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Implications of incorporating domestic margins into analyses of energy taxation and climate change policies

Everett B. Peterson [a,*], Huey-Lin Lee [b]

[a] Department of Agricultural and Applied Economics, Virginia Tech, Blacksburg, VA 24061, United States
[b] Department of Economics, National Chengchi University, 64 Sec. 2, Zhi-Nan Rd., Taipei 11605, Taiwan

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ABSTRACT

In most applied general equilibrium (AGE) analyses, the domestic transportation, wholesaling, and retailing services that facilitate the flow of goods and services from producers to consumers are not identified by commodity or use. 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. This paper incorporates domestic trade and transport margins into the GTAP-E model, which has previously been used to analyze climate change policies. Models that do not explicitly incorporate domestic margins over-estimate the reduction in CO_2 emissions from a given carbon tax or under-estimate the level of a carbon tax needed to achieve a specific abatement target when domestic margins are fixed or when the carbon tax is treated as a consumption tax with variable domestic margins. However, this result can be reversed when the carbon tax is treated as an output tax with variable domestic margins.

1. Introduction

Increases in atmospheric levels of carbon dioxide (CO_2) over the past century, mainly due to the burning of fossil fuels, has led to concerns of global climate change. Various policies aiming to reduce CO_2 and other greenhouse gas (GHG) emissions have been proposed under international accord (e.g. Joint Implementation (JI) and Clean Development Mechanism (CDM) under the Kyoto Protocol). Ideally, such policies require multiple country participation to be effective at reducing atmospheric accumulation of GHGs. Thus, climate change policies are inter-regional and have the potential to affect the competitiveness of countries, even those that are not part of the agreement, in international markets. Because of their ability to model trade linkages, applied general equilibrium (AGE) models have been widely used to assess the economic impacts of the proposed climate change policies (e.g., Dagoumas et al., 2006; Nijkamp et al., 2005; Burniaux, 1998).

In most AGE models, and all AGE models that use the GTAP data base[1], the domestic margins services (transportation, wholesale trade, and retail trade) that facilitate the flow of goods from producers to buyers are not explicitly modeled. To illustrate this point, of seventeen AGE models identified in a recent survey article by Böhringer and Löschel (2006), only the Monash model (Dixon and Rimmer, 2002) explicitly incorporated domestic margins. This reflects the treatment of margins in the conventional Input–Output (I–O) Accounts; the underlying data used in AGE models. Producer values are reported in the I–O tables. Thus, all of the marketing activities associated with purchase of commodities are accounted for in the sales of domestic margin services and not associated with a particular commodity. For example, the price of gasoline the buyer pays does not include the cost of transportation, wholesale, and retail services necessary to get gasoline from the refinery to the buyer. Instead, it is assumed that the buyer purchased these margins services directly from the margins industries. This treatment of domestic margins can lead to inappropriate demand response (Dixon et al., 1982).

The magnitude of the domestic trade and transport margins for energy products can be substantial, particularly for private households. Peterson (2006) found that the value of domestic trade and transport margins for refined petroleum products sold to private households in the United States (US) is approximately 60% of the producer value. In the absence of taxes, domestic margins create a wedge between the producer (factory gate) and buyer prices, with the buyer price equaling the sum of producer price and unit margin costs. When energy taxes are imposed, it is the presence of this wedge that will create differential effects on producer and buyer prices compared to models that do not distinguish domestic margins. For example, in an analysis of global technical change in agricultural crops, Peterson (2006) found when

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* Corresponding author. Tel.: +1 540 231 6108.
E-mail address: petrsone@vt.edu (E.B. Peterson).

[1] The GTAP data base, developed and maintained by the Center for Global Trade Analysis, Purdue University, includes only international transport margins. See https://www.gtap.agecon.purdue.edu/products/packages.asp for more details on the GTAP data base.

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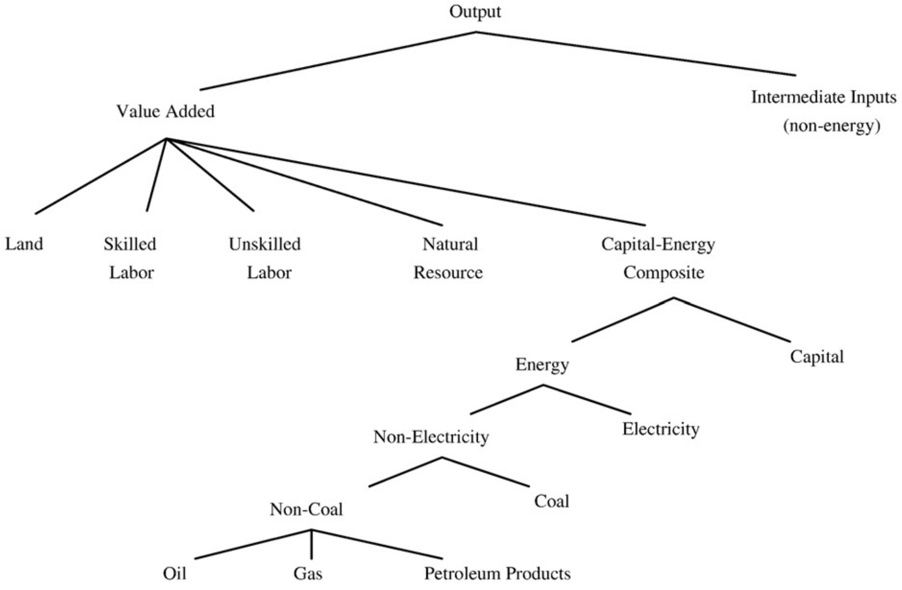

Fig. 1. Structure of production in GTAP-E model.

domestic margins were explicitly modeled only 50–80% of the reduction in crop prices was passed through to consumers.

