POLICY RESEARCH WORKING PAPER 9443

Supporting Carbon Tax Implementation in Developing Countries through Results-Based Payments for Emissions Reductions

Jon Strand

WORLD BANK GROUP
Development Economics
Development Research Group
October 2020

Policy Research Working Paper 9443

Abstract

This paper discusses compensation mechanisms to strengthen incentives for lower-income countries to adopt carbon taxes through donor-funded support programs. The paper considers two cases: the provision of climate finance when the host country uses the additional mitigation to meet its own greenhouse gas mitigation target (the "incremental cost price"); and a transaction in an international carbon market with the mitigation credit created by host country mitigation transferred outside the country (the "opportunity cost price"). Both offset the host country's deadweight loss from imposing a carbon tax, which is lower when the host country enjoys large co-benefits from mitigation. Formulas are derived for the incremental cost price and the opportunity cost price. The opportunity cost price is always larger than the incremental cost price, as the host country under the opportunity cost price must use additional, more expensive mitigation policies to reach its mitigation target. The paper discusses additional costs and barriers that deter hosts from adopting carbon taxes. These arguments can help to explain why few low-income countries have so far adopted carbon taxes, and why the necessary compensation for tax adoption may exceed theoretical assessments.

This paper is a product of the Development Research Group, Development Economics. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://www.worldbank.org/prwp. The author may be contacted at jstrand1344@gmail.com.

Produced by the Research Support Team

Supporting Carbon Tax Implementation in Developing Countries through Results-Based Payments for Emissions Reductions[1]

Jon Strand

Consultant, Climate Change Group, the World Bank

Jstrand1344@gmail.com

JEL Classification Codes: H23; Q54; Q56

Key words: greenhouse gas mitigation; carbon taxation; deadweight loss; donor-supported tax implementation.

---

[1] The author thanks Gabriela Mundaca, Klaus Oppermann and Michael Toman for very helpful discussions and comments on previous versions of the paper, and the World Bank Climate Change Group for supporting this research. The author is solely responsible for the content of the paper.

Supporting Carbon Tax Implementation in Developing Countries Through Results-Based Payments for Emissions Reductions

1. Introduction

The focus of this paper is to define and interpret methodologies for determining the size of payments by donor countries needed to induce low-income (L, or host) countries to implement or enhance domestic carbon taxes. Our particular objective is to study how much is needed to pay per unit of induced mitigation, for L countries to be willing to adopt the respective additional, donor-supported, carbon taxes.

The background for this work is that the current level of greenhouse gas (GHG) mitigation activity in L countries is far lower than what is required to reach the main mitigation targets for the 2015 Paris Agreement (PA). Comprehensive carbon pricing in many countries may well be a necessary component of policies to reach that goal. Today few L countries have any form of carbon pricing, and even fewer have broad-based carbon taxes. We assume that there is interest from the donor community to increase incentives for L countries to adopt carbon taxation, and as needed, to compensate these countries when doing so. The rationale is that comprehensive carbon pricing is the most cost-effective way to achieve substantial and meaningful GHG emissions reductions at manageable cost (see Appendix 3 for a summary of the rationale). In particular, it is a necessary condition for achieving renewable energy transition with deep involvement of the private sector.[2] Carbon taxation can also be beneficial for L countries by raising sorely-needed tax revenues.

How much L countries need to be paid for adopting comprehensive carbon taxation is less clear. This paper aims to clarify that issue, by deriving expressions for measures of the direct economic costs imposed on host countries when they implement comprehensive carbon taxation. Our discussion will focus mostly on factors explained by traditional economic theory, i.e., deadweight losses lowering production and consumption, but it will also recognize that other (more politically-oriented) factors and issues can play a major role for many L countries.

---

[2] See discussion in World Bank 2019a, and Strand 2020; see also an extensive literature which includes Acemoglu et al 2016, Aghion et al 2016, Cramton et al 2017, Tvinnereim and Mehling 2018, and Andersson 2019. A consensus in this literature is that comprehensive carbon taxation is necessary but not sufficient for “deep decarbonization”, which also requires support to renewable energy investments, in the L countries and globally.

There is reason to suppose that at least moderate rates of carbon taxation can provide net economic benefits for many lower-income countries (see Appendix 2). Why then have they not already implemented carbon taxes? The explanation likely involves political considerations. Like any other tax, a carbon tax redistributes resources in the economy, and it can be extremely difficult to achieve a sufficient degree of public consensus on those redistributional effects. They include both deadweight losses across the economy and sector-specific transition costs. In the real world these items are not as fungible as assumed in simple economic models.

