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Climate Policy and Fiscal Constraints

*Do Tax Interactions Outweigh
Carbon Leakage?*

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Abstract

Climate policymaking faces twin challenges of carbon leakage and public sector revenue requirements. A large literature advocates the use of carbon dioxide (CO₂) pricing and recycling the revenues to lower distorting taxes as a way to minimize costs. In this paper, we explore the implications of labor tax interactions for the cost-effectiveness of border adjustments and other measures to cope with leakage. We find that, for plausible values of labor supply elasticities, the cost savings from revenue recycling are significant—from 15 to 25 percent. The cost savings from anti-leakage measures are generally smaller, but also significant, particularly for small coalitions or more binding reduction targets. Tax interactions further enhance the cost savings from border adjustments, but make other measures like rebates or exemptions less attractive.

Key Words: climate policy, carbon leakage, tax interactions, border adjustments

JEL Classification Numbers: Q5, H21, Q37

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Introduction

Today, the major economies are grappling with two grave challenges to sustainable development: the emissions associated with global climate change and the public sector deficits associated with current recessions and looming demographic changes. Addressing each challenge has such large economic implications that they should not be considered separately.

Sustained and growing public sector expenditures must be paid for with tax revenues that, for reasons of equity and expediency, are typically levied on factors of production like labor and capital. As of 2010, income taxes average 35 percent of labor costs in countries of the Organisation for Economic Co-operation and Development (OECD 2011). These taxes drive a wedge between labor supply and demand. Additional consumption tax rates averaging 20 percent further lower the real wage and distort household trade-offs between supplying labor and enjoying leisure.

Carbon dioxide (CO₂) emissions are endemic in the economy, and efforts to regulate them will raise the costs of energy and energy-intensive goods. These cost increases also lower the real wage, and the resulting interactions with the preexisting taxes have been shown to significantly raise the cost of environmental regulation (e.g., Bovenberg and Goulder 1996). As a result, a large literature on the “double dividend” has advocated using CO₂ pricing mechanisms (such as a carbon tax or auctioned cap-and-trade) and recycling the revenues to lower income taxes as a way to minimize costs (see Goulder 2002 for an overview). Revenue recycling is likely to be more important for CO₂ than for conventional pollutants regulated in the past with market mechanisms, because of the sheer scope of the emissions revenue potential. In a study of

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the American Clean Energy and Security Act of 2009, which proposed to reduce CO₂ emissions in the United States using an economy-wide cap-and-trade system, the Energy Information Administration (EIA) placed a central estimate of the value of allowances at \$160 billion in 2020 (EIA 2009), or roughly equal to 20 percent of the projected budget deficit (CBO 2010). In 2020, the EU ETS will encompass 1.78 billion allowances; at the projected price of €16, that value represents roughly 0.2 percent of projected GDP and plausibly 10 percent of general government deficits if they return to pre-crisis shares of GDP.¹

At the same time, another important distortion presents challenges for climate policy—the incompleteness of global regulation. Whereas emissions and damages are global in nature, emissions pricing will be undertaken at a subglobal level. In this case, cost increases among energy-intensive, trade-exposed (EIT) sectors in regulated countries would cause energy-intensive activities to shift to noncoalition countries, resulting in “carbon leakage.” Another strand of literature has studied the effects of measures to reduce carbon leakage, including output-based rebates (OBR) and particularly border carbon adjustments (BCA), the focus of this special issue.

In this paper, we explore the effects of BCA and other options on the cost-effectiveness of climate policy in a context of tax interactions, both from a global and a regional perspective. Our approach begins with theoretical foundations and then utilizes a computable general equilibrium model based on GTAPinGAMS-EG, into which we incorporate a labor-leisure trade-off. The theoretical results motivate some caution in applying BCAs beyond narrowly defined, emissions-intensive sectors. The simulations allow us to compare the scope of the cost savings of the controversial trade measures with those from revenue recycling. We also assess how the use of the remaining emissions revenues influences the relative cost-effectiveness of the antileakage measures.

Literature

A broad literature has analyzed the design of climate policies under incomplete global and sectoral coverage. It is well understood that an optimal policy (in an ideal world, barring other major distortions) requires uniform emissions pricing across sectors and countries, ensuring

¹ Sources: http://ec.europa.eu/clima/policies/ets/cap/index_en.htm; <http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/10/215>; and http://ec.europa.eu/economy_finance/publications/european_economy/2011/pdf/ee-2011-1_en.pdf

that marginal abatement costs are equal. When such coverage cannot be complete, a variety of second-best policies have been considered to complement emissions pricing among the covered sectors.

One option is to tax the output of the uncovered sectors in line with their embodied emissions (Bernard et al. 2007); however, while consumers then face carbon-inclusive prices, producers in the uncovered sectors lack direct incentives to reduce their emissions intensity, resulting in an efficiency loss relative to optimal policy. When sectors are uncovered because of jurisdictional differences, as when whole countries remain outside the carbon pricing coalition, such a tax may be applied only to traded goods, as with border carbon adjustment, a restriction further limiting the benefits of the embodied emissions tax.

Still, border adjustment is more cost-effective than a carbon price alone. Early theoretical work by Markusen (1975) and Hoel (1996) establish that the optimal unilateral tax structure includes both an emissions price and a tariff, which is expected to be positive under normal circumstances for imports of polluting goods. A large modeling literature (such as in this special issue) has now been addressing the relative efficiency and distributional effects of such policies.

When other emitting sectors can neither be regulated nor taxed nor border adjusted, in theory the next best policy is to subsidize the output of the regulated sectors at the same time their emissions are taxed (Bernard et al. 2007). Output-based rebating helps keep product prices from rising, and thus discourages substituting toward uncovered alternatives as a means of reducing emissions. On the other hand, OBR also discourages conservation as a means of reducing emissions, resulting in an efficiency trade-off. The optimal subsidy reflects the value of the emissions in the unregulated sector that are crowded out by additional output in that regulated sector (Bernard et al. 2007). Fischer and Fox (2009) solve for optimal rebates (from a global perspective) in conjunction with a carbon tax and show that they are higher for goods that are stronger complements with employment and stronger substitutes for unregulated goods, such as in energy-intensive, trade-exposed manufacturing sectors. Böhringer et al. (2011) show that as the climate coalition gets relatively large, the efficiency costs of the lost conservation incentives with OBR ultimately outweigh the benefits of reducing leakage.

A final option is to set lower emissions prices for the EIT sectors or to exempt them altogether. This option is even more costly, as it forgoes some important incentives for those sectors to engage in abatement activities. Still, it can improve global cost-effectiveness when leakage effects are very strong. Böhringer et al. (2010) find substantial justification for emissions price differentiation to deter leakage: in their computable general equilibrium model, second-best

carbon prices for EIT sectors are roughly 40 percent lower than for other sectors overall. However, in terms of global welfare, using these differentiated prices only slightly lowers the welfare cost of unilateral climate policy over uniform pricing. Babiker and Rutherford (2005) consider policy options for a coalition of Annex I countries, comparing a reference without border adjustment with adjustment measures like import tariffs, export rebates, exemption of energy-intensive industries, and voluntary export restraints on the part of noncoalition countries. They find that the exemptions produce the least leakage overall but are associated with higher carbon prices; from a welfare perspective, most countries prefer tariffs.

However, the vast majority of these carbon leakage studies ignore the issues of pre-existing tax distortions by ignoring the response of labor supply to changes in the real wage. Markusen (1975) assumed production factors in perfectly inelastic supply, and most CGE models fix domestic labor (and capital) supply.

Yet recent studies in the tax interaction literature that compare the welfare costs of alternative uses of the emissions revenues find substantial effects from labor tax distortions. For example, Parry and Williams (2010) estimate that the direct cost of reducing CO₂ emissions in the United States to 9 percent below business-as-usual levels in the year 2020 is \$9 billion (in 2007 dollars). However, the overall welfare costs range from negative \$6 billion a year when revenues are used to cut income taxes to \$53 billion a year when revenues are distributed lump-sum, such as by grandfathering or per capita dividend programs.