The objective of this paper is to assess the significance of incorporating domestic trade and transport margins in an AGE model when analyzing energy taxation and climate change policies. To achieve this goal, domestic trade and transport margins are incorporated into an existing AGE model that has been utilized to analyze climate change policies, the GTAP-E model (Burniaux and Truong, 2002). Simulation results from the GTAP-E model and domestic margin inclusive model, hereafter nicknamed GTAP-ME, are compared for two different sets of experiments. The first set of experiments simulates the impact of real tax of $25, $50, $75, and $100 US dollars per metric ton of carbon emitted in selected regions. The second set of experiments compares the results of scenarios with and without emissions trading to achieve the CO_2 emissions abatement targets under the Kyoto Protocol. Due to the wedge between producer and buyer prices created by incorporating domestic margins, an energy tax increase is expected to have a smaller effect on the buyer price of energy commodities, leading to higher marginal abatement costs in the GTAP-ME model compared to the GTAP-E model. In addition, because the magnitudes of the domestic margins vary between countries and energy commodities, any relative changes in the marginal abatement costs between countries will change the cost-effective allocation of carbon abatement between countries.

2. Model structure

The GTAP-ME model is a static, perfectly competitive, multi-region, multi-sector AGE model, based on the GTAP model (Hertel, 1997). The model specifications that are most relevant to this paper are discussed below.

2.1. Regional household demand

In each region, there is a single representative household that collects all of the factor income and tax receipts and spends this income on private consumption of goods and services, government consumption, and savings. The utility function for the representative household consists of two levels. At the top-level, a Cobb–Douglas utility function is specified such that shares of private consumption, government consumption, and savings remain constant. At the second-level, a non-homothetic Constant Difference Elasticity of substitution (CDE) utility function is used to represent preferences for private consumption (see Liu et al., 1998 for a more complete discussion of the CDE). Also at the second-level, a Cobb–Douglas utility function is used to represent preferences for government consumption.

2.2. Production

Similar to the GTAP-E model, a nested Constant Elasticity of Substitution (CES) production structure, as illustrated in Fig. 1, is specified in the GTAP-ME model. Each sub-nest in the production structure represents the possibility for substitution between individual or composite inputs. Each composite input is composed of the commodities at the next lower level in the tree structure of Fig. 1. At the top level of the production structure, firms produce output by using non-energy intermediate inputs and a primary factor composite (or value added).[2] The elasticity of substitution between the primary factor composite and non-energy intermediate inputs (σ_T) is assumed to equal zero, implying a constant ratio of input to output for all non-energy intermediate inputs and the primary factor composite. The primary factor composite is composed of land, skilled labor, unskilled labor, natural resources, and a capital-energy composite with a constant elasticity of substitution (σ_{VA}) between them.

Within the capital-energy composite, firms may substitute the energy composite for capital (σ_{KE}) if the aggregate energy price decreases relative to the capital rental rate. There are also three inter-fuel substitution possibilities: (a) electricity and the non-electricity composite (σ_{ELY}); (b) coal and the non-coal composite (σ_{COAL}); and (c) between oil, gas, and petroleum products (σ_{FU}). For example, producers may substitute coal for the non-coal composite of oil, gas and petroleum products when coal becomes relatively less expensive than non-coal fuels.

As pointed out by Burniaux and Truong (2002), the advantages of this specification are that it allows for substitution between fuels and the potential for capital and energy to be either substitutes or complements, depending on the chosen values of the elasticities of substitution. Using the formula derived by Keller (1980) for the Allen partial elasticities of substitution (APES) for nested CES production functions, the APES

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[2] For clarity, the substitution possibilities between imports and between a domestically produced input and the composite imported input are not shown in Fig. 1. Instead, they are highlighted in Fig. 2.

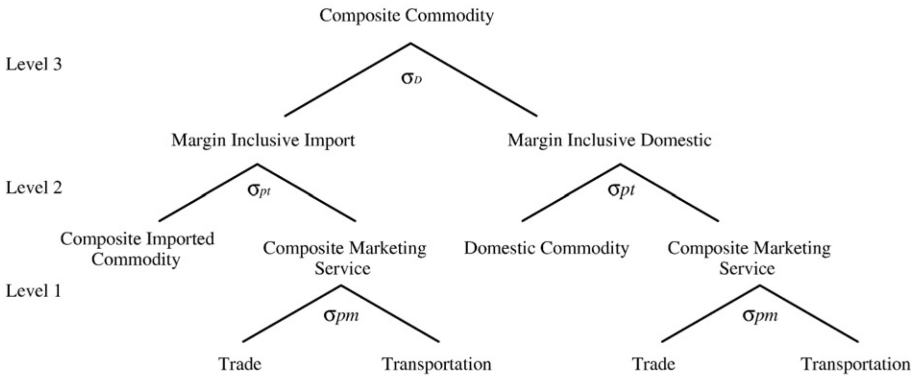

Fig. 2. Structure of domestic marketing margins in GTAP-ME.

between capital and energy, assuming a Leontief structure between non-energy intermediate inputs and value added is:

$$\sigma_{ij} = [\sigma_{\mathrm{KE}} - \sigma_{\mathrm{VA}}]1/s_{\mathrm{KE}} + \sigma_{\mathrm{VA}}/s_{\mathrm{VA}},$$

where S_{KE} and S_{VA} are the cost shares of the capital-energy and value added composites. So if σ_{KE} is less than σ_{VA}, then it is possible for capital and energy to be complementary.

