tax and differences in the change in the market price. For the private households in the US, EU, and Japan, the smaller increase in the power of the carbon tax on gas is the main determinant of smaller price increase in the GTAP-ME model compared to the GTAP-E model. For electricity, the domestic margins are equal to zero and there is no carbon tax applied directly to its use. Thus, the differences in the price paid for electricity by the private household between the GTAP-ME and GTAP-E models are solely due to differences in the market prices. These differences are relatively small across the different levels of the real carbon tax, with a maximum difference of 3 percent for the private household in Japan. Finally, for the energy intensive commodity, the difference in the price paid by the private household between the two models is solely due to presence of domestic margins because it is also not taxed directly. Because the magnitude of domestic margins for the energy-intensive commodity is substantial in all regions, there is a smaller increase in the price of the energy-intensive commodity paid by the private household in the GTAP-ME model compared to the GTAP-E model.

The implication of smaller price increases for the private household is a smaller decrease in consumption of that good. For the energy-intensive commodity, the decrease in consumption

[4] We limit our discussion to the US, EU, and Japan because these are the relatively largest emitters of $CO_2$.
[5] The energy commodities coal and oil are not included in this discussion because only relatively small amounts are consumed directly by the private household in all regions.

is about 60 percent smaller for the US and Japanese private household when domestic margins are included and 40 to 50 percent less for the EU private household. Also, consumption of oil_pcts by the US private household is about one-third less. Conversely, the larger price decreases for oil_pcts in the EU leads to a 20 to 30 percent larger decrease in consumption by the private household. Overall, the smaller decreases in consumption by the private household imply a smaller reduction in $CO_2$ emissions from private consumption when domestic margins are included in the model.

Because the intermediate use of energy commodities depends on the level of output and relative price of the primary factors and the energy commodities themselves, one can not simply compare the composite energy prices between the GTAP-ME and GTAP-E models to determine how the intermediate use of energy differs between the two models.[6] In both models, the intermediate use of the energy composite decreases in all sectors when a carbon tax is imposed. For the US, the decrease in intermediate energy use is smaller for all sectors when domestic margins are included. However, for the EU and Japan, there are several sectors where the decrease in intermediate energy use is larger in the GTAP-ME model than for the GTAP-E model. In the EU, oil_pcts, energy-intensive products, trade, and transport sectors have relatively larger decreases in energy use when domestic margins are included in the model. For oil_pcts, this difference is due entirely to a larger decrease in refined oil product production in the GTAP-ME model. For energy-intensive products, trade, and transport, there is a larger difference in the relative composite price of energy and the composite price capital and energy in the GTAP-ME model. This same effect also occurs for trade and transport in Japan, which leads

[6] Comparing the composite intermediate energy price is further complicated because the intermediate own-use of coal, oil, gas, and refined oil products is not subject to the carbon tax. This leads to the sign of the composite energy price differing across sectors which complicated the interpretation of the ratio between the two models.

to slightly larger decreases in energy use in those sectors when domestic margins are included in the model.

### 4.2 Implementing Kyoto Protocol Emission Reductions

While the first set of experiments identified that when applying an equivalent carbon tax, the predicted reductions in $CO_2$ emissions are smaller are smaller when domestic margins are included in the model compared to when they are not. Another question is how big of an increase in carbon taxes are necessary to achieve a certain reduction in $CO_2$ emissions in the GTAP-ME model compared to the GTAP-E model? Table 8 presents the results of three different experiments that determine the level of carbon taxes required to attain the country-specific abatement targets to abide by the Kyoto Protocol under different emission trading schemes. In the first experiment, no emission trading is permitted among Annex 1 countries, requiring each country to achieve its abatement target individually. Comparing the required carbon tax between the two models, the required tax is 4 percent higher for the EU, 10 percent higher for ROA1, 14 percent higher for Japan, and 32 percent higher for the US in the GTAP-ME model.[7] Thus, with the exception of the carbon tax in the EU, the GTAP-E model substantially under-estimates the required carbon taxes in the other Annex 1 countries.

The last two experiments consider the impacts of different emission trading schemes on the level of carbon taxes. The first experiment allows emission trading between all Annex 1 countries and the second experiment all emission trading worldwide. In both experiments, the GTAP-ME model predicts carbon taxes that are 9 percent higher than those predicted by the GTAP-E model. In addition, the allocation of carbon abatement across countries also changes,

[7] Because of emission surplus in Eastern Europe and the former Soviet Union (EEFSU), no reduction in emissions is required for this scenario.

with smaller abatement in the US and larger abatement in all other regions. This shift in carbon abatement is due to the larger domestic margins in the US.