Only a few studies have considered the interaction between labor tax distortions and policies to counteract emissions leakage. By limiting the product price increases, policy mechanisms that combine an output rebate with the emissions price have the potential to reduce tax interactions (by mitigating the fall in real wages) as well as leakage. An important basis for deciding which sectors to make eligible for rebates is whether the leakage and tax interaction benefits outweigh the costs of price distortions for conservation. Fischer and Fox (2007) compare output-based allocations in which the sectoral distributions are based on value-added with those based on emissions shares. In a comprehensive domestic cap-and-trade program, the value-added option generates effective subsidies similar to a broad-based tax reduction, performing similar to revenue recycling. OBR tied to historical emissions supports the output of “dirtier” industries, which more effectively counteracts carbon leakage but is more costly in welfare terms, potentially even more so than grandfathering allowances. Fischer and Fox (2010) find that OBR (based on sector average emissions) improves welfare when applied to EIT sectors by addressing leakage. Extending OBR to the electricity sector (as was effectively proposed in U.S. climate legislation) can be more desirable if the remaining emissions rents would otherwise have been

given away lump-sum, because of the smaller tax interactions, but that revenue use is less effective than recycling to lower distorting taxes.

BCAs have yet to be explored in this context, and one would expect some different effects to arise. By ensuring that embodied carbon costs are passed through to coalition consumers, border adjustments for imports preserve conservation incentives, but this price pass-through tends to lower the real wage and exacerbate the pre-existing tax distortions. Some of this effect can be offset if the regulating country retains the import tax revenues. On the other hand, noncoalition trade partners may experience their own tax interaction effects.

We find that tax interactions enhance the global (and coalition) cost savings from border adjustments for EIT sectors, while other measures like rebates or exemptions become less attractive. These results may further temper the conclusions of Boehringer et al. in this special issue, who focus on the distributional effects these different policy options. The cost savings from border adjustments are also put into context by comparing them to the cost savings from revenue recycling. We find that, for plausible values of labor supply elasticities, revenue recycling lowers welfare costs from 15–25 percent. The cost savings from anti-leakage measures are generally smaller, but also significant, particularly for small coalitions or more binding reduction targets.

Theory

In this section, we present a simple model of two regions, each with a representative consumer, and two goods. Let good 1 be produced in the climate coalition region (COA), and good 2 be produced in the non-coalition region (NCOA). The production of each good entails emissions. Production and consumption choices are undertaken in a decentralized setting, in which consumers and firms take as given all prices, wages, and tax rates, as well as pollution externalities.

After characterizing the market behavior, we consider the effect on global welfare of an increase in the border adjustment factor, β —that is, the share of the emissions embodied in imports that form the calculated basis of the tariff. In actual policy, this factor could well range from a fraction of embodied emissions (as with a best-available technology rule for calculating emissions), to 100 percent, or even higher (such as a presumption of the worst-available technology). We discuss the underlying conditions justifying a positive adjustment factor, and then derive the optimal adjustment factor and discuss the drivers that influence it.

Decentralized Markets

Consumer Problem. The representative household in region h maximizes utility with respect to consumption and leisure, subject to a budget constraint:

$$\max_{C_1^h, C_2^h, L^h} U(C_1^h, C_2^h, 1 - L^h) - \lambda^h \left(p_1^h C_1^h + p_2^h C_2^h - w^h (1 - t_L^h) L^h - \pi^h - \tau^h A^h \right),$$

where p_i is the consumer price for good i , w is the wage rate, t_L is the labor tax rate, π is shareholder profits from the representative firm (although these will be zero), and A is the value of any lump-sum allocation of emissions allowances. The first-order conditions are:

$$(C_1^h) \frac{\partial U^h}{\partial C_1} = p_1^h \lambda^h; \quad (C_2^h) \frac{\partial U^h}{\partial C_2} = p_2^h \lambda^h; \quad (L) \frac{\partial U^h}{\partial L^h} = \lambda^h w^h (1 - t_L^h). \quad (1)$$

Since each region has only one sector, we have $w^{COA} = w_1$ and $w^{NCOA} = w_2 = 1$, where the noncoalition wage is the numeraire.

Producer Problem. Production in each sector ($i = 1, 2$) is a function of labor and emissions: $Q_i = f_i(L_i, E_i)$, where $\partial Q / \partial L > 0$, $\partial Q / \partial E > 0$, $\partial^2 Q / \partial L^2 < 0$, $\partial^2 Q / \partial E^2 < 0$, and $\partial^2 Q / \partial L \partial E > 0$ are the standard properties reflecting diminishing returns to a given factor. Equivalently, labor in each sector can be specified as a function of output and emissions: $L_i = L_i(Q_i, E_i)$, where $\partial L / \partial Q > 0$, $\partial^2 L / \partial Q^2 > 0$, $\partial L / \partial E < 0$, $\partial^2 L / \partial E^2 > 0$, and $\partial^2 L / \partial Q \partial E < 0$ are the corresponding functional relationships.

The representative firm in each sector i chooses labor and abatement to maximize profits, given the prevailing product prices q , and emissions price, τ :

$$\pi_i = q_i Q_i - w_i L_i(Q_i, E_i) - \tau_i E_i,$$

from which we obtain

$$(Q_i) \quad q_i = w_i \frac{\partial L_i}{\partial Q_i}; \quad (E_i) \quad -\frac{\partial L_i}{\partial E_i} = \frac{\tau_i}{w_i}. \quad (2)$$

The first expression implies that the output price equals the marginal cost (or, with some rearranging, that the value of the marginal product of labor equals the wage rate). The second means that the labor cost savings from using more emissions equal the tax.

For the nonregulating country, zero emissions tax ($\tau_2 = 0$) implies labor demand is strictly a function of output, and emissions will be proportional to output; with constant returns to scale technologies, labor is also proportional to output, and we have $L_2 = \alpha_2 Q_2$, and $E_2 = m_2 Q_2$. From the first-order (and, equivalently, the zero-profit) condition, we find $q_2 = \bar{\alpha}_2$.

Government. Governments have an exogenous public good provision requirement, which requires a fixed amount of labor, G , for which it must pay the prevailing wage. For the noncoalition region, the government must raise enough tax revenues such that the tax on the total labor supply (whether for the industrial or the government good) equals the necessary labor payments for the government good: i.e., $w_2 G^{NCOA} = t_L^{NCOA} w_2 L^{NCOA}$ or $G^{NCOA} = t_L^{NCOA} L^{NCOA}$. In the coalition, the emissions price is set at τ_1 (although that price will adjust in the global equilibrium to meet the emissions target), and the border adjustment rate is β . The coalition government collects revenue from auctioning emissions allowances (net of lump-sum allocations A) and from border adjustments, and a tax on total labor supply must make up any shortfall. The expression for total government costs equaling total revenues, divided by the prevailing wage rate, is:

$$G^{COA} = \frac{\tau_1}{w_1} (E_1 - A_1 + \beta C_2^{COA}) + t_L^{COA} L^{COA}.$$

Market Equilibrium. In equilibrium, we have the following conditions. Global consumption must equal production of each good: $C_1^{COA} + C_1^{NCOA} = Q_1$; $C_2^{COA} + C_2^{NCOA} = Q_2$.

Labor demand from production and government must equal labor supply in each region:

$$L_1 + G^{COA} = L^{COA}; \quad L_2 + G^{NCOA} = L^{NCOA}.$$

The balance of payments is equal: $q_1 C_1^{NCOA} = q_2 C_2^{COA}$. Furthermore, $p_i^i = q_i$, $p_j^i = q_j + \tau_i \beta m_j$ for $j \neq i$, and the revenue and emissions constraints are met.