2.3. Incorporating domestic margins

Domestic margins are incorporated following the specification used in the ORANI model (Dixon et al., 1982), the MONASH model (Dixon and Rimmer, 2002), and the perfectly competitive specification of Bradford and Gohin (2006). This approach specifies a nested CES structure shown in Fig. 2. At the top of this structure is a composite commodity that is purchased by the private household, government household, or firms. Similar to the GTAP-E model, the composite commodity is a combination of the margin inclusive composite imported commodity and a margin inclusive domestic commodity (see Level 3 of Fig. 2), where σ_D is the Armington 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[3] and the domestically produced commodity are combined with a 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 σ_{pt}. As shown in Level 1, the composite marketing service is itself a CES aggregate of all trade and transport services needed to get the good from the producer to the purchaser. The constant elasticity of substitution σ_{pm} governs the degree of substitutability between individual marketing services, such as land and air transport, as relative prices vary. Levels 1 and 2 do not exist in the GTAP-E model.

The domestic trade and transport services needed to get a given commodity from the domestic producer to the port of departure are also explicitly modeled.[4] Similar to Fig. 2, a two-level nested CES structure is utilized. At the bottom level, domestic trade and transport services are combined to create a composite marketing service. At the top level, this composite marketing service is combined with exports to create the *f.o.b.* export composite commodity.

2.4. CO_2 emissions and carbon taxes

The emission of CO_2 per unit of energy commodities used is assumed to be constant across users and regions, but varies by energy commodity. Formally, the level of CO_2 emissions from energy commodity *e* in region *r* is specified as:

$$CO2(r,e) = \left[\frac{C(e)}{V(e)}\right]\left[\frac{V(e)}{Q(e)}\right]\Big\{\sum_{j\in\mathrm{prod\_comm}}[QFD(e,j,r) + QFM(e,j,r)] + QPD(e,r) + QPM(e,r) + QGD(e,r) + QGM(e,r)\Big\} \tag{1}$$

where *CO2* is defined as millions of metric tons (MT) of carbon emitted; (*C/V*) is the amount of CO_2 emissions per mtoe (million tons of oil equivalent); (*V/Q*) is the mtoe per unit of energy commodity; *QFD* and *QFM* are the quantities of domestic and imported energy commodities used as intermediate inputs; *QPD* and *QPM* are the quantities of domestic and imported energy commodities purchased by the private household; and *QGD* and *QGM* are the quantities of domestic and imported energy commodities purchased by the government. The terms (*C/V*)(*V/Q*) convert the physical quantities of the energy commodity into the level of CO_2 emissions. The percentage change in CO_2 emissions is:

$$\begin{aligned} CO2(r,e)*gco2(r,e) = {} & \sum_j [EDINT(e,j,r)*qfd(e,j,r) + EMINT(e,j,r)*qfm(e,j,r)] \\ & + EDHH(e,r)*qpd(e,r) + EMHH(e,r)qpm(e,r) \\ & + EDGV(e,r)*qgd(e,r) + EMGV(e,r)*qgm(e,r), \end{aligned} \tag{2}$$

where *gco2* is the percentage change in CO_2 emissions; *EDINT*, *EMINT*, *EDHH*, *EMHH*, *EDGV*, and *EMGV* are the amount of CO_2 emitted from domestic and imported intermediate energy inputs and energy commodities by the private and government households; and *qfd*, *qfm*, *qpd*, *qpm*, *qgd*, *qgm*, are the percentage changes in the use of energy commodities by firms, private households, and the government.

The energy tax used in this paper is a per-ton tax levied on the quantity of CO_2 emitted from the use of energy commodities. The carbon tax inclusion value of energy commodities in the GTAP-ME model is the sum of value at producer prices plus the value of domestic margins plus the value of the carbon tax. In the GTAP-E model, the carbon tax inclusion value of energy commodities is the value at producer prices plus the value of the carbon tax. Thus, for a given carbon tax rate, the value of the carbon tax will be a smaller percentage of the after-tax value of energy commodities in the GTAP-ME model compared to the GTAP-E model. Holding the producer price constant, a given carbon tax will then result in a smaller increase in the after-tax price in the GTAP-ME model than in the GTAP-E model. This implies that a higher carbon tax rate will be required in the GTAP-ME model to achieve the same carbon abatement target compared with the GTAP-E model.

Because taxes in the standard GTAP model, including the GTAP-E model, are treated as ad valorem taxes, the carbon tax is converted to an ad valorem basis. The power of the carbon tax, which translates a specific tax into its ad valorem equivalent, is:

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

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[3] The composite imported commodity is a CES aggregate of imports from various source regions. This nest is not shown in Fig. 2.

[4] Bradford and Gohin (2006) do not include domestic margins on intermediate inputs or exports in their model.

Table 1
Average domestic margins on commodities purchased by the private household

Commodity[b]	Region[a]							
	US	EU	EEFSU	JPN	ROA1	EEX	CHIND	ROW
	Share of retail value at market prices							
agr	0.412	0.333	0.149	0.441	0.378	0.244	0.139	0.229
coal	0.620	0.424	0.165	0.516	0.337	0.150	0.120	0.299
oil[c]	N/A	0.030	0.020	N/A	0.000	0.033	0.000	0.036
gas	0.000	0.086	0.013	0.000	0.088	0.004	0.002	0.043
oil_pcts	0.603	0.285	0.454	0.324	0.490	0.294	0.176	0.313
ely	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
engy_int	0.454	0.408	0.257	0.476	0.487	0.358	0.175	0.344
other	0.151	0.158	0.123	0.192	0.159	0.176	0.093	0.155

Source: Peterson (2006), GTAP-M data base.

[a] Regional abbreviations are defined as follows: (US) United States; (EU) European Union; (EEFSU) Eastern Europe and Former Soviet Union; (JPN) Japan; (ROA1) rest of Annex I countries; (EEX) net energy exporting countries; (CHIND) China and India; and (ROW) rest of world.

[b] Commodity abbreviations are defined as follows: (agr) agriculture; (oil_pcts) refined oil and petroleum products; (ely) electricity; (engy_int) energy intensive industries; (other) other industries and services; (trd) trade services; and (trans) transportation. Note that by definition, no margins are applied to trade services and transportation.

