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# Incentivizing Carbon Taxation in Low-Income Countries

## Tax Rebating versus Carbon Crediting

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## Abstract

Border carbon adjustments imply that high-income countries set taxes on energy-intensive imports that are proportional to the carbon content of these imports, to match their own carbon taxes. This paper considers the impacts of such a policy on exporter countries, many of which have no or very low carbon taxes today. The paper first studies a policy whereby the importer allows the exporter's border tax to be reduced by its own comprehensive carbon tax ("tax rebating"). The analysis finds that the exporter is then incentivized to set its own comprehensive carbon tax at the same rate as the border tax, up to a maximal rate. When the border tax is higher, the exporter instead reduces its carbon tax. Border tax revenues of the high-income country can be returned to incentivize higher carbon taxes in the exporting countries ("carbon crediting"). When tax rebating is not allowed but tax revenues are fully returned, even higher exporter carbon taxes can then be incentivized, possibly exceeding $60 per ton of carbon dioxide in the numerical examples. Border taxation can give rise to export diversion away from border tax-setting countries, which reduces the scope for incentivizing the exporter's carbon tax. The paper also studies how taxes on oil extraction by oil exporters can be incentivized by oil importing countries, by increasing their oil import prices above world market rates, or more efficiently through support to investments in exporters' renewable energy capacity.


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# Incentivizing Carbon Taxation in Low-Income Countries: Tax Rebating versus Carbon Crediting[1]

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## Introduction

### 1.1 Setting of the study

An important policy issue today is the potential use of border carbon adjustments (BCAs) to "level the playing field" for producers of carbon-intensive goods who face high domestic carbon taxes, which are not faced by foreign competitors. This paper focuses on mechanisms by which BCAs can serve as instruments for incentivizing GHG mitigation policies in countries exporting energy-intensive goods and which have no or ineffective such policies today. The main policy focused on is carbon taxes on GHG emissions in L countries; but we also discuss oil extraction taxes in oil-exporting countries (OEs).

The following two key mechanisms will play a central role for our main policy:

1. A BCA scheme can be combined with "tax rebating", which means rebating of the border carbon taxes in response to implementation of comprehensive carbon taxation in the exporting countries. Under such circumstances, the BCA scheme can by itself serve as a device to incentivize carbon taxation in L countries exporting energy-intensive goods to the BCA-implementing H countries.
2. Revenues obtained from BCA taxes levied on L countries' exports to H countries can be used to further incentivize carbon taxation in these L countries ("carbon crediting"), regardless of whether or not rebating is allowed.

We have recently seen an increased interest in the prospect of applying BCA measures by certain high-income (H) countries. While discussion around BCA schemes has been active since the signing of the Kyoto Protocol in 1997, virtually all of this discussion, both academic and political, has focused on the implementing (H) countries' interest to use BCA as a means to protect their own energy-intensive industries against competition from foreign producers not subject to carbon taxation, and to prevent carbon leakage. No actual BCA policy has so far been implemented.[2] But a proposal to implement a BCA scheme on energy-intensive imports has recently been made by the EU, related to the EU's "Green New Deal" (European Commission 2020; Marcu et al. 2020; World Bank 2021), to implement the EU's ambitious stated climate policy to reduce GHG emissions by 55% relative to "baseline" (1990 emissions) by 2030.

Our interest in BCA schemes in this paper has other backgrounds. Most importantly, we view the application of BCA schemes by H countries as a possibly fruitful incentive mechanism to promote more GHG mitigation in L countries. Application of BCA against countries that select to not implement carbon taxation will raise revenues which can be applied by the BCA-implementing (H) countries to incentivize GHG mitigation in a wider set of L countries. But we also consider BCA applied less traditionally, to incentivize oil extraction taxes in oil-exporting countries (OEs). A BCA can serve as a "stick" by punishing countries that do not implement carbon taxation; and also as a "carrot" by rewarding implementation of carbon (including wellhead) taxes. While the least developed countries (LDCs) would likely be exempt from a BCA (Jensen 2020), by far most energy-intensive imports of industrial goods from non-OECD countries would be subject to a BCA, if applied.

We will here present and compare two mechanisms for incentivizing carbon taxation in lower-income (L) countries. The first mechanism is to *rebate BCA taxes facing L countries' exports, and use all remaining export tax revenues to support carbon tax implementation in the L countries*. This will be compared to the impact of using *policy crediting when tax rebating is not allowed.*

A "BCA-like" arrangement can also potentially be used to help incentivize oil extraction taxes in OEs. The basic rationale for (H) countries will in this case however differ from a standard BCA policy. We find that a border tax arrangement with the aim to incentivize oil extraction taxes must (usually) have a substantial "carrot" element to make it attractive to the OEs. A mechanism explored in this paper is to let the oil import price paid by BCA-imposing countries depend on the oil extraction tax in the respective OE. The politics of the relevant border tax arrangements could

[2] There has however been legislative interest in BCA policies in the United States; first related to the unsuccessful Waxman-Markey climate bill in 2009; and recently as a possible basis for future U.S. climate policy; see Flannery et al. 2020.

in such cases be complex, something we will come back to later. Our man interest is of an analytical nature, as background to future, more practical, analyses and applications.

While no BCA mechanism is in force today, tariffs on imported goods are ubiquitous and substantial. As documented by Shapiro 2021, import tariffs by industrial countries tend to be (far) higher on "clean" goods than on "dirty" goods (with higher embedded carbon emissions). The main reason seems to be that clean goods are often higher valued and more in a competitive relation to H countries' own industrial outputs, and are for those reasons given more trade protection.[3] Widespread BCA arrangements would upend that and provide a more leveled playing field (with less relative subsidy) for goods with high carbon contents.

Goods to be targeted by BCA from industrial countries are mostly industrial goods with high carbon content in their production, and less basic commodities which are either not produced in the industrial countries, or already highly protected by agricultural policies in many H countries. This has implications for our analysis. In particular, trade in industrial goods typically relies on particular markets with less room for substitution; while pure commodities (fossil fuels, ores and agricultural goods) are more easily substitutable between markets. This has implication both for our analysis in section 2, focusing on industrial goods; and section 3, focusing on a particular commodity, namely petroleum.

**1.2 Background to BCA mechanisms – forms that border adjustment measures can take**

A border carbon adjustment (BCA) mechanism (as a tax measure to raise the cost of energy-intensive industrial imports from countries with low or no carbon tax) can be imposed in several alternative ways. Four discussed alternatives are:

1. Border taxes based on carbon content of imports.

2. Border taxes based on carbon content of similar produced goods by the taxing country.

3. Border taxes based on carbon content of imports, jointly with a similar tax relief for the taxing country's exports.

[3] The continued existence of fossil-fuel subsidies in many countries adds to the same problem and underlines the urgent need for carbon pricing in most developing and emerging economies today.

4. “Nordhaus taxes”: a fixed tariff on all goods exported from a (non-compliant) country to a country with carbon taxes. These are presented in Nordhaus 2015, also discussed in Peszko, Mensbrugghe and Golub 2020, and Peszko et al. 2020.

Of the four alternatives listed, the first two have as their main objective to “level the playing field” between domestic and foreign producers and reduce carbon leakage. Alternative 1, focused on in this presentation, is the most commonly proposed alternative, built into the new EU proposal (European Commission 2020; Marcu et al. 2020). Alternative 2 can be relevant for at least two reasons: it is less complicated to implement than alternative 1 (as the carbon content of imported goods is often difficult to observe); and as it protects the carbon tax burden of domestic firms, determined by the carbon content of their products. Alternative 2 will in most cases imply a lower border tax than alternative 1, as the carbon content in importer country production is typically lower (no higher) than for similar imported goods. Alternative 3 is discussed e.g. by Mattoo et al. 2009, but it will not play any role for our analysis.

The fourth alternative has a different main objective (more in line with our focus), namely to provide incentives for exporting countries to adopt carbon taxes. Nordhaus 2015 argues that alternative 4 is superior for enforcing compliance on carbon taxation by making the export countries adopt carbon taxes. “Nordhaus taxes” impose harsh penalties on non-compliant countries; and provide good incentives for enforcing this policy, as relatively low general tariffs are beneficial for the tariff imposer, and harmful for countries subject to the tariff. This alternative, standing on its own, is however problematic if it does not serve to enforce a (high) carbon tax in these countries. It is also not related to carbon emissions nor leakage, but is rather a more traditional trade-related tool, and is likely to be problematic relative to WTO rules.

In addition to these four alternatives, H countries can also implement border taxes (or tariffs) on the carbon content of their imports, with no option for tax rebating, but instead with the option to return the tax revenues with the aim to incentivize carbon taxation in the export country. This alternative will be considered in section 2.6 below.

In our discussion below we will have in mind the following general typology of BCA cases:

A) Only BCA with no rebating (“BCA stick” only);

B) BCA with rebating of L country domestic carbon taxes (BCA + “BCA carrot”);

C) BCA with rebating and transferring excess H country BCA revenues to developing countries as climate finance (BCA + rebating + "climate finance carrot").

D) BCA with no rebating, and transferring all H country BCA revenues to developing countries as climate finance (BCA + "climate finance carrot").

Our aim is to consider and compare mitigation and welfare/efficiency impacts of these four cases.

### 1.3 Incentivizing taxes on oil extraction, including with BCA mechanisms

Section 3 studies a special case where a BCA mechanism is applied to the globally most significant commodity, oil. We consider whether BCA mechanisms can help to incentivize excise taxes on petroleum extraction ("wellhead taxes"). When an oil extraction tax is global (paid by all oil producers), it will lead to a mark-up of the global oil price, determined by demand and supply relations in the global oil market. Any regional, national or local consumer carbon tax will add to the oil extraction tax. When this tax is imposed in some oil-producing countries but not in others, it will lead to a less complete increase in the global oil price. When imposed in only a few smaller FF-producing countries, it will reduce the resource rents for producers in the countries that impose wellhead taxes, and do little to increase the oil price in the global market. Total oil rents to all oil-producing countries will then remain close to constant, but more of this rent will be transferred from the private to the public sector in the oil-producing countries.

