# Output-based rebating of carbon taxes in a neighbor's backyard:

## Competitiveness, leakage and welfare

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*Abstract.* We investigate how, in an open economy, carbon taxes combined with output-based rebating (OBR) perform in interaction with the carbon policies of a large neighboring trading partner. Analytical results suggest that, whether the purpose of the OBR policy is to compensate firms for carbon tax burdens or to maximize welfare (accounting for global emission reductions), the OBR rate should be positive in policy-releveant cases. Numerical simulations for Canada, with the US as the neighboring trading partner, indicate that the impact of US policies on the OBR rate will depend crucially on the purpose of the Canadian OBR policies. If, for a given US carbon policy, Canada's aim is to restore the competitiveness of domestic emission-intensive and trade-exposed (EITE) firms to the same level as before the introduction of its own carbon taxation, we find that the necessary domestic OBR rates will be insensitive to the foreign carbon policies. However, if not only the Canadian carbon tax, but also an equally high US tax, is introduced compensatory Canadian OBR rates will be up to 50% lower, depending on the sector and on US OBR policy. If the policy objective is to increase economy-wide allocative efficiency (welfare) of Canadian policies by accounting for carbon leakage, the US policies will only have a minor downward pressure on desirable OBR rates in Canada. Practical choices of OBR rates hardly affect overall domestic economic performance – thus output-based rebating qualifies as an instrument for compensating EITE industries without bigger regrets on potential losses in economy-wide allocative efficiency.

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## 1. Introduction.

In the absence of effective worldwide cooperation to curb global warming, some countries have introduced national or regional climate policies such as unilateral carbon emissions pricing. Proactive governments in the climate policy area express two major concerns, however. The first is the risk of carbon leakage, i.e., the relocation of emissions to countries with no or more lenient emission regulations. For a country that cares about the global climate, leakage will contribute to reducing the efficiency gain of its domestic emissions pricing. The second concern relates to distributional impacts of decreasing the competitiveness of domestic energy-intensive and trade-exposed firms.

As a single country cannot directly regulate emissions outside its territory, a potential policy response to both carbon leakage and loss of competitiveness is to rebate its own energy-intensive and trade-exposed firms for the tax payments in proportion to their output. This is known as output-based rebating (OBR); see Bernard, Fischer and Fox (2007). According to second-best theory, carbon leakage is most cost-effectively counteracted by border carbon measures, i.e., tariffs on the carbon embodied in imports and tax rebates for the carbon embodied in exports (Markusen 1975, Hoel 1996). However, such countermeasures are controversial from a free trade perspective and may not comply with WTO law – see Böhringer, Bye, Fæhn and Rosendahl (2012) for a discussion. OBR appears to be less provocative in light of WTO law (Fischer and Fox 2012, Branger and Quirion 2013). Even though OBR is likely to be less effective against carbon leakage, Fischer and Fox (2012) conclude that, for selected energy-intensive industries in Canada, the US and Europe, OBR could be a legally feasible and relatively effective substitute for the more controversial border measures. Böhringer, Fischer and Rosendahl (2014); BFR, draw similar conclusions. For the same trade-political reasons, output-based compensation may also be the preferred countermeasure against the loss of EITE competitiveness, as Rivers (2010) and Fischer and Fox (2012)[1] conclude in the Canadian case.

While domestic OBR as a response to carbon leakage and competitiveness concerns has been addressed by several authors, this paper contributes to the existing literature by focusing on how, in an open economy, the performance of carbon taxes combined with OBR depends on the carbon policies of a larger trading partner. We look for second-best, welfare-optimal OBR rates under different climate policies of the foreign trading partner. For a single country that cares about climate change, OBR will not just affect its welfare by distorting market prices, but also through the overall effects on global emissions. Furthermore, in order to shed light on the possible trade-offs between efficiency and competitiveness concerns in practical policymaking, we address how OBR responses to the actions of an influential neighbor affect the competitiveness of individual domestic industries.

We combine theoretical analysis with numerical simulations. Our theoretical, partial equilibrium analysis first addresses compensatory OBR policy designed to counteract competitiveness losses. The main conclusion is, as expected, that carbon taxation by an influential trading partner tends to reduce compensatory domestic OBR levels, while the opposite is true if the trading partner also introduces OBR. If the political aim of domestic OBR is not primarily to compensate competitiveness losses, but to reduce the welfare costs of domestic carbon policies, we still find that domestic optimal OBR rates mostly tend to be

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[1] Fischer and Fox (2012) find that, in contrast to the US and EU, OBR is the preferable policy for several of the Canadian industries with no border adjustments in the EU or the US.

positive for a country that values global emissions abatement. The optimal OBR rate decreases with the carbon tax of an influential neighbor, while the latter's OBR policies will have an ambiguous, but negligible effect. However, terms-of-trade effects are uncertain and can potentially overturn these conclusions. Moreover, even in this simple, partial equilibrium setting, counteracting mechanisms are at play in the form of price interactions and changes in marginal production and abatement costs, which need to be quantified to reach robust conclusions.

The theoretical analysis is accompanied by a numerical study of Canadian OBR policy in the presence of carbon policies (including OBR) in Canada's large trading partner, the US. As Peters and Hertwich (2008) show, Canada's trade is more emission-intensive than that of the US. Canada's high energy intensity, limited fuel-switching possibilities, and significant exposure to international markets make climate policy a hot topic in the Canadian debate. The Canadian action plan to combat climate change was originally formulated in the 2007 *Turning the corner* plan and the follow-up regulatory framework.[2] It includes intensity-based regulation of emission-intensive industries, i.e., industry targets for unit emissions rather than total emissions. If they are tradable, such unit emission permits provide incentives that equal those resulting from the combination of emissions pricing and output-based rebating system studied here, i.e., they simultaneously put a price on marginal emissions and subsidize production (Rivers and Jaccard 2010, Fischer and Fox 2012).

We address the Canada/US interaction by means of a global multi-region, computable general equilibrium (CGE) model that represents the emission-intensive, trade-exposed (EITE) industries and energy supply sectors in detail. CGE analysis adds to the theoretical analysis in several ways. It provides realistic parameters that help to emphasize the various effects of the theoretical model based on empirical evidence. More importantly, it adds relevant mechanisms that are absent in the theoretical setting, e.g., by accounting for comprehensive and complex, price-responsive, input-output transmissions, as well as the interaction effects between climate policies (including OBR) and existing distortions in the Canadian economy. While most previous studies (of domestic OBR policy) consider full rebating (i.e., all tax payments paid by the industries are rebated back to the industries), we investigate a broader range of OBR rates to identify the optimal rates given different assumptions about US policies and given different policy aims.

Turning first to competitiveness policies, we find that the appropriate OBR policy for Canada as a reaction to US carbon policies will depend on the exact aim of the policy. If, for a given US carbon policy, Canada's aim is to restore the competitiveness of domestic EITE firms to the same level as before the introduction of its own carbon taxation, we find that more or less the same Canadian OBR system will be required irrespective of the US carbon policy regime. This conclusion holds for different competitiveness measures, including activity, trade and market share indicators. On the other hand, if the aim is to compensate the firms for the combined actions taken by the US and Canada, the necessary Canadian OBR rates will naturally be lower if the US also regulates its emissions. If the US introduces 100% OBR, about half of the Canadian competitiveness gain from US policies evaporates, irrespective of the competitiveness measure. More importantly, the effects of US policies vary greatly among Canadian industries. When considering OBR responses, it will be important to pay attention to

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[2] See http://publications.gc.ca/collections/collection_2009/ec/En88-2-2008E.pdf and http://www.ec.gc.ca/doc/media/m_124/report_eng.pdf

industry-specific US policies and conditions. This is compatible with previous findings on industry differences in the competitiveness effects of Canada's own carbon policies (Dissou 2006, Fischer and Fox 2012).

Our numerical welfare analysis differs from earlier CGE studies of Canada in Dissou (2006) and Rivers (2010) by including an assessment of global abatement as part of the welfare metric. Carbon leakage will thereby be considered a cost for the country, which is reasonable given the global nature of the climate problem. When the US introduces carbon taxation, Canadian carbon leakage drops. So does its optimal OBR rate, though only very slightly. Our findings on carbon leakage and welfare-optimal OBR rates for Canada mostly confirm the results from the analytical partial equilibrium model. Moreover, the US OBR policies have hardly any effect on Canadian carbon leakage, nor on its optimal OBR rates. An important finding is that the efficiency costs of deviating from the second-best optimal OBR rates are minor and therefore provide little guidance on practical OBR policies. These conclusions from the numerical analysis suggest that OBR policy can be guided by other motivations than economy-wide welfare. Importantly, sensitivity analyses reveal that the optimum rate is quite sensitive to central parameter values and, in particular, to what is assumed about EITE product heterogeneity across countries (i.e., the choice of Armington elastisicities for EITE products).

Our findings can be readily transferred to similar climate policy regimes in place or under consideration in other regions. Besides tradable intensity-based policy regulations, various policy designs contain incentives that are equivalent to those of emission pricing with OBR. Metcalf (2013) suggests output-based tax credits as a practicable design in cases of carbon taxation. For the case of emissions trading instead of carbon taxation, Böhringer and Lange (2005) and Monjon and Quirion (2011) analyze output-based allocation (OBA) of free quotas. Most prominently, the EU Emissions Trading System (EU ETS) has practiced free allocation of emission allowances for several years, conditional on the installations' output capacities combined with the sectors' trade exposure and emission payments. Similar schemes for the EITE industries, but based on output rather than installed capacity, are under consideration in the US and Australia and have been proposed in Japan.[3]

## 2. Theoretical background.

Consider a home region *H*, a foreign region *F* and the rest of the world *R* that each produces the good $x^j$ at the price $p^j$ ($j=H, F, R$). There is trade and each good *j* is consumed in all regions (*H*,*F*,*R*), i.e., $x^j = x_H^j + x_F^j + x_R^j$, where the three goods are assumed to be imperfect substitutes. The costs of producing in region *j* are $C^j(x^j,e^j)$, where $e^j$ is the emissions intensity. The cost function is assumed to be convex and increasing in $x^j$, while decreasing in $e^j$. We assume that region *H* introduces a fixed emission tax $\sigma^H$, set equal to the marginal damage costs of emissions.[4] Furthermore, we assume that the home region considers rebating (parts of) the emissions payments through an output-based rebate (subsidy) $s^H$.

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[3] For further reading about measures dealing with carbon leakage and competitiveness, and schemes proposed in different regions, see, e.g., Heilmayr and Bradbury (2011), Zhang (2012), and Hallegatte, Fay and Vogt-Schilb (2013).