[c] Direct purchases of oil by consumers is either zero or very small in all regions.

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.

We treat the carbon tax as a sales or consumption tax and apply the ad valorem tax rate to the margin-inclusive price of the energy commodities. For example, in the United States, a consumption tax is applied on all motor fuels (gasoline and diesel) that are used for transportation. We believe that this would also be common in other regions as well. An alternative assumption would be to apply the carbon tax to the producer price (e.g., an output tax), before the domestic margins are applied. In the case of fixed margins, it does not matter whether the carbon tax is modeled as a consumption tax or a production tax (e.g., applied pre- or post-domestic margin). However, in the case of variable domestic margins, this is not the case. With variable margins, treating the carbon tax as a production tax would increase the after-tax price of the energy commodity relative to the composite margin price, leading to substitution away from the energy commodity and more intensive use of domestic margin activities. This could lead to a greater reduction in CO_2 emissions compared to the fixed margin case. To assess the importance of modeling the carbon tax as a consumption or output tax, all experiments are conducted using both specifications.

2.5. Emission trading

2.5.1. Not participating in emissions trading

When a country does not participate in the emissions trading market, its marginal abatement cost may differ from other countries. A carbon tax variable, both on a real and nominal basis, is used to represent the marginal abatement costs in the model. In levels form,

$$NCTAX(r) = GDPIND(r)^{*}RCTAX(r), \tag{3}$$

where *NCTAX*(*r*) and *RCTAX*(*r*) are the nominal and the real carbon tax rate for region *r* and *GDPIND*(*r*) is the GDP deflator of region *r*. The change in the nominal tax rate is specified as:

$$nctax(r) = GDPIND(r)^{*}rctax(r) + 0.01^{*}NCTAX(r)^{*}pgdp(r), \tag{4}$$

where *nctax*(*r*) and *rctax*(*r*) are the changes in the nominal and the real carbon tax rates for region *r* and *pgdp*(*r*) is the percentage change in the GDP deflator in region *r*.

2.5.2. Participating in the emissions trading

When a group of countries join an emissions trading scheme, the marginal abatement costs are equalized across countries through the trading of CO_2 emissions quota. In terms of Eq. (3), this implies that *NCTAX*(r) is equalized in all participating countries. Formally, the value of emissions trading is specified in the model as:

$$DVCO2TRA(r) = [CO2Q(r) - CO2T(r)]^{*}NCTAX(r) \tag{5}$$

where *CO2Q*(*r*) is the CO_2 emissions quota for region *r*; *CO2T*(*r*) is the total CO_2 emissions of region *r*; and *DVCO2TRA*(*r*) is the dollar value from CO_2 emissions trading of region *r*. If *DVCO2TRA*(*r*) is negative, country *r* is buying emissions permits, as it emits more than its allocated quota. If *DVCO2TRA*(*r*) is positive, country *r* is selling emissions permits, as it emits less than its allocated quota. The change in the dollar value of emissions trading is specified as:

$$\begin{aligned} dvco2tra(r) = {} & 0.01^{*}NCTAX(r)^{*}[CO2Q(r)^{*}gco2q(r) - CO2T(r)^{*}gco2t(r)] \\ & + nctax(r)^{*}[CO2Q(r) - CO2T(r)], \end{aligned} \tag{6}$$

where *dvco2tra*(*r*) is the change in dollar value from CO_2 emissions trading; *gco2q*(*r*) and *gco2t*(*r*) are the percentage changes in the CO_2 emissions quota and total CO_2 emissions.

3. Model aggregation and data

The data used to implement the GTAP-ME models is based on the GTAP version 6 data base Dimaranan (2006), including the GTAP version 6 energy data base that contains the initial CO_2 emissions for each region by energy commodities. Peterson (2006) has developed a domestic margin inclusive version of the GTAP version 6 data base that contains information on trade and transportation margins for all intermediate input purchases, purchases by households, and purchases by governments of domestically produced and imported commodities. It also includes all domestic trade and transport margins required to get exports to the port of departure. This margin data is based on data from the Input–Output accounts of 22 countries.[5] For regions where no margin data are available, average margin shares are used (see Peterson (2006) for more details).

An eight region and ten commodity aggregation of the database is used in this paper. The eight regions are the United States (US), 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 (coal), 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 used in Burniaux and Truong (2002).

Tables 1 and 2 list the average value shares of the domestic margins (retail and wholesale trade, and transport) associated with purchases of domestically produced plus imported goods by private households and by firms.[6] These values illustrate that domestic margins vary substantially across commodities, regions, and uses. Comparing Tables 1 and 2, one can see that domestic margins are larger for commodities purchased by private households than for intermediate inputs or exports. This is due to higher amounts of wholesale/retail

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[5] The countries are Australia, Austria, Belgium, Denmark, Estonia, Germany, Greece, Finland, France, Hungary, Italy, Japan, Malta, the Netherlands, Poland, Portugal, Spain, Sweden, Slovakia, Slovenia, the United Kingdom, and the United States.

[6] The margin shares in Tables 1 and 2 are averaged over domestically produced and imported commodities. The national accounts in some countries report only the total domestic margins for the aggregate of imported and domestic commodities. For these regions, the margin shares on domestic and imported commodities are assumed to be equal.