## *5. Summary and Conclusions*

This paper highlights the importance of including domestic trade and transport margins in models that are developed to analyze energy and environmental policies. Overall, models without domestic margins will over-estimate the amount of $CO_2$ emission reductions compared to models with domestic margins. In experiments that varied a real tax on carbon emissions from $25 per ton to $100 to ton, the standard GTAP-E model over-estimated the reduction in carbon emissions, compared to the GTAP-ME model that includes domestic margins, by 34 to 80 million metric tons (approximately 10 to 15 percent). A corollary to this result is that larger carbon tax increases would be necessary to achieve specified reductions in $CO_2$ emissions in models that include domestic margins. Experiments that compared the level of carbon taxes required to attain the country-specific abatement targets specified in the Kyoto Protocol, found that the standard GTAP-E model without domestic margins substantially under-estimated the required carbon tax compared to a model with domestic margins. With emission trading either worldwide or by Annex 1 countries, the standard GTAP-E model under-estimates the required carbon tax by 9 percent compared to the GTAP-ME model. However, if emission trading is not allowed, the GTAP-E model under-estimated by required level of carbon taxes by 4 percent for the EU to 32 percent for the US.

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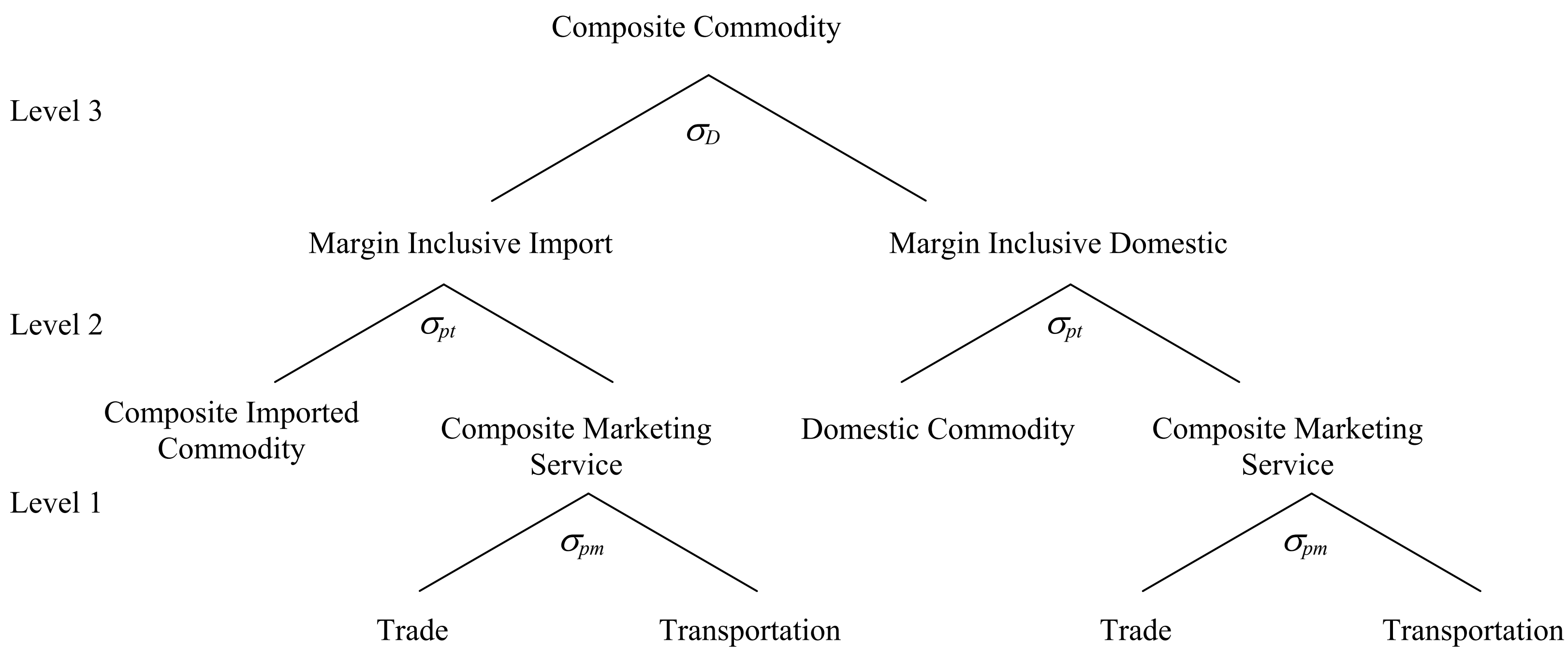