Oil is a commodity which can represent a counterexample to exported industrial goods studied in section 2 where we assume, as a base case, no export diversion in response to border taxes. For oil the other extreme case, complete export diversion is instead relevant. In Appendix 3 (tied to section 3 of the paper) we show that oil extraction taxes can be incentivized through a BCA scheme with rebating of the exporting country's oil extraction tax. Because of the extreme diversion assumption, such a scheme must involve higher prices for these oil producers' exports to the importing countries that impose BCA. There are severe limitations on such an incentive mechanism: only relatively limited oil export taxes can be directly incentivized in this manner. This means that a border tax and price arrangement, which can incentivize oil extraction taxes, works better if coupled with additional measures, such as a scheme for supporting renewable investments in the oil-exporting country, or a direct transfer scheme.

## 1. BCA based on carbon content of imported goods – analytical discussion

In this section we focus on the "standard" BCA alternative 1 (border taxes on energy-intensive imports based on the carbon content in their production). We consider an L country subject to BCA imposed by H countries. We first briefly consider the border tax case as a simple tariff without rebating. We next assume, as our main case, that the border tax is reduced in proportion to a carbon tax imposed on the same goods by the L country itself.

Implementation of BCA which affects L countries' exports imposes burdens on these countries. The weight of these burdens will depend on the L countries' responses to the BCAs, and on compensatory measures taken by H countries to lessen the burdens. We consider two possible policy responses by L countries: 1) simply accepting the BCA without implementing its own carbon tax; and 2) meeting the BCA with a domestic carbon tax. Under alternative 2, we consider three cases:

a) A domestic carbon tax is introduced in the L country on only the sector subject to BCA.
b) A domestic carbon tax is imposed on the entire L country's economy.
c) A domestic carbon tax for the entire energy-intensive export sector of the L economy.

Cases a and b are discussed in this section; case c is considered in Appendix 1. A further issue is whether exports that initially went to BCA-implementing countries can and will be diverted to countries without BCA, or whether previously exported products are instead consumed domestically when importers implement BCA regimes.

### 2.1 No BCA rebating

We first assume that a BCA is imposed on energy-intensive imports, with no tax rebating option (so that a carbon tax implemented by the exporter is not rebated by the importer). The exporter has then no direct benefit from a carbon tax, and will not impose any domestic carbon tax. Consider the following basic (linear-quadratic) welfare function for an L country for the case of no border taxes:[4]

(1)
$$W_L = R_L - \frac{\gamma}{2} R_L^2 - pR_L .$$

[4] See Strand (2013, 2020a, b) for other applications of this specification.

Here, $R_L$ is the fossil fuel consumption in the L economy, $p$ is the fossil fuel price, and $\gamma$ a positive fixed parameter in the production function. Consider an L country with no carbon tax of its own, subject to a border tax $q$ for a share of its energy-intensive exports, exported to the BCA-imposing H country. The L country's exports subject to BCA make up a share ρσ of total nationwide emissions in a baseline with no border or carbon taxes in the L country, where $\rho$ is the export share in total emissions for the L country, and $\sigma$ is the share of exports subject to BCA, with shares defined in terms of carbon emissions. The border tax increases the "reference cost" of the L country's energy-intensive export sector. Welfare related to the BCA-exposed sector can be written as:

(2) $$W_{LE} = R_{LE} - \frac{\gamma}{2}\frac{1}{\rho\sigma}R_{LE}^{\ 2} - (p+q)R_{LE},$$

Assume no diversion of L country exports due to the border tax.[5] Maximizing (2) with respect to $R_{LE}$, for an L country facing a border tax q for exports to the BCA-imposing country, yields:

(3) $$\frac{dW_{LE}}{dR_{LE}} = 1 - \frac{\gamma}{\rho\sigma}R_{LE} - (p+q) = 0 \Leftrightarrow R_{LE} = \frac{\rho\sigma}{\gamma}(1-p-q).$$

In (3), mitigation equals the carbon tax, $q$, multiplied by the factor $\rho\sigma/\gamma$, and where $\rho\sigma$ represents the share of the L economy subject to carbon taxation.[6]

The L country welfare level related to this sector is

(4) $$W_{LE} = \frac{\rho\sigma}{2\gamma}(1-p-q)^2.$$

### 2.2 BCA rebating, and carbon tax required only in the BCA-exposed sector

Consider case a above, where the L country implements a carbon tax for only its energy-intensive sector subject to BCA.[7] This border tax rule implies that when the L country charges a carbon tax, $q_L$, to the exported goods subject to BCA, the BCA is reduced equivalently (rebated) up to the

[5] Most of the analysis will here simply take "post-BCA" exports, after possible diversion, as given.
[6] This is a generic result which also applies to other taxed shares of the economy (including the entire economy where the share is 1). See Strand 2013 for more elaborate derivation and discussion.
[7] Our assumption that domestic carbon taxes are imposed on exported sectors is somewhat at odds with some countries' policies; e.g., the proposed EU BCA policy exempts exports from this tax. This is not the case here.

level $q_L = q$.[8] When setting $q_L = q$, the only impact of this for the L country is that the country can then keep all its own carbon tax revenues and not hand these over to the importer country. The welfare level of the L country, related to exports from the energy-intensive sector, is then

(5) $$W_{L1} = \frac{\rho\sigma}{2\gamma}\left[(1-p)^2 - q^2\right].$$

We see that $W_{L1} > W_{LE}$. The difference is the carbon tax revenues, now kept by the L country, which in the previous case were retained by the BCA-implementing H country. The L country is then given a direct incentive to impose its own carbon tax, equal to the BCA, on its energy-intensive export sector facing the BCA, and this sector only. There will be no additional mitigation in the L country from such rebating: the same mitigation, only for the BCA-exposed exports, is incentivized by the border tax as by the L country's domestic carbon tax.

This BCA arrangement consists of both a "stick" (imposing the BCA) and a "carrot" (avoiding all or part of the tariff penalty when the L country imposes its own carbon tax).

### 2.3 H country BCA with rebating of economywide carbon taxes in the L country

Assume next that the L country, in order to have its BCA rate on exports reduced, is required to impose a (uniform) carbon tax on *all* its carbon emissions. We analyze whether such a tax will be imposed, and in case at what level. Call the domestic carbon tax in the L country $q_L$. Exports to the BCA-imposing country would still face an effective carbon tax q, of which now $q_L$ is paid to the home country, and the remainder, $q-q_L$, to the importing H country. We still assume no diversion of exports from the L country to the BCA-imposing H country, due to the BCA.

The emissions level from export sectors facing the BCA is given by (3). Emissions from sectors that face only the domestic carbon tax $q_L$ are

(6) $$R(tax) = \frac{1-\rho\sigma}{\gamma}(1-p-q_L).$$

[8] It can in practice be complicated to calculate the correct rebate to the BCA; this is here ignored.

The welfare impact for the L country of implementing a comprehensive domestic carbon tax $q_L$ is given by the sum of private-sector welfare levels for these two sectors, plus the government's carbon tax revenue, under the constraint $q_L \leq q$:

(7) $$W_L(q_L) = \frac{1}{2\gamma}\left[\rho\sigma(1-p-q)(1-p-q+2q_L) + (1-\rho\sigma)[(1-p)^2 - q_L{}^2]\right].$$

In (7), $(1-\rho\sigma)q_L^2/2\gamma$ is the production deadweight loss (DWL) suffered by the (non-BCA) domestic L country economy. Maximizing (7) with respect to $q_L$ yields:[9]

(8) $$\frac{dW_L(q_L)}{dq_L} = \frac{1}{2\gamma}\left[2\rho\sigma(1-p-q) - 2(1-\rho\sigma)q_L\right] = 0.$$

leading to

(9) $$q_L = \frac{\rho\sigma}{1-\rho\sigma}(1-p-q).$$

$q_L$ in (9) is a decreasing function of $q$ given $q_L < q$: a higher border tax allows only a lower implemented carbon tax in the exporting L country. This may seem surprising, but is due to the fact that a high $q$ reduces the amount of BCA-affected trade, and at the same time reduces the scope for the L country to gain (in terms of reducing the BCA burden) by raising $q_L$; while the DWL from the domestic carbon tax for the other sectors only depends on $q_L$.

When inserting for (9) in (7) we find the following expression for optimized L country welfare:

(7a) $$W_L(q) = \frac{1}{2\gamma}\left[(1-\rho\sigma)(1-p)^2 + \frac{\rho\sigma}{1-\rho\sigma}(1-p-q)^2\right].$$

The H country's net tax revenue from the BCA on imports from the L country is

(10) $$T = \frac{\rho\sigma}{\gamma}(1-p-q)(q-q_L) = \frac{\rho\sigma}{\gamma(1-\rho\sigma)}(1-p-q)[q-\rho\sigma(1-p)].$$

For this solution to be valid it must yield $q_L \leq q$. This implies the following condition:

[9] Given $q_L \leq q$ from (9), such a solution exists as the second-order condition for a maximum with respect to $q_L$ in (8) is fulfilled.

(11) $$q \geq \rho\sigma(1-p) \equiv q_0 .$$

Thus when the border tax is sufficiently high that (11) holds ($q \geq q_0$), the constrained optimal (comprehensive) carbon tax in the L country is determined from (9).

GHG mitigation in the L country incentivized by the border tax is then given by

(12) $$M(q;q_L) = \frac{1}{\gamma}[\rho\sigma q + (1-\rho\sigma)q_L] .$$

Inserting for $q_L$ from (9) yields

(13) $$M(q;q_L) = \frac{1}{\gamma}\rho\sigma(1-p) .$$

When instead the border tax $q$ is *lower than* $q_0$, $q_L = q$. The L country then sets its comprehensive carbon tax at the same level as the border tax. (9) then no longer holds. Mitigation is now

(14) $$M(q;q) = \frac{q}{\gamma} < \frac{1}{\gamma}\rho\sigma(1-p) .$$

To recapitulate, optimal economy-wide mitigation by the L country, using a single domestic carbon tax for all its carbon-emitting sectors, is given by (13) when $q \geq q_0$. When $q$ is lower, the L country will set its own carbon tax at $q$. Mitigation is then smaller. Note that 1-$p$ can be interpreted as the net value per unit of carbon emissions from production in the L economy, while $\rho\sigma$ is the share of carbon emissions from the BCA-exposed export sector.