This creates a case for external donor support of carbon tax implementation in developing countries even when domestic benefits exceed domestic costs at low tax rates, given an interest on the part of donors in increasing the size (for them and the world at large) of benefits from reducing risks of climate change. However, such support does not necessarily undo political barriers to tax implementation. Our focus here is on compensating for deadweight losses from carbon taxation, as these may be the most important barrier with moderate carbon tax rates.

To better characterize the compensation needed to offset those deadweight losses, two basic compensation formulas, or "price points", will be derived:

(i) The "incremental (marginal) cost price" (ICP). This is the price per ton of CO_2e, reduced in the host country in response to a supported incremental carbon tax, that is needed to be paid to the client country, to make the client accept the tax. A premise for the ICP is that the GHG mitigation induced by the supported carbon tax can be used for compliance purposes by the host country, toward its (not yet fulfilled) Nationally Determined Contribution (NDC) under the Paris Agreement (PA).

(ii) The "opportunity cost price" (OCP). This is the equivalent cost to the host country of implementing the donor-supported carbon tax, given that the supported tax *cannot* be used for compliance purposes by the host country toward its (not yet fulfilled) NDC. In this case, credit for the achieved emission reductions is transferred to other parties, and is not available for host NDC compliance. See World Bank 2020a for discussion.

Both price points *represent a minimum compensation to the host country for implementing a given amount of GHG mitigation, based on the additional carbon tax enabled in the host country by the respective carbon tax support program*. To repeat, the fundamental difference between the two price concepts is that while the first opens up for claiming this mitigation toward the host country's (unconditional) NDC, the second does not provide that option. It is then natural to presume that the OCP will be at least as high as the ICP; and that it is typically higher when the host country has not fulfilled its NDC before implementing a new program-supported carbon tax, and thus seeks donor-supported mitigation to meet its (not yet fulfilled) NDC.

We will also stress in what follows that the compensation principle stated in the previous paragraph is not the only possible principle for compensating the host country for implementing a carbon tax. Another compensation principle would be to let the payment depend (at least in part) on *the value for program funders of the resulting mitigation enabled by the supported carbon tax*. A presumption behind the supported action is that the value to program funders is at least as high as the implementation cost for the host, and usually higher, perhaps much higher. For example, when the supported increase in the host country's carbon tax is \$10 per ton of CO_2 e, the cost to the host country will typically be less than the amount of mitigation times \$10,[3] while the value to the program sponsor or financer(s) easily could be (at least) the amount of mitigation times \$40 or more, depending on what carbon price is optimal from a donor perspective. This indicates that there could be a substantial *net value surplus* for funders related to such program implementation. We will throughout assume that this surplus is retained by the institution which implements the program and the donor countries which support it. A logical justification is that the money available for such funding is limited, and that more projects can be implemented in host countries for a given budget (and more mitigation accomplished) within this budget when the "minimum cost" rule is retained.

When deriving price points as compensation to host countries for implementing carbon taxes, we abstract from administrative and political economy problems and costs. The latter costs, while real, are likely to be more country-specific and difficult to account for in a general way. In Section 6 we discuss how these factors will typically increase program implementation costs and thus also the ICP and OCP price points. One approach might be to add "policy costs" as a given multiple or mark-up on the basic economic cost; but this fraction would vary between countries.

---

[3] This is found from our derived formulas for the ICP, and in some cases for the OCP, in sections 2-4. The ratio of benefits to costs derived from our formulas does depend in part on the particular functional forms assumed in the analysis.

Another, even more fundamental, price point for compensating host countries when implementing comprehensive carbon taxes could be defined as the "development support price". Some countries may develop plans to implement their own comprehensive carbon taxes independent of knowledge about carbon tax support programs, and in principle could be willing to implement such taxes even without support. However, these countries might not have the capacity to develop and implement a carbon tax; or it may be politically difficult to do it on their own. The donor community might then want to provide the necessary funding to cover the host country's policy costs in order to overcome such barriers. Such a "development support price" ought to be lower (or at least no higher) than either of the two price points derived here.