[4] Here, we mean the marginal damage costs of emissions as perceived by the home region.

### *2.1. Domestic output effects of domestic and foreign carbon policies.*

Since changes in output can measure competitiveness effects (see the discussion in Section 4), we start by deriving the effects on domestic output of domestic and foreign carbon policies. Perfectly competitive firms in the home region maximize profits, $\pi^H$:

$$\pi^H = p^H x^H - C^H(x^H, e^H) + s^H x^H - \sigma^H e^H x^H \tag{1}$$

w.r.t. $x^H$ and $e^H$ . First order conditions are as follows:

$$p^H = \partial C^H / \partial x^H + \sigma^H e^H - s^H \tag{2}$$

$$-\partial C^H / \partial e^H = \sigma^H x^H \tag{3}$$

Market equilibrium for the home product is given by:

$$x^H = x_H^H\left(p^H, p^F, p^R\right) + x_F^H\left(p^H, p^F, p^R\right) + x_R^H\left(p^H, p^F, p^R\right) \tag{4}$$

Let us first consider the effects on home production of introducing domestic carbon policies, consisting of a carbon tax $\sigma^H > 0$ and an output-based rebate $s^H > 0$. We differentiate eq. (4) and rearrange:

$$\begin{aligned} dx^H = {} & (x_{HH}^{H'} + x_{FH}^{H'} + x_{RH}^{H'})(\frac{\partial p^H}{\partial \sigma^H} d\sigma^H + \frac{\partial p^H}{\partial s^H} ds^H) + (x_{HF}^{H'} + x_{FF}^{H'} + x_{RF}^{H'})(\frac{\partial p^F}{\partial \sigma^H} d\sigma^H + \frac{\partial p^F}{\partial s^H} ds^H) \\ & + (x_{HR}^{H'} + x_{FR}^{H'} + x_{RR}^{H'})(\frac{\partial p^R}{\partial \sigma^H} d\sigma^H + \frac{\partial p^R}{\partial s^H} ds^H) \end{aligned} \tag{5}$$

where $x_{ji}^{H'} = \partial x_j^H \big/ \partial p^i$ and $(j,i=H,F,R)$ denotes the direct and cross-price effects on demand. In its first bracket, the first term in eq. (5) contains the direct price derivatives that are all negative. To examine its second bracket, we use the derivatives of the first order condition in eq. (2):

$$\frac{\partial p^H}{\partial \sigma^H} = \frac{\partial C_x^H}{\partial \sigma^H} + \sigma^H \frac{\partial e^H}{\partial \sigma^H} + e^H \tag{6}$$

and

$$\frac{\partial p^H}{\partial s^H} = \frac{\partial C_x^H}{\partial s^H} + \sigma^H \frac{\partial e^H}{\partial s^H} - 1 \tag{7}$$

where $C_x^H = \partial C^H \big/ \partial x^H$ .

In most realistic cases, the sign of eq. (6) will be positive, as the direct home price effect of introducing a carbon tax (the last term) is likely to dominate the two other indirect, and probably counteracting, effects. The second term captures the fact that the emission intensity is likely to fall with the carbon tax, while the first term says that, with decreasing returns, marginal costs will increase with the output scale.

In eq. (7), the direct home price effect of an output subsidy (OBR) is negative (the last term). The two remaining effects are likely to modify but not offset the direct effect. The first term reflects increased costs as output increases, and the second term reflects increased emission intensity, both effects being related to increasing marginal costs.

The second and third terms in eq. (5) are the cross-price effects on domestic demand of changes in prices abroad. In these two terms, the first bracket expresses the positive effect on demand for the home good within all three markets of higher prices for the *F* and *R* products, respectively. The second bracket of the second and third term captures the price changes, which tend to move in the same direction as the domestic price. Thus, these indirect effects will modify the direct price effects on output of the home product, and will be stronger the closer substitutes the products of *F* and *R* are for the domestic product. For sufficiently small home countries, domestic carbon policies will not be able to affect prices of large trading partners, i.e., $\partial p^F / \partial \sigma^H = \partial p^R / \partial \sigma^H = \partial p^F / \partial s^H = \partial p^R / \partial s^H = 0$.

To sum up, the direct effect of carbon taxation reduces output by increasing the costs of emissions, and it is stronger the larger the emission intensity, while introducing OBR has a direct favorable output effect. Additional effects do occur, however, through

a) foreign price changes in the same direction as for home prices if the goods are substitutes and the home country is sufficiently large,
b) marginal cost adjustments in the same direction as output scales if there are decreasing returns,
c) abatement and, thus, lower emissions payments as a result of the carbon tax.

Next, we investigate how domestic production depends on the carbon policies in the foreign region.[5] We consider both solely introducing a carbon tax, $\sigma^F$, which may or may not equal the home tax, $\sigma^H$, and supplementation with an OBR rate, $s^F$. Similar first-order conditions and market equilibrium as in eqs. (2) – (4) for the home product carry over to the foreign product. We can then express the total effects of both domestic and foreign carbon taxes and OBR by differentiating eq. (4). To simplify the discussion, we assume that both countries are sufficiently small to disregard price effects on the other products. Rearranging, we get:

$$dx^H = \left(x_{HH}^{H'} + x_{FH}^{H'} + x_{RH}^{H'}\right)\left(\frac{\partial p^H}{\partial \sigma^H} ds^H + \frac{\partial p^H}{\partial s^H} d\sigma^H\right) + \left(x_{HF}^{H'} + x_{FF}^{H'} + x_{RF}^{H'}\right)\left(\frac{\partial p^F}{\partial \sigma^F} ds^F + \frac{\partial p^F}{\partial s^F} d\sigma^F\right) \quad (8)$$

The first term in eq. (8) and the first bracket in the second term are recognizable from eq. (5) and they are both negative. The last bracket represents the price effects on good *F* of the carbon policies in the foreign region. The price effects of foreign policies in the foreign region will have channels and signs analogous to the corresponding price effects in the home country; see the discussion above. It then follows that introducing a carbon tax in the foreign country has a positive, direct effect on the output of the home product, and the more so the higher the emission intensity in the foreign region and the larger the sensitivity of demand for the domestic good to the price of the foreign good. It also follows from the discussion above that the direct contribution of OBR in the foreign region is to reduce the home output. The sensitivity will increase with the relative significance of the foreign to the domestic good in the three markets. These direct mechanisms dominate, but similar additional effects apply as for domestic policies; see a) to c) above.

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[5] So far, we have assumed that emission intensities in regions *R* and *F* are exogenous given that these countries do not adopt emission control policies. This assumption is relaxed now for region *F* undertaking domestic emission regulation.

Though the signs of the various partial and net effects are well-known from the carbon leakage literature, and are not surprising, the relative strengths of the various factors will vary from industry to industry depending on industry-specific characteristics. We will return to this in our numerical analysis in Section 4.

### *2.2. Second-best optimal OBR policies with no foreign carbon policies.*

We now search for the optimal level of $s^H$ in the home region, assuming first that there is no climate policy in the two other regions. The behavior by firms in the home region is given by eqs. (1)-(3) above, and welfare is given by:

$$W^H = U^H(x_H^H, x_H^F, x_H^R) - C^H(x^H, e^H) - p^F x_H^F - p^R x_H^R + p^H x_F^H + p^H x_R^H - \sigma^H(e^H x^H + e^F x^F + e^R x^R) \tag{9}$$

where $U^H$ denotes consumption utility. Note that we assume that the home region also cares about global emissions valued at the carbon tax $\sigma^H$.

We maximize $W^H$ with respect to $s^H$, noting that all variables are functions of $s^H$. Using eq. (4) and the relationship $\partial U^H / \partial x_H^j = p^j$, *j=H,F,R,* and utilizing the fact that the first square bracket in eq. (2) equals $-s^H$ and the second square bracket in eq. (3) equals zero, we get the following expression for the second-best optimal domestic subsidy rate:

$$s^H = \sigma^H \left[ e^F \frac{-\partial x^F / \partial s^H}{\partial x^H / \partial s^H} + e^R \frac{-\partial x^R / \partial s^H}{\partial x^H / \partial s^H} \right] - \frac{\partial p^F / \partial s^H}{\partial x^H / \partial s^H} x_H^F - \frac{\partial p^R / \partial s^H}{\partial x^H / \partial s^H} x_H^R + \frac{\partial p^H / \partial s^H}{\partial x^H / \partial s^H} (x_F^H + x_R^H) \tag{10}$$

The last three terms in eq. (10) are terms-of-trade effects. If these are negligible, we see that the optimal home subsidy rate should equal the value of the emissions avoided abroad (with the unit value $\sigma^H$). Note that a possible rise in the domestic emissions intensity caused by OBR is not of importance to the optimal OBR rate, because, on the margin, the subsequent rise in abatement costs will be exactly offset by the reduction in emissions payments (see eq. (3)). The decrease in foreign emissions depends on the emissions intensities in regions *F* and *R*, as well as on the sensitivity of production in these two regions to changes in home production. This, in turn, depends on how well the production in these two regions substitutes the home product in demand. The same factors as discussed in Section 2.1 determine the changes in domestic, foreign and rest-of-the-world output as a consequence of changes in the home subsidy rate.

We note that, in the special case where emission intensities are the same in all regions ($e^H = e^F = e^R$), and the production decrease in *F* and *R* equals the production increase at home ($\partial x^H / \partial s^H = -\partial x^F / \partial s^H - \partial x^R / \partial s^H$), the optimal subsidy rate would be $s^H = \sigma^H e^H$. That is, the emissions payments are fully rebated to the firms (in aggregate) through the subsidy payments – this is often referred to as full or 100% rebating; 100% rebating is the standard way of modeling output-based rebates (OBR) and we will refer to this as the subsidy rate $s^{H*}$.

The substitution effects, i.e., the fractions $(-\partial x^j / \partial s^H) \big/ (\partial x^H / \partial s^H)$ where *j=F,R,* will typically be positive but lower than one altogether, both because the three goods are imperfect substitutes and because marginal costs tend to be increasing. On the other hand, if the emission intensities are lower in the home region than in the foreign and rest-of-the-world regions, the optimal subsidy rate increases. As long as we consider climate policy in the home region only, emission intensities abroad will tend to exceed intensities at home. Hence, we cannot rule out the possibility that $s^H$ may exceed $s^{H*}$.