(13) shows that when $q \geq q_0$, total mitigation induced by the L country is independent of q, as long as ρσ is constant and there is no export diversion.[10] A higher $q$ increases mitigation in the L country's sector exporting to the H country, but reduces mitigation by the same amount in other sectors as the L country's own optimal carbon tax is reduced. Intuitively, a higher BCA reduces the L country's exports to the BCA-setting country, which reduces the positive fiscal impact, in terms of lower tariff expenditures, of a higher domestic carbon tax for the L country.

[10] With export diversion in response to a higher $q$, $\rho\sigma$ will drop and mitigation also drop from (13). This result holds within our model as long as $q < 1-p$, so that emissions from the exporting sector subject to BCA is positive, and output in that sector is positive. Our linear-quadratic production model is a reasonable approximation to the true production structure only when changes, including those induced by $q$, are "not too large".

When $q \geq q_0$, the optimal welfare level of the L country is:

(15) $$W_{L1}(q_L) = \frac{\rho\sigma}{2\gamma}(1-p-q)\left[(1-p-q)+2q_L\right] + \frac{1-\rho\sigma}{2\gamma}\left((1-p)^2 - q_L{}^2\right).$$

Inserting for $q_L$ from (9) yields

(16) $$W_{L1}(q_L) = \frac{\rho\sigma(1+\rho\sigma)}{1-\rho\sigma}\frac{(1-p-q)^2}{2\gamma} + \frac{1-\rho\sigma}{2\gamma}\left((1-p)^2 - \frac{(\rho\sigma)^2}{(1-\rho\sigma)^2}(1-p-q)\right).$$

Welfare for the L country is lower when tax rebating requires that a carbon tax be imposed in its entire economy, than when its carbon tax can be constrained to BCA-exposed goods. As seen in section 2.2, the L country will then set a carbon tax only in this sector, equal to the border tax. When the L country must use an economy-wide carbon tax, $q_L$, to meet the BCA, $q_L < q$ when $q > q_0$ from (11). Economy-wide DWLs then need to be traded off against the revenue gains from the tax, as the border tax is reduced when $q_L$ is increased.

Consider next $q < q_0$, so that $q_L = q$. An increase in q then also increases $q_L$ by the same amount, and GHG mitigation increases in all sectors of the L economy, given no export diversion.

To summarize: If the H country introduces a BCA at a sufficiently low rate, rebating incentivizes the L country to impose its own comprehensive carbon tax at the BCA rate. A higher BCA rate incentivizes the L country to reduce its own carbon tax. Without rebating, the L country would impose no carbon tax regardless of q. Mitigation in the L country would then occur only in the BCA-exposed sector. These effects are summarized in Table 1.

**Table 1: Main incentives from BCA taxation on L country general carbon tax policy with no return of BCA tax revenues**

| **BCA rate** | **L-country tax rebating** | |
|---|---|---|
| | No | Yes |
| **BCA low** | No incentive | Positive incentive |
| **BCA high** | No incentive | Negative incentive |

### 2.4 Strategies for BCA-imposing (H) countries with no return of carbon tax revenues

For the H country which implements its BCA, we now seek to derive the net benefits from its own BCA policy, including from the L country's policy response, in terms of its carbon tax in response to the BCA. When the L country implements its own carbon tax in response to the BCA, this has (at least) two effects of concern for the H country.

First, the H country gives up the potential carbon tax revenues that follow from the border tax.

Secondly, there is a GHG mitigation impact of the L country's policy response to the BCA.

Consider the H country's decision to set its own carbon and border taxes. We separate between the cases where $q \geq q_0$, and $q < q_0$.

**2.4.1 Case 1: $q \geq \rho\sigma(1-p) = q_0$**

In this case there is no impact from a change in q on mitigation in the L country, as greater mitigation in the export sector is counterbalanced by less mitigation in the rest of the economy through the lower general carbon tax, from (9). This means that a higher carbon and border tax than $q_0$ in the H country is ineffective with respect to incentivizing increased mitigation in the exporting countries.

The H country's utility from its own fossil fuel consumption, including its own carbon tax (including BCA), is in this case assumed to be given by [11]

$$W_H = R_H - \gamma_H \frac{1}{2} R_H{}^2 - (p + v_H) R_H + \rho\sigma \frac{1-p-q}{\gamma}(q - q_L) . \qquad (17)$$

The last term here expresses the H country's border tax revenues from the L country.

Consider the $q$ that maximizes (17) by taking the derivative of this expression with respect to $q$, facing relevant constraints. $R_H$ is determined by the private sector in the H country facing a carbon price of $q$, with solution corresponding to (3). We then find:

[11] (17) assumes the same basic structure of the H and the L economy. It is reasonable to assume that the H economy is more productive than the L economy at transferring fossil-fuel inputs into final output. Our assumptions about the structure of the H and L economies have however no fundamental impact on our main results here; see also Strand (2020a, b) for similar analyses.

(18) $$\frac{dR_H}{dq} = \frac{1}{\gamma_H}(v_H - q) + \frac{\rho\sigma}{1-\rho\sigma}\frac{1}{\gamma}[(1+\rho\sigma)(1-p) - 2q] = 0 .$$

We find $q = v_H$, the standard case, when the last term is ignored. When the last term is not ignored, $q > v_H$ given that $v_H < (1+\rho\sigma)(1-p)/2$, which is highly reasonable. The constrained optimal carbon (and border) tax in the H country then exceeds $v_H$, motivated by the border tax revenue generated by such a higher tax.

### 2.4.2 Case 2: $q < \rho\sigma(1-p)$)

When $q < q_0$, $q_L = q$. A higher $q$ then increases $q_L$ by the same amount. The H country in this case obtains no border tax revenues from the L country, and the last term in (17) drops out. Instead of (17), the relevant expression for H country welfare is

(19) $$W_H = R_H - \gamma_H \frac{1}{2} R_H{}^2 - (p + v_H)R_H - \frac{1-p-q}{\gamma} v_H .$$

Carbon emissions from the L country are now incorporated in the H country's welfare function as these are now affected by the H country's BCA policy. Taking into consideration the private sector's determination of $R_H$ facing a carbon tax of $q$, (19) takes the form

(19a) $$W_H = \frac{(1-p-v_H)^2}{2\gamma_H} - \frac{(v_H - q)^2}{2\gamma_H} - \frac{1-p-q}{\gamma} v_H .$$

Setting the derivative of $W_H$ with respect to $q$ equal to zero we obtain

(20) $$q = \left(1 + \frac{\gamma_H}{\gamma}\right) v_H .$$

When the H country's unit carbon value, $v_H$, is "sufficiently small", the solution for $q$ from (20) is less than $q_0$ $(= \rho\sigma(1-p))$. The optimal carbon tax $q$ set by the H country, combined with an equally-valued BCA tax, then exceeds the H country's carbon value. The reason is that q then incentivizes increased mitigation in both H and L countries. When $q$ is low, the DWL for the L country from implementing this tax (quadratic in the L country's carbon tax) is smaller than the gain from reduced border tax expenditures (linear in the L country's carbon tax) as the higher domestic carbon tax in the L country perfectly offsets border taxes on the L country's exports. The ratio $\gamma_H/\gamma$

represents the "relative scope for mitigation", in the L country relative to in the H country, when applying the carbon and border tax $q$,

### 2.5 BCA rebating, full return of carbon tax revenues when q is "high"

The application of BCA to L country exports leads to taxation of L countries by H countries when $q$ is "high" (> $q_0$). It may seem unreasonable that H countries retain these tax revenues, both from a global income distribution perspective, and as H countries here are assumed to have as an aim to stimulate L countries' mitigation activity.

Alternatively, we can then consider the H country's BCA revenues to be applied to further incentivize carbon taxation in the L country, given rebating of the L country's own carbon tax. We consider incentivizing a higher carbon tax in the L country on goods and activities not subject to BCA (as goods subject to BCA already face a tax of $q$). In case 1, in section 2.4.1 above,[12] the net tax revenues for the H country from the border tax on its L country imports are given from (10). Consider transferring this amount to the L country, with the objective to incentivize a maximally high carbon tax $q_{M1}$ in the L country.[13] This gives us the following relation:

$$(21) \qquad \frac{\rho\sigma}{\gamma(1-\rho\sigma)}(1-p-q)[q-\rho\sigma(1-p)] = \frac{1}{2\gamma}(1-\rho\sigma)\left[{q_{M1}}^2 - {q_L}^2\right].$$

The left-hand side of this equation is the border tax revenue for the H country, from (10). The right-hand side expresses the increased DWL to the L country when increasing this country's domestic carbon tax (on all goods except those subject to BCA) from the initial tax rate $q_L$, to the highest achievable tax rate $q_{M1}$. This DWL must be compensated through returned tax payments, for the L country to accept the new comprehensive carbon tax $q_{M1}$. We find the following expression solving for $q_{M1}$:

$$(22) \qquad {q_{M1}}^2 = \frac{\rho\sigma}{(1-\rho\sigma)^2}(1-p-q)[2(q-\rho\sigma(1-p)) + \rho\sigma(1-p-q)].$$

---

[12] Case 2 is here irrelevant since it yields no BCA tax revenues.

[13] This procedure for deriving the "best" carbon tax in the L country is equivalent to the procedure developed in Strand 2020b for deriving "price points" for carbon tax implementation through results-based climate finance payments. This differs from carbon tax implementation via carbon market support which is generally more expensive for the donor.

$q_{M1}$ increases in $q$ given that

(23)
$$q < \frac{1}{2-\rho\sigma}(1-p).$$

An increase in $q$, using all BCA revenues to incentivize higher carbon taxes in the L country, then leads to higher GHG mitigation in both the H and the L country. The optimal carbon/border tax in the H country then exceeds $v_H$, using an argument parallel to that used in section 2.4.1.