**Figure 1. Structure of Demand for Domestic Marketing Margins in GTAP-ME**

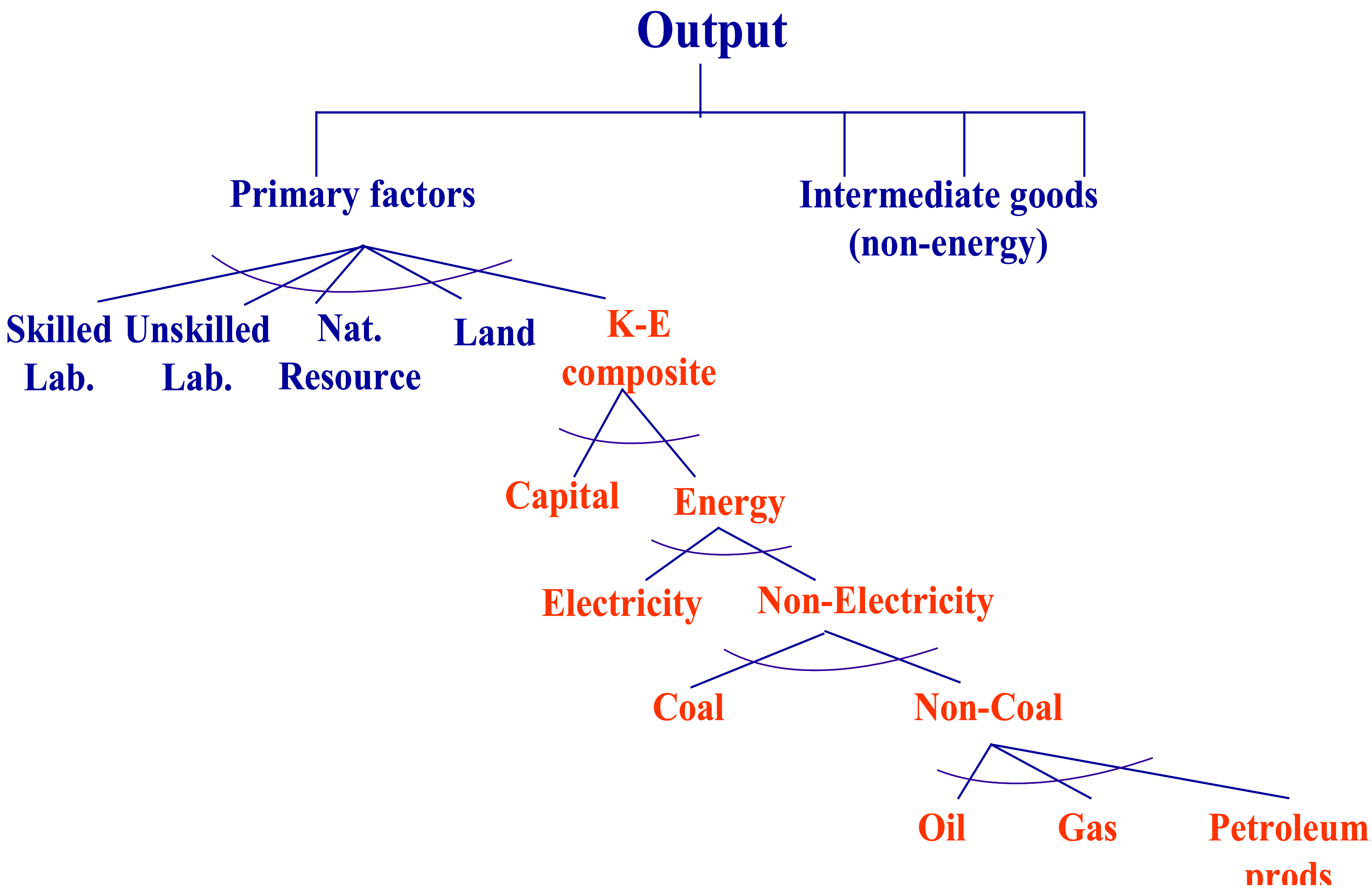


**Figure 2. Production Structure in the GTAP-E model**

Table 1. Average Domestic Margins on Commodities Purchased by the Private Household

| | Region | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Commodity | US | EU | EEFSU | JPN | ROA1 | EEX | CHIND | ROW |
| | Share of Retail Value at Market Prices | | | | | | | |
| agr | 0.460 | 0.337 | 0.109 | 0.445 | 0.359 | 0.208 | 0.129 | 0.233 |
| col | 0.620 | 0.455 | 0.156 | 0.513 | 0.341 | 0.079 | 0.100 | 0.305 |
| oil | 0.000 | 0.022 | 0.019 | 0.000 | 0.195 | 0.041 | 0.023 | 0.057 |
| gas | 0.000 | 0.123 | 0.041 | 0.000 | 0.047 | 0.001 | 0.002 | 0.040 |
| oil_pcts | 0.603 | 0.284 | 0.487 | 0.324 | 0.491 | 0.264 | 0.166 | 0.288 |
| ely | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| engy_int | 0.454 | 0.407 | 0.243 | 0.476 | 0.505 | 0.299 | 0.170 | 0.326 |
| other | 0.147 | 0.158 | 0.098 | 0.187 | 0.156 | 0.148 | 0.097 | 0.171 |