Table 2
Average domestic margins on intermediate energy inputs

Purchasing industry											
Commodity/region	agr	coal	oil	gas	oil_pcts	ely	engy_int	other	trd	trans	Average
US	Share of retail value at market prices										
coal	N/A[a]	0.324	N/A	0.000	0.153	0.217	0.315	0.308	0.297	0.295	0.219
oil	N/A	N/A	0.038	0.312	0.032	0.189	0.182	0.000	0.000	0.009	0.033
gas	0.000	0.000	0.001	0.204	0.031	0.030	0.082	0.002	0.000	0.008	0.044
oil_pcts	0.128	0.204	0.146	0.312	0.044	0.185	0.132	0.282	0.507	0.348	0.280
EU											
coal	0.103	0.101	0.000	0.080	0.026	0.088	0.120	0.112	0.124	0.174	0.079
oil	0.000	0.000	0.000	0.001	0.001	0.013	0.005	0.028	0.030	0.030	0.001
gas	0.005	0.032	0.004	0.009	0.001	0.016	0.019	0.035	0.012	0.022	0.020
oil_pcts	0.084	0.115	0.086	0.020	0.015	0.052	0.060	0.090	0.103	0.094	0.062
JPN											
coal	N/A	0.198	N/A	0.200	0.235	0.141	0.211	0.168	0.231	N/A	0.191
oil	N/A	N/A	N/A	0.111	0.041	0.159	0.177	0.000	N/A	0.000	0.044
gas	N/A	N/A	N/A	0.129	0.041	0.159	0.180	0.036	0.000	0.000	0.143
oil_pcts	0.214	0.000	N/A	0.074	0.103	0.172	0.102	0.207	0.320	0.249	0.181
ROA1											
coal	0.107	0.125	0.000	0.000	0.031	0.072	0.184	0.242	0.171	0.153	0.077
oil	N/A	0.000	0.040	0.035	0.014	0.044	0.063	0.000	N/A	0.000	0.014
gas	0.016	0.039	0.009	0.022	0.014	0.022	0.067	0.050	0.073	0.048	0.037
oil_pcts	0.131	0.154	0.127	0.120	0.038	0.101	0.107	0.130	0.149	0.175	0.131

Source: Peterson (2006), GTAP-M data base.

[a] N/A refers to case when industry does not purchase the energy commodity.

trade services associated with commodities purchased by private households. For energy related commodities purchased by private households, coal, refined oil products (oil_pcts), and energy intensive industries (engy_int) have larger domestic margins than oil and gas. For electricity (ely), the domestic margins are zero because, in the Input–Output accounting and the sectoral definitions used in the GTAP data base, electricity distribution (or transmission) is considered as part of the activities of the electricity industry in each region. Gas distribution may also be included as part of the natural gas industry in some countries. For example, there are no margin services used to distribute gas to private households in the US and Japan. But for the EU and the ROA1, domestic margins are approximately 9% of the retail market value while the remaining regions have very low domestic margins for gas delivered to private households. As shown in Table 2, the domestic margins on coal, refined oil products (oil_pcts), and energy intensive industries (engy_int) used as intermediate inputs are larger than the domestic margins on oil and gas, which are mainly delivery by pipeline. This is mainly due to the pipeline/grid system of distribution for these energy commodities. Export margins on energy commodities, with the exception of coal, tend to be small with similar magnitudes to intermediate use.

Comparing domestic margins across regions, the US has larger margins that other Annex 1 countries, particularly for oil_pcts purchased by the private household and by the trade and transport industries. The higher margin for oil_pcts in the US cannot solely be attributed to higher transportation costs due to longer shipping distances in the US. Approximately 95% of the total domestic margin for oil_pcts is accounted for by trade services, which is also the case in all other regions.

To illustrate the importance of the wedge created by including domestic margins in the GTAP-ME model, consider the case of oil_pcts purchased by private households in the US. If the producer price of oil_pcts increases by 5%, all else constant, then the retail price of oil_pcts paid by private households will increase by approximately 2% because only 40% (i.e., 1–0.603, see Table 1) of the retail value is attributed to the physical commodity. An increase in the price of oil_pcts will also increase the cost of domestic trade and transport services, which also comprises a part of the domestic margin. As long as the increase in the composite price of domestic margin services is less than the increase in the producer price of oil_pcts, the consumer price will increase by less than the producer price.

The production and trade elasticities of substitution utilized in the both the GTAP-ME and GTAP-E models are listed in Table 3. All production and trade elasticities are set equal to values used by Burniaux and Truong (2002). There is no substitution between non-energy intermediate inputs and value-added (σ_T). Unlike the standard GTAP model, the elasticities of substitution among the components of value-added (σ_{VA}) for agriculture and gas sectors are allowed to vary across regions. For energy sectors (i.e., coal, oil, gas, and oil_pcts sectors), there is no substitution allowed between energy and capital

Table 3
Production and trade elasticities of substitution

	Production					Trade	
Sectors	σ_T	σ_{KE}	σ_{ELY}	σ_{COAL}	σ_{FU}	σ_D	σ_M
agr	0.0	0.5	1.0	0.5	1.0	2.4	4.6
coal	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	30.0	30.0
gas	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	1.9	3.8
ely	0.0	0.5	1.0	0.5	1.0	2.8	5.6
engy_int	0.0	0.5	1.0	0.5	1.0	2.3	4.6
other	0.0	0.5	1.0	0.5	1.0	2.3	6.1
trd	0.0	0.5	1.0	0.5	1.0	1.9	3.8
trans	0.0	0.5	1.0	0.5	1.0	1.9	3.8
CGDS	0.0	0.0	0.0	0.0	0.0		

Production

σ_{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
coal	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

(σ_{KE}), electricity and non-electricity (σ_{ELY}), and coal and non-coal (σ_{COAL}), and between non-coal energy intermediate inputs (σ_{FU}). All other sectors have limited substitution possibilities. Finally, the elasticities of substitution between domestic and the composite imported commodity (σ_D) and between imported commodities (σ_M) are equal to the values in the GTAP v6 data base except for oil, where the trade elasticities are set equal to 30, reflecting the belief that crude oil is a more homogeneous commodity.