We will in section 2 discuss the ICP and OCP in the most basic cases. We will revert to more general discussion of the ICP in section 3 for our main case, where the host country's NDC is not yet fulfilled. A more general discussion of OCP follows in section 4. Section 5 uses basic data on specific countries to calculate illustrative compensation amounts using our price formulas.

The concepts of "unconditional" and "conditional" NDCs are useful for understanding the issues considered in the paper. While these concepts are not addressed in the Paris Agreement (PA) text, they are used by many PA signatories in their NDC documents submitted to the UNFCCC. The "unconditional NDC" is the target that a given country aims to attain by itself, without outside finance or technical assistance. The "conditional NDC" is assumed to require outside help for its achievement, and it is always as or more ambitious than the unconditional NDC plan. Note that for support to a lower-income host country for carbon tax implementation to be meaningful, the host country's unconditional NDC must be "real:" the target must at a minimum correspond to the host country's "business-as-usual" (BAU) emissions rate.

2. Price points for carbon tax implementation: Basics

2.1 The "incremental cost price" (ICP)

We will now derive rules for financial support per unit of induced GHG mitigation by a donor-supported carbon tax implemented in the host country, required for the host country to accept this carbon tax. We start with considering the ICP in the most basic and simple case. To recapitulate, the ICP assumes that the host country can use the resulting mitigation, induced by the supported carbon tax, toward fulfilling its unconditional NDC under the PA.

The most relevant case is here when the host country's unconditional NDC mitigation target has not yet been reached (the country's emissions level is higher than that target). We will, for simplicity, assume that the host country has imposed no other carbon tax before adopting the donor-supported tax, t_H.[4]

Assume that the welfare (net utility) level of the L country related to its fossil-fuel energy consumption, before adopting any carbon tax, can be expressed by the following quadratic function (from (3.1) in Strand 2020)[5]

$$W_L(0) = R_L - \frac{1}{2}\gamma R_L{}^2 - pR_L . \tag{1}$$

$W_L(0)$ represents host country welfare with no carbon tax in that country, R_L is the country's fossil fuel consumption, and p the (world) market price of fossil fuels. Maximizing (1) with respect to R_L yields the host country's optimal GHG emissions before implementing the carbon tax t_H:

$$\mathrm{R}_{L0} = \frac{1-p}{\gamma} . \tag{2}$$

From (1) and (2), the welfare level of the L country before receiving tax funding is:

$$W_L(0) = \frac{1}{2\gamma}(1-p)^2 . \tag{3}$$

Consider imposing the donor-supported carbon tax t_H in the host country. Given that the revenue from this tax is retained by the host government, the objective function representing private agents in the host country can be expressed as

$$W_L(t_H) = R_L - \frac{1}{2}\gamma R_L{}^2 - pR_L - t_H R_L . \tag{4}$$

(4) is maximized by private agents with respect to R_L to yield

---

[4] This discussion builds heavily on section 5 in Strand 2020, on transformational policy-based mitigation finance.

[5] This is a highly simplified representation of any actual such welfare function, and it can be expected to hold only over a relatively small domain for changes in fossil energy consumption (and carbon emissions). We are, in particular ignoring any "co-benefits", utility-enhancing for the host country itself, which will be considered later.

(5) $$\frac{dW_L(t_H)}{dR_L} = 1 - \gamma R_L - p - t_H = 0 \Leftrightarrow R_L = \frac{1-p-t_H}{\gamma}.$$

The GHG mitigation induced by the carbon tax t_H is the last term in the equation to the right in (5), and equals t_H/γ. The per-unit support paid to the host country per mitigated unit, for imposing a carbon tax t_H, is what we call the "incremental cost price" (ICP). We denote this by $\alpha_1 t_H$, where α_1 is a fixed coefficient (the "price point" parameter related to ICP). The total support, $Q_1(t_H)$, is given by this rate times the amount of mitigation induced by this tax:[6]

(6) $$Q_1(t_H) = \alpha_1 t_H \frac{t_H}{\gamma} = \alpha_1 \frac{{t_H}^2}{\gamma},$$

We will here study what value α_1 needs to take to make implementing this carbon tax attractive to the L country.

The support payment Q_1 is given from (6). Emissions are in this case assumed to be reduced to fulfill the country's unconditional NDC before (or jointly with) implementing the tax.