Global Welfare Effects of Border Adjustment

We will consider changes in welfare given a fixed global emissions target, such that $E_1 + E_2 \leq \bar{E}$. Therefore, we abstract from the issue of climate damages or the optimal emissions price. Global welfare is

$$W = U^{COA}(C_1^{COA}, C_2^{COA}, 1 - L^{COA}) + \omega U^{NCOA}(C_1^{NCOA}, C_2^{NCOA}, 1 - L^{NCOA}).$$

The question is, given that the global emissions target is implemented with a unilateral carbon price, under what circumstances do stronger border adjustments improve global welfare?

The essence of the problem can be seen by totally differentiating welfare with respect to the border adjustment factor, β :

$$\begin{aligned} \frac{dW}{d\beta} &= \frac{\partial U^{COA}}{\partial C_1^{COA}} \frac{dC_1^{COA}}{d\beta} + \frac{\partial U^{COA}}{\partial C_2^{COA}} \frac{dC_2^{COA}}{d\beta} - \frac{\partial U^{COA}}{\partial l^{COA}} \frac{dL^{COA}}{d\beta} \\ &+ \omega \left(\frac{\partial U^{NCOA}}{\partial C_1^{NCOA}} \frac{dC_1^{NCOA}}{d\beta} + \frac{\partial U^{NCOA}}{\partial C_2^{NCOA}} \frac{dC_2^{NCOA}}{d\beta} - \frac{\partial U^{NCOA}}{\partial l^{NCOA}} \frac{dL^{NCOA}}{d\beta} \right) \end{aligned} \quad (3)$$

Let us assume that the relative welfare weights are the inverse of the marginal utilities of income, so that $\omega = \lambda^{COA} / \lambda^{NCOA}$.² From the first-order conditions from the consumer problem, $\partial U / \partial C_i = p_i \lambda$, and $\partial U / \partial l = \lambda w(1 - t_L)$, so this equation simplifies to

$$\begin{aligned} \frac{dW}{d\beta} / \lambda^{COA} &= q_1 \frac{dC_1^{COA}}{d\beta} + (q_2 + \tau_1 \beta) \frac{dC_2^{COA}}{d\beta} - (1 - t_L^{COA}) w_1 \frac{dL^{COA}}{d\beta} \\ &+ \left(q_1 \frac{dC_1^{NCOA}}{d\beta} + q_2 \frac{dC_2^{NCOA}}{d\beta} - (1 - t_L^{NCOA}) w_2 \frac{dL^{NCOA}}{d\beta} \right) \\ &= (\tau_1 \beta) \frac{dC_2^{COA}}{d\beta} + q_1 \frac{dQ_1}{d\beta} + q_2 \frac{dQ_2}{d\beta} - (1 - t_L^{COA}) w_1 \frac{dL^{COA}}{d\beta} - (1 - t_L^{NCOA}) w_2 \frac{dL^{NCOA}}{d\beta} \end{aligned}$$

From the emissions constraint, $dE_1 = -dE_2$. Since government's labor requirement is fixed, $dL^{COA} = dL_1$ and $dL^{NCOA} = dL_2$. Totally differentiating the production function gives us $dL_i = \frac{\partial L_i}{\partial Q_i} dQ_i + \frac{\partial L_i}{\partial E_i} dE_i$. Using the producer first-order conditions, where $\partial L_i / \partial Q_i = q_i / w_i$, $-\partial L_i / \partial E_i = \tau_i / w_i$, and market equilibrium conditions, this implies that $dE_1 = (q_1 dQ_1 - dL_1) / \tau_1$. For sector 2, $\tau_2 = 0$, so lacking any incentive to change emissions intensity, emissions in the unregulated sector are proportional to output changes: $dE_2 = m_2 dQ_2$, where m is the marginal emissions rate. Thus, substituting and rearranging the emissions constraint, we simplify the useful expression, $w_1 dL_1 = q_1 dQ_1 + \tau_1 m_2 dQ_2$. Meanwhile, $w_2 dL_2 = q_2 dQ_2$.

² This assumption implies that changes in consumption are given equal weight across regions, rather than being weighted by the marginal utility of income. It avoids incentives to improve global welfare simply by transferring income toward the region with the higher marginal utility of income.

Substituting, we get the marginal welfare impacts of a change in the import adjustment rate (relative to the marginal utility of consumption):

$$\frac{dW}{d\beta} / \lambda^{COA} = \tau_1 \beta \frac{dC_2^{COA}}{d\beta} + t_L^{COA} q_1 \frac{dQ_1}{d\beta} - \left((1-t_L^{COA}) \tau_1 m_2 - t_L^{NCOA} q_2 \right) \frac{dQ_2}{d\beta}$$

For welfare to be increasing with border adjustment, starting from $\beta = 0$, it must be that

$$\left. \frac{dW}{d\beta} / \lambda^{COA} \right|_{\beta=0} = t_L^{COA} q_1 \frac{dQ_1}{d\beta} - \left((1-t_L^{COA}) \tau_1 m_2 - t_L^{NCOA} q_2 \right) \frac{dQ_2}{d\beta} > 0 \quad (4)$$

Note that without the labor tax distortions, this condition would imply $-\tau_1 m_2 dQ_2 / d\beta > 0$, which holds as long as the border adjustment is effective at decreasing foreign production ($dQ_2 / d\beta < 0$) and thereby leakage. With pre-existing labor taxes, this condition is reinforced to the extent that border adjustment expands domestic production ($dQ_1 / d\beta > 0$), which draws in labor supply that is underprovided with the tax distortion, but it is tempered by interactions between the coalition labor tax and the consumption cost increase from the tariff and by foreign tax interactions.

The sign of $dQ_i / d\beta$ depends on a variety of factors, including the elasticities of leisure and consumption, as well as the specification of the production function. In circumstances representing the case of many trade-exposed sectors, in which substitution elasticities are high, one would expect that $dQ_2 / d\beta < 0$ and $dQ_1 / d\beta > 0$ would hold in the general equilibrium (including all price and tax adjustments). However, this need not be the case in the presence of complementarities between goods or between consumption and leisure.³

Assuming the conditions are such that Equation (4) holds, the returns to raising the border adjustment factor diminish as long as $dC_2^{COA} / d\beta < 0$, which one expects under normal conditions, since the tariff raises the cost of the imported good. At the welfare optimum, border adjustment balances these factors:

³ These other interesting relationships can be explored with a parameterized version of this analytical model.

$$\tau_1 \beta^* = \left(\tau_1 m_2 (1 - t_L^{COA}) - t_L^{NCOA} q_2 \right) \frac{dQ_2}{dC_2^{COA}} - t_L^{COA} q_1 \frac{dQ_1}{dC_2^{COA}} \quad (5)$$

Recalling the preceding assumptions, the change in noncoalition production has the same sign as the change in coalition imports ($dQ_2 / dC_2^{COA} > 0$), while coalition production takes the opposite sign as a change in coalition imports ($dQ_1 / dC_2^{COA} < 0$).⁴

The typical proposal for border adjustments is to levy the emissions charge on average embodied emissions, i.e., $\beta = m_2$. In the absence of the labor tax distortions, the optimal import adjustment would only account for the value of the emissions displaced. However, displaced emissions are not quite the same thing as embodied emissions; note that $\beta = m_2$ is optimal only if there is a one-for-one relationship between changes in coalition imports and noncoalition production ($dQ_2 = dC_2^{COA}$), meaning noncoalition production suffers no other general equilibrium effects. While this may not be unreasonable as a first-order approximation, in general $|dQ_2| < |dC_2^{COA}|$, since foreign demand typically absorbs some of the excess supply created by a reduction in coalition demand (see Balistreri et al. 2012).

Distorting labor taxes in the noncoalition region give additional cause to temper the import adjustment. The tariff exacerbates the existing underprovision of labor and therefore production in that region. Indeed, the noncoalition tax interaction can fully offset the leakage effect if $\tau_1 m_2 < t_L^{NCOA} q_2$; that is, if the relative labor tax burden exceeds the emissions value embodied in the noncoalition product. This seems likely to be the case for all but the most emissions intensive products.