Table 2.  Average Domestic Margins on Intermediate Inputs in the US, EU, and Japan

| Commodity/Region | agr | col | oil | gas | oil_pcts | ely | engy_int | other | trd | trans | CGDS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *US* | | | | Share of Retail Value at Market Prices | | | | | | | |
| agr | 0.114 | 0.092 | 0.329 | 0.105 | 0.076 | 0.000 | 0.139 | 0.095 | 0.202 | 0.054 | 0.000 |
| col | 0.008 | 0.324 | 0.000 | 0.000 | 0.314 | 0.187 | 0.326 | 0.308 | 0.296 | 0.313 | 0.000 |
| oil | 0.000 | 0.300 | 0.039 | 0.312 | 0.085 | 0.155 | 0.201 | 0.000 | 0.000 | 0.009 | 0.000 |
| gas | 0.000 | 0.000 | 0.000 | 0.245 | 0.084 | 0.022 | 0.111 | 0.000 | 0.000 | 0.008 | 0.000 |
| oil_pcts | 0.126 | 0.205 | 0.145 | 0.342 | 0.112 | 0.186 | 0.131 | 0.289 | 0.506 | 0.345 | 0.000 |
| ely | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| engy_int | 0.213 | 0.241 | 0.191 | 0.226 | 0.128 | 0.147 | 0.156 | 0.182 | 0.215 | 0.253 | 0.073 |
| other | 0.057 | 0.108 | 0.009 | 0.003 | 0.012 | 0.009 | 0.056 | 0.067 | 0.043 | 0.016 | 0.079 |
| *EU* | | | | | | | | | | | |
| agr | 0.092 | 0.077 | 0.051 | 0.160 | 0.014 | 0.012 | 0.105 | 0.090 | 0.115 | 0.116 | 0.108 |
| col | 0.195 | 0.153 | 0.062 | 0.060 | 0.021 | 0.077 | 0.149 | 0.144 | 0.169 | 0.170 | 0.000 |
| oil | 0.026 | 0.027 | 0.003 | 0.001 | 0.002 | 0.000 | 0.009 | 0.031 | 0.029 | 0.036 | 0.016 |
| gas | 0.011 | 0.007 | 0.004 | 0.021 | 0.003 | 0.014 | 0.033 | 0.030 | 0.008 | 0.005 | 0.000 |
| oil_pcts | 0.093 | 0.089 | 0.092 | 0.059 | 0.043 | 0.042 | 0.080 | 0.091 | 0.088 | 0.084 | 0.000 |
| ely | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| engy_int | 0.113 | 0.107 | 0.147 | 0.131 | 0.070 | 0.055 | 0.103 | 0.113 | 0.136 | 0.122 | 0.112 |
| other | 0.053 | 0.040 | 0.071 | 0.023 | 0.019 | 0.020 | 0.037 | 0.045 | 0.042 | 0.026 | 0.034 |
| *Japan* | | | | | | | | | | | |
| agr | 0.058 | 0.206 | 0.208 | 0.067 | 0.263 | 0.000 | 0.218 | 0.169 | 0.335 | 0.304 | 0.000 |
| col | 0.000 | 0.200 | 0.000 | 0.204 | 0.235 | 0.132 | 0.171 | 0.216 | 0.228 | 0.204 | 0.000 |
| oil | 0.000 | 0.000 | 0.182 | 0.136 | 0.041 | 0.147 | 0.190 | 0.011 | 0.000 | 0.000 | 0.000 |
| gas | 0.000 | 0.000 | 0.105 | 0.136 | 0.041 | 0.147 | 0.172 | 0.013 | 0.000 | 0.000 | 0.000 |
| oil_pcts | 0.197 | 0.200 | 0.241 | 0.085 | 0.103 | 0.140 | 0.100 | 0.227 | 0.306 | 0.251 | 0.000 |
| ely | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| engy_int | 0.254 | 0.189 | 0.201 | 0.112 | 0.309 | 0.151 | 0.116 | 0.181 | 0.221 | 0.244 | 0.017 |
| other | 0.126 | 0.057 | 0.020 | 0.010 | 0.015 | 0.005 | 0.038 | 0.084 | 0.094 | 0.017 | 0.073 |

