

Böhringer, Christoph; Bye, Brita; Fæhn, Taran; Rosendahl, Knut Einar

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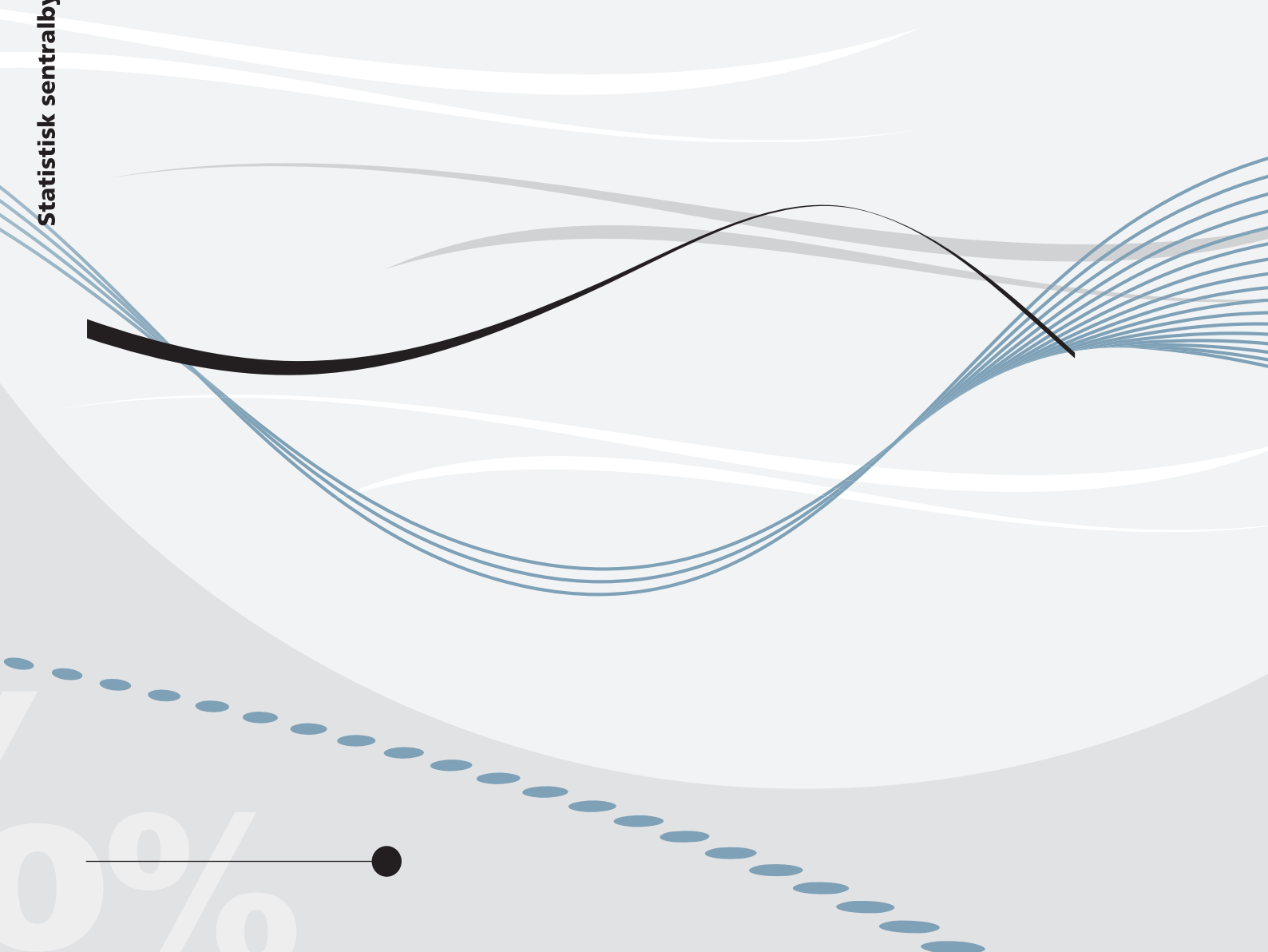
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*Christoph Böhringer, Brita Bye, Taran Fæhn, and
Knut Einar Rosendahl*

Output-based rebating of carbon taxes in the neighbor's backyard

Competitiveness, leakage and welfare



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Abstract:

We investigate how carbon taxes combined with output-based rebating (OBR) in an open economy 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 second-best OBR rate should be positive in most cases. Further, it should fall with the introduction of carbon taxation in the neighboring country, particularly if the neighbor refrains from OBR. Numerical simulations for Canada with the US as the neighboring trading partner, indicates that the impact of US policies on the second-best OBR rate will depend crucially on the purpose of the domestic OBR policies. If the aim is to restore the competitiveness of domestic emission-intensive, trade exposed (EITE) firms at the same level as before the introduction of its own carbon taxation for a given US carbon policy, we find that the domestic optimal OBR rates are relatively insensitive to the foreign carbon policies. If the aim is to compensate the firms for actions taken by the US following a Canadian carbon tax, the necessary domestic OBR rates will be lower if also the US regulates its emissions, particularly if the US refrains from OBR. If the goal is rather to increase the efficiency of Canadian policies in an economy-wide sense by accounting for carbon leakage, the US policies have but a minor reducing impact on domestic optimal OBR rates.

Keywords: carbon leakage, second-best optimal carbon policies, output-based rebates

JEL classification: Q43, Q54, H2, D61

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Address: Christoph Böhringer, Department of Economics, University of Oldenburg, Germany.
E-mail: christoph.boehringer@uni-oldenburg.de

Brita Bye, Statistics Norway, Research Department. E-mail: brita.bye@ssb.no

Taran Fæhn, Statistics Norway, Research Department. E-mail: taran.faehn@ssb.no

Knut Einar Rosendahl, Norwegian University of Life Sciences, School of Economics and Business. E-mail: knut.einar.rosendahl@nmbu.no

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Sammendrag

Vi analyserer hvor effektivt produksjonssubsidier (*Output-Based Rebating*, OBR) til spesielt utsatte sektorer kan kompensere for de negative effektene innenlandske karbonskatter har på konkurranseevne, karbonlekkasjer og velferd. Spesielt undersøker vi hvordan karbonpolitikken hos viktige handelspartnere virker inn på effektiviteten til den innenlandske OBR-politikken.

Vi utleder analytiske resultater i en global, partiell markedsmodell for energiintensiv, konkurranseutsatt industriproduksjon. Deretter undersøker vi ved hjelp av en numerisk global likevektsmodell hvilken betydning klimapolitikken til USA, som den viktige handelspartneren, har for OBR-politikken til Canada. Den numeriske modellen tar hensyn til flere effekter og mekanismer enn den analytiske.

Konsekvensene av viktige handelspartneres karbonpolitikk på OBR-politikken til et mindre land, vil avhenge av formålet med OBR-politikken. Dersom målet er å motvirke konkurranseevnefallet som følge av *egen* karbonpolitikk, finner vi at den nødvendige innenlandske OBR-raten i Canadas tilfelle er lite sensitiv for USAs karbonpolitikk. På den annen side, dersom formålet med OBR-politikken er å kompensere for totaleffekten av *både* nabolandets og egen politikk, vil innføring av karbonpolitikk i USA redusere behovet for drive egen OBR-politikk, særlig dersom USA avstår fra OBR-politikk.