The interaction with the coalition labor tax is ambiguous, depending essentially on the net effect on labor supply (which can be expressed as $-(\tau_1 m_2 dQ_2 / dC_2^{COA} + q_1 dQ_1 / dC_2^{COA})$). On the one hand, to the extent that border adjustment mitigates leakage, it loosens the emissions abatement requirement, which lowers labor demand per unit of output as a substitute for emissions in production. On the other hand, to the extent that import protection expands domestic production, it also boosts labor demand. Since the labor tax wedge means that labor is underprovided, the net effect on equilibrium labor supply determines whether border adjustment mitigates or exacerbates the pre-existing distortion.

⁴ We note that if these assumptions are violated, border adjustments may reduce welfare.

From these tax interactions we can understand that the use of the emissions and tariff revenues will also affect the optimal border adjustment rate. Although these choices operate in the background of the equations as presented, they influence the equilibrium tax rates, prices and quantity responses.⁵ For example, returning the tariff revenues to the exporting country would allow the noncoalition labor tax rate to be lower, shrinking the noncoalition tax interaction effect. On the other hand, the coalition labor tax would then need to be higher, so the net effect depends on the sign and magnitude of the labor supply effect in the coalition. Allocating the emissions revenues in a lump-sum manner rather than lowering the labor tax rate is known to increase the welfare costs (Parry et al. 1999), and it can also influence the optimal border adjustment by increasing those tax interactions as well.

In practice, policymakers do not typically attempt to set optimal adjustment rates. The intuition developed in this section is useful in understanding when border adjustments might be justified, such as with highly emissions-intensive and trade-sensitive sectors, and why added caution should be taken in light of the general equilibrium effects and tax distortions. However, exploring the potential magnitude of the tax interaction effects in combination with border adjustments requires numerical simulations. With these ideas in mind, we next analyze the leakage and welfare effects of various policy options using a detailed global trade model.

Numerical Model

We employ a modified version of the model used in Fischer and Fox (2010). This computable general equilibrium model from the Global Trade Analysis Project (GTAP) is based on version 5.4 of the GTAPinGAMS package developed by Thomas Rutherford and documented for version 4 of the data set and model in Rutherford and Paltsev (2000). The GTAP-EG model serves as the platform for the model outlined here. The GTAP-EG data set used is a GAMS data set merging the GTAP economic data with information on energy flows. We adapt the framework to employ the latest official release of the GTAP database, version 7.0, which updates the analysis to 2004, the base year of the latest GTAP database. Complainville and van der Mensbrugge (1998) provide a more complete discussion of the energy data used.

⁵ See Parry et al. (1999) for a more complete derivation in a single-country model. As further derivations are more tedious than illuminating in this multi-region setting, we discuss some intuition and then turn to numerical simulations.

The model is a static multisector, multiregion general equilibrium model of the world economy. The model does not incorporate dynamic responses or allow for technological change. It does allow, however, for capital reallocation.⁶ As such, our results should be considered illustrative of short- to medium-term effects (say, three to five years, a relatively short perspective for climate policy). Our primary simulations rely on the 2004 base year. We also conduct simulations for a 2020 base year, in which we project trends in economic activity, trade, and energy use into the future.

We include energy requirements and their corresponding carbon emissions into this framework. The production function incorporates most intermediate inputs in fixed proportion, although it builds energy inputs into a separate energy nest. For the chemicals sector, which includes petrochemicals, we divide its energy use into feedstock requirements, which are treated as intermediate inputs, and the remainder, which is treated as energy, using the feedstock use ratios for oil and gas given by Lee (2002). We also use EIA data to set the feedstock ratio.⁷

We incorporate process emissions into the modeling framework for refined petroleum and coal products; chemicals; iron and steel; and nonferrous metals. We draw these data from the U.S. Environmental Protection Agency.⁸ Process emissions are produced in fixed proportions with the activity level of the corresponding sector. For other countries and regions in the model, we apply the same intensity of emissions measured in CO₂ per dollar to production. Once we account for energy feedstocks and include process emissions, we benchmark total emissions per country or region to 2004 emissions data from EIA.⁹

⁶ In the default setting, capital reallocation occurs within, not across, regions. Paltsev (2001) conducts sensitivity analysis with respect to this assumption and finds that the carbon leakage rate does not change significantly with greater international capital mobility.

⁷ Lee (2002) proposes a feedstock ratio of 0.9148 for petroleum and coal products used in the U.S. chemicals sector; EIA data indicate that for 2004 the ratio is 0.5270. We employ the latter. U.S. Energy Information Administration, Manufacturing Energy Consumption Survey for 2006, Tables 1.1 and 2.1. See <http://www.eia.gov/emeu/mecs/contents.html>.

⁸ Process emissions in millions of metric tons of CO₂ equivalent for 2004 are as follows: chemicals, 49.8; iron and steel, 50.9667; nonferrous metals, 7.7667; nonmetallic minerals, 61.0000; petroleum and coal, 3.8667. Data Annex to Interagency Report on Competitiveness and Emission Leakage. See <http://www.epa.gov/climatechange/economics/economicanalyses.html#interagency>.

⁹ Emissions are scaled up by a range of 10.8% to 40.1% to match EIA emissions data. Energy Information Administration, *International Energy Annual 2006*, Table H.1co2. See <http://www.eia.doe.gov/iea/>.

We make certain adjustments to the extractive energy sectors to calibrate supply elasticities. In other sectors, capital is fully mobile; however, in the extractive sectors, capital is divided between a fixed portion (the natural resource) and mobile capital. These splits are adjusted so as to target particular elasticities of supply: 0.8 for crude oil, 2.0 for natural gas, and 2.5 for coal.

Energy use in production is a constant elasticity of substitution function nested to three levels. At the lowest level, oil and gas easily substitute (2.0) for one another to form a composite. The oil and gas composite then is a complement (0.5) with coal, forming a non-electric energy composite. Lastly, non-electric sources have very low substitutability (0.1) for electricity to form the energy composite. Energy in turn is a complement (0.5) to the labor-capital composite from the value-added nest. Within the value-added nest, labor, private capital, and public capital have unitary elasticity. The energy-value-added nest then combines in fixed proportions with Armington composites of the remaining goods and services, with the elasticities drawn from Hertel et al. (2004).

Consumption is a composite of goods, services, and in our modification, leisure. The energy goods oil, gas, coal, and electricity enter into final demand with an elasticity of substitution of 0.2 in the energy nest. Other final demand goods and services have an elasticity of substitution of 0.5. The energy composite is then substitutable at 0.25 with other final demand goods and services. Goods and services (including energy) are then substitutable against leisure. The model employs both compensated and uncompensated elasticities of labor supply to parameterize the labor-leisure choice. Our approach follows that of Ballard (2000) and is laid out in Fox (2002) and Fischer and Fox (2007). Values of 0.29 for compensated and 0.20 for uncompensated labor supply elasticities are used. The value for compensated labor supply elasticity of 0.29 is consistent with the tax policy literature.¹⁰ The difference between the two elasticities defines the value of leisure relative to measured GDP, in this case about 10 percent.

Government demand is represented by a similar demand structure and private consumption, with the exception of the labor-leisure component. Government demand is held

¹⁰ See, for example, Saez et al. (2012): “While there are no truly convincing estimates of the long-run elasticity, the best available estimates range from 0.12 to 0.40.” A meta-analysis of uncompensated labor supply elasticities by Evers et al. (2006) shows the choice of 0.20 is consistent with the literature: the mean of studies sampled is 0.10, the median 0.24, and the standard deviation 0.42.

fixed through all the experiments, although the funding mechanism (adjustment of a lump-sum tax or the tax on labor) varies by scenario.

Three features added to the GTAP-EG structure allow us to model the effects of the policy scenarios. First, we add a carbon price that is applied to the covered sectors. Second, we incorporate the appropriate structure for simulating an output-based allocation scheme. Third, we give the household a labor-leisure choice such that labor taxes are distorting, allowing us to conduct simulations that recycle revenue from pollution permits to offset the distorting tax instrument.