Table 3. Comparison of Initial Energy Tax Bases

| Regions | Energy Related Commodities col | oil | gas | oil_pcts |
|---|---|---|---|---|
| *Margin Inclusive Model* | | $ millions | | |
| USA | 36866.34 | 47.19 | 50285.87 | 288333.09 |
| EU | 18447.75 | 144.92 | 46089.05 | 418006.44 |
| EEFSU | 15875.74 | 558.34 | 54437.41 | 57118.55 |
| JPN | 7735.17 | 2247.46 | 9605.84 | 156864.69 |
| ROA1 | 5197.28 | 52.03 | 8846.70 | 65474.43 |
| EEX | 3486.89 | 2170.68 | 26080.62 | 111532.91 |
| CHIND | 15841.79 | 485.90 | 2903.49 | 69146.34 |
| ROW | 14206.46 | 217.02 | 8953.39 | 131171.45 |
| *Standard GTAP-E* | | | | |
| USA | 29660.48 | 34.14 | 48878.41 | 157251.28 |
| EU | 16648.19 | 144.81 | 44132.54 | 399682.75 |
| EEFSU | 15077.96 | 542.94 | 53681.50 | 47949.75 |
| JPN | 6656.89 | 1908.70 | 8589.63 | 138628.58 |
| ROA1 | 4725.54 | 50.39 | 8434.46 | 54990.20 |
| EEX | 3259.37 | 2134.57 | 25887.48 | 97623.35 |
| CHIND | 14485.88 | 473.86 | 2840.56 | 61860.53 |
| ROW | 13323.10 | 211.06 | 8819.37 | 116234.95 |
| *Ratio of Margin Inclusive to Standard GTAP-E Model* | | | | |
| USA | 1.243 | 1.382 | 1.029 | 1.834 |
| EU | 1.108 | 1.001 | 1.044 | 1.046 |
| EEFSU | 1.053 | 1.028 | 1.014 | 1.191 |
| JPN | 1.162 | 1.177 | 1.118 | 1.132 |
| ROA1 | 1.100 | 1.033 | 1.049 | 1.191 |
| EEX | 1.070 | 1.017 | 1.007 | 1.142 |
| CHIND | 1.094 | 1.025 | 1.022 | 1.118 |
| ROW | 1.066 | 1.028 | 1.015 | 1.129 |

Table 4. Initial $CO_2$ Emissions

| Region | col | oil | gas | oil_pcts | Total |
|---|---|---|---|---|---|
| | | | Millions of Metric Tons of Carbon | | |
| USA | 544.9 | 0.2 | 394.6 | 692.5 | 1632.2 |
| EU | 237.8 | 1.0 | 211.9 | 527.0 | 977.7 |
| EEFSU | 307.9 | 3.4 | 330.4 | 201.0 | 842.6 |
| JPN | 92.0 | 12.0 | 37.9 | 208.8 | 350.7 |
| ROA1 | 78.0 | 0.3 | 68.9 | 128.9 | 276.2 |
| EEX | 66.2 | 14.6 | 229.6 | 438.1 | 748.5 |
| CHIND | 862.1 | 3.0 | 27.2 | 221.9 | 1114.2 |
| ROW | 210.8 | 1.4 | 56.0 | 396.0 | 664.2 |

Table 5. Production, Margin, and Trade Elasticities of Substitution

| | Production | | | | | Margin | | Trade | |
|---|---|---|---|---|---|---|---|---|---|
| Sectors | $\sigma_T$ | $\sigma_{KE}$ | $\sigma_{ELY}$ | $\sigma_{COAL}$ | $\sigma_{FU}$ | $\sigma_{pt}$ | $\sigma_{pm}$ | $\sigma_D$ | $\sigma_M$ |
| agr | 0.0 | 0.5 | 1.0 | 0.5 | 1.0 | 0.0 | 0.0 | 2.4 | 4.6 |
| col | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.8 | 5.6 |
| oil | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 30.0 | 30.0 |
| gas | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.8 | 5.6 |
| oil_pcts | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.9 | 3.8 |
| ely | 0.0 | 0.5 | 1.0 | 0.5 | 1.0 | 0.0 | 0.0 | 2.8 | 5.6 |
| engy_int | 0.0 | 0.5 | 1.0 | 0.5 | 1.0 | 0.0 | 0.0 | 2.3 | 4.6 |
| other | 0.0 | 0.5 | 1.0 | 0.5 | 1.0 | 0.0 | 0.0 | 2.3 | 6.1 |
| trd | 0.0 | 0.5 | 1.0 | 0.5 | 1.0 | 0.0 | 0.0 | 1.9 | 3.8 |
| trans | 0.0 | 0.5 | 1.0 | 0.5 | 1.0 | 0.0 | 0.0 | 1.9 | 3.8 |
| CGDS | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | |

| Production | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $\sigma_{VA}$ | USA | EU | EEFSU | JPN | ROA1 | EEX | CHIND | ROW |
| agr | 0.03 | 0.20 | 0.06 | 0.22 | 0.15 | 0.11 | 0.11 | 0.12 |
| col | 0.40 | 0.40 | 0.39 | 0.40 | 0.40 | 0.39 | 0.40 | 0.39 |
| oil | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 | 0.37 |
| gas | 0.04 | 0.38 | 1.16 | 1.31 | 1.06 | 0.76 | 0.86 | 0.41 |
| oil_pcts | 1.26 | 1.26 | 1.26 | 1.26 | 1.26 | 1.26 | 1.26 | 1.26 |
| ely | 1.26 | 1.26 | 1.26 | 1.26 | 1.26 | 1.26 | 1.26 | 1.26 |
| engy_int | 1.19 | 1.19 | 1.19 | 1.19 | 1.19 | 1.19 | 1.19 | 1.19 |
| other | 1.27 | 1.27 | 1.27 | 1.27 | 1.27 | 1.27 | 1.27 | 1.27 |
| trd | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 |
| trans | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 |
| CGDS | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