Welfare for the L country, including tax implementation support payments, is:

(7) $$W_{L1} = \frac{1}{2\gamma}[(1-p)^2 - {t_H}^2] + \alpha_1 \frac{{t_H}^2}{\gamma}.$$

The second term in the square bracket represents the pure allocation loss, or "deadweight loss" (DWL), associated with implementing the comprehensive carbon tax t_H in the host country. This is the net welfare loss that follows from the activity-reducing impact of the carbon tax on the host economy. Note that (7) does not include any environmental costs or benefits related to imposing this carbon tax.

We seek the value that α_1 must take for the host country to be willing to adopt a comprehensive carbon tax t_H, when GHG mitigation induced by this tax can be applied toward fulfilling the host country's unconditional NDC. The net gain for the host country is

---

[6] The result that the required ICP compensation is proportional to the square of t_H follows from the quadratic specification of (1), and (4). The" true" compensation formula may have other shapes; for example when using the Enerdata simulations as done in section 5, the compensation increases less rapidly in t_H.

(8) $$G_{L1} = \alpha_1 \frac{t_H^{\ 2}}{\gamma} - \frac{t_H^{\ 2}}{2\gamma}.$$

The first term on the right-hand side of (8) expresses support payments, from (6), while the last term is the DWL. The condition on α_1 for G_{L1} to be non-negative is[7]

(9) $$\alpha_1 \geq \frac{1}{2}.$$

This means that the host country will implement the additional carbon tax t_H if the host country is paid (at least) half the new carbon tax, t_H. multiplied by the amount of mitigation induced by this tax.

2.2 The "opportunity cost price" (OCP)

We next consider the second support price concept, the "opportunity cost price" (OCP), in its simplest form. The host country is now required to transfer the mitigation credit out of the country. We also assume that the host country has not yet fulfilled its unconditional NDC, and decides to use its own carbon tax, t_L, to achieve the NDC. It cannot use the mitigation induced by international financial support toward its NDC target, because in this case, the financial support comes with the agreement that the emission credit will be transferred out of the country. When applying the model introduced in section 2.1, the target (an NDC value maximizing host country welfare) would equal t_L/γ. Assume here that $t_H \leq t_L$ (the mitigation induced by the donor-supported domestic carbon tax does not over-fulfill the host country's NDC mitigation target). When the host implements its NDC mitigation target using its own carbon tax, t_L, and does not (yet) engage the supported carbon tax, t_H, its emissions level will be

(10) $$\mathrm{R}_{L2}(t_L) = \frac{1-p}{\gamma} - \frac{t_L}{\gamma},$$

and its welfare level is

(11) $$W_{L2} = \frac{1}{2\gamma}[(1-p)^2 - t_L^{\ 2}].$$

---

[7] This is identical to (5.8) in Strand 2020.

When the country now adopts the supported carbon tax of t_H *on top of* its own national carbon tax t_L, fossil-fuel consumption (and carbon emissions) in the host country is

$$R_{L2}(t_L + t_H) = \frac{1-p}{\gamma} - \frac{t_L + t_H}{\gamma}. \tag{12}$$

The host country's net economic welfare level, including the tax support, is now

$$W_{L2S} = \frac{1}{2\gamma}[(1-p)^2 - (t_H + t_L)^2] + \alpha_2 \frac{t_H^2}{\gamma}. \tag{13}$$

The condition for the host to accept the supported carbon tax is $W_{L2S} \geq W_{L2}$, which gives the following condition on the OCP compensation parameter (or "price point"), α_2:

$$\alpha_2 \geq \frac{2t_L + t_H}{2t_H} = \frac{t_L}{t_H} + \frac{1}{2}. \tag{14}$$

From (14), α_2 must equal 3/2 or higher (given $t_L \geq t_H$ as assumed). It must be at least three times as high as α_1, the ICP parameter from (9), which equals ½.

Stipulating that the donor-supported mitigation cannot be used by the host country for its own compliance purposes makes the necessary mitigation to reach its unconditional NDC target more expensive for the host country. OCP is (much) higher than ICP since the deadweight loss increases with the square of the (compounded) tax rate. The compounded carbon tax is in the OCP case increased to a level where the deadweight loss is much higher, as the total volume of mitigation is increased, and the unit cost per unit reduction in emissions is also higher.

2.3 Further comments

The ICP and OCP price points are both derived assuming that the host country aims to fulfill its unconditional NDC target. The basis for the ICP price point is the DWL from implementing the supported carbon tax, t_H; compensated via the ICP price point parameter, α_1, from (9).

