Trade and Carbon Taxes

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We study various scenarios for taxing emissions of carbon dioxide (CO_2). The question is how carbon tax policies will perform, given international trade, if countries adopt different tax rates. We investigate this question quantitatively using CIM-EARTH, a newly developed open-source computable general equilibrium (CGE) model.

Since climate change is a function of global CO_2 emissions, an efficient strategy for controlling emissions would be to impose the same price wherever they occur. Such an approach presents a free-riding problem, however, because nations have an incentive not comply, while gaining the benefits of reduced emissions elsewhere. Moreover, because of distributive concerns and claims about responsibility for past emissions, many developing nations will be reluctant to impose emissions prices at the same level as developed nations.

If some nations opt out, it will be more costly for those imposing a tax or other price on emissions to attain any goal of reduced global emissions. International trade accentuates the problem because non-taxing nations will likely increase emissions, a phenomenon known as carbon leakage. Carbon leakage will also be central to debates surrounding passage of a carbon pricing regime because politicians worry about production (and the resulting jobs) in their regions shifting to other parts of the world. One policy response is to impose a tax on the import of carbon-intensive goods, with a rebate for exports so that domestic producers are not at a disadvantage (in either domestic or foreign markets) relative to producers in countries that do not have a carbon price.[1]

The issue of carbon leakage has generated significant discussion, and studies have produced a wide range of leakage projections.[2] We contribute to this literature with a simple analysis of the underlying economics and a quantitative analysis employing CIM-EARTH. A complete presentation of results is available in our background paper, Elliott et. al. (2010).

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[1] There are two problems with border taxes and rebates in this context. First, many forms of border taxes may be illegal under WTO law; legal border taxes may have to take a less efficient form than ideal taxes. Second, it will be expensive and in some cases impossible to determine emissions from goods produced abroad; hence the importing country may not be able to determine the correct border tax at a reasonable cost. We will not address these problems here.

[2] Mustafa B. Babiker (2005), using the MIT EPPA model, predicts leakage in excess of 100 percent in one scenario, driven by an assumption of increasing returns to scale. Ton Manders and Paul Veendendaal (2008) use a model similar to that used here, finding modest carbon leakage of about 3 percent from a policy to reduce emissions in the EU in 2020 to 20 percent below 1990 levels. Applying full border tax adjustments virtually eliminates carbon leakage. In contrast, Babiker and Thomas F. Rutherford (2005) model the Kyoto Protocol in a CGE framework and find more substantial leakage and small effects from border taxes. Recent work by Aaditya Mattoo, Arvind Subramanian, Dominique van der Mensbrugghe, and Jianwu He (2009) highlights how border tax adjustments could harm developing economies.

I. Basic Analytics

We illustrate some basic principles of carbon taxation using a simple two-country analysis. The countries, home and foreign, are each endowed with labor L and an energy resource E, such as coal deposits. These two factors of production enter a Cobb-Douglas production function to produce an energy-intensive good (henceforth ei-good) with labor share β. A second good is produced using only labor. Production technologies exhibit constant returns to scale and are identical across countries. Consumers spend a share α of their income on the ei-good. Labor is perfectly mobile between sectors, both goods are costlessly traded, and markets are competitive. Trade is driven by differences in factor endowments and by tax policy.

The object of the tax policy is to reduce world carbon emissions, which we take to be proportional to world production of the ei-good. For taxes to have any effect on world production of the ei-good it is necessary that β be greater than zero: If $\beta = 0$, then a tax simply lowers the rents to owners of E, as would be the case if E were petroleum reserves that could be tapped at zero marginal cost. In what follows, assume $\beta > 0$ so that shifting labor out of the ei-sector lowers emissions.

We take the labor-intensive good as numeraire, set its price to 1, and choose units so that the wage in home and foreign is also 1. Let the price of the ei-good on the world market be p, and let τ be an ad valorem tax on production of this good and t a tax on its consumption. The after-tax price paid by consumers is $p_c = p(1 + t)$, and the price received by producers is $p_p = p/(1 + \tau)$ (a middleman buys at price p_p, pays the tax, and sells at price p). Income Y, including rebated tax revenue T, is $L + rE + T$, where r is the rental price of E.