Since labor tax data are not incorporated in the GTAP-EG database, we add labor tax rates based on tax wedge calculations by OECD for its member countries and by the U.S. Agency of International Development for non-OECD countries.¹¹ These tax wedges represent the difference between labor costs and net take-home pay and include payroll taxes, whether paid by employee or employer, and income taxes for average wage earners. Table 1 reports the calculated tax wedges; regional averages are weighted by total pretax payments to labor.

Table 1. Weighted-Average Labor Tax Rates for Model Regions

Country or region	Labor tax (%)
Europe	42.9
United States	29.8
Other Annex I countries	28.6
Russia	32.6
China	31.3
India	29.7
Energy-exporting countries	17.8
Middle-income countries	17.2
Low-income countries	12.4

To incorporate the pollution permit requirement, we introduce the carbon permit as a Leontief technology in an additional composite fossil fuel nest to production in the covered sectors. The composite of permit and energy input is then included in the production block for

¹¹ We use 2004 data for the former, to match the GTAP base year, but 2007 for non-OECD countries, since earlier data were not readily available. For the OECD countries, the differences were minor.

the output good. In this manner, one permit is demanded for each unit of carbon that enters into production, and we can track pollution permits through the model.

To model output-based rebating, we incorporate a distortion in the form of an endogenous subsidy into the sector's production function. The value of the subsidy is determined by constraints that establish the carbon price and the per unit allocation, which equals average emissions in equilibrium.

Policy Scenarios

Given the coalition reduction targets of 20 percent below our base year of 2004 (as featured throughout this special issue), we consider a range of additional measures to combat leakage, evaluated in a context with tax interactions. For each scenario we compare two default uses of the remaining emissions revenues: lowering labor taxes ("Recycle") and lump-sum distribution ("Grandfathering").¹² To further explore the role of tax interaction, we also run these scenarios without the labor-leisure trade-off (i.e., with the more typical representation of fixed national labor supply), in which the use of the revenues is irrelevant.

We conduct this analysis for each of the featured coalitions—EU, Annex I (A1), and Annex I countries plus China (A1+China)—and since U.S. climate policy is also of interest to us, we add the coalition EU plus the United States (EU+US).

Following the practical guidance, we restrict the eligibility for the additional measures to the sectors that are both energy intensive and trade exposed. We define our EIT sectors as the four main energy-intensive manufacturing sectors: chemicals (CRP); nonmetallic minerals (NMM), which include cement, glass, and ceramics; iron and steel industry (I_S); and nonferrous metals (NFM), including copper and aluminum. The special issue's comparison exercise adds to this list refined petroleum and coal products (OIL). We compared the effects of this variation in eligibility definition (i.e., with and without OIL) and found that including OIL decreased the performance of the output-based rebating and exemption policies (in terms of coalition and overall costs).

We report results for the following scenarios:

¹² Given that the model has a single representative household and sectors have constant returns to scale and therefore zero operating profits, the distribution of windfall emissions values across stakeholders or sectors has equivalent effects.

- **REF:** a reference case of an emissions price alone within the coalition, with no adjustment policies;
- **Tariff (Imp.):** border adjustment for imported goods in the EIT and OIL sectors, based on embodied direct and indirect (electricity) emissions, with revenues retained by the coalition countries;
- **Tariff (Exp.):** border adjustment for imported goods in the EIT and OIL sectors, based on embodied direct and indirect emissions, with revenues retained by the countries of export;
- **OBR:** output-based rebating for goods in the EIT sectors, with rebates benchmarked to sector average direct and indirect emissions; and
- **Exempt:** EIT sectors are exempt from the carbon pricing policy.

The Tariff scenarios are those related to the theory section (optimal rebating with tax interactions is discussed in the literature review). We also simulated the effects of full border adjustment (i.e., border adjustment for imports plus export rebates in the same sectors). The results are somewhat stronger but mostly similar to the Tariff results. For this reason, and given the greater policy focus on import adjustments, we leave this scenario aside to limit the number of results reported.

For sensitivity analysis, we conduct two additional experiments with the suite of policy scenarios: (1) using the 2020 baseline instead of the 2004 reference case; (2) turning off the global energy price response, essentially limiting leakage to production shifting through trade.

Results

We report three sets of analyses. First, we analyze the influence of tax interactions on the simulated cost savings from anti-leakage policies. Second, we put the cost savings from addressing carbon leakage into context by comparing them to the cost savings from revenue recycling. Third, we present the sensitivity analysis.

Tax Interactions with Antileakage Policies

The entire distinction between revenue recycling and grandfathering in our simulations is due to the labor-leisure trade-off. In the model comparison project (reported in XXX in this issue), to keep in better alignment with the other models, we turned off this trade-off; we now compare that set of runs with those in the current analysis.

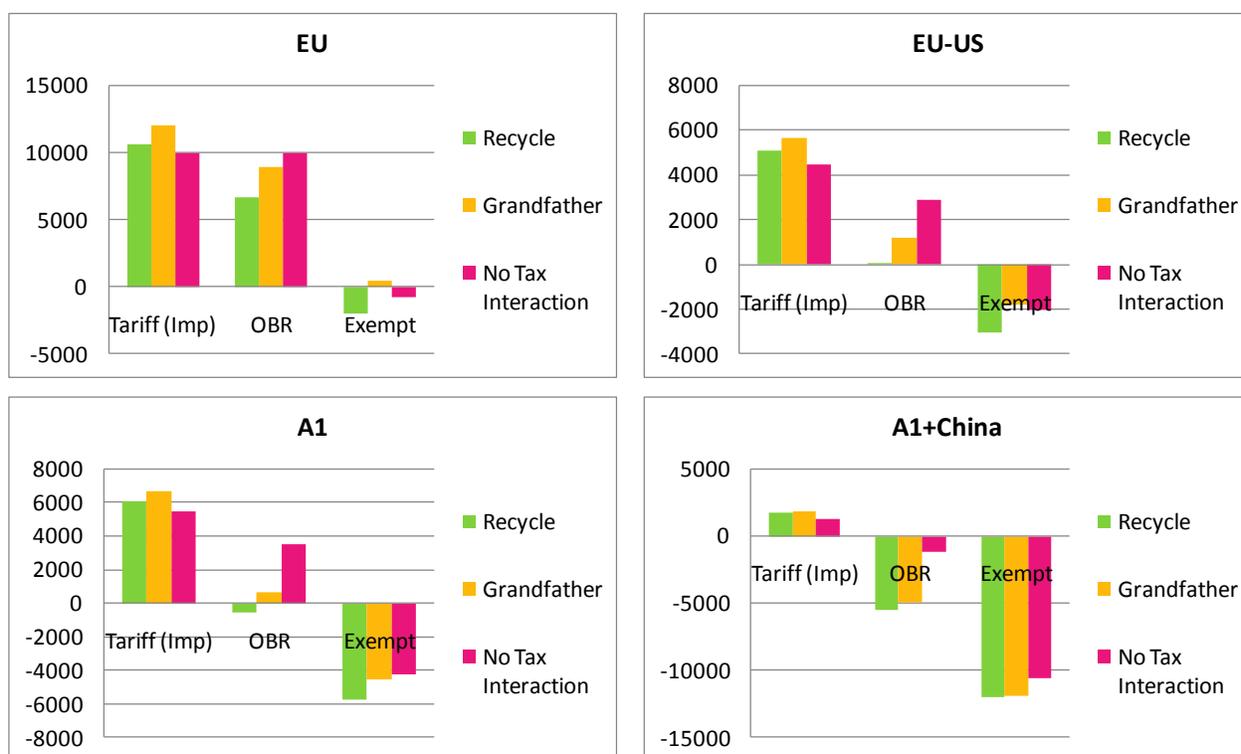
To understand the influence of tax interactions on the desirability of border adjustments and other measures, we look at the incremental effects of the antileakage measures. Figure 1 reports the global cost savings in millions of 2004 \$ for each policy option and coalition size. Cost savings are calculated as changes in equivalent variation, to account for the value of leisure as well as consumption changes. Global cost savings are aggregated in utilitarian fashion.