Om formålet med den innenlandske OBR-politikken snarere er å maksimere den totale velferden for landet, vil myndighetene måtte veie kostnader og gevinster ved OBR-politikken opp mot hverandre. Den viktigste *kostnaden* vil normalt knytte seg til OBR-subsidiens prisvridende effekt i markedene for energiintensive, konkurranseutsatte varer. Den viktigste *gevinsten* for et lite land som ønsker å oppnå globale utslippsreduksjoner, vil være at karbonlekkasjene blir mindre. I tillegg kan det oppstå bytteforholdseffekter dersom landet er stort nok til å påvirke verdensmarkedsprisene. Disse vil normalt være negative siden eksportprisene faller som følge av OBR-politikk. De kan imidlertid bli positive, dersom landet er av en viss størrelse og importerer mye energiintensive varer som faller i pris. De teoretiske resultatene viser at den innenlandske OBR-raten vanligvis vil være positiv, men falle dersom nabolandet innfører karbonskatt og dermed får lavere utslippsintensitet. Dette finner vi også numerisk, men fallet er neglisjerbart. Velferdseffekter ser i det hele tatt ikke ut til å være et viktig hensyn i valget av OBR-politikk for Canada.

1. Introduction

In the absence of effective world-wide cooperation to curb global warming, some countries have introduced national or regional climate policies such as unilateral carbon emissions pricing. However, as the climate problem is global, unilateral action leads to carbon leakage, i.e., the relocation of emissions to countries with no or more lenient emission regulations. Carbon leakage counteracts the mitigating impact on climate change. A single country cannot directly regulate emissions outside its territory, but can alleviate the welfare costs of leakage by second-best policies. Theory suggests border carbon measures that impose 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 the free trade perspective and may not comply with the WTO law – see Böhringer et al. (2012) for a discussion.

Another unilateral countermeasure is to rebate emission-intensive firms for their tax payments in proportion to their output, so-called Output-Based Rebating (OBR) (Bernard et al., 2007). OBR rules also raise trade regulation issues and may be harmful according to WTO, but to a lesser degree than border carbon measures (Fischer and Fox, 2012; Branger and Quirion, 2013). However, they are also likely to be less effective against carbon leakage (Böhringer et al., 2014). Fischer and Fox (2012) conclude that OBR for selected energy-intensive industries can nevertheless be a legally feasible and relatively effective substitute for the more controversial border measures. From an economy-wide perspective the optimal choice of OBR rate will depend on the achievements in terms of global abatement, i.e. when accounting for carbon leakage. For the case of emissions trading instead of carbon taxation Böhringer and Lange (2005) and Monjon and Quirion (2011) suggest so-called output-based allocation (OBA) of free quotas. OBA will function quite similarly to OBR in the case of carbon taxation.

The other concern for governments aspiring to conduct unilateral policies is the potential competitiveness loss for domestic energy-intensive and trade-exposed industries. Rivers (2010) compares competitiveness policies and suggests OBA of carbon quotas for energy-intensive tradables to be a better option than other measures in the case of carbon pricing in Canada. Goulder (2001) finds that rebating just a smaller fraction of emission quotas significantly alleviates the competitiveness pressure that originates from carbon pricing. Moreover, he concludes that the economy-wide welfare costs of the carbon policies become minor. Dissou (2006) challenges this conclusion and argues that

when heterogeneity among carbon-intensive industries is accounted for competitiveness concerns are more serious and countermeasures less effective.

This paper contributes to the existing literature by focusing on how carbon taxes combined with OBR in an open economy perform dependent on the carbon policies of a larger trading partner. We combine theoretical analysis with numerical simulations using a global, regionalized computable general equilibrium (CGE) model with detailed representation of emission-intensive, trade exposed (EITE) industries and energy supply sectors. We look for second-best optimal OBR-rates under different climate policies of the foreign trading partner, given that global emissions are of concern to the home country. Furthermore, there may be trade-offs between efficiency and competitiveness concerns that are important for policy decisions. Hence, we also take the perspective of individual industries, and examine which OBR-rates are required to sustain competitiveness in the form of sustained initial output levels, given different policies by the foreign trading partner.

Our numerical example is carbon pricing and OBR in Canada and similar policies in Canada's large trading partner, the US. Competitiveness concerns have been on the forefront of the climate policy debate in Canada. As Peters and Hertwich (2008) show, Canada's trade is more emission-intensive than the US'. Canada's high energy intensity, limited fuel-switch possibilities and significant exposure to international markets make climate policy a hot topic. Canada has decided upon a climate action plan, called *Turning the corner*¹, for the current and forthcoming decades. It includes intensity-based policy regulations of emission-intensive industries, i.e., industry targets for unit rather than total emissions. If tradable, such unit emissions permits give similar incentives to those of a combined emissions pricing and output-based rebating system; see Rivers and Jaccard (2010).

Our findings can be readily transferred to other, similar policy regimes and regions that exist or are under consideration. Most prominently, the EU Emissions Trading System (EU ETS) has practiced free allocation of emission allowances for several years, conditioned on the installations' output capacities combined with the sectors' trade exposure and emissions payments. Similar schemes for EITE industries, but based on output rather than installed capacity, are under consideration in the US and Australia and have been proposed in Japan.²

¹ http://publications.gc.ca/collections/collection_2009/ec/En88-2-2008E.pdf

² For further reading about measures dealing with carbon leakage and competitiveness and proposed schemes in different regions, see, e.g., Heilmayr and Bradbury (2011), Zhang (2012), and Hallegatte et al. (2013).

When evaluating the economy-wide welfare impacts of OBR policies, and to what extent competitiveness and welfare concerns overlap, there are several factors to account for. In general, the second-best optimal rebate level will differ across sectors, as illustrated by Bernard et al. (2007). They show that sectors that are highly exposed to leakage due to high degree of substitutability should typically have a higher rebate rate, whereas sectors with lower degree of substitutability should have lower rates. They also find that even if some rebating is optimal, 100% rebating can be more costly in terms of the social planner's welfare losses than no rebating. Other factors affecting optimal rates are terms-of-trade effects and initial (distorting) taxes. Lennox and Nieuwkoop (2010) find tax interaction effects in the New Zealand economy that call for rates between zero and 100%, but in principle both terms-of-trade and tax-interaction effects could drive the optimal OBR rates above 100% or below zero. Also, higher emission intensities abroad than domestically or (un-rebated) carbon tax pass-through from electricity or other emission-intensive inputs will drive optimal rebate rates of the industry upwards, possibly above 100%.³

Our theoretical analysis explains how these mechanisms influence what OBR rates to choose by single economies in a partial equilibrium setting, where domestic firms interact with competitors abroad. The normative conclusions depend on the policy objectives pursued by the domestic government. Competitiveness concerns tend to call for positive, differentiated OBR rates to compensate firms for carbon tax-induced profit losses, unless large offsetting effects occur through reduced foreign prices or increased marginal production or abatement costs. With similar reservations, domestic competitiveness tends to benefit from a carbon tax while suffer from OBR conducted by trading partners. If the political aim is, rather, to increase the efficiency of domestic policies, we still find that domestic OBR rates should be positive when global abatement is positively evaluated, unless terms-of-trade losses are significant. Further, we would expect the optimal OBR rate to decrease with the carbon tax of influential neighbors, while their OBR policy will normally have an ambiguous, but negligible effect.