What about the terms-of-trade effects? As discussed in Section 2.1., the subsidy will increase output of the home good and, since the three goods are substitutes, all prices will fall. Thus, the two first terms-of-trade terms are positive (lower import costs), while the last term is negative (lower export revenues). The price fall of the domestic good will tend to be greater than the price fall of the products from abroad (since the latter prices are only indirectly affected), in which case the overall terms-of-trade effect becomes negative. However, if the home region is a net importer of the three goods (on aggregate) the composite terms-of-trade effect may be positive. The closer substitutes the goods are, the more will import prices drop, which contributes positively to domestic welfare. In other words, terms-of-trade effects can imply optimal OBR rates that are either negative or greater than 100%. For a small-sized open economy, the terms-of-trade effects will tend to be less important than the emissions effect (i.e., the first term of eq. (10)). To simplify our exposition, we will therefore disregard the terms-of-trade effects in the remaining analysis in this section.

### *2.3. Second-best optimal domestic OBR rate in the presence of foreign carbon policies.*

When exploring the sensitivity of the optimal subsidy rate $s^H$ with respect to the carbon policies in the foreign region, we consider two alternatives:

i) The foreign region introduces a carbon tax $\sigma^F$, which may or may not equal the emissions tax at home, $\sigma^H$.

ii) The carbon tax $\sigma^F$ is supplemented by rebating through an output subsidy $s^F$.

We differentiate eq. (10) with respect to $\sigma^F$ and $s^F$. We simplify the expression by denoting $\partial x^j / \partial s^H = x_s^j$, $j=H,F,R$. As before, we assume that $x_s^H > 0$, $x_s^F, x_s^R < 0$ and $-(x_s^F + x_s^R) < x_s^H$. Note that the emission intensities $e^H$ and $e^F$ are now endogenous, while $e^R$ is still exogenous. We then get (after inserting for $s^H$ from eq. (10)):

$$
\begin{aligned}
ds^H &= \frac{\sigma^H}{x_s^H}\left[-\frac{\partial e^F}{\partial \sigma^F}x_s^F - e^F\frac{\partial x_s^F}{\partial \sigma^F} - e^R\frac{\partial x_s^R}{\partial \sigma^F} + \left(e^F\frac{x_s^F}{x_s^H} + e^R\frac{x_s^R}{x_s^H}\right)\frac{\partial x_s^H}{\partial \sigma^F}\right]d\sigma^F \\
&+ \frac{\sigma^H}{x_s^H}\left[-\frac{\partial e^F}{\partial s^F}x_s^F - e^F\frac{\partial x_s^F}{\partial s^F} - e^R\frac{\partial x_s^R}{\partial s^F} + \left(e^F\frac{x_s^F}{x_s^H} + e^R\frac{x_s^R}{x_s^H}\right)\frac{\partial x_s^H}{\partial s^F}\right]ds^F
\end{aligned}
\tag{11}
$$

Let us first consider only a carbon tax in the foreign region, $d\sigma^F>0$ and $ds^F=0$. The term in front of the square bracket in eq. (11) is clearly positive. Moving to the first term inside the (first) square bracket, it is clear from Section 2.1 that the emission intensity in a region decreases with the emissions price in that region. The term is therefore negative, which means that the emissions reduction in the foreign region as a result of using $s^H$ diminishes. The three last terms in the square bracket capture scale effects on the sensitivity of output in the three regions with respect to $s^H$. A larger output scale will increase the output's sensitivity to $s^H$. Since the negative impact of carbon pricing in the foreign region is stronger on the output of $x^F$ than its positive substitution effect on the two other goods (see Section 2.1), it is reasonable to expect the sensitivity of $x^F$ with respect to $s^H$ to drop by more than the joint increase in the sensitivity of $x^R$ and $x^H$, i.e., $\partial x_s^F / \partial \sigma^F < 0$, while $\partial x_s^R / \partial \sigma^F > 0$ and $\partial x_s^H / \partial \sigma^F > 0$, where the first effect is the larger. Finally, we know from the discussion of eq. (10) that $x_s^i / x_s^H < 0$ for $i$=$F$, $R$, i.e., the domestic OBR policy increases domestic production at the expense of reduced production abroad. Hence, we can conclude that the second term is positive, while the two last terms are negative, but all three are dominated by the first negative term. In sum, carbon pricing in the foreign region will most probably reduce the optimal subsidy $s^H$ in the home region.

Assume, next, that the foreign region also imposes an output subsidy, $s^F$, in addition to the carbon tax. This will only affect $e^F$ to the extent that a firm's optimal emission intensity varies with output. In most realistic cases, this effect will be small and positive; see Section 2.1. The effects of $s^F$ on $x_s^j$ $(j=H,F,R)$ will tend to be the opposite of the effects of $\sigma^F$ discussed above, as there is a shift back to $x^F$, from $x^H$ and $x^R$. They will still be of little significance, however. Overall, the effect on the optimal domestic OBR rate of introducing OBR in the foreign region is ambiguous, but probably close to zero for realistic levels of the foreign OBR rate.

## 3. Numerical model and data.

### *3.1. Computable general equilibrium model.*

For our quantitative economic impact analysis of OBR rates, we use a three-region (USA, Canada, rest-of-the-world (ROW)), multi-sector CGE model of global trade and energy established for the analysis of greenhouse gas emission control strategies (see, e.g., BFR 2010, for a detailed algebraic description).[6] CGE models build on general equilibrium theory that combines behavioral assumptions about rational economic agents with analysis of equilibrium conditions. They provide counterfactual ex-ante comparisons, comparing the outcomes with a reform in place to what would have happened had it not been introduced. The main virtue of the CGE approach is its comprehensive micro-consistent representation of price-dependent market interactions in a setting with various, existing public interventions. The simultaneous explanation of the origin and spending of the agents' income makes it possible to address both economy-wide efficiency and distributional impacts of policy reforms.

Our model features a representative agent in each region that receives income from three primary factors: labor, capital and fossil fuel resources. Labor and capital are intersectorally mobile within a region, but immobile between regions. Fossil fuel resources are specific to fossil fuel production sectors in each region. The production of commodities other than primary fossil fuels is captured by three-level, constant elasticity of substitution (CES) cost functions describing the price-dependent use of capital, labor, energy, and materials (KLEM). At the top level, a CES composite of intermediate material demands trades off with an aggregate of energy, capital and labor subject to a constant elasticity of substitution. At the second level, a CES function describes the substitution possibilities between intermediate demand for the energy aggregate and a value-added composite of labor and capital. At the third level, capital and labor substitution possibilities within the value-added composite are captured by a CES function, whereas different energy inputs (coal, gas, oil and electricity) enter the energy composite subject to a constant elasticity of substitution. In the production of fossil fuels, all inputs except for the sector-specific fossil fuel resource are aggregated in fixed proportions. This aggregate trades off with the sector-specific fossil fuel resource at a constant elasticity of substitution.

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[6] Figures A1. - A4. in the Appendix provide a graphical exposition of the nesting structures in production and consumption.

Final consumption demand in each region is determined by the representative agent, who maximizes welfare subject to a budget constraint with fixed investment (i.e., a given demand for savings) and exogenous government provision of public goods and services. The total income of the representative agent consists of net factor income and tax revenues net of subsidies. The consumption demand of the representative agent is given as a CES composite that combines consumption of composite energy and an aggregate of other (non-energy) consumption goods. Substitution patterns within the energy bundle, as well as within the non-energy composite, are reflected by means of CES functions.

Bilateral trade is specified using Armington's differentiated goods approach, where domestic and foreign goods are distinguished by origin (Armington 1969). All goods used on the domestic market in intermediate and final demand correspond to a CES composite that combines the domestically produced good and the good imported from other regions. A balance of payments constraint incorporates the base-year trade deficit or surplus for each region. Public budgets are also kept unchanged from the base year, which is ensured by endogenous lump-sum transfers to/from the representative household.

$CO_2$ emissions are linked in fixed proportions to the use of fossil fuels, with $CO_2$ coefficients differentiated by the specific carbon content of fuels. Restrictions on the use of $CO_2$ emissions in production and consumption are implemented through a $CO_2$ tax or (in the sensitivity analysis) as an (equivalent) exogenous emission constraint. $CO_2$-emission abatement takes place by fuel switching (interfuel substitution) or energy savings (either by fuel-non-fuel substitution or by a scale reduction of production and final consumption activities).

### *3.2. Data.*

Our CGE analysis of OBR rates is based on version 8 of the Global Trade, Assistance and Production (GTAP) database, which includes detailed national accounts for production and consumption (input–output tables) together with bilateral trade flows and $CO_2$ emissions for the year 2007 (see Narayanan, Aguiar and McDougall 2012). GTAP can be flexibly aggregated to form a composite dataset that accounts for the specific requirements of the policy issue under investigation. Our choices of sector and commodity aggregates are given in Table 1.

TABLE 1
Sectors and commodities

| |
|---|
| **Energy** |
| Coal (COA) |
| Crude oil (CRU) |
| Natural gas (GAS) |
| Petroleum and coal products (refined)[a] (OIL) |
| Electricity (ELE) |
| **Emission-intensive and trade-exposed sectors (EITE)[a]** |
| Chemical products (CRP) |
| Non-metallic minerals (NMM) |
| Iron and steel industry (I_S) |
| Non-ferrous metals (NFM) |
| **Other sectors** |
| Air transport (ATP) |
| Water transport (WTP) |
| Other transport (OTP) |
| Fishery (FSH) |
| Agriculture (AGR) |
| Paper and pulp and print (PPP) |
| All other manufactures and services (AOG) |

[a] Included in the composite *Emission-intensive, trade-exposed industries* (EITE) when implementing output-based rebates.

For model parameterization, we follow the standard calibration procedure for applied general equilibrium analysis: the base-year input-output data determine the free parameters of the functional forms (cost and expenditure functions), so that the economic flows represented in the data are consistent with the optimizing behavior of the model agents. The responses of agents to price changes are determined by a set of exogenous elasticities taken from pertinent econometric literature. Elasticities in international trade (Armington elasticities) indicate the substitutability between varieties of each good between the three regions, which is a key characteristic of the analysis. These Armington elasticities are mostly taken from the GTAP database.[7] The GTAP database also provides substitution possibilities in production (between primary factor inputs). The elasticities of substitution in fossil fuel sectors are calibrated to match exogenous estimates of fossil fuel supply elasticities (Graham,Thorpe and Hogan 1999, Krichene 2002).