First of all, we notice that the benefits of anti-leakage measures (in absolute terms) are generally declining as the coalition size grows. Second, we see a clear ordering of the policies in terms of cost savings: border adjustments outperform OBR, which in turn outperforms exemptions; indeed, the latter option almost always raises costs. These results are consistent with Boehringer et al. (this issue).

However, tax interactions play a role in the strength of these effects. In particular, they tend to expand the cost savings from border adjustment; although this result was ambiguous in the theory, our numerical model indicates that the net effect of border adjustment for EITE sectors is to enhance labor supply and cost savings. Meanwhile, tax interactions shrink the savings (or exacerbate the additional costs) of the alternative policies. (We find this holds from a coalition as well as a global perspective, though we only report the latter here). For example, without the labor-leisure tradeoff, OBR achieves the majority of the cost savings of the Tariff policy for all but the largest coalition, and has nearly identical effects when the EU is alone in carbon pricing. However, with the labor-leisure tradeoff (regardless of the use of the emissions revenues), the OBR cost savings are relatively insignificant for coalitions larger than the EU and turn negative sooner. Meanwhile, in the presence of tax interactions, the cost savings from anti-leakage measures are always larger when emissions revenues are grandfathered than when they are recycled. In particular, the incremental benefits of OBR are higher under grandfathering than recycling, since the smaller price pass-through limits the fall in the real wage, though not as well as revenue recycling.¹³ We also find that when the labor-leisure trade-off is turned off, there is less difference in the global welfare savings when importers or exporters retain the revenues.

¹³ See Fischer and Fox (2010) for a fuller description of this mechanism.

Figure 1: Cost Savings from Anti-Leakage Measures (in Millions of 2004 \$), by Coalition



The Relative Scope for Cost Savings

To consider the scope of the potential efficiency gains, Figures 2–4 report the cost savings of policy alternatives compared with the reference carbon policy with grandfathering, using simulations from the 2004 base year. “Recycle” is the reference scenario with revenue recycling, while the other policies assume remaining revenues are grandfathered.

Recycling revenues consistently lowers the cost to the coalition of meeting the global reduction target by about 20 percent or more for all coalition sizes (Figure 2). When the coalition is just EU, which has relatively high labor tax rates as well as high abatement costs, the cost savings from recycling revenues is 30 percent. The cost savings from Tariff (Imp.) are somewhat smaller but still of a similar scope to revenue recycling, reducing coalition costs by roughly 20 percent as long as China is outside the coalition. Coalition cost savings from Tariff (Exp.) are still positive although the revenues accrue to the noncoalition countries. OBR produces fewer cost savings than Tariff (Imp.) but more than Tariff (Exp.) except for the largest coalition; for EU and EU+US, the savings are about 10 percent. Exempting EIT sectors can produce a 4 percent cost savings for small coalitions, but it raises costs for larger coalitions.

Figure 2. Coalition Cost Savings Relative to Grandfathered Caps (2004 Base Year)

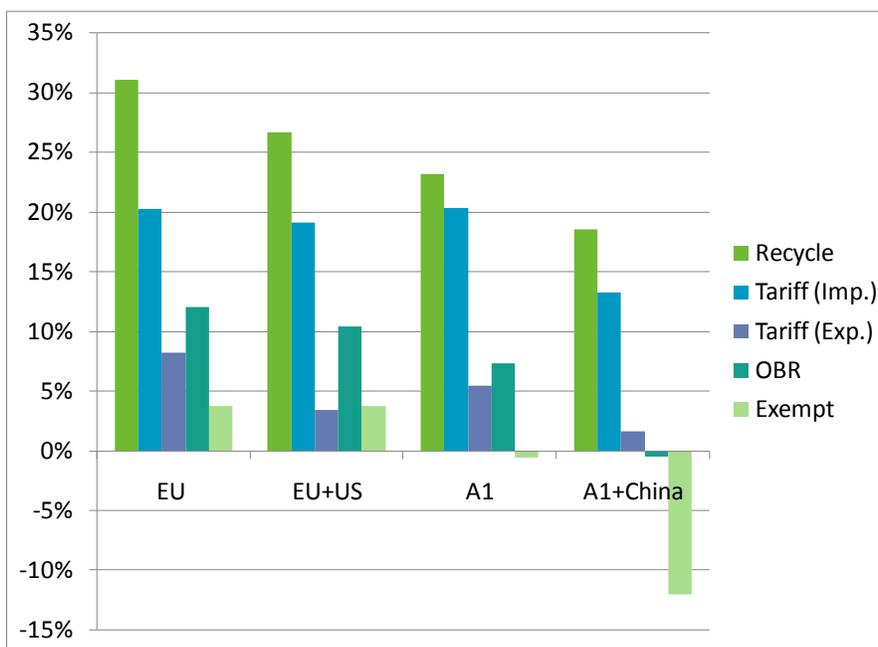
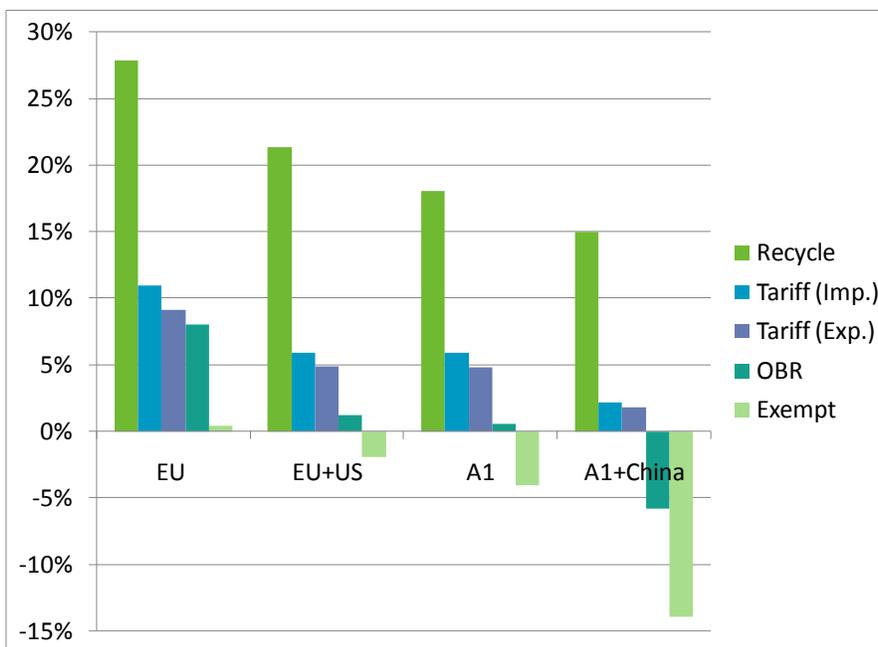


Figure 3. Global Cost Savings Relative to Grandfathered Caps (2004 Base Year)



