

## Trade and Carbon Taxes

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We study various scenarios for taxing emissions of carbon dioxide (CO<sub>2</sub>). 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<sub>2</sub> 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 to 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 nontaxing 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.<sup>1</sup>

The issue of carbon leakage has generated significant discussion, and studies have produced a wide range of leakage projections.<sup>2</sup> 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, Joshua Elliott et al. (2010).

### 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

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<sup>1</sup> 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.

<sup>2</sup> Mustafa B. Babiker (2005), using the MIT Emissions Predictions and Policy Analysis (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 three percent from a policy to reduce emissions in the European Union 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 Mensbrugge, and Jianwu He (2009) highlights how border tax adjustments could harm developing economies.

of production enter a Cobb-Douglas production function to produce an energy intensive good (henceforth ei-good) with labor share  $\beta$ . A second good is produced using only labor. Production technologies exhibit constant returns to scale and are identical across countries. Consumers spend a share  $\alpha$  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  $\beta$  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 one, and choose units so that the wage in home and foreign is also one. (We assume that relative endowments are not too different, so that both countries produce the labor intensive good.) Let the price of the ei-good on the world market be  $p$ , and let  $\tau$  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 worldwide production tax  $\tau$  or consumption tax  $t = \tau$  lowers global production of the ei-good to the same level.<sup>3</sup> 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

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

<sup>3</sup> Let  $L^w$  and  $E^w$  be world endowments and consider a uniform production tax  $\tau$ . Equating world supply,

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

with world demand for the ei-good,

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

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

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  $\tau$ , 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 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

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.

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

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

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

adjustment (BTA). Starting with a home country production tax at rate  $\tau$ , a full BTA involves a tax rebate for home's exports and a tax  $\tau$  on imports of the ei-good. A full BTA turns the production tax into a consumption tax at rate  $\tau$ . 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  $\tau$  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 Global Trade Analysis Project (GTAP) data for 2004. Virtual carbon is the CO<sub>2</sub> emissions associated with the production of a good.<sup>5</sup> 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).<sup>6</sup>

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 United States exported 319 million tonnes of CO<sub>2</sub> to non-Annex B countries. Elements on the diagonal are local consumption, the CO<sub>2</sub> 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<sub>2</sub>. 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 from imports and exporting less than 14 percent of the carbon it emits in production. Recall that we are recording trade flows

<sup>5</sup> We say that carbon is traded when a country imports goods that generated emissions of CO<sub>2</sub> 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).

<sup>6</sup> 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. Our 2020 projections assume no improvements in either productivity or emission-reducing technology.

TABLE 1—TRADE IN CARBON

|                      | Annex B          |                   | Non-AB<br>NAB      | Total<br>production |
|----------------------|------------------|-------------------|--------------------|---------------------|
|                      | USA              | OAB               |                    |                     |
| USA                  | 4,618<br>(5,612) | 404<br>(457)      | 319<br>(410)       | 5,341<br>(6,479)    |
| OAB                  | 484<br>(587)     | 7,586<br>(9,907)  | 647<br>(972)       | 8,717<br>(11,466)   |
| NAB                  | 710<br>(925)     | 1,415<br>(1,804)  | 9,840<br>(16,782)  | 11,965<br>(19,511)  |
| Total<br>consumption | 5,812<br>(7,124) | 9,405<br>(12,168) | 10,806<br>(18,164) | 26,023<br>(37,456)  |

Note: Values in millions of metric tonnes of CO<sub>2</sub> as of 2004 (2020 BAU projections in parentheses).

only of embedded, or virtual, carbon and not fossil fuel imports, which are obviously high for the United States.

The projections for 2020 show substantial increases in every entry, but they are by no means uniform. While global emissions increase by 44 percent, US emissions increase by only 21 percent by 2020. By 2020 non-Annex B countries produce more virtual CO<sub>2</sub> 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  $y/\bar{y}$  is output,  $x_i/\bar{x}_i$  is input  $i$  and  $\gamma_i$  is the efficiency of that input, all relative to base-year values. The parameter  $\sigma$  controls the degree to which the inputs can be substituted for one another. The function is calibrated to the expenditure shares  $\theta_i$  on each input  $i$  in the base year (2004) from the GTAP version 7 database 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

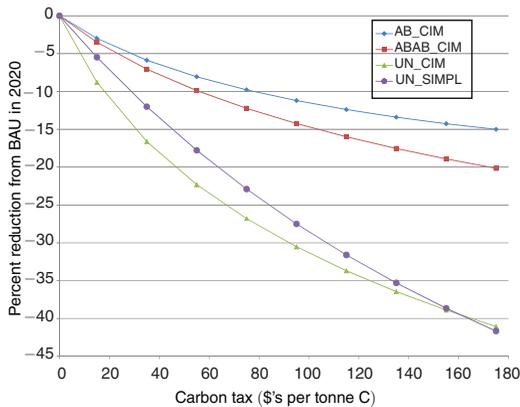


FIGURE 1. REDUCTIONS IN GLOBAL EMISSIONS

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 (five to ten 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<sub>2</sub>): (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 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.<sup>7</sup> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub>) leads to a 33 percent reduction in US emissions from BAU in 2020. In contrast, a uniform tax applied globally at that same tax rate produces a 29 percent reduction from 2020. Note that the Annex B production tax leads to a greater reduction in US

<sup>7</sup> As a reality check, we evaluated equation (1) from our simple analytics, setting  $\alpha = 0.05$  (share of ei-good in consumption) and  $\beta = 0.8$  (share of labor in ei-good production) and choosing  $\gamma$  to closely mimic the projections from CIM-EARTH. The line marked “UN\_SIMPLE” shows the result (plotting  $\lambda$  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<br>NAB   | Total<br>production |
|----------------------|-------------------|-------------------|-----------------|---------------------|
|                      | USA               | OAB               |                 |                     |
| USA                  | -1,839<br>(-32.8) | -135<br>(-29.5)   | -163<br>(-39.8) | -2,137<br>(-33.0)   |
| OAB                  | -202<br>(-34.4)   | -2,917<br>(-29.4) | -416<br>(-42.8) | -3,535<br>(-30.8)   |
| NAB                  | 257<br>(27.8)     | 408<br>(22.6)     | 577<br>(3.4)    | 1,242<br>(6.4)      |
| Total<br>consumption | -1,784<br>(-25.0) | -2,644<br>(-21.7) | -2<br>(0.0)     | -4,430<br>(-11.8)   |

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

emissions, aided by production shifts associated with carbon leakage.

Table 2 show how an Annex B production tax of \$105 changes bilateral trade in virtual CO<sub>2</sub> 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 a full border tax adjustment (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 BTA halts carbon leakage. Furthermore, while consumption declines in Annex B it rises elsewhere. Full export and import BTAs in coalition countries lead to dramatic changes in bilateral carbon flows, with the US cutting CO<sub>2</sub> imports from non-Annex B regions by 44 percent, leaving them nearly 30 percent below BAU. Global emissions are not hugely affected.

## 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<sub>2</sub> 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<sub>2</sub>). Adding full border tax adjustments eliminates this leakage, leaving global emissions slightly lower since Annex B countries are net

importers of virtual carbon. These results are suggestive but not definitive without further work: (i) evaluating the sensitivity of results to the key parameters used in the model, (ii) experimenting with alternative modeling approaches, particularly for international trade, and (iii) 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.

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