For all experiments using the GTAP-ME model, the values σ_{pm} are set equal to zero. Thus no substitution is allowed between margin services. The values of σ_{pt} are set equal to zero in the case of fixed domestic margins, or set equal to 1 for the variable margins case. The later choice is made for two reasons. First, it is an upper bound of the elasticities of substitution for food products in Wohlgenant (1989). Second, Bradford and Gohin (2006) show that a reduced form mark-up model is compatible with imperfect competition in the margins sectors. This approach assumes that domestic margins are an exogenous percentage of the retail value, accommodating cost-plus or percent mark-up pricing rules, implying a Cobb–Douglas relationship between commodities and margin services.

The demand parameters and the elasticities of substitution from the GTAP v.6 data base are utilized in both models. Because the budget shares differ between the GTAP-ME and 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. Similarly, because the cost shares for intermediate inputs will differ between the two models, there are slight differences in the compensated input demand elasticities.

4. Simulations and results

Two different sets of experiments are conducted. The first set of experiments considers increases in the real carbon tax in the US, EU, Japan, and the rest of the Annex I countries (ROA1). The second set of experiments 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 GTAP-E model (i.e., the no domestic margins model) and the GTAP-ME model. The first set of experiments compares the differences between the two models holding levels of the carbon tax constant. The second set of experiments replicate the experiments reported in Burniaux and Truong (2002) and then compare the required level of carbon taxes to attain country-specific abatement targets under the Kyoto Protocol.

Table 4
Comparison of results for exogenous changes in real carbon tax

Variable	Fixed margin	Variable margin	
		Consumption[a]	Output[b]
	Ratio of GTAP-ME to GTAP-E		
Change in CO_2 emissions			
US	0.828	0.804	1.060
EU	0.988	0.974	1.022
Japan	0.905	0.905	1.043
Rest of annex I	0.941	0.943	1.030
Global	0.889	0.858	1.054
Leakage	0.753	0.842	1.006
Change in CO_2 emissions from coal			
US	0.856	0.785	1.099
EU	0.959	0.931	1.047
Japan	0.863	0.831	1.098
Rest of annex I	0.958	0.949	1.041
Change in CO_2 emissions from gas			
US	0.960	0.959	1.015
EU	0.976	0.967	1.003
Japan	0.889	0.878	1.019
Rest of annex I	0.959	0.955	1.010
Change in CO_2 emissions from oil products			
US	0.683	0.705	1.040
EU	1.047	1.047	1.010
Japan	0.949	0.981	1.013
Rest of annex I	0.889	0.920	1.033

[a] Carbon tax is implemented as a consumption tax, post-domestic margins.
[b] Carbon tax is implemented as an output tax, pre-domestic margins.

4.1. Exogenous change in real carbon tax

Four different levels of real carbon taxes are consider in the first set of experiments: \$25, \$50, \$75, and \$100 per metric ton of carbon emissions are imposed on coal, oil, gas, and oil_pcts. Table 4 reports the results from these experiments. Because the relative differences between the GTAP-E and GTAP-ME models are similar across the four experiments, only the average of the ratio of the GTAP-ME to GTAP-E model result is reported.

In the case of fixed domestic margins, the predicted reduction in CO_2 emissions in the regions that implement the carbon tax in the GTAP-ME are smaller than those predicted by the GTAP-E model. Again, this is due to a smaller increase in the power of the carbon tax in the GTAP-ME model. However, these differences vary substantially across regions. The US has the largest difference of 17.2% while the EU has the smallest difference of 1.2%. These variations can be attributed to differences in the relative size of the domestic margins for energy commodities and the initial taxes on energy commodities. From Tables 1 and 2, the US has the largest average domestic margins on energy commodities, particularly for oil_pcts, while the EU has the smallest average domestic margins. In addition, on an ad valorem basis, the US has the lowest initial tax rate on energy commodities while the EU has the highest initial tax rate. Thus, the larger the domestic margins on energy commodities, the smaller the power of carbon tax when compared with models that do not incorporate domestic margins, and the larger the difference in the predicted reduction in CO_2 emissions. Conversely, higher initial tax rates on energy commodities will diminish the importance of domestic margins because the margins become a smaller percentage of the tax base, implying a smaller difference in the power of the carbon tax between models that do or do not include domestic margins. This leads to smaller differences in the reduction of CO_2 emissions. For Japan and the ROA1, whose average domestic margins and initial energy taxes lie between those of the US and EU, the differences in the reduction of CO_2 emissions predicted by the GTAP-ME and GTAP-E models are less than for the US but larger than for the EU. Japan has a larger difference than the ROA1 due to larger domestic margins on intermediate energy inputs. The initial tax rates on energy commodities are similar in both regions.

Globally, the GTAP-ME model predicts an 11.1% smaller reduction in CO_2 emissions, ranging from 23 to 70 million metric tons of carbon, compared to GTAP-E. Because the carbon tax is applied to only a subset of regions in the model, some carbon leakage occurs with the EEFSU, EEX, CHIND, and ROW increasing their emissions. However, because of the smaller increases in the power of the carbon tax, the magnitude of the carbon leakage is approximately 25% smaller in the GTAP-ME model than in the GTAP-E model.

In addition to differences in the total reduction of CO_2 emissions across regions, there are also differences in CO_2 emissions across energy commodities. For the US, because of the relatively large domestic margins for oil_pcts, the reduction in CO_2 emissions from oil_pcts is 31.7% smaller in the GTAP-ME model compared to the GTAP-E model. Because of relatively large domestic margins on intermediate use of coal and gas, and a relatively small margin on oil_pcts purchased by the private household in Japan, the reduction in CO_2