A world-wide production tax τ or consumption tax $t = \tau$ lowers global production of the ei-good to the same level.[3] We can use this result to solve for the uniform tax rate required to lower global emissions by a given factor $\lambda < 1$. To compare with the results of CIM-EARTH, we convert to an excise tax rate $e =$

$p_p(\tau)\tau/c$, where c is the carbon content of the ei-good. Doing so gives

$$(1) \qquad e(\lambda) = \gamma \left(1 + \frac{\alpha\beta}{1-\alpha}\right)\left(\frac{1 - \lambda^{1/\beta}}{\lambda}\right),$$

where $\gamma = p(0)/c$ is the value of the ei-good (at a zero carbon tax) relative to its carbon content.[4]

If a tax is imposed only in the home country, perhaps because of free-riding by the foreign country, the distinction between a production tax and a consumption tax is crucial. A consumption tax t leaves $p_p = p$ in both countries with no distortion of production decisions. To equate world supply and demand, the tax drives down the equilibrium world price p, hence reducing production at home and abroad. The price faced by home consumers $p_c = (1+t)p$ rises, reducing consumption in the home country, which is partially offset by an increase in consumption abroad. A production tax τ, by contrast, leaves $p_c = p$ in both countries so that there is no distortion of consumption. A production tax drives up the equilibrium world price p to reduce consumption in both countries while raising foreign production (carbon leakage). The price faced by home producers $p_p = p/(1 + \tau)$ declines, reducing home production by more than the increase in production abroad.

In the relevant case in which the home country is poorly endowed with E, it will typically obtain higher welfare with a home-country consumption tax rather than a home-country production tax yielding the same global emissions. Furthermore, as mentioned above, the consumption tax has political advantages. Yet, in

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[3] Let L^w and E^w be world endowments and consider a uniform production tax τ. Equating world supply,

$$Q_e^w = p^{\beta/(1-\beta)}(1+\tau)^{-\beta/(1-\beta)}E^w,$$

with world demand for the ei-good,

$$C_e^w = \frac{\alpha}{p}L^w + \alpha p^{\beta/(1-\beta)}(1-\beta+\tau)(1+\tau)^{-1/(1-\beta)}E^w,$$

yields world output:

$$Q_e^w(\tau) = \left(\frac{\alpha}{(1-\alpha)(1+\tau)+\alpha\beta}\right)^\beta (L^w)^\beta (E^w)^{1-\beta}.$$

A consumption tax would drive the same wedge between p_p and p_c, hence leading to the same equilibrium world output. Relative to a production tax it shifts the distribution of world income toward the country relatively poorly endowed with E, but with identical homothetic preferences this shift is irrelevant for world demand.

[4] Continuing from the previous footnote, define $\lambda = Q_e^w(\tau)/Q_e^w(0)$. Solving for the ad valorem tax rate yields

$$\tau(\lambda) = \left(1 + \frac{\alpha\beta}{1-\alpha}\right)\left(\lambda^{-1/\beta} - 1\right).$$

Noting from the world supply equation that $p_p(\tau)/p(0) = \lambda^{(1-\beta)/\beta}$, we obtain the result.

practice, a production tax is simpler to administer because of the relatively few sources of carbon emissions that would need to be taxed (see Gilbert E. Metcalf and David A. Weisbach, 2009). The likely preference for a consumption tax and the practical advantage of taxing producers advocates for a production tax with a border tax adjustment (BTA). Starting with a home-country production tax at rate τ, a full BTA involves a tax rebate for home's exports and a tax τ on imports of the ei-good. A full BTA turns the production tax into a consumption tax at rate τ. The reason is that the BTA levels the playing field for home and foreign producers: both escape taxes in supplying foreign consumers, and both face a tax τ in supplying home consumers. Equilibrium thus requires $p_p = p$ and hence $p_c = (1 + \tau)p$.