## 4. Numerical simulations.

We consider the effects of implementing economy-wide carbon taxes, combined with OBR in Canada. The EITE industries as defined in Table 1 are expected to be most affected by emission control policies, and are therefore the prime candidates for compensatory measures such as OBR.[8] Our main interest is in how the effects of OBR change if Canada's most important trading partner,[9] the US, also implements carbon taxes with or without OBR. The OBR scheme rebates EITE sectors for a percentage of each sector's emissions payments. The rebate for a specific firm is proportional to the firm's output level and is implemented in the model as an output subsidy (exogenous to the firm, but endogenously determined in the model).[10] Note that an OBR rate of 100% is the same as $s^{H*}$ in Section 2. We examine different OBR rates ($s^H/s^{H*}$) and also look at effects of varying OBR rates among industries. Across all simulations, the provision of public goods and services is kept constant at the business-as-usual level. The public budget to finance public good provision is balanced lump-sum, i.e., any residual revenue from carbon taxes (net of rebates) is recycled lump-sum to the representative household. We abstain from investigating alternative revenue-recycling schemes. It should be noted, however, that initial tax distortions provide scope for a so-called weak double dividend from environmental regulation (Goulder 1995): The economic costs of adjustment to emission pricing can be reduced by using additional public revenues to cut initial distortionary taxes (such as capital or payroll taxes).

In addition to the competitiveness impacts on individual EITE industries, our discussion of the simulation results focuses on carbon leakage and welfare impacts. The welfare analysis

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[7] We have increased the Armington elasticity between domestic and foreign goods from 2.1 to 4.0 for refined oil (OIL). Balistreri, Al-Qahtani and Dahl (2010) estimate even higher elasticities for a range of oil products, so our choice is a compromise between the GTAP number and their findings. As is evident below, the Armington elasticities for the EITE sectors are crucial for the optimal OBR rates (Armington elasticities for the other EITE sectors are between 3.0 and 4.2). In addition, the elasticity of natural gas has been reduced from 11.9 to 2.0, due to the importance of infrastructure for transporting this energy good.

[8] See footnote 14 for a comment on competitiveness effects in other industries.

[9] See Table A3 for trade data.

[10] The total emission tax payments from a sector are equal to the emission price ($\sigma$) times the sector's emission level ($e$), while the total subsidy payments to the sector are equal to the sector's subsidy rate ($s$) times its output level ($x$). Thus, if the OBR rate is $k$, the subsidy rate becomes $s = k\sigma e/x$.

includes the identification of second-best, welfare-optimal Canadian OBR rates under various US policies.

The competitiveness of domestic EITE sectors is of major concern to countries contemplating unilateral climate policy. Unilateral action will be less feasible if the consequence is loss of competitiveness by influential domestic EITE industries. We measure competitiveness impacts by three different indicators: changes in output quantities, changes in net export quantities and changes in domestic firms' market shares in the home markets. The choice of indicator will depend on the political focus. All output quantity effects will potentially affect employment and the industrial and geographical activity patterns, concerns that are often linked to the competitiveness issue. On the other hand, Rivers (2010) argues that a competitiveness measure should not cover quantitative changes caused by dampened demand, as these are intended effects of carbon policies. If the competitiveness concern is primarily motivated by cost differences between domestic and foreign firms and a wish to level the playing field, the effects are better captured by the other two measures. They are less affected by market sizes than the output quantity measure, which responds to market size changes both domestically and abroad. The net export measure corrects for changes in domestic consumption; however, this also removes interesting information about competitiveness effects on the import content of consumption, while export effects are still influenced by market size changes abroad. The domestic market share indicator avoids influence from changes in the size of the domestic market. However, if the composition of competitors in the foreign markets differs from that in the domestic markets, it will not represent overall competitiveness well. Importantly, OBR policies targeting selected industries will have smaller impacts on demand than will economy-wide carbon taxation. The choice of indicator for measuring OBR impacts is therefore less critical than for measuring carbon tax impacts. Unless the results differ significantly, we will concentrate on the numerical changes in the output quantity indicator in the competitiveness discussion below. This indicator is also in line with the one in the theoretical exposition in Section 2.

The Canadian leakage rate is measured as the increase in emissions abroad (US and ROW) divided by the emissions reduction in Canada resulting from Canadian policy changes relative to its business as usual (BaU).[11] Carbon leakage is closely related to the competitiveness loss, but it also captures the effects of potential differences in emission intensities between Canadian firms and their competitors in the domestic and international markets.

Our welfare measure includes the monetary value of reduced global emissions relative to BaU in order to ensure a coherent cross-comparison of scenarios with different global emissions, cf. the theoretical analysis in Section 2. The value of global emission reductions is added to the utility effect of all economic reallocations that take place as a result of the policy shifts, measured as the Hicksian equivalent variation, i.e, the household income change from BaU that is necessary to restore the utility level (based on ex-ante relative prices). To derive the contribution of global abatement to Canadian welfare, we assume that Canada values global emission changes by the carbon price it imposes. In our main scenarios, this tax rate is assumed to be USD 30 per ton of $CO_2$.[12]

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[11] Note that, for the calculation of these indicators, not only do the emissions at home and abroad due to Canada's carbon policy depend on the US policy regime, the BaU emissions do so as well.

[12] The fully integrated approach would be to model the consumer utility of global emissions reductions, but this would call for a major extension to an integrated assessment framework. The carbon tax rate is in line with global marginal cost

We measure the impact of variations in Canadian climate policy design for three alternative policy scenarios in the US: i) BaU (no carbon policy), ii) a carbon tax of USD 30 per ton of $CO_2$ without OBR,[13] and iii) a carbon tax of USD 30 per ton of $CO_2$ with 100% OBR. In our graphical exposition of results below, we refer to Canadian climate policy along the x-axis, i.e., the entry "BaU" indicates no climate policy regulation in Canada, whereas the entry "0" indicates an emission tax of USD 30 per ton of $CO_2$ with a zero OBR rate. As we move to the right on the x-axis, we adopt increasingly higher OBR rates for domestic (Canadian) EITE industries. Along the y-axis, we measure the effects relative to the scenario where both Canada and the US have no carbon policy (BaU-BaU).

### *4.1. Effects on the competitiveness of EITE industries.*

Figure 1 shows changes in output, which is our main indicator for competitiveness changes, for the Canadian aggregate EITE industries. In the case of no carbon policies in the US, we see that a Canadian carbon tax without any OBR reduces EITE output by 3.6%. As expected from the analytical exposition above and from previous OBR studies of Canada (see Dissou 2006, Rivers 2010 and Fischer and Fox 2012), supplementing the carbon tax with domestic OBR improves competitiveness. However, the OBR has to be as high as 189% to be able to restore aggregate EITE output to the BaU level. Underlying this result is a large variation among EITE industries that we will return to below. If market shares rather than output activity are the concern behind OBR policies, it would be relevant to correct for the demand reductions resulting from carbon policies, as discussed above. Table 2 reveals that the compensatory OBR rate necessary to restore competitiveness is then reduced to 138%, while net exports will be restored by an OBR rate of only 128%.

Turning now to the effects of US policies, the first main observation from Figure 1 is that, if the US has a carbon tax, this will not alter the effect of adding a carbon tax in Canada, i.e., compared with the case without a Canadian tax the output in Canada will still fall by 3.6% (from a level 1.2% above the BaU-BaU case to a level 2.4% below; see Figure 1). Similarly, if the US combines the carbon tax with 100% OBR the direct effect of a Canadian carbon tax (without OBR) is still a 3.6% output reduction for the Canadian EITE industries compared with the domestic no-tax case. The same insensitivity applies to the effectiveness of Canadian OBR policies; for a given domestic OBR rate the percentage output effects for the EITE industries are the same irrespective of the carbon policy regime in the US. In other words, the compensatory *effectiveness* of Canadian OBR policy, i.e., its capability to restore output to the same level as before the domestic carbon tax was introduced, is insensitive to US carbon policies. These observations appear in Figure 1 as virtually parallel output curves for the three depicted regimes. Using the other competitiveness indicators would not change this.

The explanation for the linearity and parallel shift is that the rebate works like a production subsidy. When the OBR rate is, e.g., doubled, the subsidy is approximately doubled, too. The size of this implicit subsidy to a particular sector is proportional to the carbon tax, its emissions and (the inverse of) its production (cf. footnote 10). As all these variables are only

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estimates for 2020 of meeting the two degree target of the 2010 Cancun UNFCCC agreement in, e.g., IEA (2012) and Nordhaus (2010), but falls in the lower range of the interval reported by WGIII report of IPCC (2014).

[13] The carbon tax reduces Canadian emissions by 15%, cf. Table A1. By comparison, the Canadian INDC (intended nationally determined contribution) to the Paris meeting in 2015 is a 30% reduction in GHG emissions by 2030 (compared with 2005). The reduction vis-à-vis BaU emissions in 2030 is stated to be higher, but Canada may also use international mechanisms to achieve the target (cf. http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx).

slightly changed for the EITE industries between scenarios and across OBR rates, the implicit subsidy rate is also fairly constant. Moreover, there are no significant scale effects in the model (for given input prices), which could have been the case if some absolute limitations were present or if economies of scale were widespread. Thus, the effects on the competitiveness of the EITE industries of increasing the OBR rate are more or less identical, irrespective of US policy and the initial OBR rate.

(PLEASE INSERT FIGURE 1 APPROX. HERE)

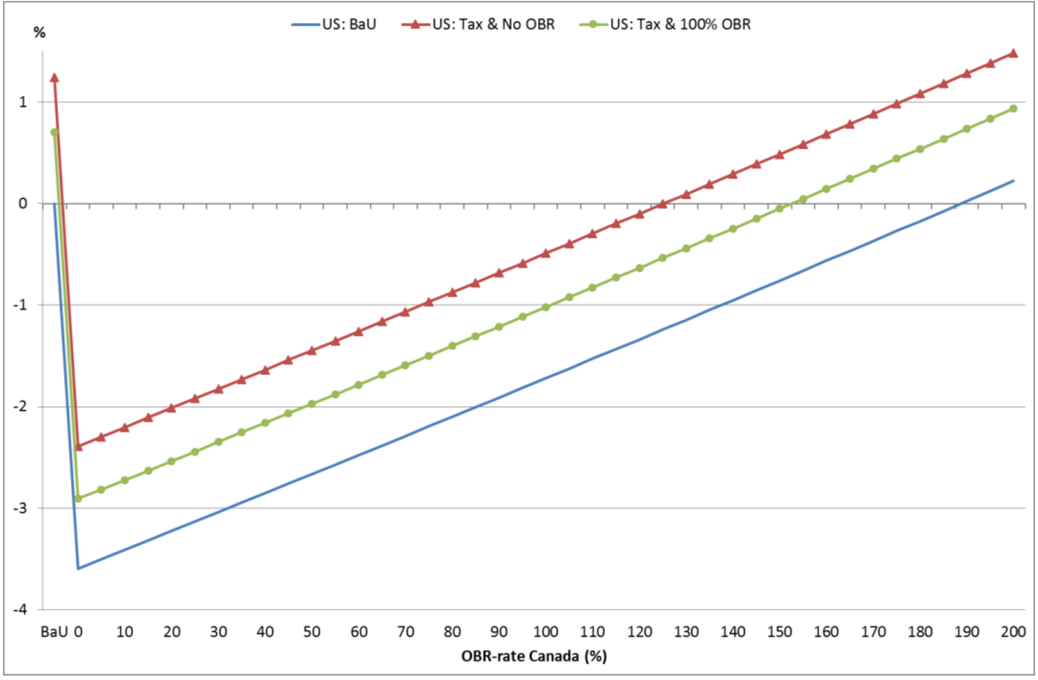

FIGURE 1 Output effects for Canadian EITE industries (% change from BaU-BaU) under different domestic OBR rates and three alternative assumptions about US climate policy