Table 5
Carbon taxes and emission reductions required to achieve Kyoto targets

	No emission trading				Annex I emission trading				Worldwide emission trading			
	Variable margins				Variable margins				Variable margins			
Region	NM[a]	FM[b]	Cons[c]	Output	NM[a]	FM[b]	Cons[c]	Output	NM[a]	FM[b]	Cons[c]	Output
	Carbon tax ($/ton of carbon)											
US	115.37	149.83	152.47	105.54	82.88	96.34	97.61	77.67	36.30	40.56	41.82	33.94
EU	149.16	155.97	156.63	144.66	82.88	96.34	97.61	77.67	36.30	40.56	41.82	33.94
EEFSU[d]	0	0	0	0	82.88	96.34	97.61	77.67	36.30	40.56	41.82	33.94
JPN	248.28	286.26	277.59	235.94	82.88	96.34	97.61	77.67	36.30	40.56	41.82	33.94
ROA1	148.11	164.63	162.92	142.22	82.88	96.34	97.61	77.67	36.30	40.56	41.82	33.94
EEX	0	0	0	0	0	0	0	0	36.30	40.56	41.82	33.94
CHIND	0	0	0	0	0	0	0	0	36.30	40.56	41.82	33.94
ROW	0	0	0	0	0	0	0	0	36.30	40.56	41.82	33.94

[a] GTAP-E (no margin) model.
[b] GTAP-ME model with fixed domestic margins.
[c] Carbon tax modeled as consumption tax.
[d] 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.

emissions from coal and gas are much smaller than the reduction in CO_2 emissions from oil_pcts. The opposite is true for the ROA1.

The GTAP-ME model with fixed domestic margins does not always predict smaller reductions in CO_2 emissions from all energy commodities compared to the GTAP-E model. In the case of CO_2 emissions from oil_pcts in the EU, the GTAP-ME model predicts a 4.7% larger reduction in CO_2 emissions. In the GTAP-E model, the imposition of the carbon tax increases the purchase price of energy commodities, leading to a reduction in the demand and a reduction in their market price. The market price (before tax) for oil_pcts decreases by 0.5 in the EU. The power of the carbon tax is 3.4% for oil_pcts in the EU, leading to a 2.9% increase in the tax-inclusive price. In the GTAP-ME model, imposing a carbon tax also leads to a decrease in the demand and market price for energy commodities. However, because the carbon tax also leads to increases in the cost of providing trade and transport services, this offsets the reduction in the market price of oil_pcts and the margin inclusive price of oil_pcts remains unchanged. While the power of the carbon tax is smaller in the GTAP-ME model, 3.2%, the percentage increase in the after-tax price of oil_pcts in the EU larger than in the GTAP-E model. This leads to a larger reduction in CO_2 emissions from oil_pcts in the GTAP-ME model compared to the GTAP-E model.

In the case of variable domestic margins, the effect of introducing domestic margins on CO_2 emissions, compared to models that do not incorporate domestic margins, depends on whether the carbon tax is treated as a consumption or output tax. For a consumption tax, allowing for variable domestic margins does not significantly affect the reductions in CO_2 emissions compared to a model with fixed domestic margins. In the US and EU, there are slightly smaller reductions in CO_2 emissions for the case of variable margins due to increased use of coal in electricity generation. This occurs because the imposition of the carbon tax leads to a reduction in the demand for coal, lowering its before-tax market price. Since the cost of margin services (trade and transport) increase, there is substitution away from margin services towards coal. This increase is offset somewhat by a larger reduction in CO_2 emissions from oil_pcts, whose before-tax market price increases, due to higher energy input costs, relative to the cost of margins services for oil_pcts. For Japan and the ROA1, the increased CO_2 emissions from coal use in electricity generation are slightly more than offset by larger reductions in CO_2 emissions from oil_pcts. Thus, when a carbon tax is imposed as a consumption tax, the value of σ_{pt} is not crucial to determining the impacts of the tax on CO_2 emissions.

However, this is not the case if the carbon tax is imposed as an (before margin) output tax. In this case, the output tax increases the after-tax price of energy commodities relative to cost of margin services. This leads to a substitution away from the energy commodities towards more margin services. If this substitution effect is strong enough, it will lead to a larger reduction in the use of energy commodities, as is the case when σ_{pt} equals one. Thus if a carbon tax is imposed as an output tax, the value of σ_{pt} is critical in determining the impacts of the tax on CO_2 emissions.

4.2. Implementing Kyoto Protocol emission reductions

The first set of experiments showed that the predicted changes in CO_2 emissions can be significantly different for a given carbon tax when domestic margins are included in the model compared to when they are not. Another question is how the introduction of domestic margins will affect the size of the carbon tax necessary to achieve a certain reduction in CO_2 emissions? Table 5 presents the results of three different experiments that determine the level of carbon taxes required to attain the country-specific abatement targets specified in 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.[7] Introducing fixed domestic margins into the analysis leads to substantially higher carbon taxes in the US, Japan, and the ROA1 required to achieve their abatement targets relative to the carbon taxes predicted by the GTAP-E model. For the US and Japan, the required carbon tax is $34.45 and $37.97 per ton higher (29.9% and 15.3% respectively). For the ROA1, the increase is $16.52 per ton or 11.1%. The EU has the lowest increase of $6.81 per ton, or 4.6%. Because the introduction of domestic margins results in a smaller power of a given carbon tax, relative to a model without domestic margins, then a higher carbon tax will be required to achieve a specific abatement target. As was the case for the experiments with exogenous carbon taxes, the higher the domestic margins and the lower the initial energy taxes, the larger the difference in the predicted carbon taxes.

The effects of allowing variable domestic margins are similar to those in the exogenous carbon tax experiments. If the carbon tax is treated as a consumption tax, the differences between models with fixed and variable domestic margins are not large. If the carbon tax is treated as an output tax, with variable domestic margins there is a substitution away from energy commodities towards margins services, thereby allowing countries to achieve their specific abatement targets at lower tax rates per ton of carbon. Again, if this substitution effect is large enough, the carbon tax rates can be lower than those predicted by models that do not incorporate domestic margins.