Table 6. Comparison of Simulation Results for Models With and Without Domestic Margins

| Region/Commodity | Real Carbon Tax ($/Ton) $25 | $50 | $75 | $100 |
|---|---|---|---|---|
| *Change in $CO_2$ Emissions* | Ratio of Margin Inclusive to No Margin Model | | | |
| USA | 0.82 | 0.83 | 0.84 | 0.84 |
| EU | 0.98 | 0.97 | 0.98 | 0.98 |
| EEFSU | 0.88 | 0.87 | 0.86 | 0.88 |
| JPN | 0.90 | 0.91 | 0.92 | 0.93 |
| ROA1 | 0.95 | 0.95 | 0.95 | 0.96 |
| EEX | 0.63 | 0.71 | 0.70 | 0.72 |
| CHIND | 1.00 | 1.14 | 1.25 | 1.25 |
| ROW | 0.82 | 0.81 | 0.83 | 0.82 |
| *Power of Carbon Tax* | | | | |
| *Coal* | | | | |
| USA | 0.78 | 0.76 | 0.75 | 0.74 |
| EU | 0.89 | 0.88 | 0.88 | 0.88 |
| JPN | 0.85 | 0.84 | 0.84 | 0.84 |
| ROA1 | 0.90 | 0.89 | 0.89 | 0.88 |
| *Oil* | | | | |
| USA | 0.72 | 0.71 | 0.70 | 0.72 |
| EU | 0.99 | 0.99 | 0.99 | 0.99 |
| JPN | 0.84 | 0.84 | 0.84 | 0.84 |
| ROA1 | 0.96 | 0.96 | 0.96 | 0.96 |
| *Gas* | | | | |
| USA | 0.97 | 0.97 | 0.97 | 0.97 |
| EU | 0.96 | 0.96 | 0.95 | 0.96 |
| JPN | 0.89 | 0.89 | 0.89 | 0.89 |
| ROA1 | 0.95 | 0.95 | 0.95 | 0.94 |
| *Refined Oil Products* | | | | |
| USA | 0.54 | 0.54 | 0.54 | 0.54 |
| EU | 0.94 | 0.94 | 0.95 | 0.94 |
| JPN | 0.89 | 0.88 | 0.87 | 0.87 |
| ROA1 | 0.83 | 0.83 | 0.83 | 0.83 |
| *Composite Price for Private Household* | | | | |
| *USA* | | | | |
| gas | 0.97 | 0.97 | 0.97 | 0.97 |
| oil_pcts | 0.60 | 0.60 | 0.59 | 0.59 |
| ely | 1.00 | 1.01 | 1.02 | 1.02 |
| engy_int | 0.67 | 0.61 | 0.63 | 0.63 |
| *EU* | | | | |
| gas | 0.98 | 0.98 | 0.98 | 0.98 |
| oil_pcts | 1.30 | 1.26 | 1.21 | 1.19 |
| ely | 1.00 | 1.00 | 0.99 | 0.99 |
| engy_int | 0.67 | 0.73 | 0.75 | 0.76 |

Table 6. Continued

| Region/Commodity | Real Carbon Tax ($/Ton) $25 | $50 | $75 | $100 |
|---|---|---|---|---|
| | Ratio of Margin Inclusive to No Margin Model | | | |
| *Composite Price for Private Household* | | | | |
| *Japan* | | | | |
| gas | 0.91 | 0.90 | 0.90 | 0.90 |
| oil_pcts | 1.00 | 1.00 | 0.99 | 0.98 |
| ely | 1.00 | 1.03 | 1.02 | 1.03 |
| engy_int | 0.67 | 0.67 | 0.71 | 0.73 |
| *Composite Quantity Purchased by Private Household* | | | | |
| *USA* | | | | |
| gas | 0.97 | 0.97 | 0.98 | 0.98 |
| oil_pcts | 0.60 | 0.62 | 0.64 | 0.66 |
| ely | 1.01 | 1.01 | 1.01 | 1.01 |
| engy_int | 0.38 | 0.36 | 0.41 | 0.41 |
| *EU* | | | | |
| gas | 0.98 | 0.98 | 0.98 | 0.98 |
| oil_pcts | 1.35 | 1.28 | 1.22 | 1.19 |
| ely | 0.99 | 1.00 | 1.00 | 1.00 |
| engy_int | 0.47 | 0.60 | 0.63 | 0.64 |
| *Japan* | | | | |
| gas | 0.91 | 0.92 | 0.92 | 0.93 |
| oil_pcts | 1.02 | 0.98 | 0.97 | 0.98 |
| ely | 1.01 | 1.00 | 1.03 | 1.02 |
| engy_int | 0.37 | 0.33 | 0.44 | 0.42 |
| *Composite Energy Use by Firms* | | | | |
| *USA* | | | | |
| agr | 0.89 | 0.91 | 0.91 | 0.91 |
| col | 0.88 | 0.89 | 0.91 | 0.92 |
| oil | 0.67 | 0.68 | 0.69 | 0.71 |
| gas | 0.98 | 0.98 | 0.99 | 0.99 |
| oil_pcts | 0.57 | 0.60 | 0.61 | 0.63 |
| ely | 0.97 | 0.98 | 0.98 | 0.99 |
| engy_int | 0.81 | 0.83 | 0.84 | 0.84 |
| other | 0.97 | 0.96 | 0.96 | 0.97 |
| trd | 0.69 | 0.70 | 0.72 | 0.73 |
| trans | 0.67 | 0.68 | 0.69 | 0.70 |