II. Trade in Carbon

Table 1 shows bilateral trade in virtual carbon, calculated from GTAP data for 2004. Virtual carbon is the CO_2 emissions associated with the production of a good.[5] In parentheses we include CIM-EARTH projections for 2020 under a business-as-usual (BAU) scenario of no carbon taxes. We have collapsed the regional detail to the United States (USA), Other Annex B (OAB), and non-Annex B (NAB).[6]

The rows of Table 1 correspond to regions as producers and exporters while the columns represent regions as importers and consumers. Thus, for example, the U.S. exported 319 million tonnes of CO_2 to non-Annex B countries. Elements on the diagonal are local consumption, the CO_2 emissions associated with goods both produced and consumed in the local market. The last row is total consumption, the sum of local consumption and imported virtual CO_2. The last column is total emissions produced by each region. The lower right corner gives the total emissions entering the Earth's atmosphere.

The United States is a net importer of virtual carbon getting over 20 percent of its carbon consumption

[5]We say that carbon is traded when a country imports goods that generated emissions of CO_2 in the production process. We ignore trade in fossil fuels since carbon emissions are produced only when these fuels are used (ignoring fuels used in the process of extraction).

[6]Annex B refers to the set of countries/regions with emission limitations under the Kyoto Protocol, including the United States, Australia, Canada, the EU, Japan, New Zealand, and Russia. Non-Annex B refers to all other countries in the world.

TABLE 1—TRADE IN CARBON

	Annex B		Non-AB	Tot.
	USA	OAB	NAB	Prod.
USA	4618	403	319	5340
	(5569)	(473)	(437)	(6479)
OAB	483	7588	647	8718
	(649)	(9759)	(1061)	(11469)
NAB	710	1414	9841	11965
	(1026)	(1990)	(16496)	(19511)
Tot.	5811	9406	10806	26024
Cons.	(7243)	(12222)	(17994)	(37459)

Values in millions of metric tonnes of CO_2 as of 2004 (2020 BAU projections in parentheses).

from imports and exporting less than 14 percent of the carbon it emits in production. Recall that we are recording trade flows only of embedded, or virtual, carbon and not fossil fuel imports, which are obviously high for the U.S.

The projections for 2020 show substantial increases in every entry, but they are by no means uniform. While global emissions increase by 44 percent, U.S. emissions increase by only 21 percent by 2020. By 2020 non-Annex B countries produce more virtual CO_2 than Annex B countries taken as a whole. This relative increase by regions that have generally resisted imposing a price on carbon poses a challenge for efforts to reduce global emissions.

III. CIM-EARTH Framework

CIM-EARTH (see http://www.cim-earth.org), like other CGE models, is built from repeated application of nested constant elasticity of substitution (CES) functions that represent production relationships, consumer preferences, and import demands. In calibrated form, these functions appear as

$$\frac{y}{\bar{y}} = \left(\sum_i \theta_i \left(\gamma_i \frac{x_i}{\bar{x}_i} \right)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}},$$

where $\frac{y}{\bar{y}}$ is output, $\frac{x_i}{\bar{x}_i}$ is input i and γ_i is the efficiency of that input, all relative to base-year values. The parameter σ controls the degree to which the inputs can be substituted for one another. The function is calibrated to the expenditure shares θ_i on each input i in the base year (2004) from the GTAP version 7 data-

base of global expenditure values (Badri Narayanan Gopalakrishnan and Terrie L. Walmsley, 2008).

The nested structure of the production and utility functions and the values of the substitution elasticities used in this study are closely related to those used by the EPPA group (Babiker, John M. Reilly, Monika Mayer, Richard S. Eckaus, Ian SueWing, and Robert C. Hyman, 2001), except for Armington trade elasticities, where the more detailed estimates available in GTAP version 7 are used. We use a model configuration with 16 production sectors, 16 regions, and recursive-myopic dynamics in which most drivers of economic growth are modeled with exogenous time trends.