Our CGE simulations supplement the theoretical analysis with realistic parameters for different industries and account for comprehensive and complex price-responsive input-output transmissions absent in the theoretical setting, as well as the interaction effects among the climate policies and existing distortions of the economy. Contrary to most previous studies, which consider 100% rebating (i.e., all tax payments paid by the industries is rebated back to the industries), we investigate a broader range of OBR rates. We find that necessary OBR rates to compensate for competitiveness losses due

³The EU allows the member states to compensate their EITE industries for higher electricity prices triggered by the EU ETS.

to Canadian carbon policies differ significantly among the EITE industries, in accordance with the findings in Dissou (2006). The key factor is the degree of substitutability between imported and domestic products. The impact of the foreign trading partner US policies will depend on the target of competitiveness policies. If the aim is to restore the competitiveness of domestic EITE firms at the same level as before the introduction of its own carbon taxation for a given US carbon policy, we find that more or less the same Canadian OBR system will be required irrespective of the US carbon policy regime. On the other hand, if the aim is to compensate the firms for actions taken by the US following a Canadian carbon tax, the necessary domestic OBR rates will be lower if the US regulates its emissions, particularly if the US refrains from OBR.

The numerical findings on Canadian carbon leakage and welfare-optimal OBR rates mostly confirm the results from the analytical partial model. When the US introduces carbon taxation Canadian carbon leakage drops. So does its optimal OBR rate, though only very slightly. Moreover, US OBR policies have hardly any effect on the Canadian carbon leakage, nor on its optimal OBR rates. An important finding is that welfare costs of deviating from the second-best optimal rates are found to be minor and are therefore of little guidance to practical OBR policies. Even more importantly, sensitivity analyses reveal that the optimum rate is highly sensitive to central parameter values, most prominently, what is assumed about EITE product heterogeneity across countries (i.e. the highly uncertain Armington elasticities assigned to the EITE products).

2. Theoretical background

Consider a home region H , a foreign region F and the rest of the world R . The home region produces the good x^H , the foreign region produces the good x^F , and the rest of the world produces the good x^R . The three goods are assumed to be imperfect substitutes. There is trade, and region j ($j=H,F,R$) consumes x_H^j , x_F^j and x_R^j , so that $x^j = x_H^j + x_F^j + x_R^j$. The international prices of goods x^H , x^F and x^R are p^H , p^F and p^R .

Costs of producing in region j are $C^j(x^j, e^j)$, where e^j is the emissions intensity (total emissions divided by total production). The cost function is assumed to be convex and increasing in x^j , while decreasing in e^j .

We assume that the home region H introduces a fixed emission tax σ^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 .

2.1 Effects on home production of home and foreign carbon policies

Firms in the home region maximize profits, π^H :

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

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

$$(2) \quad p^H = \partial C^H / \partial x^H + \sigma^H e^H - s^H$$

$$(3) \quad -\partial C^H / \partial e^H = \sigma^H x^H$$

Eq. (2) states that optimal production ensures that the price covers marginal production costs plus net marginal payments to the regulator (emissions payments minus the subsidy). Eq. (3) states that the marginal costs of reducing the emission intensity should equalize the marginal gains of reduced emissions payments, i.e., the carbon price multiplied with output.

Market equilibrium for the home product is given by:

$$(4) \quad x^H = x_H^H(p^H, p^F, p^R) + x_F^H(p^H, p^F, p^R) + x_R^H(p^H, p^F, p^R).$$

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:

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

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

where $x_{ji}^{H'} = \frac{\partial x_j^H}{\partial p^i}$, ($j, i=H, F, R$) denotes the direct and cross price effects on demand. The first term in eq. (5) contains in its first bracket 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):

$$(6) \quad \frac{\partial p^H}{\partial \sigma^H} = \frac{\partial C_x^H}{\partial \sigma^H} + \sigma^H \frac{\partial e^H}{\partial \sigma^H} + e^H \quad \text{and}$$

$$(7) \quad \frac{\partial p^H}{\partial s^H} = \frac{\partial C_x^H}{\partial s^H} + \sigma^H \frac{\partial e^H}{\partial s^H} - 1,$$

$$\text{where } C_x^H = \frac{\partial C^H}{\partial x^H}.$$

In eq. (6), the last term represents the direct effect on the home price of introducing a carbon tax. It is positive and more so the higher is the emission intensity. In most realistic cases, the sign of eq. (6) will be positive, as this price-increasing effect 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, thus modifying emissions payments. The first term depends on the scale elasticity. With decreasing returns, marginal costs will increase with the output scale.

Eq. (7) expresses the home price effects of introducing an output subsidy in home (OBR). The direct effect of such an output subsidy is of course negative (last term). Again, the two remaining effects are likely to modify but not offset the direct effect. They both depend on the scale economies. With increasing marginal costs, the first term reflects increased costs as output increases, and the second reflects increased emission intensity that also relates to increasing marginal costs.

The second and third terms in eq. (5) are the cross price effects on domestic demand through changes in prices abroad. In these two terms, the first bracket expresses the positive effect on the demand for the home good within all three markets of higher prices of 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, the indirect effects (captured by the second and third term) will modify the direct price effects on output of the home product. The indirect effects will be stronger the closer substitutes the products of F and R are to the domestic product. However, for sufficiently small home countries domestic carbon policies will not be able to affect foreign prices, i.e.,

$$\frac{\partial p^F}{\partial \sigma^H} = \frac{\partial p^R}{\partial \sigma^H} = \frac{\partial p^F}{\partial s^H} = \frac{\partial p^R}{\partial s^H} = 0.$$

We can now conclude that the direct effect of carbon taxation reduces output by increasing the costs of emissions, and it is stronger the larger is the emission intensity: $\frac{dx^H}{d\sigma^H} < 0$. Introducing OBR has a

direct favorable output effect: $\frac{dx^H}{ds^H} > 0$. Additional effects do, however, occur 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 F .⁵ We consider both a sole introduction of a carbon tax, σ^F , which may or may not equal the home tax, σ^H , and the 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 home and foreign carbon taxes and OBR (assuming no carbon policies in rest of the world) by totally differentiating equation (4). To simplify the discussion we assume that both countries are sufficiently small to disregard price effects on the other products. Rearranging, we get:

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

The first term in equation (8) and the first bracket in the second term are recognizable from equation (5). The last bracket represents the price effects on good F of the carbon policies in region F . The price effects in the foreign region of foreign policies will have analogous channels and signs as the

corresponding price effects in the home country, i.e., the likely net effects are $\frac{\partial p^F}{\partial \sigma^F} > 0$ and

$$\frac{\partial p^F}{\partial s^F} < 0.$$

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.

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 more so the higher the emission intensity in F and the larger is the sensitivity of the demand for the domestic good to the price of the foreign good. The direct contribution of OBR in the foreign region is to reduce the home output. These direct mechanisms dominate so that $\frac{dx^H}{d\sigma^F} > 0$ and $\frac{dx^H}{ds^F} < 0$, but similar additional effects as for domestic policies apply; see a) to c) above.