However, the finding that the compensatory effectiveness is unaltered by US policies does not imply that US policy is irrelevant to Canada's OBR decisions. Compared with a benchmark with no policy in either country (BaU-BaU), restoring Canadian competitiveness by means of OBR will be less strenuous if the US also introduces a carbon tax. This is not surprising, but the numerical results and the mechanisms explaining them are nevertheless interesting. As can be seen from Figure 1, if the US implements the same carbon tax as Canada, the Canadian EITE output declines by 2.4% instead of 3.6%, i.e., a reduction of about one third. US OBR policies on top, on the other hand, would counteract the US tax effect; if 100% OBR is implemented in the US, the net effect of both US and Canadian policies would be a 2.9% output decline in Canada. Thus, even with 100% OBR in the US, the Canadian firms will be better off than without US carbon policies, but the Canadian competitiveness gain from the US carbon taxation is approximately halved. This result is fairly stable across the competitiveness metrics (see Table 3 for the percentage changes in the domestic market share). This is as expected, since OBR policies only have small impacts on market size, as discussed above.

TABLE 2
OBR rates (%) necessary to restore Canadian competitiveness given Canadian carbon tax and different US policies; three different competitiveness measures

| | EITE competitiveness metrics | | |
|---|---|---|---|
| US policy | Output | Net export | Domestic market share |

| | | | |
|---|---|---|---|
| BaU | 189 | 128 | 138 |
| Tax & No OBR | 126 | 56 | 69 |
| Tax & 100% OBR | 153 | 89 | 101 |

Still, if EITE activity levels are the major concern, 100% OBR in Canada will not be sufficient to restore domestic output completely to the BaU-BaU level. Figure 1 shows that an OBR rate of 126% is needed if the US implements a carbon tax without OBR, whereas 153% is necessary if the US supplements its tax with 100% OBR. Table 2 shows the corresponding necessary OBR rates for the other competitiveness indicators. Using the market share indicator, the necessary Canadian OBR rate amounts to 69% to compensate for its own and US carbon taxation, as opposed to 138% if only Canada taxes carbon. This large reduction reflects the fact that the US has a substantial market share (22% in BaU) in the Canadian EITE market, but its introduction of a carbon tax is far from sufficient to offset the whole competitiveness impact of Canada's own taxation. When the US has full OBR, the necessary rate in Canada is 101%, i.e., approximately the same carbon policies in Canada as in the US restore Canadian shares in the domestic EITE markets to BaU-BaU. This is also clear from Table 3.

TABLE 3
Change (% from BaU-BaU) in domestic market shares for Canadian EITE industries under different US and Canadian climate policies

| | Canadian policy | | |
|---|---|---|---|
| US policy | BaU | Tax & No OBR | Tax & 100% OBR |
| BaU | 0[a] | -1.28 | -0.35 |
| Tax & No OBR | 0.63 | -0.64 | 0.29 |
| Tax & 100% OBR | 0.34 | -0.93 | -0.00 |

[a] The market share of Canadian firms in the domestic market is 64% in the BaU-BaU scenario.

The numerical CGE analysis allows us to investigate output impacts at a more disaggregated level and thereby identify those specific industries whose competitiveness might be particularly adversely affected. Table 4 shows the output effects for the five different EITE industries under different assumptions about US and Canadian climate policies.[14] First, we note that the output effects of a unilateral carbon tax in Canada vary quite substantially across EITE sectors (see the column Tax & No OBR), which is in accordance with the results of Dissou (2006). Our simulations show that outputs of refined oil (OIL) and non-ferrous metals (NFM) drop by 6.7% and 4.5%, respectively, whereas the remaining EITE industries face more moderate contractions, the smallest being for non-metal minerals (NMM), with a decline of a mere 0.7%. As predicted by the theoretical model in Section 2, the main explanation for this pattern is to be found in the different emission intensities (OIL and I_S have particularly high emission intensities). Another important explanation, disregarded in the theoretical model, is that input-output effects increase the competitiveness losses of many of the EITE industries. OIL is hit on the output side by a fall in demand for transportation and heating activities. On the input side, higher electricity prices have a marked cost-driving effect; moreover, some EITE

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[14] Output in other Canadian energy-intensive industries (non-EITE industries), such as the transport and energy sectors, also falls as a result of carbon taxation. However, these are not focused on here as they are less trade-exposed and, thus, less affected by US policies. Carbon taxation will tend to reallocate resources to industries with relatively low energy intensities. We find increased output in the composite sector comprising all remaining manufacturers and services. However, when the Canadian OBR rate is 100%, this industry also contracts due to smaller reductions in EITE output, as seen in Table 4.

industries use substantial amounts of EITE goods as intermediate inputs. We see such input price effects for the hard hit NFM in particular.

Compared to a benchmark where neither country introduces carbon policies, the domestic output contractions caused by Canada's own emission tax is to some extent counteracted by a similar tax in the US. However, the effects of US policies vary considerably from industry to industry, as expected from the variety of effects identified in the theoretical analyses in Section 2. The different US impacts on Canadian industries are explained by the US industry-specific, input-output-corrected emission intensities, the degree of heterogeneity between Canadian and foreign goods, and by how dominant the US is as a trading partner. Compared to the smaller economy of Canada, a dominant trading partner is characterized by relatively large foreign price effects of domestic carbon taxation (see also Section 2). Tables A3 and A4 (see the Appendix) provide data on relative emission intensities and trade.

For the NMM industry, the introduction of a US tax rate equal to the Canadian rate has a stronger effect on Canadian NMM output than the Canadian tax has, i.e., US taxation more than compensates for the competitiveness loss. This is driven by the much higher emission intensity of this industry in the US than in Canada; see Table A4. OIL, on the other hand, is very little compensated by a US tax. This reflects the fact that the supply of refined oil products mainly comes from domestic producers (84%). For the remaining EITE industries, the US tax roughly halves the output drops caused by the unilateral Canadian tax. Table 4 further shows that, when the US combines the carbon tax with full OBR, this substantially counteracts the US tax effect for Canadian NMM producers, while it has relatively little impact on Canadian NFM producers. The reason is that the OBR policy in the US stimulates US NMM production to a larger degree compared to NFM production, which is still quite negatively affected by the US climate policy. This mirrors similar, but counteracting effects of Canadian OBR policies, which we turn to now.

TABLE 4
Output effects (% change from BaU-BaU) for Canadian EITE industries under different assumptions about US and Canadian climate policy[a]

| | | Canadian policy | | |
|---|---|---|---|---|
| | US policy | BaU | Tax & No OBR | Tax & 100% OBR |
| OIL | BaU | - | -6.7 | -4.0 |
| | Tax & No OBR | 1.0 | -5.7 | -3.0 |
| | Tax & 100% OBR | 0.3 | -6.4 | -3.7 |
| NFM | BaU | - | -4.5 | -3.6 |
| | Tax & No OBR | 1.9 | -2.7 | -1.7 |
| | Tax & 100% OBR | 1.6 | -3.0 | -2.1 |
| I_S | BaU | - | -2.8 | -0.5 |
| | Tax & No OBR | 1.0 | -1.8 | 0.5 |
| | Tax & 100% OBR | 0.6 | -2.3 | 0.1 |
| NMM | BaU | - | -0.7 | -0.1 |
| | Tax & No OBR | 0.8 | 0.1 | 0.7 |
| | Tax & 100% OBR | 0.2 | -0.5 | 0.2 |
| CRP | BaU | - | -1.8 | 0.1 |

| | | | | |
|---|---|---|---|---|
| | Tax & No OBR | 1.2 | -0.6 | 1.3 |
| | Tax & 100% OBR | 0.7 | -1.1 | 0.8 |

[a] OIL: Refined oil products; NFM: Non-ferrous metals; I_S: iron and steel; NMM: Non-metallic minerals; CRP: Chemical products

We find that the effects of domestically rebating carbon tax payments in Canada are also quite different across sectors. While iron and steel (I_S), chemicals (CRP) and non-metallic minerals (NMM) all return more or less to their BaU ouput levels when rebating is 100%, this is far from the case for OIL and NFM (see the rightmost column in Table 4, and the rows US: BaU).[15] The effects of the OBR policies on OIL production are notable, however, but since the carbon tax alone has a big negative impact on OIL production, the rebate is far from sufficient to bring OBR output back to the BaU level. There are several explanations for the differences across sectors. First, the implicit output subsidies given by the OBR rate differ across sectors, and are higher for sectors with higher emission intensities (see footnote 10). NFM is the sector with the lowest emission intensity of the five EITE sectors, whereas OIL and I_S are the two sectors with the highest emission intensities. Second, the net effects on output of the carbon tax combined with OBR depend on the industries' ability to reduce their emission intensities. For industries such as OIL, reducing emissions per output is quite costly, and hence the net effects on output are quite negative. In fact, carbon taxation in Canada reduces the emissions least in the OIL industry even though the output reduction is highest of the five EITE sectors (in relative terms). Moreover, the OBR policies only rebate the direct emission payments from the sector. Indirect effects can be substantial, as seen above for the OIL and NFM industries. Rebating 100% far from compensates for the activity contraction in these industries.

The effects of rebating reported above are found in the case when the US maintains BaU policies, and they also hold under alternative assumptions about US policies: the OBR rates required to restore output effects to the industry-specific Canadian BaU levels are not notably affected by the US regime for these industries. Compared with the BaU-BaU level, however, where neither Canada nor the US have climate policies, the OBR rate required to restore Canadian output depends strongly on the US policy.

### *4.2. Effects on carbon leakage.*

Figure 2 shows that carbon leakage responds markedly to changes in domestic (Canadian) OBR rates and alternative settings for foreign climate policy regulation in the US.[16] When climate policies are absent in the US, the carbon leakage from a Canadian carbon tax corresponds to a rate of 13.9%. Almost one quarter of the leakage is due to higher emissions in the US. This is gradually reduced to 11.8% as Canada raises its OBR rate toward full OBR. However, whereas foreign emissions are reduced as the OBR rate is increased, domestic emissions in Canada increase due to higher EITE production (see Table A1 in the Appendix). Thus, global emissions are almost unchanged by the OBR rate (they increase marginally, cf. Table A2 in the Appendix).