IV. Tax Scenarios

We present a quantitative analysis of carbon taxes using the CIM-EARTH framework. While CIM-EARTH is dynamic, here we focus on its predictions at a single date, the year 2020. In the configuration used in this study, factors of production are fully mobile across sectors, while technology is exogenous. We interpret it as a model of the medium-run (5-10 year) response to a tax change.

We consider four scenarios, with the last three applied at tax rates ranging from $15 to $175 per tonne C ($4 to $48 per tonne CO_2): (i) business as usual (BAU) with no carbon tax serves as our baseline; (ii) a carbon tax applied uniformly across the globe; (iii) a carbon tax applied to production in Annex B countries only; and (iv) a carbon tax applied to production in Annex B countries, with complete border tax adjustments.

Figure here.

FIGURE 1. REDUCTIONS IN GLOBAL EMISSIONS

Figure 1 shows projected reductions in global emissions under different tax scenarios. The lower line marked "UN_CIM" is what comes out of CIM-EARTH for a tax applied worldwide at a uniform rate. A tax of $175 per tonne of carbon reduces emissions by 40 percent from 2020 levels (still a slight increase in global emissions from 2004 levels). Note the pronounced nonlinearity in this relationship as increasing

tax rates yield ever smaller reductions in emissions.[7] This feature results from the multiple margins of substitution along which carbon can be reduced, with the least costly margins having effect first. A critical margin turns out to be reduction in the use of coal, which accounts for 80 percent of the decline in global emissions at low tax rates, falling to 60 percent at the highest tax rates we consider.

The upper line in Figure 1, marked "AB_CIM", is the response of global emissions to an Annex B production tax. A tax imposed only in Annex B countries generates little more than one-third the emission reductions achieved with a uniform tax, largely reflecting the importance of non-Annex B countries in world production of CO_2 emissions by 2020 (as shown in Table 1). In addition, there is substantial carbon leakage under an Annex B production tax. The line marked "ABAB_CIM" indicates the contribution of Annex B countries to the reduction in global emissions. This contribution exceeds the overall reduction since non-Annex B countries increase CO_2 emissions under the Annex B production tax. The increase in emissions by non-Annex B countries relative to the reduction by Annex B countries, the standard measure of carbon leakage, ranges from 15 percent at low tax rates to over 25 percent for the highest tax rate.

In terms of emission reductions in the United States, an Annex B production tax of $105 per tonne C (about $29 per tonne CO_2) leads to a nearly 19 percent reduction in U.S. emissions from 2004 levels (a 33 percent reduction from BAU in 2020). In contrast, a uniform tax applied globally at that same tax rate produces less than a 14 percent reduction from 2004 (a 29 percent reduction from 2020). Thus, this tax rate is in a range that could meet the current U.S. administration's pledge of a 17 percent reduction in U.S. emissions from 2005 levels. Note that the Annex B production tax accomplishes this goal at a lower tax rate, aided by production shifts associated with carbon leakage.

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[7] As a reality check, we evaluated equation (1) from our simple analytics, setting $\alpha = .05$ (share of ei-good in consumption) and $\beta = .8$ (share of labor in ei-good production) and choosing γ to closely mimic the projections from CIM-EARTH. The line marked "UN_SIMPLE" shows the result (plotting λ on the vertical and $e(\lambda)$ on the horizontal axis) with $\gamma = 200$ (so that the ei-good is just over 3 times as valuable as coal per tonne of embodied carbon). The simple model can approximate the substitution possibilities underlying the CIM-EARTH model, but cannot match the degree of nonlinearity.