Though the signs of the various partial and net effects are not surprising, the relative strengths of the various factors will vary from industry to industry depending on the industry-specific characteristics. The discussions above will therefore be helpful for understanding the variation across heterogeneous industries in our numerical analysis; see 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 F and R . The firm behavior in region H is given by (1) to (3) above. Welfare in the home region is given by:

(9)

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

where U^H denotes consumption utility in the home region. Note that we assume the home region to also care about global emissions valued at the carbon tax σ^H .

We now maximize W^H with respect to s^H , noting that all variables are functions of s^H . After rearranging, we then get:

$$(10) \quad \begin{aligned} \frac{\partial W^H}{\partial s^H} = & \left[p^H - (\partial C^H / \partial x^H) - \sigma^H e^H \right] (\partial x^H / \partial s^H) - \left[(\partial C^H / \partial e^H) + \sigma^H x^H \right] (\partial e^H / \partial s^H) \\ & - (\partial p^F / \partial s^H) x_H^F - (\partial p^R / \partial s^H) x_H^R + (\partial p^H / \partial s^H) (x_F^H + x_R^H) - \sigma^H \left[e^F (\partial x^F / \partial s^H) + e^R (\partial x^R / \partial s^H) \right] = 0 \end{aligned}$$

where we use (4) and the relationship $\partial U^H / \partial x_H^j = p^j$, $j=H,F,R$.

Using eq. (2) the first square bracket equals $-s^H$ and using eq. (3) the second square bracket equals zero. We then get the following expression for the second-best optimal domestic subsidy rate:

$$(11) s^H = \sigma^H \left[e^F \frac{-\partial x^F / \partial s^H}{\partial x^H / \partial s^H} + e^R \frac{-\partial x^R / \partial s^H}{\partial x^H / \partial s^H} \right] - \frac{\partial p^F / \partial s^H}{\partial x^H / \partial s^H} x_F^H - \frac{\partial p^R / \partial s^H}{\partial x^H / \partial s^H} x_R^H + \frac{\partial p^H / \partial s^H}{\partial x^H / \partial s^H} (x_F^H + x_R^H)$$

The three last terms in eq. (11) are terms-of-trade effects. If these are negligible, we see that the optimal home subsidy rate should equal the value of the avoided emissions abroad (with unit value σ^H) when domestic production increases marginally. 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 the sensitivity of production in these two regions with respect to changes in home production, which again depends on how well they substitute the home product in demand. The changes in domestic, foreign and rest-of-the-world output as a consequence of changes in in the home subsidy rate are determined by the same factors as discussed in Section 2.1.

We notice that in the special case where emission intensities are the same in all regions ($e^H = e^F = e^R$), and 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 $\frac{-\partial x^j / \partial s^H}{\partial x^H / \partial s^H}$ ($j=F,R$), will typically be positive but jointly

lower than one, both because the three goods are imperfect substitutes and because marginal costs will tend to be increasing. On the other hand, if the emissions 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 as 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 larger 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 (in 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 larger than 100%. For a small-sized open economy, the terms-of-trade effects will tend to be inferior relative to the emissions effect (i.e., the first term of eq. (11)). To simplify our exposition, we will hence disregard terms-of-trade effects in the remaining analysis of this section.

2.3 Second-best optimal domestic OBR rate in 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 F , we consider two alternatives:

- i) The foreign region F introduces a carbon tax σ^F , which may or may not equal the emissions tax at home, σ^H .
- ii) The carbon tax σ^F is supplemented with rebating through an output subsidy s^F .

We differentiate eq. (11) with respect to σ^F and s^F . We simplify the expression by denoting $\frac{\partial x^j}{\partial s^H} = x_s^j$,

$j=H,F,R$. 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 now are endogenous, while e^R is still exogenous. We then get (after inserting for s^H from eq. (11)):

$$(12) \quad ds^H = \frac{\sigma^H}{x_s^H} \left[-\frac{\partial e^F}{\partial \sigma^F} x_s^F - e^F \frac{\partial x_s^F}{\partial \sigma^F} - e^R \frac{\partial x_s^R}{\partial \sigma^F} + \left(e^F \frac{x_s^F}{x_s^H} + e^R \frac{x_s^R}{x_s^H} \right) \frac{\partial x_s^H}{\partial \sigma^F} \right] d\sigma^F$$

$$+ \frac{\sigma^H}{x_s^H} \left[-\frac{\partial e^F}{\partial s^F} x_s^F - e^F \frac{\partial x_s^F}{\partial s^F} - e^R \frac{\partial x_s^R}{\partial s^F} + \left(e^F \frac{x_s^F}{x_s^H} + e^R \frac{x_s^R}{x_s^H} \right) \frac{\partial x_s^H}{\partial s^F} \right] ds^F$$

Let us first consider only a carbon tax in region F , $d\sigma^F > 0$ and $ds^F = 0$. The term in front of the square bracket is clearly positive. Moving to the first term inside the (first) square bracket, it is clear from Section 2.1 that the emissions intensity in a region decreases with the emissions price in that region. The term is therefore negative, meaning that the emissions reduction in region F 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 is going to increase the output's sensitivity to s^H . Since the negative impact of carbon pricing in F 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 that the

sensitivity of x^F with respect to s^H drops more than the joint increase in the sensitivity of x^R and x^H , i.e., $\frac{\partial x_s^F}{\partial \sigma^F} < 0$, while $\frac{\partial x_s^R}{\partial \sigma^F} > 0$ and $\frac{\partial x_s^H}{\partial \sigma^F} > 0$, where the first effect is the larger. Finally, we know from

the discussion of eq. (11) that $\frac{x_s^i}{x_s^H} < 0$ 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 and the two last terms are negative, but all three are dominated by the first negative term. In sum, carbon pricing in region F will most probably reduce the optimal subsidy s^H in the home region.

Assume, next, that region F also imposes an output subsidy s^F , in addition to the carbon tax. This will only affect e^F to the degree that a firm's optimal emissions 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 opposite of the effects of σ^F discussed above, as we get a shift back to x^F , from x^H and x^R . Still they will be of little significance. Overall, the effect on the optimal domestic OBR rate of introducing OBR in F 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., Böhringer et al., 2010, for a detailed algebraic description). CGE models build upon general equilibrium theory that combines behavioral assumptions on rational economic agents with the analysis of equilibrium conditions. They provide counterfactual ex-ante comparisons, assessing the outcomes with a reform in place with what would have happened had it not been undertaken. 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 as well as 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. 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.

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. Total income of the representative agent consists of net factor income and tax revenues. 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 following the 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 imported good from other regions. A balance of payment constraint incorporates the base-year trade deficit or surplus for each region.