When the US has a carbon tax, leakage due to Canadian climate policies falls by about 0.7 percentage points compared with the same Canadian policy under a US no-policy (BaU)

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[15] The I_S, CRP, NMM and OIL sectors need 125%, 90%, 120% and 240% rebating, respectively, to maintain output, whereas the NFM sector requires more than 300%. When considering market shares in the Canadian market, the necessary OBR-rates are 120%, 85%, 80%, 95% and above 300%, respectively.

[16] The Canadian leakage rate is measured as the increase in emissions abroad (US and ROW) over the emission reduction in Canada. When the US imposes climate policies, carbon leakage from Canadian climate policies is calculated by comparing emissions with and without Canadian climate policies (holding US policy fixed).

regime (see Figure 2). Canadian taxation now causes larger cuts in domestic emissions (see Table A1 in the Appendix), since reductions take place from larger initital output and emissions scales (i.e., a scale effect as identified in effect b) in Section 2.1). Emission increases abroad also decline, because emission intensities in the US are lower and reduced leakage to the US is not fully offset by increased leakage to the ROW. Figure 2 also shows that, in the presence of a combined tax and full OBR policy in the US, Canadian carbon policies cause virtually the same leakage rate as under a US tax regime without OBR. Emissions in all three regions are only indirectly and insignificantly affected, as explained in Section 2.1. In particular, leakage to the US does not respond to US OBR policy, because US emission intensities stay fairly unaffected. Scale effects in all three regions are also weak.

(PLEASE INSERT FIGURE 2 APPROX. HERE)

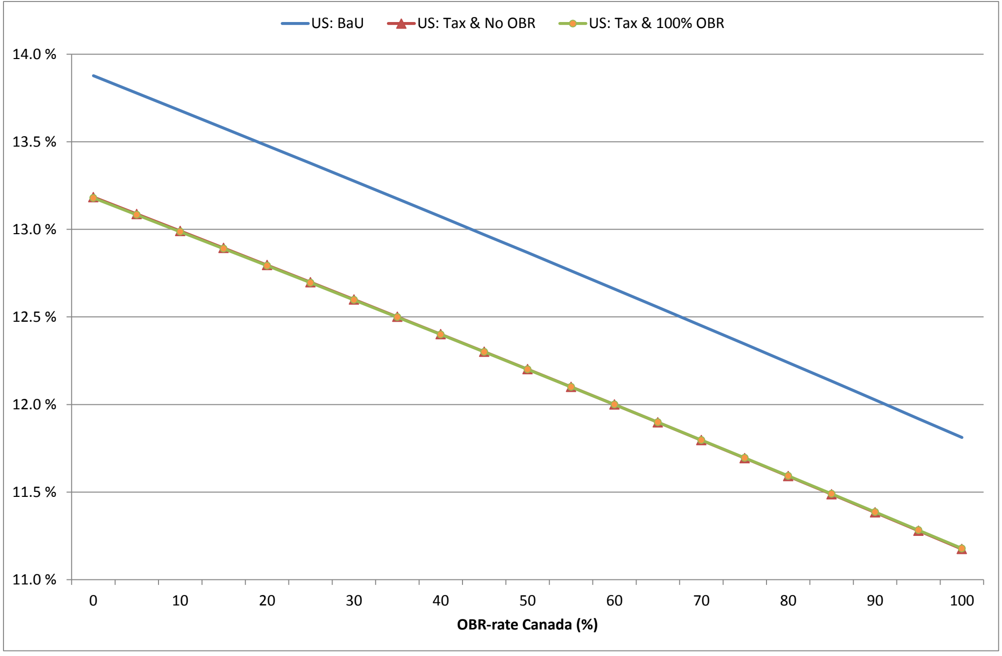

FIGURE 2 Carbon leakage as a result of Canadian climate policies (carbon tax and different OBR rates) under three alternative assumptions about US climate policy

### *4.3. Welfare impacts of domestic OBR policies.*

The Canadian welfare effects of the carbon policies in Canada and in the US are shown in Figure 3. As described above, the welfare measure is the sum of the simulated Hicksian equivalent variation and the monetary value of reduced global emissions in relation to the BaU. First, we notice that introducing a Canadian carbon tax equal to the perceived marginal value to Canada of global abatement (here: USD 30 per ton of $CO_2$) increases domestic welfare (not by much, though; note the scale of the y-axis). This is not surprising. Disregarding the welfare effects of carbon leakage for a moment, it is clear that the average costs of reducing domestic emissions are typically lower than the marginal costs (i.e., the carbon tax), implying improved welfare. Carbon leakage will modify this welfare gain, but, as we saw in the previous section, the carbon leakage is relatively modest. Thus, Canada’s perceived gross gain in terms of global abatement is larger than its gross national abatement costs.

Next, we see that the OBR rate for EITE production that maximizes welfare amounts to 92% when Canada acts unilaterally. A positive second-best optimal OBR rate is in line with our theoretical analysis, cf. eq. (11). Output-based rebates increase domestic EITE production at the expense of production abroad, which leads to a reduction in carbon leakage. However, the benefits of lower emissions abroad must be traded off against the costs of distortionary output subsidies for a selected part of the economy at the expense of other industries and at the expense of domestic abatement. Distorting reallocations also include potentially adverse terms-of-trade effects for the domestic economy. Canada is a net exporter of EITE goods, and rebating will tend to decrease the prices of the rebated products. Hence, export revenues will decline.

(PLEASE INSERT FIGURE 3 APPROX. HERE)

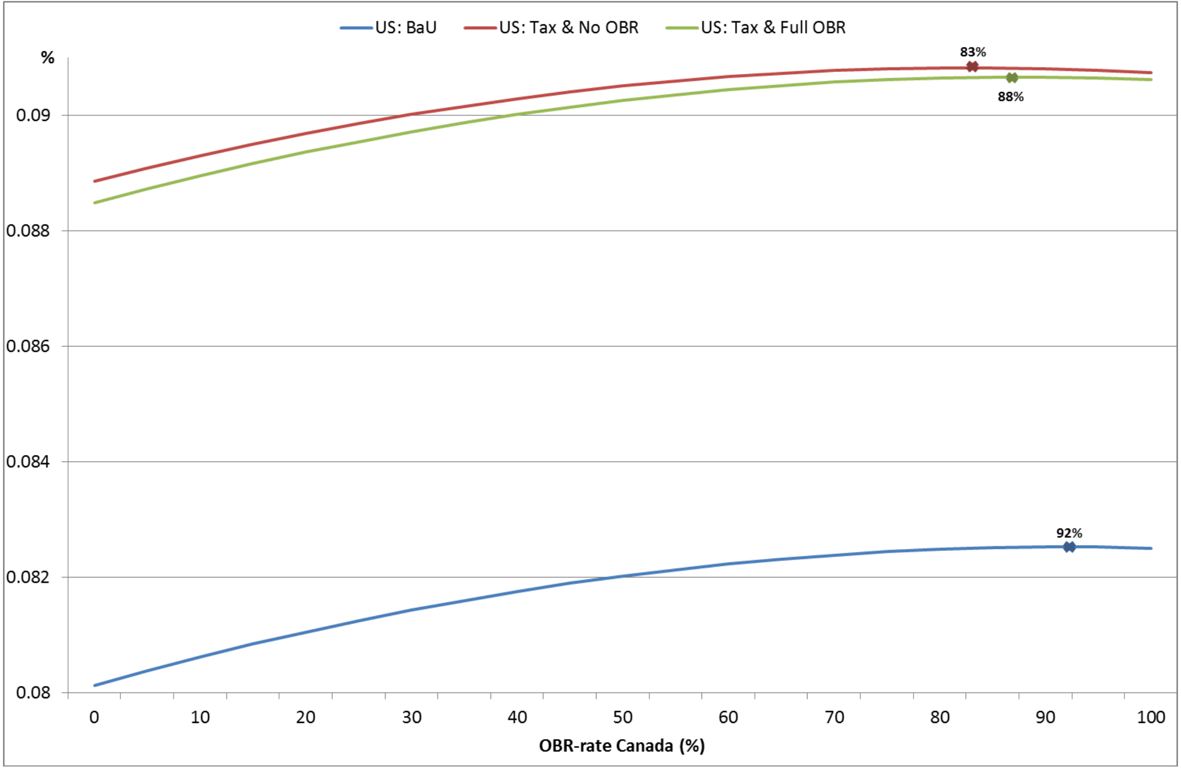

FIGURE 3 Welfare (% change from BaU-BaU) in Canada under different domestic OBR rates and three alternative assumptions about US climate policy

However, we also note that welfare is virtually unaffected by the OBR rate within the depicted range. In other words, welfare considerations seem to be of little relevance to the choice of OBR rates. This conclusion also holds if we disregard the value of reduced global emissions, since global emissions are virtually unaffected by the OBR rate (see Table A2 in the Appendix). One policy implication that can be drawn from this is that rebating policies can, at least to some extent, be determined on the basis of other concerns than aggregate welfare effects, such as the competitiveness of trade-exposed industries.[17]

Turning to the effects of US policies, we first observe in Figure 3 that US carbon taxation has a net positive economic welfare impact on Canada that far exceeds the positive impact of Canada's own OBR policies. The welfare gain is moderated as abatement costs are transmitted from the US to the Canadian economy, reflecting the strong links between the two economies.

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[17] When ignoring the benefits of reduced global emissions, the small welfare gain for Canada is replaced by a slightly higher welfare loss of around 0.18% in all the cases shown in Figure 3. The Canadian welfare costs per ton of global emission reduction are around USD 20 per ton $CO_2$, i.e., somewhat below the carbon tax. Note that residual revenue from carbon taxes (net of rebates) is recycled lump-sum. When initial distortions are present reducing them would be a better recycling alternative, and the opportunity cost of increasing OBR rates would be larger.

Figure 3 shows that the optimal OBR rate declines when the US introduces the carbon tax, though the numerical change is small – from 92% to 83%. A decline is expected from the theoretical discussion of eq. (11) in Section 2.3, where the main explanation identified was a drop in emission intensity in the foreign country as a result of the tax. The numerical OBR result is also consistent with the carbon leakage impacts seen above: US taxation leads to less carbon leakage triggered by Canadian climate policy as a result of reduced emission intensities in the US. The theoretical discussion in Section 2.3 concluded ambiguously on the impact of US rebating on the optimal Canadian OBR rate. We find a slight increase in the optimal Canadian OBR rate – to 88% – when the US rebates its own EITE industries for 100% of their emission tax payments.