The last two experiments consider whether the differences in carbon tax rates predicted by the GTAP-E and GTAP-ME models diminish when

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

Table 6
Sensitivity analysis with respect to production and trade elasticities

Region	Mean	Elasticities						
		All	σ_{COAL}	σ_{ELY}	σ_{FU}	σ_{KE}	σ_{VA}	σ_D and σ_M
		Standard deviation						
	Ratio of GTAP-ME to GTAP-E							
Change in CO_2 emissions, exogenous $50 real carbon tax								
US	0.824	0.018	0.002	0.012	0.009	0.009	0.002	0.001
EU	0.989	0.011	0.003	0.0005	0.0004	0.008	0.006	0.0002
JPN	0.904	0.019	0.001	0.012	0.001	0.015	0.002	0.0004
ROA1	0.940	0.009	0.001	0.005	0.003	0.006	0.002	0.0004
Nominal carbon tax, no emission trading								
USA	1.299	0.040	0.005	0.029	0.014	0.020	0.006	0.0003
EU	1.045	0.011	0.001	0.003	0.002	0.010	0.001	0.001
JPN	1.152	0.027	0.0001	0.021	0.001	0.021	0.004	0.0005
ROA1	1.110	0.014	0.0002	0.008	0.004	0.011	0.001	0.001
Nominal carbon tax, Annex 1 emission trading								
	1.167	0.022	0.003	0.015	0.009	0.014	0.001	0.001
Nominal carbon tax, global emission trading								
	1.118	0.022	0.0004	0.012	0.006	0.017	0.003	0.00004

emission trading is allowed between regions in the model. The first experiment allows emission trading between all Annex 1 countries and the second experiment allows emission trading worldwide. For the case of fixed domestic margins, as the number of regions involved in emission trading increases, the difference in the predicted carbon tax rates between the GTAP-ME and GTAP-E model declines from 16.2% when only Annex I countries are allowed to trade emissions to 11.7% for global emission trading. This result also holds when using a consumption tax with variable domestic margins. However, the relative differences in carbon tax rates between the GTAP-ME and GTAP-E models does not diminish as more regions are allowed to trade emission when the carbon tax is an output tax with variable domestic margins. It remains also constant across the two experiments.

4.3. Sensitivity analysis

Because there is uncertainty about the values of various model parameters, a sensitivity analysis that focuses on the production and trade elasticities is conducted for the exogenous real carbon tax scenarios and for the implementation of the Kyoto Protocol. The consumer demand parameters are not included in the sensitivity analysis because the parameters of the CDE expenditure function cannot be independently varied.

Symmetric order-three Gaussian quadratures are used for the sensitivity analysis.[8] This procedure assumes that each uncertain parameter has an independent uniform distribution with known (or estimated) endpoints. The endpoints assumed are (0,1) for σ_{KE} and σ_{COAL} and (0,2) for σ_{ELY} and σ_{FU}. The endpoints for σ_{VA}, σ_D, and σ_M are assumed to be ±50% of their values listed in Table 3. A sample of parameters is drawn from these distributions and the model is resolved using each set of parameter values. To identify the overall variation and the potential sources of variation, a comprehensive sensitivity analysis that varies all parameters as well as analyses where only individual or subset of parameters are allowed to vary are performed.

The results of the sensitivity analysis are reported in Table 6. To focus the discussion, the sensitivity analysis considers the change in total CO_2 emissions for exogenous changes in the real carbon tax, and the nominal carbon tax rate for the Kyoto scenarios in the case of fixed domestic margins (The results for variable domestic margins are similar.). Because it is the relative differences between the GTAP-ME and GTAP-E models that are of interest, the mean values and standard deviations in Table 6 are reported as the ratio of GTAP-ME to GTAP-E model results. The first column in Table 6 reports the average value of the ratio. Note that the mean values are also identical to the results reported in Tables 4 and 5.

The second column reports the standard deviation when all production and trade elasticities are allowed to vary. All of the standard deviations are one or two orders of magnitude smaller than the mean, indicating that relative differences between the two models are fairly constant regardless of the parameter values employed. The remaining columns in Table 6 consider the degree of variability in the model results from varying the production elasticities individually or the trade elasticities (both σ_D and σ_M together). In general, the differences in the model results are most sensitive to change in the values of σ_{ELY} and σ_{KE}.

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. Based on illustrations using the GTAP-E model, which has been widely used to assess energy and environmental polices, our results show that in certain instances, models that do not explicitly incorporate domestic margins can over-estimate the reduction in CO_2 emissions from a given carbon tax or under-estimate the level of a carbon tax needed to achieve a specific abatement target. This result always holds for fixed domestic margins, regardless of whether the carbon tax is consumption or production based. The severity of this over- or understatement is determined by the magnitude of the domestic margins on energy commodities with larger domestic margins leading to larger over or understatements. For example, the reduction of CO_2 emissions in the United States for an exogenous carbon tax is overstated by 17.2% and the level of a carbon tax needed to achieve the Kyoto targets are understated by approximately 29.9%.

When domestic margins are variable, the impact of incorporating domestic margins depends on whether the carbon tax is treated as a consumption or output tax. A consumption tax with variable domestic margins yields similar results as a model with fixed domestic margins. Thus, when carbon taxes are imposed as consumption taxes, it does not matter whether the domestic margins are modeled as fixed or variable. However, modeling the carbon tax as an output tax with variable domestic margins can lead to greater reductions in CO_2 emissions compared or lower carbon taxes compared with models that do not incorporate domestic margins. Whether this occurs depends on the magnitude of the elasticity of substitution between energy commodities and domestic margin services.

Because the GTAP-E model is a static model, one interesting area for future research would be to determine if the over-statement of emission reductions is larger or smaller in dynamic AGE models. As these models become more prominent in the assessment of the longer-term implications of energy and environmental policies, this information would be valuable to both modelers and policy makers.

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[8] Arndt and Hertel (1997) have shown that systematic sensitivity analyses conducted using order-three quadratures are as accurate as higher order quadratures.

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