CO₂ emissions are linked in fixed proportions to the use of fossil fuels, with CO₂ coefficients differentiated by the specific carbon content of fuels. Restrictions to the use of CO₂ emissions in production and consumption are implemented through exogenous emission constraints or (equivalently) CO₂ taxes. CO₂ 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 second-best optimal rebate rates is based on the most recent version of the Global Trade, Assistance and Production (GTAP) database which includes detailed national accounts on production and consumption (input–output tables) together with bilateral trade flows and CO₂ emissions for the year 2007 (version 8 of GTAP – see Narayanan et al., 2012). GTAP can be flexibly aggregated towards a composite dataset that accounts for the specific requirements of the policy issue under investigation. As to regional disaggregation we constrain ourselves to three regions: Canada, USA and a composite of all other regions (rest of the world – ROW). As to sectoral disaggregation our composite dataset includes all major primary and secondary energy carriers: coal, crude oil, natural gas, refined oil products (OIL), and electricity. This disaggregation is essential in order to distinguish energy goods by CO₂ intensity and the degree of substitutability. In addition, we separate the main emission-intensive and trade-exposed (EITE) sectors: chemical products (CRP), non-metallic minerals (NMM), iron and steel products (I_S), and non-ferrous metals (NFM), as they will be potentially most affected by emission control policies and therefore are the prime candidates for compensatory measures such as OBR.⁶ The remaining industries covered in our dataset include transport sectors, fishing, agriculture, paper, pulp and print, as well as a composite sector of all remaining manufacturers and services.

For model parameterization, we follow the standard calibration procedure in applied general equilibrium analysis: the base-year input-output data determines the free parameters of the functional forms (cost and expenditure functions) such 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 the 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 in the analysis. These Armington elasticities are mostly taken from the GTAP database.⁷ The GTAP database also provides substitution

⁶ Note that refined oil products (oil) also classifies as EITE industry.

⁷ We have increased the Armington elasticity between domestic and foreign goods from 2.1 to 4.0 for refined oil (OIL). Balistreri et al. (2010) estimates even higher elasticities for a range of oil products, so our choice is a compromise between the GTAP number and Balistreri et al. (2010)'s 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 for natural gas has been reduced from 11.9 to 2.0, due to the importance of infrastructure for transporting this energy good.

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 et al., 1999; Krichene, 2002).

4. Numerical simulations

We consider the effects of implementing carbon taxes, combined with OBR to the EITE industries in Canada. The OBR scheme rebates EITE sectors a percentage rate of each sectors' emissions payments. The rebate to a specific firm is proportional to the firm's output level. Note that an OBR rate of 100% is the same as s^{H^*} section 2. We examine different OBR rates (s^H/s^{H^*}) and are interested in how the effects of OBR may change if Canada's most important trading partner USA also implements carbon taxes with OBR.

We quantify effects on competitiveness of individual EITE industries, carbon leakage, and welfare. In order to derive consistent welfare impacts we need to put a value (price) on changes in global emissions, cf. the theoretical analysis in section 2. 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 30 USD per ton of CO₂.⁸

Note that 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 30 USD per ton of CO₂ 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. We measure the impact of variations in the Canadian climate policy design for three alternative policy scenarios in the USA: i) BaU (no carbon policy), ii) carbon tax of 30 USD per ton of CO₂ without OBR, and iii) carbon tax of 30 USD per ton of CO₂ with 100% OBR. 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

First, we look at how output of the EITE industries – as a proxy for competitiveness – is affected by domestic and foreign policies. Competitiveness of domestic EITE sectors is of major concern to

⁸ This value is in line with global marginal cost 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).

countries contemplating unilateral climate policy. Output and employment losses in influential EITE industries may be critical for the political feasibility of unilateral action.

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

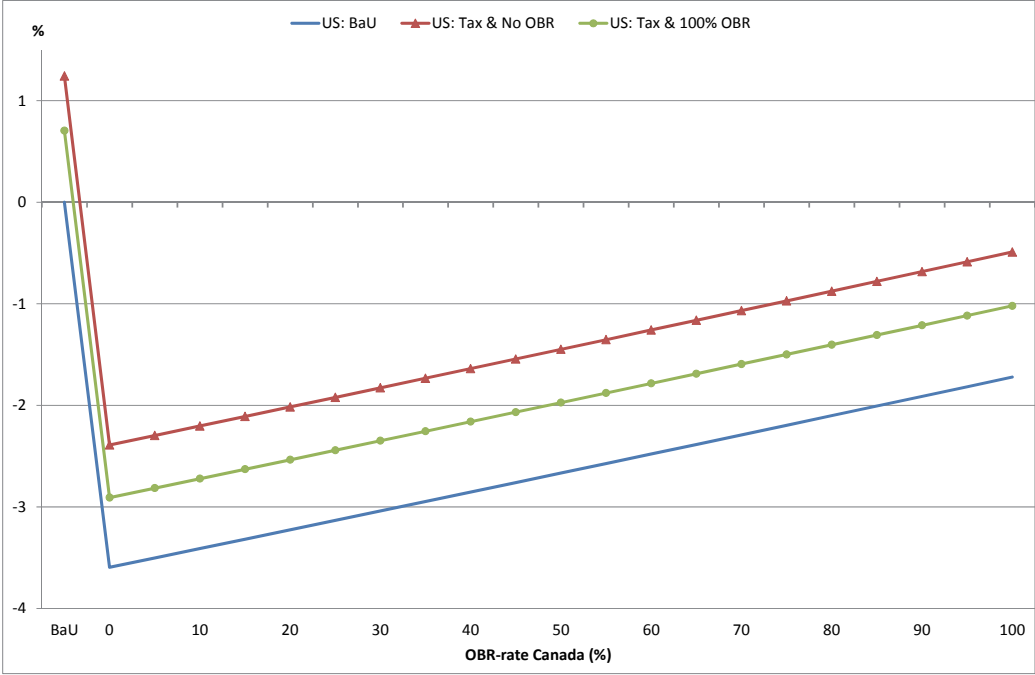


Figure 1 shows that if Canada unilaterally implements a carbon tax without any OBR, its EITE output drops by 3.6%. Further, while supplementing the carbon tax with OBR leads to less EITE reductions, we see that a 100% OBR does not restore competitiveness, in terms of reaching the initial output level. This holds across all the US policy regimes. The compensatory effectiveness for Canada of OBR is approximately the same in all the US regimes depicted by the three curves in Figure 1. However, this does not imply that US policy is irrelevant for Canada’s OBR decisions. Compared to a benchmark with no policy in either country, restoring Canadian output by means of OBR will be less strenuous if the US also introduces a carbon tax, as the output fall is reduced by 1.2 percentage points. This relief will, however, be halved if the US simultaneously adds a 100% OBR.

The numerical CGE analysis allows us to investigate output impacts at a more disaggregate level and thereby identify those specific industries that might be in particular adversely affected in competitiveness. Figures 2a and 2b show the output effects for the five different EITE industries. First, we notice that the output effects of a unilateral carbon tax in Canada vary quite substantially across the EITE sectors, 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 seen for non-metal minerals (NMM) with a decline of merely 0.7%. As predicted by the theory model, the main explanation is to be found in their different emission intensities. The numerical model also accounts for input-output effects, which tend to increase the competitiveness losses for 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 affect several EITE industries markedly; moreover, some EITE industries use substantial amounts of other EITE goods as intermediate inputs. Consistent with the theory model foreign prices, particularly those in the US, increase along with Canada's (effect a) in 2.1). As opposed to the theory model, however, the foreign price effects do not only dampen domestic output reductions, as the EITE industries use imports, which now become more expensive, as inputs.

We find that the effects of rebating carbon tax payments 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 output levels when rebating is 100%, this is far from the case for OIL and NFM. Again the explanation lies in the input-output relationships. Both the latter industries face increased input prices, of crude oil and electricity, respectively. These effects are found in the case when the US conduct BaU policies, and they also hold under alternative assumptions about US policies: The necessary OBR rates to restore output effects at the industry-specific Canadian BaU levels are not noteworthy affected by the US regime for these industries.