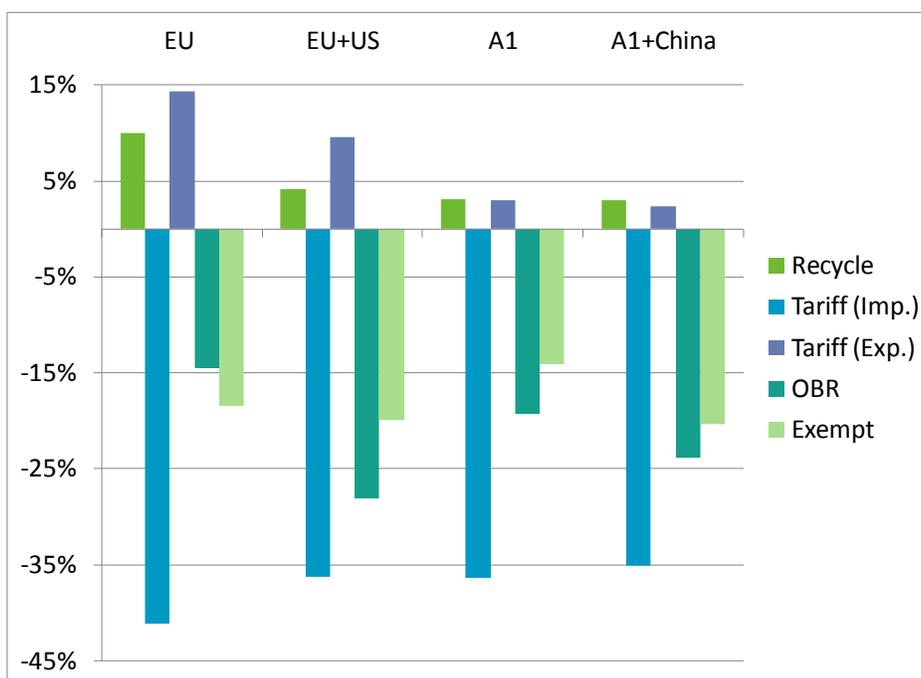
From a global perspective (Figure 3), revenue recycling reduces welfare costs by 25 percent or more for the smaller coalitions and by 15 percent for the largest. The Tariff policies produce about 10 percent global cost savings for the European coalition, 5 percent savings for

the larger industrialized country coalitions, and only 1 percent to 2 percent savings when China joins the coalition. OBR offers significant cost savings for Europe, similar to the Tariff policies, but negligible or even negative savings for larger coalitions. Exempting the EIT sectors raises costs when the coalition expands beyond Europe.

An important distinction is seen in the effects among noncoalition countries (Figure 4), which generally incur their own costs from the climate policies implemented among coalition countries. Revenue recycling not only improves the welfare of the coalition countries, but it also consistently improves noncoalition welfare. Antileakage policies, on the other hand, consistently exacerbate the costs borne by noncoalition countries. The exception is when the exporting countries retain the tariff revenues; Tariff (Exp.) confers larger benefits to the noncoalition countries than Recycle when the coalitions are small because of reduced leakage and their own tax interactions.

We find that the tax interaction effects of the adjustment policies themselves are small compared with the direct welfare effects of the policies or the tax interaction cost of emissions pricing. This result may be unsurprising, since the EIT sectors represent less than 10 percent of GDP and 25 percent of emissions in Annex I countries, so the revenue implications are much less substantial than those of the carbon price itself.

Figure 4. Noncoalition Cost Savings Relative to Grandfathered Caps (2004 Base Year)



Sensitivity Analysis

With these additional scenarios, we explore the robustness of our results and offer additional insights into the effects of some of the key assumptions that differ across models in this special issue.

Baseline Sensitivity

We use our 2020 projections to test the sensitivity to the baseline assumptions. Table 2 gives the growth rates from 2004 to 2020 by region of total emissions, output, EIT output, and the emissions intensity of the EIT sectors. Perhaps the most striking trends are the growth in China and India in emissions and output; furthermore, growth in their EIT sectors is even more rapid. As a result, despite falling emissions intensities, EIT emissions grow faster than overall emissions.

Table 2. Percentage Growth in Baseline, 2004–2020

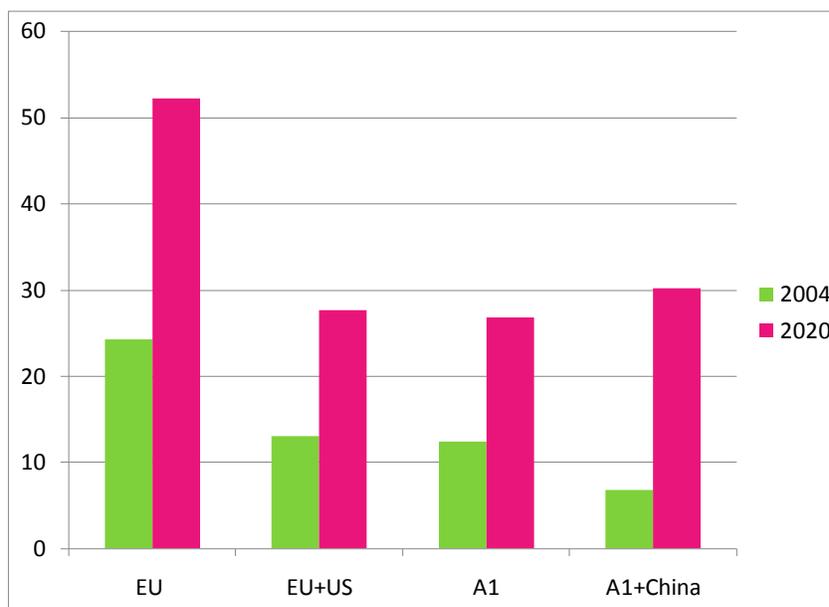
	EUR	USA	RUS	CHN	IND	RA1	EEX	MIC	LIC
Total emissions	−11.9	−6.2	34.9	127.4	130.9	4.5	107.8	55.1	144.2
Total output	14.0	21.0	79.9	300.0	233.2	21.2	94.9	85.6	145.5
EIT output	21.1	28.4	−7.1	390.7	327.8	27.8	2.8	100.4	135.7
EIT intensity (kg/\$)	−25.5	−27.9	−28.4	−43.9	−34.0	−20.8	−9.2	−22.5	17.5

These growth trends reveal themselves in leakage rates that roughly double between 2004 and 2020 in the reference scenarios; in 2020 they even become larger when China joins the coalition (Figure 5).¹⁴ This largest coalition also experiences the largest changes in the results compared with the 2004 baseline simulations. Although CO₂ prices are somewhat higher in 2020 for the EU and A1 coalitions, they are dramatically higher when China joins the coalition (Figure 6);¹⁵ whereas in 2004 they brought more cost-effective reduction opportunities to the coalition, in 2020 they bring a vastly more stringent reduction target because of their baseline emissions growth (recall that the emissions constraint is the same as in 2004).

¹⁴ Leakage rates are reported for the reference scenario with grandfathering; the rates with recycling are similar.

¹⁵ Similarly, CO₂ prices are reported for the reference scenario with grandfathering; the prices with recycling are similar and only slightly higher in the EU coalition.

Figure 5. Leakage Rates by Coalition and Base Year (Percentage of Coalition Reductions)



In terms of the global welfare effects, the antileakage measures become much more important in the A1+China coalition in 2020, whereas the relative importance of revenue recycling becomes smaller (Figure 7). The former results from the greater leakage pressures; the latter is explained by the sheer size of the Chinese economy in 2020, which has grown much more than the emissions price, while the emissions constraint remains the same as in 2004.

Another interesting feature is the relative improvement in performance of the OBR and Exempt policies, most likely because of the greater prominence of emissions from the EIT sectors, due to their baseline growth, and therefore the stronger contribution to carbon leakage. Full border adjustment (although not depicted) consistently outperforms the other options, but in 2020 OBR and Exempt perform nearly as well as the Tariff policies, and in some cases better. Only when China joins the coalition does the Exempt policy reduce efficiency.