The OCP price point is calculated assuming that the host country's NDC is fulfilled *at the expense of the host*. Compensation is then claimed on the basis of the DWL suffered when imposing the extra carbon tax, t_H, under this assumption.[8]

This leads to an asymmetry in the calculation of the two price points. For ICP, fulfilling the host's NDC requires compensation. This has intuitive appeal: the ICP reflects the cost of "helping" the host to reach its NDC target, fully or partially.

Under the OCP, the host is not helped to reach its NDC target. The mitigation induced by t_H must now in its entirety go beyond the NDC target. The host can then be considered to first reach its NDC target *on its own*, and is donor-compensated only for the extra mitigation induced by the supported tax t_H. This compensation rate, represented by OCP, is found to be three times the host's cost of simply reaching its NDC, represented by ICP.

3. The ICP: More general cases

In sections 3-4 we will analyze the two price points studied in section 2, the ICP and OCP respectively, using a more general model where we introduce "co-benefits" which make the host countries themselves more interested in and receptive to carbon taxation. In section 4, we will also consider cases with reduced return to additional mitigation for higher carbon tax rates.

We now assume that the host country intends to implement its unconditional NDC, possibly by setting a national carbon tax, t_L, but this is not yet implemented when adopting the program-supported carbon tax. The welfare (net utility) function for the L country, replacing (1), is

$$W_L(v_L) = R_L - \frac{1}{2}\gamma R_L{}^2 - (p + v_L)R_L \,. \tag{1a}$$

v_L is a negative externality related to fossil-fuel consumption in the host country, implying a "co-benefit" related to its carbon mitigation. Given competitive markets, the optimal carbon tax set by this country will equal v_L. The host country's emissions level before facing the supported carbon

---

[8] It is immaterial whether the host's mitigation policy instrument (its carbon tax t_L) is imposed before or after the program-supported tax (t_H), as the deadweight loss follows from the compounded effect of $t_L + t_H$.

tax and before imposing any carbon tax of its own is given by (2). Assume in this case $t_H \geq t_L$; the donor-supported carbon tax, t_H, is sufficient to implement the host's NDC.

From (1a) and (2), the welfare level of the L country is, before implementing the carbon tax t_H and receiving the corresponding program funding:

(3a)
$$W_{L3} = \frac{1}{2\gamma}[(1-p-v_L)^2 - (v_L)^2].$$

The carbon emissions of the L country after imposing this additional tax are

(4a)
$$\mathrm{R}_{L3} = \frac{1-p}{\gamma} - \frac{t_H}{\gamma}.$$

The support per unit of induced mitigation as a "reward" to the host country for imposing a carbon tax at level t_H, is $\alpha_3 t_H$, where α_3 is the ICP price point in this case, considered as fixed by the host. The ICP is assumed to be set as a given ratio to the supported carbon tax t_H implemented in the host country. The total support to the host, $Q(t_H)$, is

(6a)
$$Q(t_H) = \alpha_3 t_H \frac{t_H}{\gamma} = \alpha_3 \frac{{t_H}^2}{\gamma},$$

where t_H/γ is the amount of induced mitigation. The host's utility level when implementing t_H is

(7a)
$$W_{L3} = \frac{1}{2\gamma}[(1-p-v_L)^2 - (t_H - v_L)^2] + \alpha_3 \frac{{t_H}^2}{\gamma}.$$

The net gain to the host country from receiving carbon tax implementation support is

(8a)
$$G_{L3} = \alpha_3 \frac{{t_H}^2}{\gamma} - \frac{1}{2\gamma}\{(t_H - v_L)^2 - (v_L)^2\}.$$

From (7a), the net DWL, represented by the last main term in the square bracket, is smaller than the corresponding loss in section 2, from (7). The reason is that now the host enjoys certain co-benefits when implementing the new carbon tax, which were assumed not to be present in section 2. G_{L3} in (8a) is non-negative when

(15)
$$\alpha_3 \geq \frac{t_H - 2v_L}{2t_H}.$$

When $v_L > 0$, (15) gives a lower value for α_3 than (9) in the "base case" without co-benefits to the host. Intuitively, the optimal solution for the host, with no program-supported carbon tax t_H imposed, would be to select an own carbon tax $t_L = v_L$, with a mitigation level v_L/γ. When this tax is not imposed, there is a welfare gain for the host from implementing a carbon tax. This welfare gain is optimized when the donor-supported carbon tax t_H equals v_L (and the gain is exactly eliminated by having $t_H = 2v_L$). This leads to a negative α_3 when $t_H < 2v_L$. There is then no DWL that needs to be compensated for the host in order to accept the supported carbon tax t_H.