However, compared to a benchmark where neither country use carbon policies, the domestic output contraction in I_S and CRP caused by Canada's own emission tax can be somewhat, but not fully, compensated by a similar tax in the US. Thus, additional compensation by domestic OBR policies will be less needed. 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, as well as by how dominant the US is as a trading partner. The most marked example is seen for the NMM industry, where introduction of a US tax rate equal to the Canadian has stronger effect on Canadian NMM output than has the Canadian tax, i.e. US taxation more than compensates for the competitiveness loss. This is driven by a much higher emission intensity for this industry in the US than in Canada. OIL, on the other hand, is very little compensated by a US tax. This reflects that supply of refined oil products mainly come from domestic producers, and the US is not a particularly important trade partner. For the

remaining EITE industries the US tax roughly bisects the output drops caused by the unilateral Canadian tax.

We also see 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. This mirrors the observed counteracting effects of Canadian OBR policies, and again, a reason is that OBR does not compensate well for the “indirect taxation” via the input-output effects. As for all industries, the direct effects of Canadian OBR and US OBR on the Canadian OIL industry are in opposite directions, however, they also affect the global crude oil price, and this effect is positive irrespective of whether Canadian or US demand is stimulated by OBR policies. This indirectly dampens the positive output effect of Canadian OBR, while reinforces the negative effect of US OBR.

Figure 2a. Output effects (in % change from BaU) in Canadian refined oil products (OIL) and non-ferrous metals (NFM) under different domestic OBR rates and three alternative assumptions about US climate policy

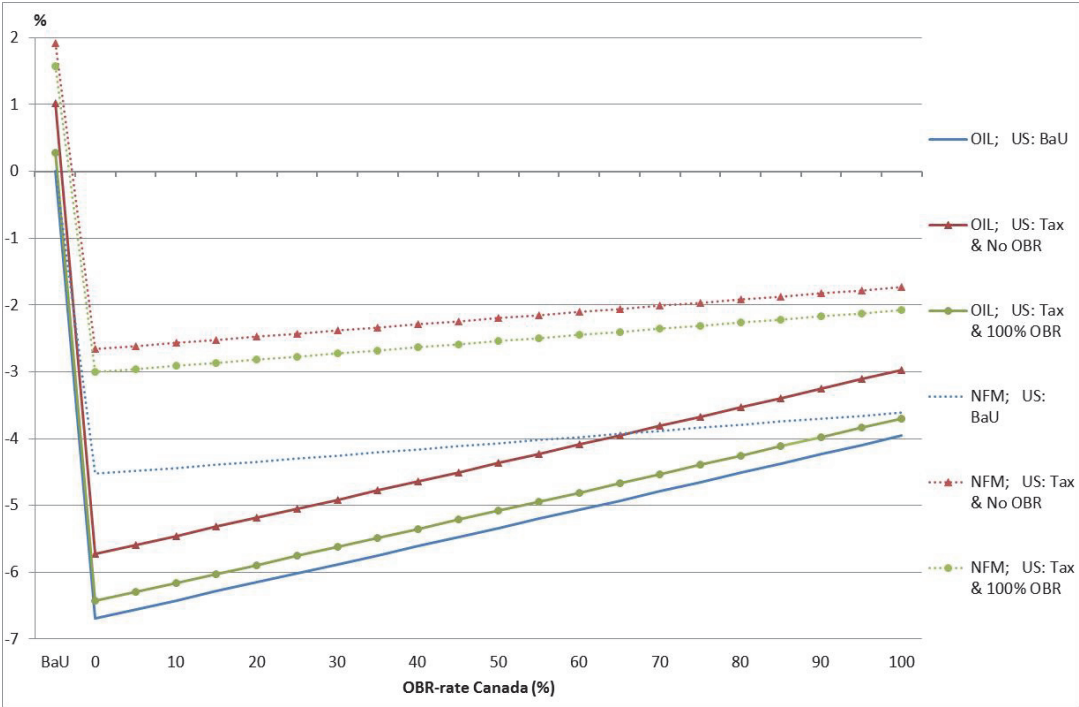
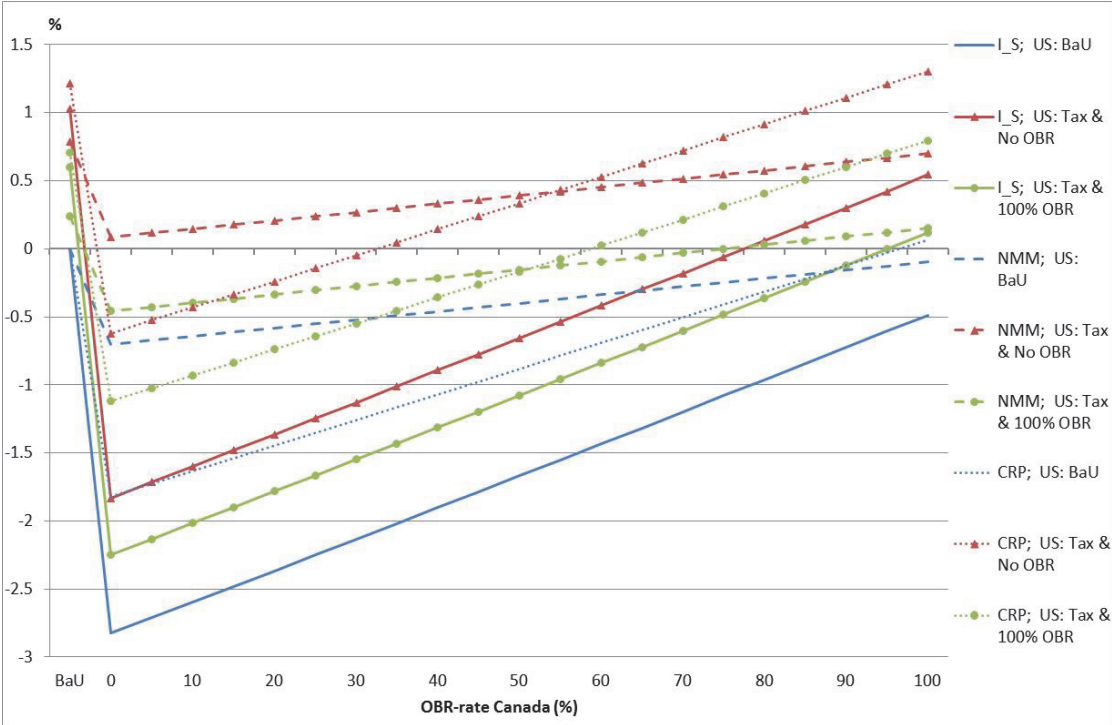


Figure 2b. Output effects (in % change from BaU) for Canadian chemical products (CRP), non-metallic minerals (NMM) and iron and steel (I_S) under different domestic OBR rates and three alternative assumptions about US climate policy