The relatively modest reactions in optimal OBR rates to changes in US policies suggest that Canadian rebating policies can be determined quite independently of its large neighbor. This conclusion is strengthened by the above observation that the welfare impacts for Canada are fairly insensitive to the domestic OBR rate. As we will see from the sensitivity analysis below, other external factors than US climate policies are much more important to the optimal Canadian OBR policies. First of all, we observe that the second-best optimal OBR rates are highly sensitive to the assumptions about EITE product heterogeneity across countries, i.e., choice of Armington elasticities.

### *4.4. Sensitivity analysis.*

We have run several sensitivity analyses, mainly focusing on the second-best optimal OBR rate for Canada under different US climate policies. The main sensitivity results are shown in Table 5.

A central parameter in our numerical analyis is trade responsiveness, which is captured by the Armington elasticities of substitution between domestic and foreign products. If we assume that EITE products in different regions substitute less easily, we would expect the optimal OBR rate for Canada to decrease for two reasons – as evident from eq. (11): First, the emissions abroad would respond less to the OBR policy of the home country and, second, the terms of trade would not improve as much due to less accentuated drops in foreign prices. This is confirmed by the simulations. First, if we decrease the substitution elasticity for OIL (one of the five EITE goods) from our benchmark choice of 4.0 to the default level of 2.1 in the GTAP database (cf. footnote 7), the optimal rebate rate drops to zero, irrespective of climate policy in the US (we do not allow for negative OBR rates).[18]

Second, if we instead increase the substitution elasticities for *all* EITE goods by 50% compared with our benchmark assumptions, the optimal OBR rate in Canada exceeds 200%, irrespective of US climate policies. Thus, the sensitivity analysis indicates that the degree of substitutability of EITE goods is much more important to the optimal OBR rate in Canada than the climate policies implemented in the US. This finding is also confirmed if we simulate OBR policies for the individual Canadian EITE sectors.

TABLE 5

Sensitivity analysis. Optimal OBR rates (%) for Canada under different US climate policies

| | **US policy** | | |
|---|---|---|---|
| | **BaU** | **Tax & No OBR** | **Tax & 100% OBR** |

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[18] This is also the case if OIL is not included in the EITE group, i.e., if there is no rebate to OIL producers.

| | | | |
|---|---|---|---|
| Armington elasticity for OIL reduced from 4.0 to 2.1 | 0 | 0 | 0 |
| Armington elasticities for all EITE goods increased by 50% | >200 | >200 | >200 |
| Fixed global emissions | 105 | 60 | 65 |
| No initial taxes | 0 | 0 | 0 |

In the simulations above, the welfare accounting included the evaluation of global emission changes, assuming that the Canadian carbon tax reflects the marginal value of abatement to Canada. To test the robustness of our results, we also perform a sensitivity test where we keep the global emissions rather than the carbon tax rate constant across scenarios. In other words, we assume a cost-effectiveness approach, and thus avoid evaluating different global emissions levels. This can be envisaged as a Canadian quota market combined with output-based allocation (OBA) of quotas, where the cap on emissions in Canada is leakage-adjusted so that global emissions remain the same across the different OBA rates (for a given policy in the US and ROW). As seen in Table 5, our main conclusions carry over to this case. That is, the optimal OBA level for Canada declines when the US also implements climate policies. We note that the optimal OBA rates differ slightly more than in our main policy scenarios with fixed carbon tax and OBR. We also obtain qualitatively similar conclusions when we increase the fixed carbon tax from USD 30 to USD 50 per ton of $CO_2$.

As found in Lennox and Nieuwkoop (2010), pre-existing taxes on labor and capital can affect the second-best optimal OBR rates when the factor supply responds to climate policy changes. Labor and capital supplies are fixed in our model, but there are industry and good-specific taxes that influence the allocation of resources in the economy and that may potentially have an impact on the optimal OBR policy. In particular, the EITE industry OIL is highly taxed initially, diverting resources away from this sector, and OBR helps to reverse this reallocation. Model simulation of the counterfactual case with the same Canadian carbon tax, but all other net taxes set to zero, shows that the optimal OBR rate then drops to zero, irrespective of US climate policy. It is worth noting that such tax interaction effects are case-dependent and difficult to establish on a generic basis.

## 5. Conclusions.

In this paper we investigate how the outcome of domestic climate policy undertaken by a small country is affected through climate policy actions of large trading partners. Our focus is on the choice of output-based rebates (OBR) to energy-intensive and trade-exposed industries (EITE) in the small country when accounting for policy concerns on EITE competitiveness, international emission spillovers (carbon leakage) and welfare. We derive, both theoretically and numerically, the industry-specific and economy-wide effects of the OBR policy of a single country, and how they depend on the carbon tax and OBR policies of a larger trading partner. The numerical illustration uses Canada and its large neighbor, the US, as an example.

Our interest in the industry-specific effects of unilateral carbon policies originates from the concerns about the loss of competitiveness and the risks of plant shut-downs expressed by lobbyists and governments. The policy debate and the research agenda have pointed to OBR as a compensatory response to such concerns. Our contribution is to study the sensitivity of the necessary OBR rates to actions taken by important trading partners. In the case of Canada, we find that, for a *given* carbon policy regime in the US, a Canadian tax will be compensated by the same domestic OBR system across all the US regimes studied. This does not imply that US policies are irrelevant to Canadian OBR policy. If the goal is to restore the competitive situation of Canadian energy-intensive and trade-exposed (EITE) firms to what it was before any carbon taxation in the two countries, taxation in the US helps to moderate the need for compensation. If the US adds 100% OBR, about half of the Canadian competitiveness gain from US policies evaporates.

An interesting insight from our analysis is how diverse the effects of US carbon tax and OBR policies are across Canadian EITE industries as regards compensatory domestic OBR rates. The large variation is explained by industry-specific differences in emission intensities between the two countries, the degree of heterogeneity between Canadian and foreign goods, and by how dominant the US is as a trading partner. In particular, if US industries face substantial carbon taxes and do not dispose of cheap abatement options, the US carbon taxes will significantly reduce the need for Canadian OBR, while simultaneous US OBR policies modify this conclusion. When considering OBR responses in Canada it will, thus, be important to pay attention to industry-specific US policies and conditions.

When shifting the perspective from the EITE industries to economy-wide allocative efficiency, we find that optimal OBR rates for Canadian EITE industries are positive. The numerical CGE analysis identifies these rates for EITE industries, in aggregate, to range slightly below 100%. We find that US carbon policies exert a downward – though rather negligible –effect on the optimal Canadian OBR rates. Moreover, our simulations indicate that deviations from the optimal OBR rate have very little impact on economy-wide welfare. In particular, we find that the degree of EITE product heterogeneity in trade turns out to be far more relevant for the optimal Canadian OBR rates than does US carbon policy design. We conclude that, at least within reasonable limits, rebating policies to EITE industries can be determined on other grounds than welfare without larger trade-offs. OBR thus can qualify as viable instrument to compensate adverse competitiveness effects for EITE industries while counteracting counterproductive carbon leakage.

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**Appendix.**

(PLEASE INSERT FIGURES A1-A4 CONSEQUTIVELY HERE)

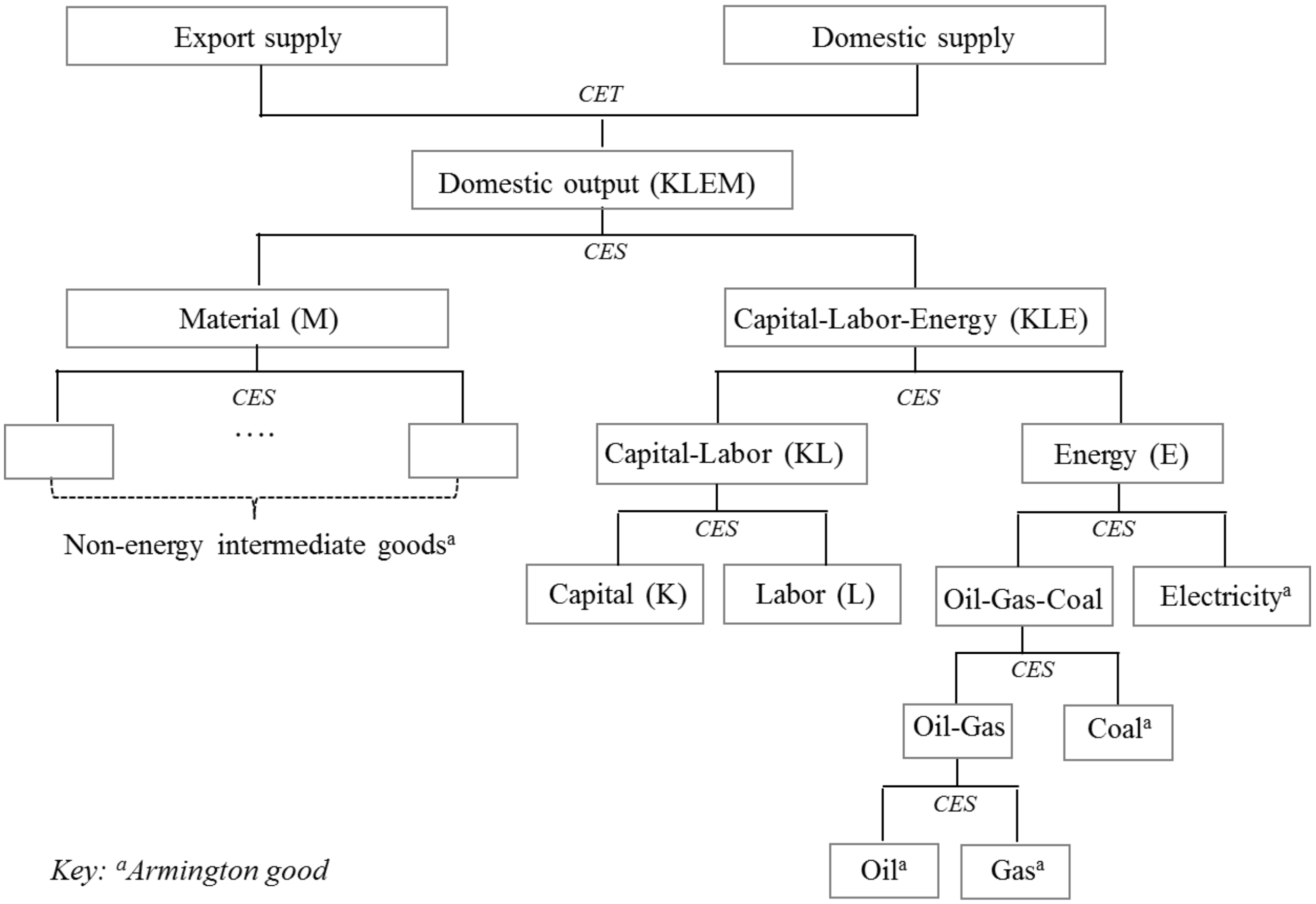

FIGURE A1 Production (other than fossil fuel)