We have in this section assumed that the host has not yet implemented its NDC when adopting the donor-supported carbon tax t_H. The host then gets "help" to implement its NDC by the tax implemented under the support program. We have before discussed whether receiving support in this fashion is appropriate. Here the case is "worse" as the host has a direct welfare gain from having the supported tax, t_H, imposed, as co-benefits are then being reaped.

An alternative case is where the host's NDC has already been implemented by the host before accepting t_H. When the NDC is already fulfilled, there is no need for access to a supported carbon tax for such fulfillment, and such access has no value to the host. In this case α_3 will be higher, at least ½ given $t_L \geq v_L$. We will not analyze this case further as the ICP price point is presumed to depend explicitly on access to crediting of the mitigation achieved by t_H.

When co-benefits are high, the host country has incentive to mitigate on its own (e. g. by setting its own carbon tax t_L) before t_H is implemented. But this does not necessarily imply that a host will accept a carbon tax t_H without any economic compensation, even when the resulting mitigation can be used by the host toward NDC fulfillment, and GHG mitigation implies substantial co-benefits for the host. If that were the case, many hosts would have already implemented carbon taxes; while hardly any developing country has done so to date. Carbon pricing in the absence of financial support can be non-optimal, due to strategic behavior of the host country, or other factors (see section 6). We will claim that underpricing of carbon emissions by host countries is relevant, and more so when donor-supported tax implementation programs exist.

4. The OCP: More general cases

We will now consider a model for the OCP which is more elaborate than that presented in section 2.2. First, we assume as in section 3 that the host may enjoy co-benefits from mitigation. Secondly, the host may now face decreasing returns to mitigation when implementing both its NDC with a domestic carbon tax, and the additional supported carbon tax. The type of cost increase focused on here is that the host is not able to apply an additional carbon tax to the entire economy, but instead to only a fraction of it (or to only particular sectors).

When the host country has not (yet) implemented any mitigation beyond its BAU level, carbon emissions after implementing t_H will be

$$\mathrm{R}_{L4} = \frac{1-p}{\gamma} - \frac{t_H}{\gamma}. \tag{16}$$

The host country needs to fulfill its NDC, and mitigation induced by t_H cannot be credited toward that target. The host country's NDC mitigation target (involving only credited mitigation) is still given by (2), implying that required mitigation toward that target is t_L/γ. Assume that $t_H \leq t_L$ (mitigation induced by t_H is not or exactly sufficient to fulfill the host country's NDC target).

One realistic scenario is that the host may not have available sufficient "cheap" mitigation alternatives for implementing its entire NDC mitigation, when it adopts a carbon tax (t_H) whose mitigation impacts cannot be credited. One problem could be (strongly) decreasing returns in mitigation with rising ("non-transformative") carbon pricing, as "low-hanging fruits" are reaped first (upon implementing t_H) and are limited. The host country may also have political difficulties to get backing for additional and comprehensive carbon taxation (adding to t_H), and may then need to resort to more expensive mitigation alternatives.

We represent this problem in a slightly different way, by assuming that mitigation toward NDC fulfillment for the host country is limited to a subset of sectors which represent a fraction $\lambda \leq 1$ of the host country's total mitigation potential. For analytical simplicity we then assume that all sectors have the same basic economic structure. Welfare due to the sector in which mitigation can be performed can be represented by the following welfare function, modifying (1):

$$W_M = R_M - \frac{1}{2\lambda}\gamma R_M{}^2 - (p + v_L)R_M. \tag{17}$$

R_M represents carbon emissions from the sector in which mitigation toward the host country's NDC takes place. We represent mitigation in this sector by a sufficiently high carbon price t_M to implement the host country's NDC target. Private utility stemming from this sector is

(18) $$\Pi_M = R_M - \frac{1}{2\lambda}\gamma R_M{}^2 - (p + t_H + t_M)R_M \, .$$

The private sector in the host country maximizing (18) with respect to R_M yields

(19) $$\mathrm{R}_M = \frac{\lambda}{\gamma}(1 - p - t_H - t_M) \, .$$

The amount of mitigation toward the country's NDC is $\lambda t_M/\gamma$, while the mitigation required for the NDC is t_L/γ. NDC implementation then requires a marginal mitigation cost equal to $t_M = t_L/\lambda \geq t_L$, in the implementing sector.