4.2 Effects on carbon leakage

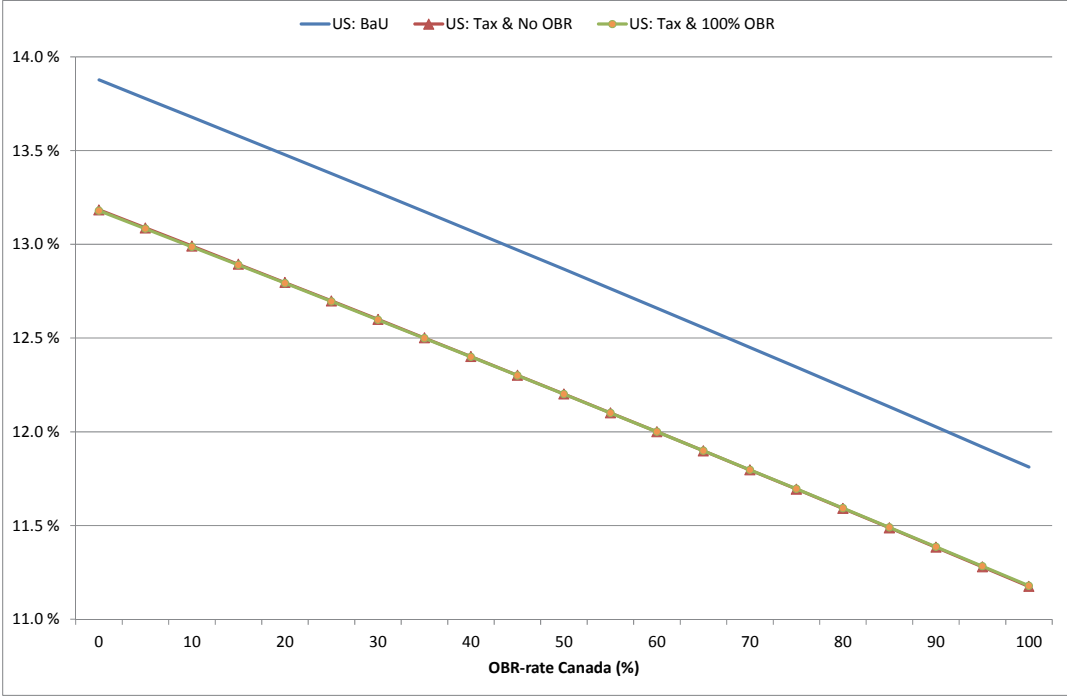
Figure 3 shows that carbon leakage responds markedly to changes in domestic (Canadian) OBR rates and alternative settings for foreign climate policy regulation in the US.⁹ When climate policies in the US is absent, the carbon leakage from a Canadian carbon tax corresponds to a rate of 13.9%. This is gradually reduced to 11.8% as Canada raises its OBR rate towards full OBR.

When the US has a carbon tax, leakage due to Canadian climate policies falls by 0.6-0.7 percentage points, compared to the same Canadian policy in the US no-policy (BaU) regime. Canadian taxation now causes larger cuts in domestic emissions, as reductions take place from larger initial 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 3 also reveals that Canadian carbon policies in presence of a combined tax and full OBR policy in the US cause virtually the same leakage rate as under a US tax regime without OBR. Emissions in all three regions are only indirectly and

⁹ The Canadian leakage rate is measured as the emissions increase abroad (US and RoW) over the emission reduction in Canada.

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.

Figure 3. Carbon leakage due to Canadian climate policies under different domestic OBR rates and three alternative assumptions about US climate policy



4.3 Welfare impacts of domestic OBR policies

Welfare effects of Canadian and US carbon policies are depicted in Figure 4. Welfare is measured in terms of the Hicksian equivalent variation in income, denoting the amount which is necessary to add to (or deduct from) the benchmark household income to restore the benchmark utility level on the basis of ex-ante relative prices. The monetary value of reduced global emissions is then added.¹⁰

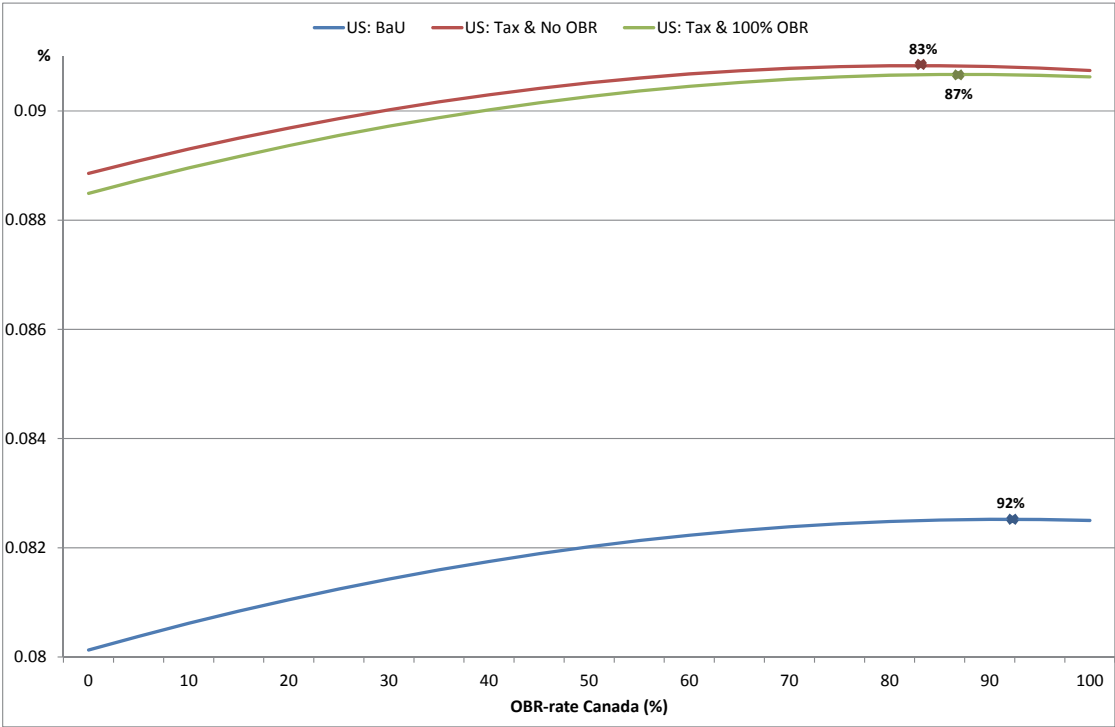
First, we notice that introducing a Canadian carbon tax equal to its perceived marginal value of global abatement (here: 30 USD per ton of CO₂) increases domestic welfare. This is not surprising as average costs of reducing emissions typically are lower than marginal costs (i.e., the carbon tax). Next, we see that the OBR rate to EITE production that maximizes welfare amounts to 92% when Canada acts

¹⁰ We add the value of the global emissions reductions from BaU (welfare is additive in global emissions) in order to assure a coherent cross-comparison of scenarios where global emissions differ. The fully integrated approach would be to model consumer utility of global emissions reductions, but this would call for a major extension towards an integrated assessment framework. We use 30 USD per ton of CO₂, i.e., the carbon tax rate implemented, as the perceived marginal climate costs of carbon.

unilaterally. However, we also notice that welfare is virtually unaffected by the OBR rate within the depicted range. 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 only marginally affected by the OBR rate.¹¹ One policy implication to draw from this is that rebating policies at least to some degree can be determined out of other concerns than aggregate welfare effects, such as competitiveness for trade-exposed industries.