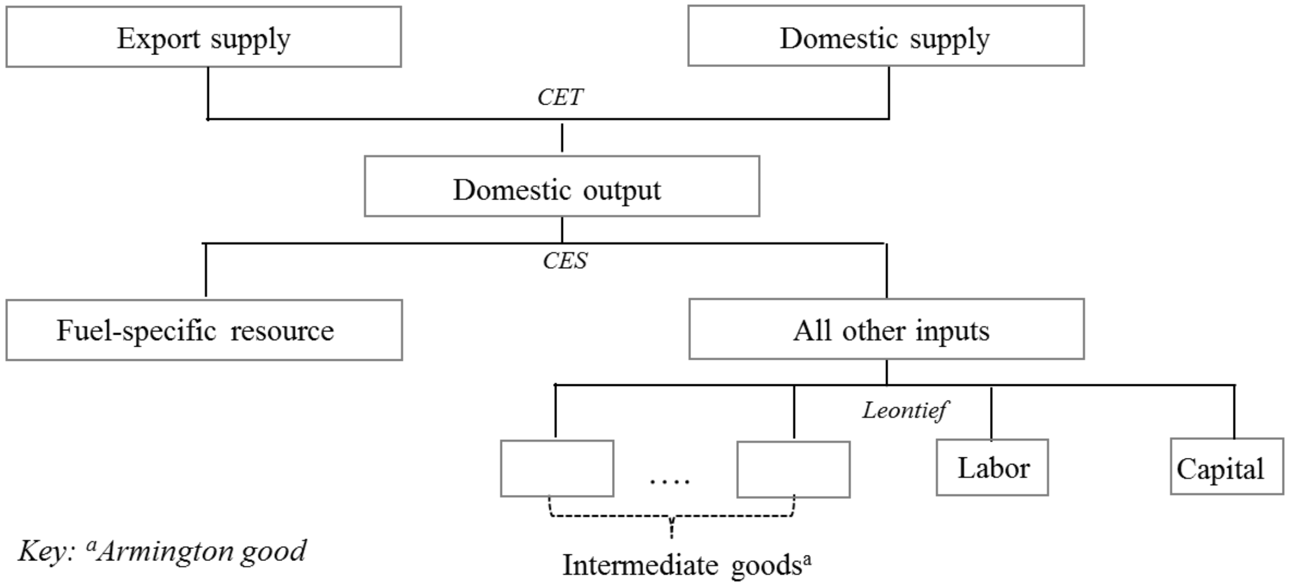

FIGURE A2 Fossil fuel production

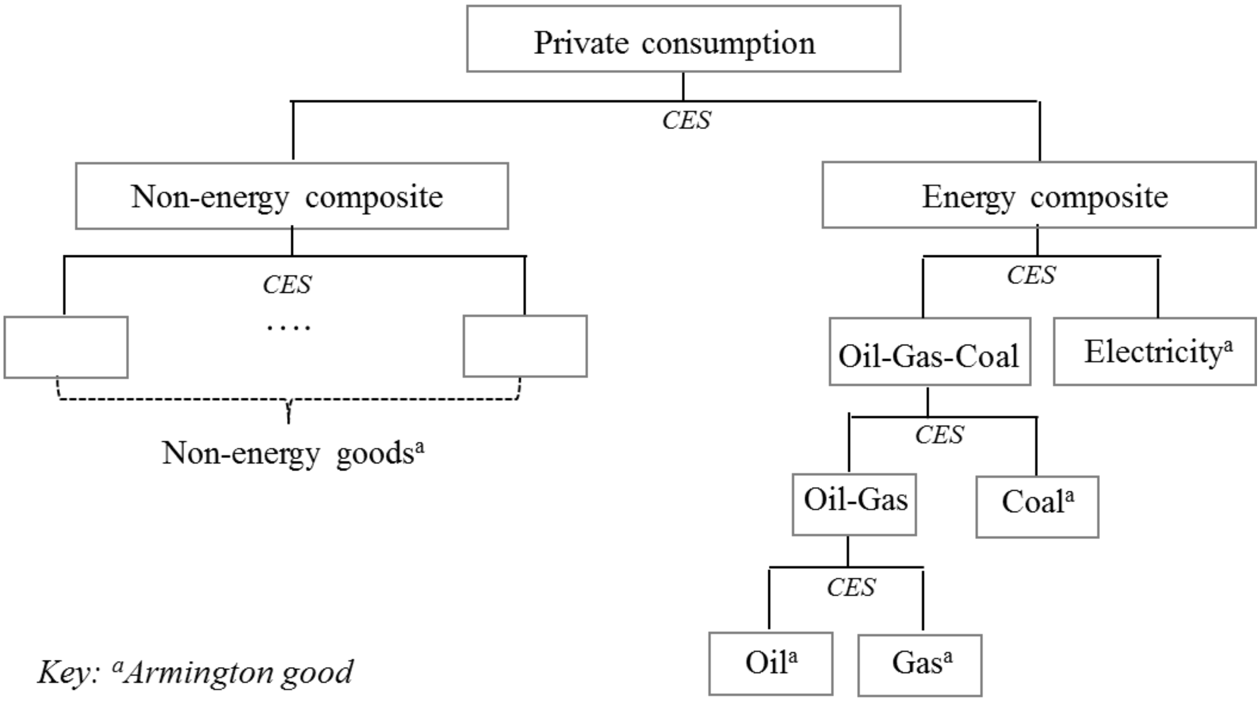

FIGURE A3 Private consumption

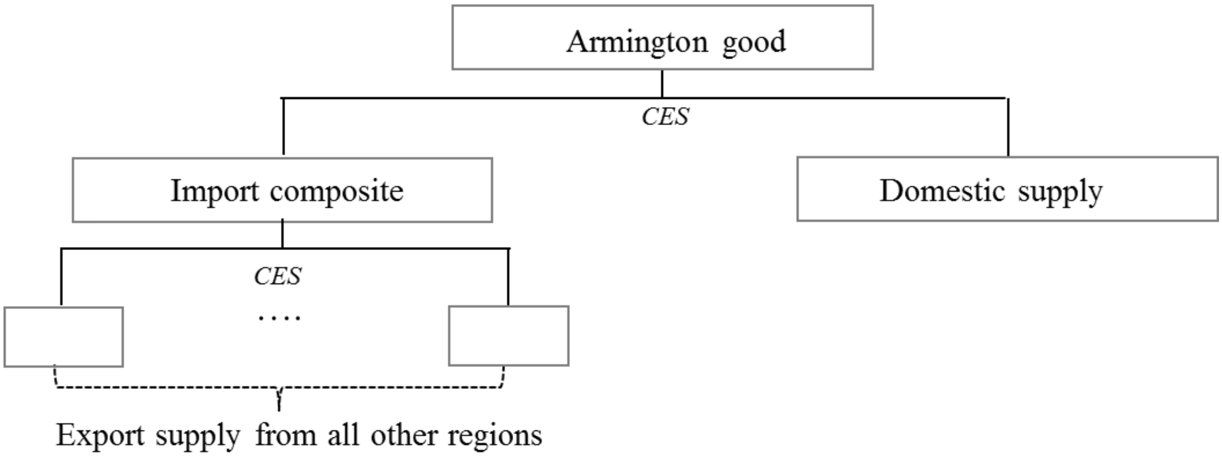

FIGURE A4 Armington composite

TABLE A1

Canadian $CO_2$ emissions under different assumptions about US and Canadian climate policy – % change from BaU-BaU

| | | **Canadian policy** | | |
|---|---|---|---|---|
| | | **BaU** | **Tax & No OBR** | **Tax & 100% OBR** |
| **US Policy** | **BaU** | - | -14.84 | -14.40 |
| | **Tax & No OBR** | 0.67 | -14.45 | -14.00 |
| | **Tax & 100% OBR** | 0.61 | -14.51 | -14.06 |

TABLE A2

Global $CO_2$ emissions under different assumptions about US and Canadian climate policy – % change from BaU-BaU

| | | **Canadian policy** | | |
|---|---|---|---|---|
| | | **BaU** | **Tax & No OBR** | **Tax & 100% OBR** |
| **US Policy** | **BaU** | - | -0.27 | -0.27 |
| | **Tax & No OBR** | -4.24 | -4.52 | -4.51 |
| | **Tax & 100% OBR** | -4.20 | -4.48 | -4.48 |

TABLE A3

Exports by source and recipient region in the base year, 2007, billion USD

| | | Importer | | | |
|---|---|---|---|---|---|
| | Exporter | CANADA | USA | ROW | SUM |
| OIL | CANADA | - | 10.8 | 0.5 | 11.3 |
| | USA | 8.0 | - | 46.9 | 54.9 |
| | ROW | 1.7 | 62.3 | 378.0 | 442.0 |
| NFM | CANADA | - | 19.3 | 13.9 | 33.2 |
| | USA | 6.2 | - | 27.7 | 34.0 |
| | ROW | 5.8 | 33.0 | 363.5 | 402.4 |
| I_S | CANADA | - | 5.3 | 1.2 | 6.5 |
| | USA | 5.1 | - | 12.7 | 17.8 |
| | ROW | 3.2 | 26.8 | 357.2 | 387.2 |
| NMM | CANADA | - | 2.2 | 0.3 | 2.5 |
| | USA | 2.6 | - | 6.3 | 8.9 |
| | ROW | 1.6 | 16.7 | 117.3 | 135.5 |
| CRP | CANADA | - | 30.7 | 9.5 | 40.2 |
| | USA | 28.6 | - | 152.0 | 180.6 |
| | ROW | 16.5 | 148.1 | 1,276.9 | 1,441.5 |

SOURCE: Version 8 of the Global Trade, Assistance and Production database.

TABLE A4

Direct, industry-specific emission intensities in Canada relative to USA and to the rest of the world (ROW) in the base year, 2007

| **Industry** | **Relative to USA** | **Relative to ROW** |
|---|---|---|
| **EITE** | 0.97 | 0.76 |
| **CRP** | 1.02 | 0.90 |
| **NMM** | 0.36 | 0.25 |
| **I_S** | 1.76 | 0.91 |
| **NFM** | 0.74 | 0.66 |
| **OIL** | 1.14 | 1.48 |
| **ELE** | 0.45 | 0.53 |

SOURCE: Version 8 of the Global Trade, Assistance and Production database.