TABLE 2—A PRODUCTION TAX IN ANNEX B COUNTRIES

| | Annex B | | Non-AB | Tot. |
	USA	OAB	NAB	Prod.
USA	-1838	-135	-163	-2136
	(-33.0)	(-28.5)	(-37.3)	(-33.0)
OAB	-202	-2917	-416	-3535
	(-31.1)	(-29.9)	(-39.2)	(-30.8)
NAB	257	408	577	1243
	(25.1)	(20.5)	(3.5)	(6.4)
Tot.	-1783	-2644	-2	-4429
Cons.	(-24.6)	(-21.6)	(0.0)	(-11.8)

Changes from BAU 2020 with a $105 Annex B
production tax (percentage changes in parentheses).

Table 2 show how an Annex B production tax of $105 changes bilateral trade in virtual CO_2 in 2020 relative to BAU (the numbers in parentheses in Table 1). Emissions in Annex B regions fall, while the non-Annex B region increases production, a reflection of carbon leakage. In line with our basic analytics consumption declines everywhere.

We also look at the consequences of introducing full import and export border tax adjustments (hence turning the production tax into a consumption tax). As predicted by our basic analytics, production rises in the Annex B regions and falls elsewhere as the BTAs halt carbon leakage. Global emissions are almost 2 percent lower with BTAs since Annex B countries are net importers of virtual carbon. While introducing BTAs leads to a dramatic decline in U.S. imports of virtual CO_2 from non-Annex B regions (by nearly 40 percent), the fraction of these imports in U.S. consumption (14.7 percent) is a half percentage point higher than in the BAU 2020 scenario.
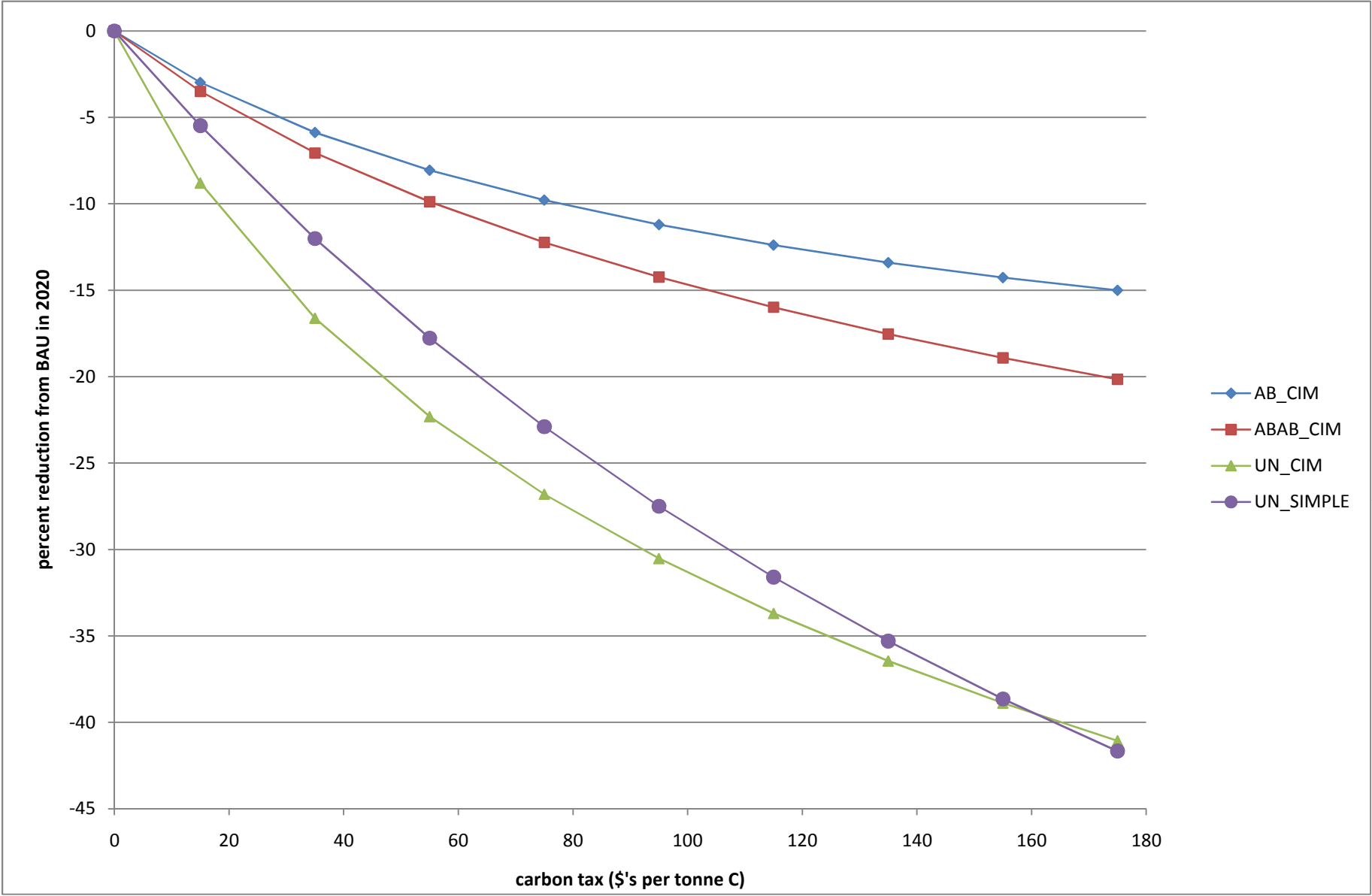
V. Conclusion