Table 6. Continued

| Region/Commodity | Real Carbon Tax ($/Ton) $25 | $50 | $75 | $100 |
|---|---|---|---|---|
| | Ratio of Margin Inclusive to No Margin Model | | | |
| *Composite Energy Use by Firms* | | | | |
| *EU* | | | | |
| agr | 1.00 | 1.04 | 1.05 | 1.04 |
| col | 0.94 | 0.95 | 0.95 | 0.96 |
| oil | 0.71 | 0.74 | 0.75 | 0.76 |
| gas | 0.94 | 0.94 | 0.95 | 0.95 |
| oil_pcts | 1.30 | 1.30 | 1.22 | 1.18 |
| ely | 0.96 | 0.97 | 0.97 | 0.97 |
| engy_int | 1.10 | 1.05 | 1.03 | 1.03 |
| other | 1.06 | 1.00 | 1.02 | 1.00 |
| trd | 1.20 | 1.20 | 1.16 | 1.14 |
| trans | 1.25 | 1.15 | 1.13 | 1.09 |
| *Japan* | | | | |
| agr | 1.00 | 0.96 | 0.95 | 0.96 |
| col | 0.89 | 0.91 | 0.92 | 0.93 |
| oil | 0.71 | 0.74 | 0.75 | 0.76 |
| gas | 0.93 | 0.93 | 0.94 | 0.94 |
| oil_pcts | 1.00 | 0.98 | 0.97 | 0.95 |
| ely | 0.97 | 0.96 | 0.97 | 0.98 |
| engy_int | 1.00 | 1.00 | 1.00 | 0.98 |
| other | 1.00 | 1.05 | 1.03 | 1.03 |
| trd | 1.11 | 1.12 | 1.12 | 1.12 |
| trans | 1.05 | 1.02 | 1.03 | 1.01 |

Table 7. Decomposition of Refined Oil Products Price Paid by Private Households

| | US | | EU | | Japan | |
|---|---|---|---|---|---|---|
| Price/Share | Margin | No Margin | Margin | No Margin | Margin | No Margin |
| *Domestic* | | | | | | |
| Market price | -0.8 | -1.1 | -0.9 | -1.3 | -0.4 | -0.7 |
| Margin share | 0.60 | 0.00 | 0.28 | 0.00 | 0.32 | 0.00 |
| Margin price | 0.3 | 0.0 | 0.2 | 0.0 | 0.2 | 0.0 |
| Margin inclusive price | -0.1 | -1.1 | -0.6 | -1.3 | -0.2 | -0.7 |
| *Import* | | | | | | |
| Import price | -0.9 | -1.3 | -0.8 | -1.2 | -0.9 | -1.3 |
| Margin share | 0.60 | 0.00 | 0.30 | 0.00 | 0.32 | 0.00 |
| Margin price | 0.3 | 0.0 | 0.2 | 0.0 | 0.2 | 0.0 |
| Margin inclusive price | -0.2 | -1.3 | -0.5 | -1.2 | -0.5 | -1.3 |
| *Composite* | | | | | | |
| Import share | 0.05 | 0.05 | 0.27 | 0.27 | 0.03 | 0.03 |
| Before tax price | -0.1 | -1.1 | -0.6 | -1.3 | -0.2 | -0.7 |
| Power of tax | 6.1 | 11.2 | 3.2 | 3.3 | 3.3 | 3.8 |
| After tax price | 6.0 | 10.1 | 2.6 | 2.0 | 3.1 | 3.1 |
| Ratio margin to no margin | 0.59 | | 1.30 | | 1.00 | |