A positive 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 leakage. The benefits of lower emissions abroad, however, must be traded off against the costs of distortionary output subsidies. The latter costs 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.

Figure 4. Welfare changes (in % change from BaU) in Canada under different domestic OBR rates and three alternative assumptions about US climate policy



¹¹ Whereas global emissions are reduced by 0.255% in the No OBR scenario for Canada, the reduction is 0.254% in the 100% OBR scenario (assuming here US BaU policy).

Turning to the effects of US policies, we first observe in Figure 4 that US carbon taxation has a net positive economic welfare impact on Canada that far outsizes the positive impact of own OBR policies. The welfare gain is moderated as abatement costs are transmitted from the US to the Canadian economy, indicating the strong links between the two economies.

Figure 4 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. (12) in Section 2.3, where the main identified explanation was a drop in the emission intensity in the foreign country caused by 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 Canadian optimal OBR-rate. We find a slight increase in the optimal Canadian OBR rate to 87% when the US rebates 100% of its emission tax payments to own EITE industries.

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 observation above 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 the US climate policies are of much more importance to the optimal Canadian OBR policies. First of all, we observe a strong sensitivity of the second-best optimal OBR rates to the assumptions about EITE product heterogeneity across countries, i.e. choice of Armington elasticities.

4.4 Sensitivity analysis

The central parameter in our numerical analysis is the trade responsiveness, 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 should 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 – if we decrease the substitution elasticity for OIL (one of the five EITE goods) by 50% compared to our benchmark choice of 4.0, the optimal rebate rate drops to zero, irrespective of climate policy in the US. (In this test the elasticity of OIL is set to the default level for OIL in the GTAP database; cf. footnote 7).

If we instead increase the substitution elasticities for *all* EITE goods by 50% compared to 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 for the optimal OBR rate in Canada than the climate policies implemented in the US. This finding is also confirmed if we simulate OBR policies towards the individual Canadian EITE sectors.

In the simulations above, we allowed the level of global emissions to respond to policy changes. The welfare accounting included the evaluation of these emission changes, by assuming that the Canadian carbon tax reflects its marginal value of abatement. 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. This design avoids evaluating different global emissions levels, because the emission changes are equal across scenarios. We simulate the case of a Canadian quota market instead of a carbon tax, combined with compensation in terms of output-based allocation of quotas (OBA) instead of an output-based subsidy rate (OBR). We let the cap on emissions in Canada be leakage-adjusted, so that global emissions remain the same across the different OBA rates (for a given policy in the US). We find that the main conclusions from our policy analyses carry over to this case. That is, the optimal OBA level for Canada declines when the US also implements climate policies, but the overall welfare impacts are not much affected by the extent of allocation. We also obtain qualitatively similar conclusions when we increase the fixed carbon tax from 30 to 50 USD per ton of CO₂.

Taxes on capital and labor may have significant interaction effects when the factor supply responds to climate policy changes (Parry et.al., 1999). Such tax interaction effects can also influence on the optimal OBR rate, cf. Lennox and Nieuwkoop (2010). When simulating our model with the same Canadian climate policies but all other taxes set to zero, the optimal OBR rate drops to zero. Especially OIL is highly taxed initially so in the no-taxes alternative the OIL production in the BAU is higher and the output response of a carbon tax only is larger, while the opposite is the case for the other EITE industries. Total leakage is smaller and introducing OBR has a smaller effect on EITE outputs. With initial taxes introducing OBR works as an implicit subsidy on the highly taxed OIL industry and a non-zero OBR-rate is optimal. The tax interaction effects present in the model¹² have a

¹² Tax response effects through labor and capital supply are absent in our model, but there are significant tax interaction effects of sector and good specific tax differences that influences the allocation of resources in the economy.

significant positive effect on the OBR rate as in Lennox and Niewkoop (2010), but the second-best optimal levels of OBR is case-dependent and difficult to establish on a generic basis.

5. Conclusions

For small countries considering unilateral climate policy action, the competitiveness, leakage and welfare outcomes are expectedly sensitive to the actions of large trading partners. We derive both theoretically and numerically the industry-specific and economy-wide effects of OBR policy of a single country, and how they depend on the carbon tax and OBR policies of the larger trading partner. The numerical illustration uses Canada and its large neighbor, the US, as the example.

Our interest in the industry-specific effects of both domestic Canadian and US carbon policies originates from the competitiveness concerns expressed by lobbyists and governments. We find large variation across Canadian EITE industries with respect to the sensitivity to both domestic and US carbon tax and OBR policies. When it comes to domestic OBR policy, in particular, some industries with high indirect carbon tax burdens through prices of inputs need OBR rates far higher than realistic levels (more than 100%) in order to restore competitiveness. For others, low rates would suffice and even rates around zero can be enough in the case where the US conducts carbon policies. Carbon taxation in the US helps moderating the need for compensation, while OBR in the US works the opposite way. However, for a *given* carbon policy regime in the US, a Canadian tax will be compensated by the same domestic OBR system across all the studied US regimes.

From an economy-wide efficiency perspective, an open economy would normally benefit from carbon taxation that equalizes marginal costs of emitting with the country's marginal gains of curbing climate change, unless large offsetting effects occur through terms of trade, tax interaction or carbon leakage that could call for supplementary second-best countermeasures like OBR. In the numerical, general equilibrium setting, when abatement costs, emission effects and terms-of-trade effects are accounted for, the optimal OBR rate is found to lie somewhat below 100% in our central case. Two caveats are, however, important to notice. First, being off the optimal rate has very little impact on welfare given realistic OBR rates. Second, in sensitivity analyses, what is assumed about EITE product heterogeneity across countries proves far more decisive for the Canadian optimal OBR rates than do US carbon policy assumptions. Hence, we should be careful in drawing clear conclusions about welfare-maximizing rates. This also implies that rebating policies can, at least within reasonable limits, be determined on other grounds than welfare. OBR may, for instance, have notable

compensatory effects on some EITE industries, and may also to some degree counteract carbon leakage.

To sum up, the answer to our main research question of whether or not foreign (US) policies are relevant for the OBR decisions in the domestic country (Canada) will depend on the Canadian aims with its OBR policy. If the aim is to restore the competitiveness of domestic EITE firms at the same level as before the introduction of its own carbon taxation for a given US carbon policy, we find that more or less the same Canadian OBR system will be required irrespective of the US carbon policy regime. On the other hand, if the aim is to compensate the Canadian firms for the net effect of Canadian and US climate policies, the necessary domestic OBR rates will be lower if the US regulates its emissions, particularly if the US refrains from OBR. Though being beyond the scope of this article, predictions of whether carbon policy changes in Canada could trigger US action – and, if so, what reactions to expect – would be relevant. Finally, if the aim is not primarily competitiveness, but rather to increase the efficiency of Canadian policies in an economy-wide sense by accounting for carbon-leakage, we find that the US policies have a reducing, but minor effect, on optimal OBR rates.

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Statistics Norway

Postal address:
PO Box 8131 Dept
NO-0033 Oslo

Office address:
Akersveien 26, Oslo
Oterveien 23, Kongsvinger

E-mail: ssb@ssb.no
Internet: www.ssb.no
Telephone: + 47 62 88 50 00

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