**2.6 Incentivizing carbon taxation through policy crediting**

An alternative for incentivizing higher carbon taxation in L countries is to consider "policy crediting" where the H country imposes a domestic carbon tax together with the same border tax on exports, with no option for rebating of the L country's own carbon taxes. The L country has then no incentive to implement any own domestic carbon tax if tax revenues are not returned. But the H country's entire border tax revenue can in this case be transferred back and spent to support carbon tax implementation in the L country.[14] The L country is in this case assumed to have no carbon tax before the transfer back of border tax revenue.

This gives rise to the following relation, replacing (21):

(24)
$$\rho\sigma\frac{1-p-q}{\gamma}q = (1-\rho\sigma)\frac{q_{M2}^{\;2}}{2\gamma}.$$

(24) deviates from (21) in two main ways. First, the left-hand side expresses the "full" carbon tax revenue from the BCA on the L country's exports (now transferred back to the L country in its entirety). This revenue generation now applies to all L country exports to the H country, since the L country in this case has no domestic carbon tax on any goods exported to the H country. The second difference is that on the right-hand side of (24) there is no "baseline" DWL, as there is no initial domestic carbon tax in the L country. The right-hand side is the DWL to the L country from implementing a domestic carbon tax of $q_{M2}$ on all sectors except the energy-intensive goods exported to the H country (which is subject to the tax $q$). Solving (24) for $q_{M2}$ yields:

[14] This is similar to the scheme applied in Strand 2020b.

(25) $$q_{M2} = \sqrt{\frac{2\rho\sigma(1-p-q)q}{1-\rho\sigma}}.$$

Comparing (25) to (22), we find $q_{M2} > q_{M1}$. The policy crediting solution then yields a better result than the BCA solution with rebating and full return of BCA revenues. This applies to all levels of $q$, also values below $q_0$.

$q_{M2}$ increases in $q$ given that

(26) $$q < \frac{1-p}{2}.$$

When the L country's carbon tax increases in $q$, the optimal $q$ set by the H country will exceed $v_H$. By how much depends also here in a somewhat complex way on the underlying relationships.

Finding $q_{M2} > q_{M1}$ may appear surprising. We have seen that the solution for $q_{M1}$ allows for rebating of the L country's carbon taxes on exports, and to a positive carbon tax in the L country even without any return of carbon tax revenues to the L country. The solution for $q_{M2}$ does not involve any positive voluntary carbon tax for the L country without the return of tax revenues. The reason for our result that $q_{M2} > q_{M1}$, is that welfare of the L country is reduced by the BCA with no rebating. The L country's utility stays at this reduced level when the revenues obtained by the H country, from taxation of the L country's energy-intensive exports, are used as "results-based climate finance" (RBCF) to "purchase" a comprehensive carbon tax increase in the L country. This is a more efficient way for the H country to incentivize carbon taxation in the L country, than via a rebate policy where the L country is first given the option to freely set its own carbon tax. The tax revenue transferred back is also larger in the policy crediting case: more funds are used for subsidizing, and incentivizing, the carbon tax $q_{M2}$, than for $q_{M1}$.

When BCA rebating is not allowed, welfare of the L country is reduced to a lower level. Is this fair? Arguably, it can be considered as "fair" if the more efficient climate-related outcome, resulting in this case, in reality serves to benefit the L country (even when this country does not, or is not willing to, recognize such a benefit). Such an outcome is more likely if the L country also enjoys substantial co-benefits from its own GHG mitigation activity, something we have ignored in our formal analysis.[15]

### 2.7 Lessons and further comments

Table 2 shows magnitudes of implementable carbon tax levels in exporting (L) countries, in response to alternative carbon tax/BCA levels in import (H) countries. We assume 1-*p* = \$300 (= the net value of output before tax in the L country per ton of $CO_2$ applied in production; a conservative estimate); two alternatives for the share of the L country's carbon emissions subject to BCA, $\rho\sigma = 0.05$ and 0.1; and three alternatives for the H country BCA level, \$40, \$100, and \$200. All these tax levels are higher than $q_0$ implying that the H country's BCA revenues will be positive in all cases considered.

The highest carbon tax that can be implemented under rebating without return of tax revenues are \$15 for $\rho\sigma = 0.05$, and \$30 for $\rho\sigma = 0.1$. These tax levels are reduced when the H country's BCA exceeds these respective levels. With no rebating but crediting there will be no incentive for the L country to set an own carbon tax, when no tax revenue is returned.

**Table 2: Implementable carbon taxes in L countries in response to BCA levels in H countries, and alternative magnitudes of relative L country emissions subject to BCA**

**US\$/t $CO_2$**

| , | BCA level | L country carbon tax level with no return of tax revenues | | L country carbon tax level with full return of tax revenues | |
|---|---|---|---|---|---|
| Export fraction | | $\rho\sigma = 0.05$ | $\rho\sigma = 0.1$ | $\rho\sigma = 0.05$ | $\rho\sigma = 0.1$ |
| Rebating | $q_0$ | 15 | 30 | | |
| | 40 | 13.7 | 28.9 | 30.1 | 38.4 |
| | 100 | 10.5 | 22.2 | 44.6 | 62.8 |
| | 200 | 5.3 | 11.1 | 45.6 | 65.7 |
| Crediting | 40 | 0 | 0 | 33.1 | 48.1 |
| | 100 | 0 | 0 | 45.9 | 66.7 |
| | 200 | 0 | 0 | 45.9 | 66.7 |

When instead all BCA tax revenue is returned to the L country with the objective to maximally incentivize comprehensive carbon taxation, the highest implementable carbon tax level in the L

[15] See Strand (2020a, b) for related analyses where co-benefits of climate policies for L countries can be significant.

countries is much higher. With only a moderate 5% of carbon emissions in the L country coming from BCA-exposed sectors, the maximal carbon tax in the L country is around \$45/t $CO_2$ under both rebating and crediting, when the BCA level is at least \$100/t $CO_2$. The figures in Table 2 also show that crediting always leads to higher implementable taxes in the L country than rebating; this difference is greater when the BCA levels are relatively low.

Below we also include three figures displaying the relationships between $q_{M1}$ and $q_{M2}$ where Figures 1 and 2 represent the cases $\rho\sigma$ = 0.05 and 0.1, and otherwise the same parametric assumptions as for the figures in Table 2. We have also included a third figure for $\rho\sigma$ = 0.2 and thus a larger BCA export-related emissions share in the L country. These figures confirm the pattern of implementable carbon tax rates found in Table 2. Figure 3 shows even higher implementable tax rates for the case of $\rho\sigma$ = 0.2, as expected: in this case, $q_0$ = \$60; and the highest level of $q_{M2}$ exceeds \$100. The difference between $q_{M1}$ and $q_{M2}$ is now larger, in particular for low levels of $q$. The reason is that in this case the BCA tax raises much more substantial revenue, and this permits the implementation of high carbon taxes in the L country, even for moderate $q$ levels. Note that the rebate policy allows for no tax revenue for the H country (paid back to stimulate carbon taxation) until $q$ exceeds \$60 (since all lower tax levels will be matched by the L country in the tax rebating case).

**Figure 1: Implementable carbon taxes $q_{M1}$ and $q_{M2}$ for different $q$ levels given $\rho\sigma$ = 0.05**

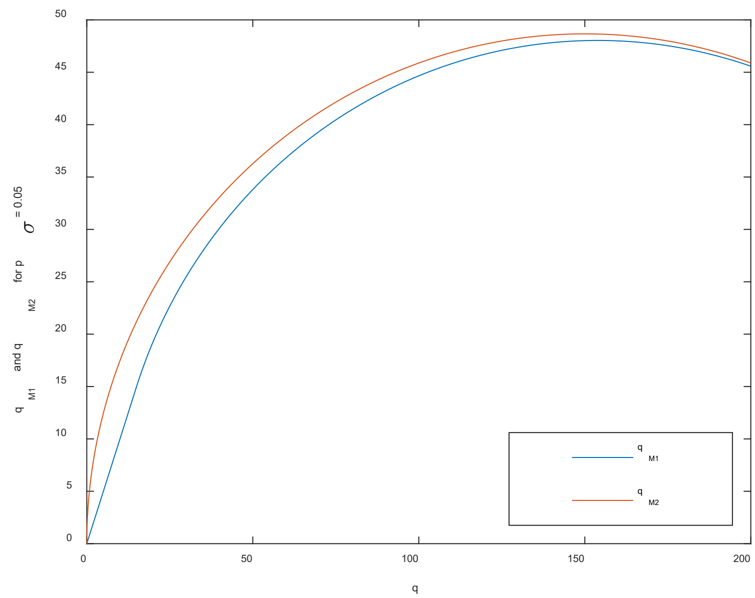



**Figure 2: Implementable carbon taxes $q_{M1}$ and $q_{M2}$ for different $q$ levels given $\rho\sigma = 0.1$**

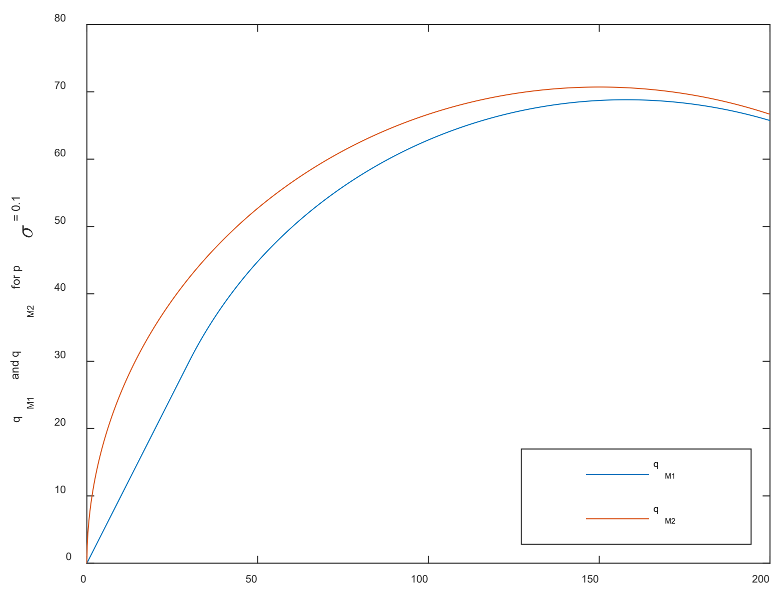
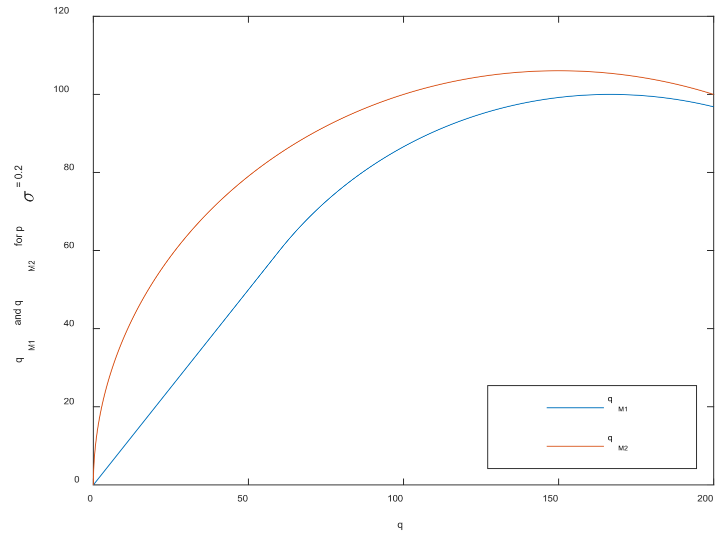