We have introduced a new CGE model, CIM-EARTH, and have shown that its qualitative predictions align with a simple economic analysis. A key quantitative prediction is that increased CO_2 emissions in developing countries would undo over 20 percent of reductions made by the Annex B Kyoto region if it were to impose a carbon tax on producers of $105 per tonne C ($29 per tonne CO_2). Adding full border tax adjustments eliminates this leakage, leaving global emissions slightly lower. These results are suggestive but not definitive without further work: (1) evaluating the sensitivity of results to the key para-

meters used in the model, (2) experimenting with alternative modeling approaches, particularly for international trade, and (3) exploiting historical episodes suitable for testing the validity of the model's predictions. We are optimistic that the open-source feature of the CIM-EARTH modeling framework will facilitate progress along each of these dimensions.

REFERENCES

Babiker, Mustafa H. M. 2005. "Climate Change Policy, Market Structure, and Carbon Leakage." *Journal of International Economics*, 65(2): 421–445.

Babiker, Mustafa H. M., and T.F. Rutherford. 2005. "The Economic Effects of Border Measures in Subglobal Climate Agreements." *The Energy Journal*, 26(4): 99–126.

Babiker, Mustafa H. M., John M. Reilly, Monika Mayer, Richard S. Eckaus, Ian Sue Wing, and Robert C. Hyman. 2001. "The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparisons of Results." MIT Joint Program on the Science and Policy of Global Change 71.

Elliott, Joshua W., Ian T. Foster, Kenneth L. Judd, Samuel S. Kortum, Todd S. Munson, Fernando Pérez Cervantes, and David A. Weisbach. 2010. "Carbon Leakage and the Role of Border Tax Adjustments using CIM-EARTH." *Preprint ANL/MCS-P1711-0110*. MCS Division, Argonne National Laboratory.

Manders, Ton, and Paul Veenendaal. 2008. "Border tax adjustments and the EU-ETS, a Quantitative Assessment." *CPB Documents*, 171. Netherlands Bureau for Economic Analysis.

Mattoo, Aaditya, Arvind Subramanian, Dominique van der Mensbrugghe, and Jianwu He. 2009. "Reconciling Climate Change and Trade Policy" *Policy Research Working Paper 5123*. The World Bank.

Metcalf, Gilbert E., and David A. Weisbach. 2009. "The Design of a Carbon Tax." *Harvard Environmental Law Review*, 33(2): 499–556.

Narayanan Gopalakrishnan, Badri, and Terrie L. Walmsley, ed. 2008. *Global Trade, Assistance, and Production: The GTAP 7 Data Base.* Global Trade Analysis Center, Purdue University.