Figure 6. CO₂ Prices by Coalition and Base Year (2004 \$ per ton)

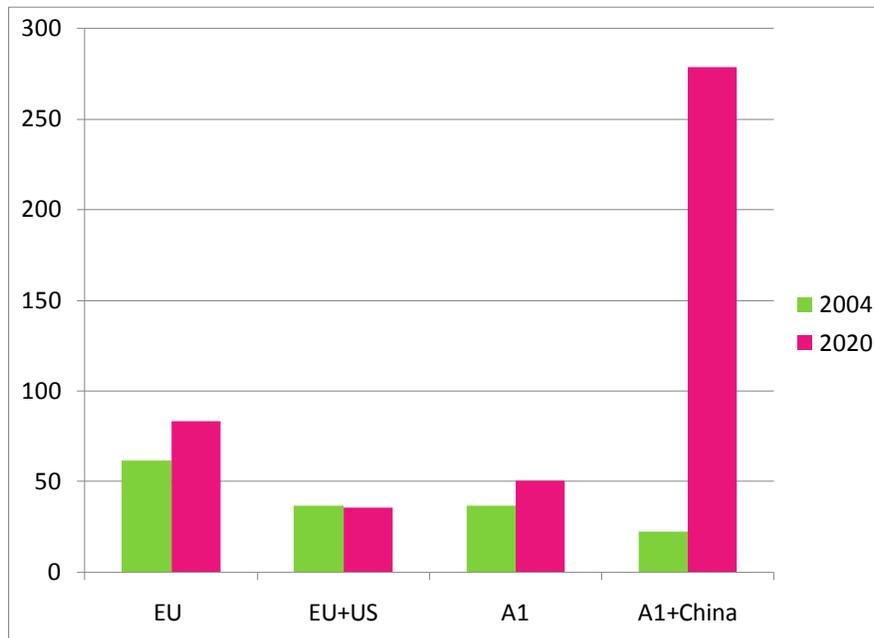
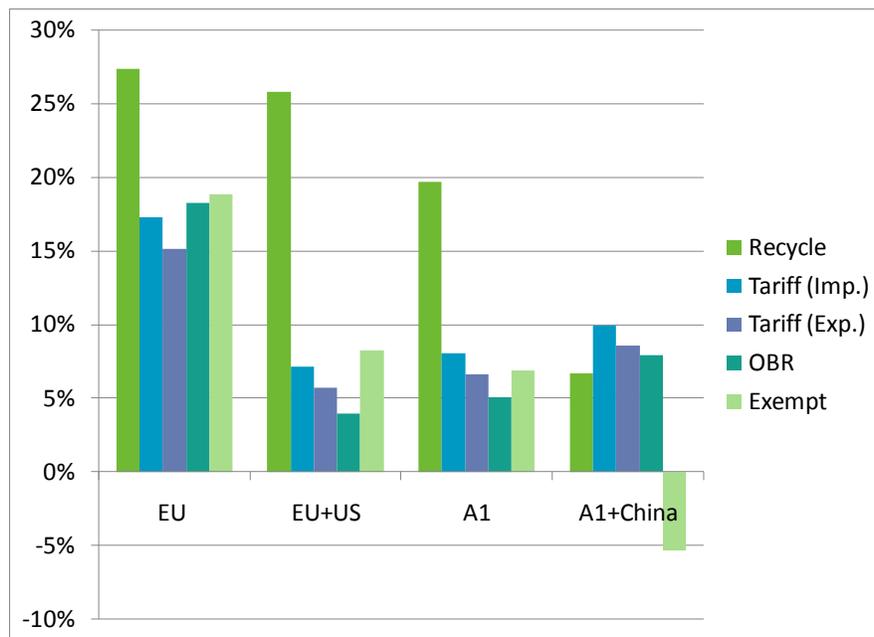


Figure 7. Global Cost Savings Relative to Grandfathered Caps (2020 Base Year)



Global Energy Price Sensitivity

In our simulations, the bulk of emissions leakage occurs through changes in global energy markets. We conduct a sensitivity analysis in which global energy prices (outside the coalition) do not adjust in response to changes in energy demand resulting from carbon pricing. Table 3 compares the leakage rates from the 2004 reference scenarios with those that would occur in the absence of global energy price adjustments, by coalition.

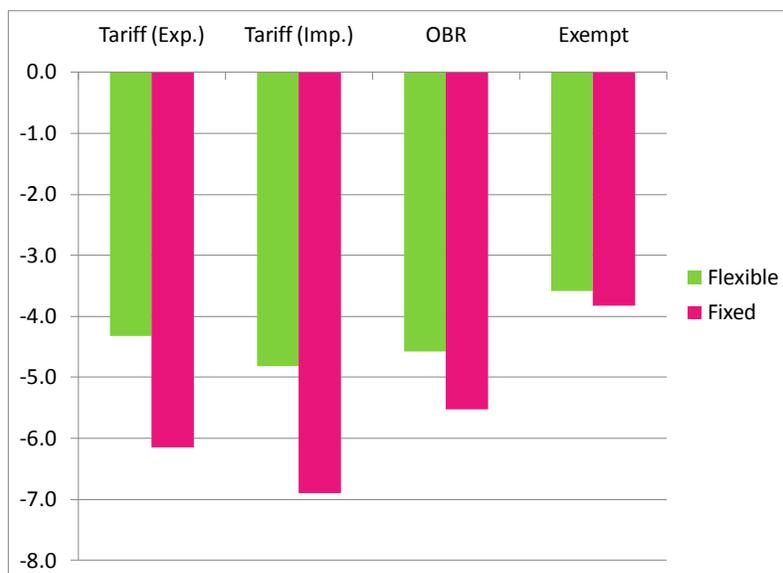
Table 3. Leakage Rates with and without Global Energy Price Adjustments (2004 Base Year; Percentage of Coalition Reductions)

	<i>EU</i>	<i>EU+US</i>	<i>AI</i>	<i>AI+China</i>
Global energy markets adjusting	23.9	12.9	12.3	6.7
Global energy prices fixed	8.8	1.3	2.3	2.1

All policies generate a larger percentage point (i.e., absolute) reduction in the leakage rate when energy prices are fixed than when they adjust (Figure 8 gives the results for the EU coalition as an example). This seems to indicate that leakage through energy market channels also undermines some of the effectiveness of the antileakage measures that operate through competitiveness channels.

Less leakage also implies lower welfare costs of meeting the targets. On the other hand, noncoalition countries bear more of the burden, since they do not benefit from lower energy prices (with the exception of the energy exporters). As for tax interactions, turning off the global energy price response has only a small effect, reducing the benefits of revenue recycling by a couple of percentage points.

Figure 8. Percentage Point Reduction in Leakage Rate by Measure for the EU Coalition (2004 Base Year, Revenue Recycling)



Conclusion

The excess burden of taxation is a major concern in economics. Incorporating labor tax distortions into a general equilibrium model of climate policies serves two goals in this paper. One is to understand the influence of tax interactions on the relative benefits of border carbon adjustments and other policies to combat leakage. The other is to put the magnitude of those benefits in context.

We find that, taking tax interactions into account, the benefits of border adjustments are somewhat enhanced, while the alternative measures become less attractive, both from a coalition and a global perspective. At the same time, the use of the emissions revenues becomes of greater importance.

For plausible values of labor supply elasticities, the cost savings from using emissions revenues to lower distorting taxes are significant: for most of the policy targets we studied, these savings range from 15 percent to 25 percent. The cost savings from dealing with the problem of international emissions leakage are generally smaller but also significant, particularly when the regulating coalitions are small or, looking ahead, the reduction targets become stricter.

Dealing with leakage is especially important for countries in the climate coalition, since it increases their costs. However, noncoalition countries are also negatively affected by carbon pricing in the coalition, and their welfare losses tend to be exacerbated by antileakage policies.

We find two policy choices that consistently benefit both groups. One is revenue recycling by coalition countries: by improving the efficiency of the global economy, it also consistently raises the welfare of noncoalition countries as well. The other is border adjustments with the tariff revenues returned to the exporting countries. These benefits also tend to be enhanced in the presence of tax distortions.

Although the implications are that these policies might not be controversial, we know that in practice they are. Border carbon adjustments remain highly contentious in trade communities and would be difficult (from the perspective of international law and relations) to implement by a single region. Tax reform is itself a difficult task, and pressures are great to distribute emissions revenues among politically important players to gain acceptance for the climate policy. This pressure is further heightened if leakage concerns are not addressed. Thus, in the absence of some global agreement to manage the leakage effects of differentiated responsibilities, the outcome of unilateral policies may be costlier for all.

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