**Figure 3: Implementable carbon taxes $q_{M1}$ and $q_{M2}$ for different $q$ levels given $\rho\sigma = 0.2$**




Note that the export shares in the L country subject to BCA can be considered to occur after a possible diversion of exports away from the BCA-taxed area, to non-tax countries. Such diversion is likely to be higher when the BCA rate is higher.[16] As an example, we could have $\rho\sigma = 0.1$ when the border tax is up to \$40; while $\rho\sigma = 0.05$ when the tax is \$100 (or higher). In such cases we would see a greater drop in the highest implementable tax rate in the L country in response to a higher BCA with no return of tax revenues; from \$28.9 with BCA at \$40, to \$10.5 for BCA = \$100. We would also see more moderate (if any) L country tax increases in response to higher BCA tax levels with full return of carbon tax revenues. In Table 2, under the rebating alternative the highest possible L country comprehensive tax would in this case increase from \$38.4 to \$44.6; while with no rebating the highest tax would *fall*, from \$48.1 to \$45.9. This illustrates, more generally, that increases in BCA levels are likely to yield smaller increases (or greater reductions) in implementable L country taxes, than what can be read directly out of Table 2, when the BCA-exposed export shares are reduced with the BCA rate.

An issue related to policy crediting, not yet discussed, is the possibility of double taxation under the policy crediting alternative, when the L country already has implemented carbon taxation. There are at least four options for resolving this issue. The first is that the L country exempts its own carbon tax on goods subject to BCA, which will avoid double taxation. The second is no exemption, which leads to double taxation.

[16] The figures 1-3 are all drawn under the assumption of no export diversion in response to increasing *q*.

A third possibility is a "middle point" where the H country rebates half of the BCA, while the L country exempts half. We can consider two such cases. In the first, such midway rebating requires (as before) that the L country implements its own comprehensive carbon tax at the BCA level. This solution would be midway between rebating and crediting. It would yield solutions in Table 2 for the highest implementable tax levels in between those for the rebating and crediting cases, both with and without return of carbon tax revenues from the H to the L country. Appendix 2 provides an analytical discussion of such a case when tax revenues are not returned.

The fourth case is midway rebating of the BCA level for energy-intensive exports to the H country without any requirement for the L country to implement a comprehensive carbon tax. Then no comprehensive carbon tax will be implemented in the L country when no tax revenues are returned to implement the tax. When tax revenues are returned, the highest implementable carbon tax in the L country is lower than in the rebating case above, since less tax revenue is collected. This lax policy then puts the H country in a less favorable position to incentivize a high comprehensive carbon tax in the L country, compared to both the initial rebating and crediting cases.

## 2. Oil extraction taxes by oil-exporting countries incentivized by H countries

### 3.1 Introduction

We will in this section discuss taxes on oil extraction by petroleum exporters (OEs), and how such taxes can be incentivized by H countries, in particular through a price premium on petroleum exports to a BCA-implementing H country. We compare such a scheme to other incentive and support schemes, including H country support to renewable energy investments in the OE.

There are several reasons for considering oil extraction taxes specifically in a BCA framework. First, petroleum is the most important commodity in international trade, and many developing and emerging economies rely heavily on it for their export revenues. It is at the same time the most important traded GHG emissions-causing commodity.

There are also two other important reasons for such special treatment. Our model in section 2 does not suit well for the international oil market, which is characterized by a very high degree of potential export diversion: petroleum is a near homogeneous commodity and the international oil market is highly competitive. Oil as a commodity represents, in our view, a very useful counterexample to our model case in section 2, where we have assumed zero or, at most, only limited export diversion. When only some H countries use such incentivize schemes, a "substantial fraction" of oil exports would go to countries with no BCA nor any interest to incentivize such taxes. An individual oil importer cannot easily punish an OE through a lower oil price. Incentives to implement oil extraction taxes must then be in the form of "carrots".

With complete export diversion of the goods considered in section 2, BCA would be rendered ineffective as a mechanism for incentivizing carbon taxation in exporting L countries. We wish to find out whether similar results apply to the oil market, or whether there for that market exist alternative incentive mechanisms with our desired impacts.

Another important point is to study policies that directly affect *the fossil-fuel (FF) supply side*: their impacts, and whether they can be incentivized by BCA-type policies. We may distinguish between cases where OEs implement *export taxes*, and *oil extraction taxes*. While the former has mainly demand-side impacts, oil extraction taxes are a supply-side policy instrument. Previous research has shown that imposing oil export taxes is an efficient policy for a large oil-exporting bloc (such as the OPEC; see e. g. Wirl 1995; Strand 2013; Karp et al 2016). A limitation on oil export taxes is however that they do not tax the OEs' own FF consumption, something that oil extraction taxes do. This should be an important part of a global GHG mitigation policy agenda (see Peszko et al. 2020). Supply-side climate policy has recently gained traction in the research literature as an important, perhaps decisive, international climate policy tool; see Sinn 2008, Harstad 2012, Collier and Venables 2014, Eichner and Pethig 2017; see also Lazarus and van Asselt 2018 and Asheim et al. 2019 for overviews.

Oil extraction taxes are potentially more effective than oil export taxes for global GHG mitigation, as they also make domestic oil consumption more costly in FFR countries. Oil extraction taxes could however be more difficult to incentivize than oil export taxes. Cooperative agreements might be required, among OEs, among oil-importing countries with concern for global GHG emissions, and between the two groups. Such cooperation could work via both "sticks" (BCA or "Nordhaus taxes"; see Nordhaus 2015), and "carrots" (higher carbon tax revenues for OEs; preferential trade agreements; technical assistance related to renewable energy technologies). This has been argued and supported in simulations by Peszko et al. 2020, and Peszko, van der Mensbrugghe and Golub 2020. They find that it can make a large difference for long-run global GHG mitigation whether taxation occurs at the export or extraction level, as OEs' fossil fuel consumption and carbon emissions could remain highly excessive for a long future period with carbon taxes only on oil exports.[17] Extraction taxes can then be part of a global cooperative solution where H countries give up carbon tax revenues to oil exporters to incentivize oil extraction taxes.

### 3.2 Petroleum extraction taxes incentivized by oil price-related mechanisms

In Appendix 3 we present a model where oil extraction taxes by OEs are incentivized through a higher oil export price paid by H countries conditional on the oil extraction tax. This mechanism is however far from fully efficient, since the higher oil export price will partly undermine the very objective of the oil extraction tax, namely to constrain the OE's oil extraction.

While an oil extraction tax reduces the OE's oil output, we consider this reduction to be too small to change the world market oil price noticeably.[18] The H country would, ideally, aim to incentivize a "high" oil extraction tax, $t$, in the OE, and also set its own (domestic) carbon tax (or BCA), $q$, "on top of" the oil extraction tax. Appendix 3 however shows that the H country's preferred level of $t$ is lower than the H country's own unit carbon value.

### 3.3 Oil extraction taxes incentivized through support to non-carbon investments

If the deadweight losses from implementing oil extraction taxes can be compensated for OEs in other ways than through an oil price premium, the H country and OE could both be made better off. There are (at least) three ways in which such alternative support can be provided:

1) Direct (explicit) financial transfer from the H country to the OE
2) A price mark-up above the world market oil price on a limited (non-marginal) quota of oil exports from the OE to the H country
3) Financial support from the H country to alternative (non-fossil) energy investments in the OE, to replace FFs with renewable energy in the OE's electricity generation and fuel mix.

We exclude alternative 1 for political reasons; alternative 2 can also be politically and practically problematic. We focus on alternative 3 as most realistic. The H country in this case provides the

[17] For example, the aggregate oil consumption of the six Gulf Cooperation Council countries (the core of OPEC) is highly excessive, currently about 6.5 million barrels per day, or about twice the U.S. level on a per-capita basis.
[18] Another way to consider our assumption that the world market oil price does not change, is to consider that H countries at the same time implement carbon taxes. The two negative effects, lower supply and lower demand, will then counterbalance and could leave the global oil market price roughly unchanged.

OE with subsidies to investments in renewable energy to replace FFs in the OE's domestic energy input. This policy can in principle lead to removal of the net FF subsidy.

A different type of support to the OE could in principle be provided through a BCA mechanism of the type discussed in section 2. This would however require that the OE has a substantial export of energy-intensive industrial goods (apart from oil exports), something we have here ruled out. Most countries that rely heavily on oil exports have small exports from other sectors such as traditional manufacturing. This makes it difficult or impossible to apply traditional BCA mechanisms to incentivize carbon taxes in these countries.

When the OE's DWL is exactly compensated by renewables investment support, the H country will aim to incentivize an oil extraction tax $t$ in the L country equal to $v_{HS}$ (the H country's value attached to one carbon unit reduction in supply of FFs). The analysis of this case is presented in Appendix 3. We there show (under certain plausible assumptions) that an optimal solution which entails $t = v_{HS}$ can be incentivized, and how.