Table 8. Carbon Taxes and Emission Reductions Required to Achieve Kyoto Targets

| Region | No Emission Trading | | Emission Trading Annex 1 Countries | | Emission Trading Worldwide | |
|---|---|---|---|---|---|---|
| | Margin | No Margin | Margin | No Margin | Margin | No Margin |
| | | | Carbon Tax ($/ton) | | | |
| USA | 152.53 | 115.59 | 89.39 | 82.00 | 38.10 | 34.83 |
| EU | 143.43 | 137.59 | 89.39 | 82.00 | 38.10 | 34.83 |
| EEFSU[a] | 0.00 | 0.00 | 89.39 | 82.00 | 38.10 | 34.83 |
| JPN | 249.04 | 219.00 | 89.39 | 82.00 | 38.10 | 34.83 |
| ROA1 | 175.83 | 160.32 | 89.39 | 82.00 | 38.10 | 34.83 |
| EEX | 0.00 | 0.00 | 0.00 | 0.00 | 38.10 | 34.83 |
| CHIND | 0.00 | 0.00 | 0.00 | 0.00 | 38.10 | 34.83 |
| ROW | 0.00 | 0.00 | 0.00 | 0.00 | 38.10 | 34.83 |
| | | | Percent Reduction in $CO_2$ Emissions | | | |
| USA | -35.6 | -35.6 | -25.6 | -27.7 | -12.3 | -13.5 |
| EU | -22.4 | -22.4 | -15.4 | -13.9 | -6.1 | -5.4 |
| EEFSU[a] | 3.2 | 3.3 | -25.6 | -23.9 | -12.2 | -11.6 |
| JPN | -31.8 | -31.8 | -15.7 | -15.2 | -5.8 | -5.6 |
| ROA1 | -35.7 | -35.7 | -23.1 | -21.7 | -10 | -9.4 |
| EEX | 2.6 | 3.1 | 2.1 | 3.1 | -9 | -8.5 |
| CHIND | -1.1 | -0.9 | -0.9 | -0.3 | -32.4 | -32.4 |
| ROW | 5.6 | 6.2 | 4.6 | 6.4 | -8.7 | -8.2 |

[a] Because of emission surplus in Eastern Europe and the former Soviet Union, no reduction in emissions is required for this region in the no trading scenario. When emission trading is permitted, the amount of the emission surplus, assumed to equal 100 million tons of carbon, is applied to the target total reductions in carbon emissions.

*Appendix: Regional and Sectoral Aggregation*

Table A1. Regional Aggregation

| Region Code | Region Name | GTAP v5.4 Regions |
|---|---|---|
| USA | United States | United States |
| EU | European Union | Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom |
| EEFSU | Eastern Europe and Former Soviet Union | Albania, Bulgaria, Croatia, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia, Estonia, Lativa, Lithuania, Russian Federation, Rest of Former Soviet Union |
| JPN | Japan | Japan |
| ROA1 | Rest of annex 1 | Australia, New Zealand, Canada, Switzerland, Rest of European Free Trade Area |
| EEX | Net energy exports | Indonesia, Malaysia, Vietnam, Mexico, Colombia, Venezuela, Rest of Andean Pact, Argentina, Rest of Middle East, Rest of North Africa, Other Southern Africa, Rest of Sub-Saharan Africa, Rest of World |
| CHIND | China and India | China, India |
| ROW | Rest of world | Bangladesh, Botswana, Brazil, Central America and Caribbean, Chile Cyprus, Hong Kong, Korea, Malawi, Malta, Morocco, Mozambique, Peru, Philippines, Rest of South Africa Customs Union, Rest of South America, Rest of South Asia, Singapore, Sri Lanka, Taiwan, Tanzania, Thailand, Turkey, Uganda, Uruguay, Zambia, Zimbabwe |

Table A2. Sectoral Aggregation

| Commodity Code | Commodity Name | GTAP v5.4 Commodity |
|---|---|---|
| agr | Agriculture | Paddy rice; wheat; cereal grains nec; vegetables, fruit, nuts; oilseeds; sugar cane and beet; plant-based fibers; crops nec; bovine cattle, sheep, and goats; animal products nec; raw milk; wool; forestry; fishing |
| col | Coal | Coal |
| oil | Oil | Oil |
| gas | Gas | Gas and gas manufacture and distribution |
| oil_pcts | Refined oil products | Petroleum and coal products |
| ely | Electricity | Electricity |
| engy_int | Energy intensive industries | Chemical, rubber, plastic products; mineral products nec; ferrous metals; metals nec; minerals nec |
| trd | Trade | Trade |
| trans | Transportation | Water transport, air transport, transport nec |
| Other | Other industries and services | Bovine meat products; meat products nec; vegetable oils and fats; dairy products; processed rice; sugar; food products nec; beverages and tobacco products; textiles; wearing apparel; wood products; paper products; motor vehicles; transport equipment nec; electronic equipment; machinery and equipment nec; manufactures nec; water; construction; communication; financial services nec; insurance; business services nec; recreational and other services; public administration, defense, eduation, health; dwellings |