### 3.4 Further remarks and some unresolved issues

A question requiring broader discussion in this section is why and how oil-importing (H) countries with deep interest in climate policy can benefit from oil extraction taxes imposed and collected by OEs, instead of themselves setting sufficiently high (user) carbon taxes and reaping the higher tax revenues. We can think of at least two possible reasons. First, as already noted, oil extraction taxes impact also on the price and thus consumption and carbon emissions from oil consumption in OEs themselves. Neither carbon taxation in H countries nor oil export taxes in OEs can themselves incentivize lower FF consumption in the OEs.

A second reason is that imposing high domestic carbon taxes can be politically difficult even in climate policy-engaged H countries. It may be more politically convenient to let part of the "job" of FF taxation be left to others, including OEs. Taxes which serve to reduce the FF extraction in OEs, and/or raise the H countries' import prices of FFs, are less transparent to the public in H countries, and may more easily be argued to be out of control of their governments.

An issue not discussed is how the H country evaluates FF production versus consumption reductions. Equation (A20) in Appendix 3 contains both of these elements. It is not fully clear how they should be valued (which relates to the relative impact of more standard demand-side policies versus supply-side policies; see e g Lazarus and van Asselt 2018; Asheim et al. 2019). This issue is left for future research.

We have assumed that the OE can sell all its oil exports in a competitive market at a given export price *p*, defining the OE's "reservation utility". With closer to complete market coverage by the BCA-imposing countries, the OE's reservation utility may be reduced (through more effective "sticks"), thus perhaps also achieving more efficient solutions. Some such solutions are illustrated through simulations in Pezko, Mensbrugghe and Golub 2020.

## 3. Conclusions and final remarks

We have discussed two main ways in which carbon border adjustments (BCA) implemented by high-income (H) countries can be used to incentivize carbon taxation in lower-income (L) and oil-exporting (OE) countries. When BCA is implemented by H countries, and these taxes are rebated by L countries' own comprehensive carbon taxes, the L country will set the same comprehensive carbon tax rate when the BCA rate is "low", and rebating is conditional on such taxation by the L country. This "low" rate could in fact be \$30/ton $CO_2$ or even higher, far higher than the carbon tax level in any low-income country today. It is however lower when the BCA-taxed exports represent a very small share of the L country's total carbon emissions, which could result when there is a high degree of diversion of the L country's exports away from BCA-imposing countries, in response to the BCA.

When the BCA rate is higher, the domestic carbon tax rate in L countries is *reduced* when the BCA rate is increased. Such higher taxes however lead to tax revenues for H countries, which can be used to further incentivize carbon taxation in the L countries. We show that far higher carbon taxes can then be implemented in these countries; in plausible examples at least \$40-\$60/t $CO_2$.

We also study impacts of importers' BCA policies when these do not allow for tax rebating. No comprehensive carbon tax will then be incentivized in the L country given that no carbon tax revenues obtained by the H country are returned to the L country. When the entire tax revenue is returned and used to maximally incentivize carbon taxation in the L country, even higher comprehensive carbon taxes can be incentivized in the L countries; although the increase relative to the case with full return of tax revenues under rebating is small.

The paper also derives results for importing BCA-imposing (H) countries' optimal carbon and border tax levels. When an H country's combined carbon and border tax incentivizes both H country mitigation and L countries' carbon tax, the H country's own optimal carbon (and border) tax is higher than the H country's "value of carbon".

The second way in which "border taxes" can incentivize carbon taxation (discussed in section 3) is by incentivizing taxes on extraction of fossil fuels, focusing on petroleum, at its source and imposed by oil exporters (OEs). A small OE typically lacks incentives to impose oil extraction taxes as this will discourage oil extraction and reduce the OE's extraction revenues, at least as long as most extraction activity is done by domestic producers. We show that taxation of oil extraction in small OEs can be incentivized by H countries through a mark-up on the price of their oil imports from these countries, where the respective OEs are rewarded by an oil export price (or imposed a negative tax) which increases (by less than one-on-one) in the oil extraction tax, and where the OE is compensated for the (deadweight) loss suffered when implementing the extraction tax.

Such a scheme is however inefficient as the oil price mark-up incentivizes higher oil production which counters the intended impact of the extraction tax, to discourage oil extraction. A better solution is to compensate the OE's utility loss (DWL) in other ways. A particularly suitable scheme is via financial and/or technical support to non-carbon energy investments in the OE. We rule out direct financial transfer schemes to OEs as politically difficult or unsuitable as these are typically not (very) poor countries.

A fundamental difference between the approaches in sections 2 and 3 relates to the nature of goods subject to border and other taxation in the two cases. Regular BCA taxation of imports from L countries is mainly aimed at industrial goods competing on international markets, where importers often retain established customer relations with exporter countries even with (moderate or even high) border taxes on these imports. For FFs (in particular oil) it is different. Petroleum is a virtually homogeneous good which can be sold at a competitive world market price. The importer cannot readily under-pay for oil through border tax schemes. A scheme to incentivize an oil extraction tax must mainly work through a "carrot" which provides additional benefits to the OE; this lies behind our scheme discussed in section 3, and presented in more detail in Appendix 3.

Also for industrial goods there are likely to be limitations on the scope for border taxation. When BCA is used by only some countries (such as the EU) and not by others, a substantial share of the initial exports to the BCA-imposing region may be diverted to other importers. This weakens the scheme's ability to incentivize comprehensive carbon taxes in the L countries.

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**Appendix 1: Case c in section 2: Carbon tax in the L country needs to be imposed on only the export sector for the L country to earn the full rebate**

Our main case b in section 2 implies that the entire L economy is required to impose the same carbon tax for the L country's exported to be BCA rebated by the import country. An alternative and less drastic case is our case c, where only the energy-intensive sectors (producing for export; or geared toward export) need to be subject to a domestic carbon tax, for the L country to benefit from BCA tax rebating. The difference from case b is that the L country is now allowed to constrain its carbon tax to the export sector, and does not need to impose it on the rest of the economy. One easily sees that case c is more advantageous for the L country than case b (with uniform and economy-wide domestic carbon taxation).

Then conditions (9) and (11), valid for case b, are altered in case c as follows, for the case of "high" $q$ levels:

(A1) $$q_{L1} = \frac{\sigma}{1-\sigma}(1-p-q)$$

(A2) $$q \geq \sigma(1-p) \equiv q_1 .$$

The L country's carbon tax, $q_{L1}$, is now higher since the share of the taxed sector that is subject to border taxation is greater ($\sigma$, versus $\rho\sigma$ in the previous case). There will now be no carbon tax in the sector which produces for domestic consumption only. The cutoff point $q_1$, above which $q$ is "high", is now also higher.

Total mitigation in the L country is now (given that (11) holds and $q$ is "high")

(A3) $$M(q;q_{L1}) = \frac{1}{\gamma}\rho[\sigma q + (1-\sigma)q_{L1}] = \frac{\rho\sigma}{\gamma}(1-p) .$$

When $q$ is "low" ($q < q_1 = \sigma(1-p)$), mitigation is

(A4) $$M(q;q) = \frac{q}{\gamma} < \frac{1}{\gamma}\rho\sigma(1-p) .$$

Economy-wide mitigation in the L country is now the same as in (12) with an economy-wide carbon tax, as long as (A2) holds. GHG mitigation will now be greater in the part of the export sector not subject to BCA (as the carbon tax will be higher), but there will now be no mitigation in the domestic sector.

Note that (A2) is a stronger condition than (11) for the case of a nation-wide carbon tax. When $q$ is between the constrained levels (11) and (A2) ($q_0 < q < q_1$), total mitigation will be less in this case, as the mitigation level from (A4) will be lower than that from (13).

Thus when the H country has set a border tax in between the levels $q_0$ and $q_1$, constrained optimal economy-wide mitigation in the L country will be greater when there is a carbon tax in the entire economy, than when the carbon tax is constrained to the export sector only.

## Appendix 2: Less than full rebate of BCA tax in section 2

Consider a case where the amount of rebate (tax reduction) for the L country with respect to its export border tax, when the L country itself implements a comprehensive carbon tax of $q_L$, is not the entire border tax charged to exports, but instead only a fraction $\tau$ (between zero and one) of the border tax (where $Q_L$ is the amount of border tax on exports rebated):

(A5) $$Q_L = \tau \frac{\rho\sigma}{\gamma}(1-p-q)q_L .$$

To derive the welfare level for the L country in this case, the original equation (7), describing the welfare level in the full-rebating case (which is basis for maximizing the L country's comprehensive tax level $q_L$) is now modified as only a share $\tau$ of the BCA level on exports is rebated to the H country:

(7b) $$W_L(q_L) = \frac{1}{2\gamma}\left[\rho\sigma(1-p-q)(1-p-q+2\tau q_L) + (1-\rho\sigma)(1-p-q_L)(1-p+q_L)\right].$$

The only difference from (7) lies in the coefficient $\tau$ in the first main expression on the right-hand side. This captures the impact of the tax rebate on welfare for the L country, which must be reduced.

Maximizing (7b) with respect to $q_L$ yields:

(9a) $$q_L = \tau \frac{\rho\sigma}{1-\rho\sigma}(1-p-q) \text{ (for } q \geq q_0\text{)}.$$

The highest level of $q_L$ that the L country can achieve in this case, $q_0$, is now

(11a) $$q_0 = \frac{\tau\rho\sigma}{1-(1-\beta)\rho\sigma}(1-p).$$

We find that the comprehensive carbon tax $q_L$ is in this case simply proportional to the rebating share $\tau$. The cutoff point $q_0$ between "low" and "high" BCA levels is a slightly more complex function; although $q_0$ always increases in $\tau$.

We thus find, as expected, that both $q_L$ (the actual implementable tax level in the L country) and $q_0$ (the highest possible L country tax level with no return of tax revenue) are both increasing functions of $\tau$.

Note also that for $q > q_0$, the amount of border tax collected by the H country is (inserting from

(10a) $$T = \left[q - \tau^2 \frac{\rho\sigma}{1-\rho\sigma}(1-p-q)\right]\frac{\rho\sigma}{\gamma}(1-p-q).$$

This formula generalizes the tax revenue formula (10), for $0 < \tau < 1$. It also provides a basis for calculating the highest achievable comprehensive carbon tax rate in the L country when tax revenues are returned, similar to (21).

In the special case of $\tau = ½$ ("midpoint rebating") we have

(9b) $$q_L = \frac{1}{2}\frac{\rho\sigma}{1-\rho\sigma}(1-p-q) \text{ (given } q \geq q_0)$$

(11b) $$q_0 = \frac{\rho\sigma}{2-\rho\sigma}(1-p).$$

It is clear that solutions to cases with $\tau$ between zero and one result in outcomes for implemented carbon taxes for L countries, which for the L country are worse than under full rebating, and better than under pure crediting. In terms of the possibility to implement carbon taxation in the L country with full return of the H country's tax receipts, this solution is also intermediate between the full rebating and pure crediting case.

We could otherwise study cases where a fraction $\tau$ of the BCA is rebated without any requirement for the L country to impose its own comprehensive carbon tax. The impact of this level of rebating will be to increase the welfare level of the L country, and forego any option to incentivize comprehensive carbon taxes in L countries. The policy would incentivize the L country to impose a carbon tax of *(1-τ)q* in the BCA-exposed sector only, to minimize the economic impact of the BCA on its own economy.

When H country tax receipts are in this case used to incentivize comprehensive carbon taxation in the L country, the highest possible L country tax is lower than with the comprehensive tax requirement in the L country.

**Appendix 3: Modeling oil extraction taxes**

Consider a base case in Section 3, with no co-benefits nor climate benefits for OE countries, and with a similar economic structure as L countries in section 2, with basic domestic economic structure (apart from the oil-producing sector) defined by (1). Assume also that OEs only export oil, and that they only implement oil extraction taxes, applied to the OE's aggregate oil extraction. We assume (with a small OE implementing the oil extraction tax) that this tax does not affect the world market oil price.[19] Oil producers then simply pay *tR* in taxes to their own government. No other taxes are charged in the OE, and domestic consumers still face an oil price of *p*.[20]

Oil producers in the OE face a periodic production/extraction profit function[21]

(A6) $$\Pi = (p-t)R - \alpha R - \frac{1`}{2}\beta R^2 - T\ ,$$

where *Π* = net profit or return from oil extraction, *R*. *p* is the oil price assumed independent of *R*, *t* is the carbon tax on oil extraction, *α* and *β* are fixed parameters in the OE's periodic oil extraction

[19] This is a simplified presentation as the "basic oil price", *p*, is here considered to remain constant. When the policies in question involve the entire oil market, *p* will be endogenous and increases in response to wellhead taxes (which reduce supply), and is reduced in response to general carbon taxation (*q* set by H countries, which reduces demand). The net impact on *p* is then unclear but is generally not zero. The fact that *p* is generally impacted however has little impact on the quality of this analysis.
[20] Appendix 3 discusses an alternative case where the domestic sector in the OE is required to face the (higher) country's oil export price. This leads to a higher deadweight loss for the OE, but also more GHG mitigation.
[21] This formulation is highly simplified and somewhat unrealistic as it does not consider oil as a limited and exhaustible stock resource. This is however not crucial for our main analytical discussion here.

function, and $T$ comprises corporate taxation of petroleum companies (assumed independent of $R$).[22] Maximizing profits with respect to the oil extraction rate $R$ yields

(A7) $$\frac{d\Pi}{dR} = p - \alpha - t - \beta R^2 = 0 \Leftrightarrow R = \frac{p - \alpha - t}{\beta}.$$

An oil extraction tax $t$ applied by the OE will then reduce the country's oil extraction by $t/\beta$.

The country's welfare level will change in the following way by the oil extraction tax (where *W(t)* and *W(0)* are welfare levels for the country given oil extraction taxes $t$, and 0, respectively):

(A8) $$\Delta W = W(t) - W(0) = \frac{1}{2\beta}[(p - \alpha - t)(p - \alpha + t) - (p - \alpha)^2] = -\frac{t^2}{2\beta}.$$

This is the welfare loss (DWL) that cannot be avoided, sustained even when oil extraction tax revenues are fully recovered by the OE. Thus, in a fully non-cooperative case, a (small) OE would not have incentives to implement an oil extraction tax $t$ under these assumptions. Some sort of cooperative arrangement is required, where the OE is compensated for the welfare loss in (A8).

Ignoring local climate benefits and co-benefits, we can consider possibilities for OEs to join a coalition of countries to engage in active climate policy, where OEs impose oil extraction taxes, and oil importers a) reward oil extraction tax implementation by OEs through preferential trade agreements (involving BCAs); and b) implement their own carbon taxes on oil consumption.

Oil exports from an OE will then be

(A9) $$R_E = R - R_D = \frac{p - t - \alpha}{\beta} - \frac{1 - p}{\gamma}.$$

There is in this case no extra DWL due to oil consumption in the OE, so that all DWLs are still given by (A8). Total welfare for the OE, before any policy is applied by the H country, is

(A10) $$W(t) = \frac{(p - \alpha)^2}{2\beta} - \frac{t^2}{2\beta} + \frac{(1 - p)^2}{2\gamma}.$$

[22] Alternatively, the corporate tax on oil extraction companies could be considered as a fixed share of profits and then also not considered to affect $R$. This would however here not be a mechanism for reducing oil extraction on which we are focusing here.

The first and third terms on the right-hand side are the net welfare levels from the oil and domestic productive sectors with no carbon taxes. The second term is the DWL from the oil extraction tax, from (A8). Welfare is thus affected only through this tax, in this simple way.

If only a small share of global oil exports is subject to BCA, the world market oil price will not be noticeably affected by the extraction nor border taxes in question. To incentivize OEs to set comprehensive oil extraction taxes, note that these OEs cannot be made worse off than when diverting their oil exports to other countries with no carbon or border taxes. Such an incentive scheme must be subject to two well-known constraints from principal-agent and contract theory (Salanié 1997):

- A "participation constraint" which says that the OE must receive at least as high utility when implementing oil extraction taxes as when it does not.
- An "incentive constraint" whereby the OE must have incentive to implement a level of the oil extraction tax which corresponds to a target which is (constrained) optimal for the BCA-implementing (H) country or bloc.

These constraints are built into the implementation mechanism designed by the H country, considered below.

**OE behavior**

Assume that the H country has set a fixed "border tax" $z > 0$, imposed on its oil imports, which is reduced according to the level of the oil extraction tax set by the OE. The BCA reduction facing the OE is assumed to equal $\theta t$, where $t$ is the oil extraction tax, and $\theta$ is a parameter between zero and one.[23] The oil price facing oil producers in the OE, net of extraction taxes, is then characterized by a linear incentive scheme, $p(NE) = p - t + \theta t - z$. The oil price obtained by the OE from exports is

(A11) $$p(E) = p - z + \theta t.$$

Oil extraction of the OE is then given by

[23] The BCA can here not be completely offset one-to-one by the border tax; this will be explained below.

(A12) $$R(NE) = \frac{p - z - (1-\theta)t - \alpha}{\beta}$$

The domestic (non-oil) sector in the OE buys oil in the international market at price p, considered exogenous. This price must be higher than the international market price for oil (to fulfill the participation constraint for the OE), so that $\theta t$ - $z > 0$. This case depends on conditionality with respect to domestic oil pricing policy in the OE.

The OE's welfare level associated with an oil extraction tax of $t$ can in his case be expressed as

(A13) $$\begin{aligned} W(NE) &= \frac{[p - \alpha - (1-\theta)t - z]^2}{2\beta} + \frac{(1-p)^2}{2\gamma} + tR(NE) \\ &= \frac{(p - \alpha + \theta t - z)^2}{2\beta} - \frac{t^2}{2\beta} + \frac{(1-p)^2}{2\gamma} \end{aligned}$$

The "baseline" welfare level for this OE is given by *W(0)*, found setting $t = z = 0$ in (A13). A necessary "participation constraint" for the OE (to be willing to impose an oil extraction tax) is $W(NE) \geq W(0)$, expressed as follows:

(A14) $$(p - \alpha + \theta t - z)^2 - t^2 \geq (p - \alpha)^2 .$$

The optimal solution for the H country implies equality in (A14). There is here no welfare loss for the domestic FF-consuming sector in the L country, which faces the exogenous world market oil price = $p$.

We wish to find the optimal oil extraction tax $t$ set by the OE under these premises. Maximizing (A13) with respect to $t$ yields:

(A15) $$t = \frac{\theta}{1-\theta^2}(p - \alpha - z) .$$

When $\theta > 0$ and $p$-$\alpha$–$z > 0$, there are gains for the OE from setting a positive oil extraction tax $t$, as a higher $t$ results in a higher export price for the country's oil exports to the H country (assuming here that the OE's entire oil exports go to this H country). This gain is linear in $t$, while the DWL (due to inefficiently low oil extraction) is quadratic in $t$. A higher $\theta$ implies that the linear gain is greater, and the optimal wellhead tax is then also greater.

Using (A15), (A14) can be simplified to yield the following condition for *z*:

(A16) $$\frac{(p-\alpha-z)^2}{1-\theta^2} \geq (p-\alpha)^2 \Leftrightarrow z \leq (1-\sqrt{1-\theta^2})(p-\alpha).$$

When solving for *z*, from (A15) and (A16), *t* can be expressed in terms of *θ*:

(A17) $$t = \frac{\theta}{\sqrt{1-\theta^2}}(p-\alpha).$$

**Optimal H country strategies**

Welfare for the H country is:

(A18) $$W(H) = R(H) - \frac{1}{2}\gamma_H R(H)^2 - (p+q-z+\theta t)R(H) + T(H) + \frac{q-z+\theta t}{\gamma_H}v_{HD} + \frac{z+(1-\theta)t}{\beta}v_{HS}$$

Here *T(H) = qR(H)* is net carbon tax revenue for the H country, *p* is the world-market oil price, and *θt-z* is the net additional unit oil provision cost for the H country due to a higher than world market price on oil imports from the OE. (A18) distinguishes between the value to the H country of reduced GHG emissions due to reduced fuel demand ($v_{HD}$), and to reduced supply ($v_{HS}$).[24] The oil consumption by the H country, *R(H)*, is determined by the private sector in the H country and found from maximizing the three first terms in (A18):

(A19) $$\frac{dW(H)}{dR(H)} = 1-\gamma_H R(H) - (p+q-z+\theta t) = 0 \Leftrightarrow R(H) = \frac{1-p-q+z-\theta t}{\gamma_H}.$$

The two last terms in (A18) comprise reductions in carbon emissions due to reduced oil extraction and consumption: first, reduced oil consumption in the H country; and second, reduced oil production in the OE.[25] Using (A19), inserting for *R(H)* we obtain:

(A20) $$W(H) = \frac{(1-p+z-\theta t)^2 - q^2}{2\gamma_H} + \frac{q-z+\theta t}{\gamma_H}v_{HD} + \frac{z+(1-\theta)t}{\beta}v_{HS}.$$

[24] Note that a unit reduction in both demand and supply will lead to a unit reduction in actual emissions. It is not immediately obvious what are the individual contributions from demand and supply to this unit value.

[25] It is unclear whether one can simply add these impacts in terms of value: this we come back to below.

The optimal net carbon tax for the H bloc is found by maximizing (A20) with respect to $q$. This yields the familiar condition

(A21) $$q = v_{HD}\,.$$

The OE determines $t$ according to (A15), with $z$ given from (A16). The change in welfare for the H country, as a result of incentivizing oil extraction taxes in the OE, is

(A22) $$\Delta W(H) = \frac{t-(\theta t - z)}{\beta} v_{HS} - \frac{t^2}{2\beta}\,.$$

The first term on the right-hand side of (A22) is the value to the H country of the reduced oil extraction (and supply) by the OE. The second term is the DWL for the OE (related to its extraction sector) when its oil extraction tax is implemented, which must be compensated by the H country to fulfill the OE's participation constraint. This loss enters via (A14) (with equality). Maximizing (A22) with respect to $t$ yields

(A23) $$\frac{d\Delta W(H)}{dt} = \frac{1-\theta}{\beta} v_{HS} - \frac{t}{\beta} = 0 \Leftrightarrow t = (1-\theta) v_{HS}\,.$$

(A23) together with (A17) solve for $t$ and $\theta$, in a rather complex way. From (A17), $\theta$ must be between zero and one; thus the optimal $t$ from (A23) is less than $v_H$. The derived mechanism for compensating OEs can then only incentivize a lower than efficient oil extraction tax. The higher oil export price works in part to undermine a main objective of the oil extraction tax, to serve as a "supply-side" climate policy by reducing OEs' oil extraction by lowering the net oil price to its producers. It would have been preferable to use other mechanisms to incentivize the oil extraction tax, either independent of oil extraction, or (better) to more directly discourage oil supply and demand, such as support to alternative energy development.

Note that a small $\beta$ relative to $\gamma$ implies that domestic FF consumption is small relative to FF exports for the FFR country. $\gamma_H$ is the equivalent demand parameter for the H country. For all these parameters, market size is proportional to respective inverses.

The scheme discussed here can also be politically difficult to implement. It is politically problematic to provide 'subsidies" to oil exports by supporting their oil export price, as payment for a "service" (the OE implementing extraction taxes). Other (and poorer) countries can probably better claim the right to subsidies from H countries.

**Support to renewables investments for OEs to incentivize oil extraction taxes**

Consider incentivizing oil extraction taxes in OEs based on H country support to OEs' renewable energy investments, to replace these countries' fossil fuel-based energy generation and consumption with generation and consumption causing zero carbon emissions. Assume also that the entire cost of energy production from such facilities related to the initial investment cost. The H country provides renewables production capacity to the OE replacing a fraction $\phi$ of the OE's FF consumption with renewable energy: the new renewables investments simply "decarbonizes" a fraction $\phi$ of this use. With the OE's domestic sector represented by (1), present discounted savings for the OE are:

(A24) $$\Delta S(a) = p\left(\phi\frac{1-p}{\delta\gamma}\right).$$

The expression in parenthesis equals the discounted value of reduced FF consumption and carbon emissions for the OE, assuming a constant and common discount rate $\delta$.[26] In order to compensate the welfare loss from imposing the oil extraction tax, these savings must equal the DWL from imposing the tax:

(A25) $$\frac{\phi}{\delta}\frac{(1-p)p}{\gamma} = \frac{t^2}{2\beta}.$$

(A25) provides a solution for $\phi$ (given that such a solution exists for $\phi \leq 1$), the share of the L country's total fossil energy capacity that must be replaced by renewable energy capacity.

The implied amount of FF consumption reduction is here the same as the amount of mitigation incentivized in the OE for this country to be compensated for its deadweight loss from implementing the wellhead tax, and equals

[26] The discount rate $\delta$ is a flexible representation of these cost replacements and may incorporate factors such as increases or decreases in the oil price over time, and probabilities that the OE shifts to (complete or incomplete) non-fossil energy use. Incorporating this factor simply reflects the issue that renewables investments are likely to have lasting impacts on the OE's FF savings.

(A26) $$M(d)=\frac{\phi}{\delta}\frac{(1-p)}{\gamma}=\frac{t^2}{2\beta p}.$$

Consider costs and benefits to the H country from providing such amount of renewable energy investment support. With a relatively small amount of such investment volume we may consider the marginal cost as a constant, so that the H country's cost per unit of FF consumption replaced with renewable power generation capacity in the OE equals *c*.

When investment support is replacing the fuel subsidy, the H country faces a possible excess cost *c-p* related to phasing out one unit of FF consumption for the OE. It is then also clear that the H country's net benefit of such phase-out equals $v_{HD}$ – *(c–p)*, Thus when

(A27) $$c-p\le v_{HD},$$

it is beneficial for the H country to compensate the L country's deadweight loss related to implementing the wellhead tax, by subsidizing renewable energy investments in the OE, This leads to additional GHG mitigation by the OE, which comes in addition to the cost-saving impact (through lower FF consumption) of these renewables investments for the OE.

**Domestic FF consumption in the OE at the FF export price**

We will in the following briefly sketch how the solution above would differ when the OE, in order to receive oil price support from the H country in response to an oil extraction tax, is required to charge the supported oil price to its own oil consumers.

The welfare level of the OE can in this case be expressed as

(A28) $$W(NE)=\frac{(p-z+\theta t-\alpha)^2}{2\beta}-\frac{t^2}{2\beta}+\frac{(1-p+z-\theta t)^2}{2\gamma}.$$

The 'participation constraint", corresponding to (A18), is now:

(A29) $$\frac{(p-z+\theta t-\alpha)^2}{2\beta}-\frac{t^2}{2\beta}+\frac{(1-p+z-\theta t)^2}{2\gamma}\ge\frac{(p-\alpha)^2}{2\beta}+\frac{(1-p)^2}{2\gamma}.$$

There are here two additional terms (containing $\gamma$) which relate to domestic FF consumption in the OE, with and without the "border tax" rule. Maximizing (A28) with respect to $t$ yields:

(A30) $$t=\frac{\theta}{1-\frac{\beta+\gamma}{\gamma}\theta^2}\left[p-\alpha-z-\frac{\beta}{\gamma}(1-p+z)\right].$$

This condition is more complex than (A15), but similar. The solution for $t$ in (A30) is likely of a similar magnitude as in (A15), in particular when $\beta$ is small relative to $\gamma$ (domestic FF consumption is a small share of total oil extraction in the OE).

In (A30), $\theta$ (set by the H country group) cannot be close to unity, as the denominator must be positive and "not close" to zero. The OE can thus never be fully compensated, in terms of an increase in its oil export price, as response to a high oil extraction tax. This is logical: with full compensation for an imposed oil extraction tax in terms of higher oil export price, the extraction tax would do nothing to reduce the OE's oil extraction, which is here the very purpose of the oil extraction tax.

In this case, (A18) is replaced by the following condition:

(A31)

$$W(H)=R(H)-\frac{1}{2}\gamma_H R(H)^2-(p+q-z+\theta t)R(H)+T(H)+\frac{q-z+\theta t}{\gamma_H}v_H+\frac{z+(1-\theta)t}{\beta}v_H+\frac{-z+\theta t}{\gamma}v_H$$

We have here added one term relative to (A18), representing the impacts of carbon emissions reductions from domestic FF consumption due to higher domestic FF price in the OE.

(A20) is in this case replaced by

(A32) $$W(H)=\frac{(1-p+z-\theta t)^2-q^2}{2\gamma_H}+\frac{q+\theta t-z}{\gamma_H}v_H+\frac{z+(1-\theta)t}{\beta}v_H+\frac{\theta t-z}{\gamma}v_H.$$

The welfare change resulting from the oil extraction tax policy for the OE is:

(A33) $$\Delta W(H)=\frac{t-(\theta t-z)}{\beta}v_H+\frac{\theta t-z}{\gamma}v_H-\frac{t^2}{2\beta}-\frac{(\theta t-z)^2}{2\gamma}.$$

The difference between (A33) and (A22) is that a second and fourth terms are added on the right-hand side of (A33), representing added domestic mitigation in the OE, and an additional DWL due to reduced domestic FF consumption in the OE. The second term is positive while the fourth is negative. There is here an added benefit for the H country by reduced domestic FF consumption in the OE, but an added DWL to this country that must be compensated by the H country. The overall impact on optimal *t* is unclear and must be left for future study.

**List of acronyms and abbreviations used in the paper:**

BCA = border carbon adjustment

$CO_2$ = carbon dioxide

DWL = dead-weight loss

ETS = emissions trading system

EU = European Union

FF = fossil fuels

FFR = fossil-fuel rich (country or economy)

GHG = greenhouse gas

H (country) = high-income country

L (country) = lower-income country

LDC = least developed country

OE = oil exporter (= oil-exporting country)

OECD = Organisation for Economic Cooperation and Development

RBCF = results-based climate finance

WTO = World Trade Organization