Social welfare for the host country is now affected by t_H, and t_L, in the following way:

(20) $$W_{M4} = \frac{1}{2\gamma}\left[(1 - p - v_L)^2 - \lambda\left(\frac{t_L}{\lambda} + t_H - v_L\right)^2 - (1-\lambda)(t_H - v_L)^2 \right].$$

This utility for the host country must be compared to utility given that no support is provided. To derive the latter utility expression, assume that the host country would have available the option to set its own carbon tax t_H (for complete or partial implementation of its NDC), and resort to more expensive mitigation beyond that tax level. This means that an additional carbon tax in the mitigating sector would need to be increased by $(t_L - t_H)/\lambda$ in order to implement the NDC. Welfare for the host country would be, in the absence of tax implementation support:

(21) $$W_{M4} = \frac{1}{2\gamma}\left[(1 - p - v_L)^2 - \lambda(\frac{t_L - t_H}{\lambda} + t_H - v_L)^2 - (1-\lambda)(t_H - v_L)^2 \right].$$

The only difference between (20) and (21) is that mitigation induced by the supported carbon tax cannot be used for crediting toward the host country's NDC in the former case, while such crediting would be allowed in the latter case.[9] Note that we now assume $t_L \geq t_H$. The key problem here is not that the supported carbon tax, t_H, is higher than (ideally) desired, but that the resulting mitigation cannot be claimed toward the host country's NDC fulfillment. We find the following expression for the total welfare impact of implementing the supported carbon tax t_H in this case:

---

[9] The host country is here thus always allowed to implement a comprehensive carbon tax t_H, but never any higher fully comprehensive carbon tax.

(22) $$G_{M4} = \alpha_4 \frac{t_H^{\,2}}{\gamma} - \frac{t_H}{2\gamma}\{\frac{2t_L - t_H}{\lambda} + 2(t_H - v_L)\}.$$

The condition for the carbon tax including its support to be acceptable for the host country is now:

(23) $$\alpha_4 \geq \frac{1}{2t_H}\left[\frac{2t_L - t_H}{\lambda} + 2(t_H - v_L)\right].$$

(23) generalizes (14) in section 2.2 in two ways, by adding two new parameters, λ and v_L When $\lambda = 1$ and $v_L = 0$, α_4 coincides with α_2 in (14). $\lambda < 1$ and $v_L > 0$ are however relevant here. Then $\alpha_4 > \alpha_2$ in most relevant cases, and more so the lower λ is.

α_4 depends on four parameters, t_L t_H, v_L and λ. Consider first a simple example where $t_L = t_H = v_L$, and $\lambda = ½$. In this case, (from (15)) $\alpha_3 < 0$, while $\alpha_4 = 1$. Setting $\lambda = ½$ might appear as a reasonable example: a part of the host country's economy with half of its total carbon emissions can be used for local mitigation purposes through carbon taxation. (This corresponds approximately to the share of coverage of the EU-ETS in Europe.) The NDC target is then optimal to reach for the host; and donor-supported mitigation is exactly sufficient to fulfill the host's NDC target.

When instead $\lambda = ½$ and $v_L = 0$, $\alpha_4 = 2$, four times the price point for ICP, which is ½.

When $\lambda = 1$, and $t_L = t_H = v_L$, $\alpha_4 = ½$, while the ICP price point from (15) is negative.

To sum up, α_4 is always higher than the ICP price point, α_3. a_4 applies when the host does not have available a fully efficient and comprehensive carbon tax (economically, or politically), on its own for implementing its unconditional NDC, but must instead resort to more expensive mitigation opportunities.

Three further issues need mention. First, our basic results in this section do not depend on the host country needing to apply carbon taxation to fulfill its unconditional NDC. Various other policies (c-a-t schemes covering the relevant sectors; direct purchase of emissions reductions) have the same fundamental effect.

Secondly, in deriving α_4 we assume maximal efficiency of implemented mitigation in a share λ of the host economy. When efficiency is lower (as is likely when carbon taxation is not available), the derived OCP would be even higher.

Thirdly, the OCP price point would increase also when there are (significantly) reduced mitigation opportunities in response to an increased carbon tax beyond the program-supported tax t_H. Reduced mitigation opportunities could occur in two ways: limitation on the sectors in which a carbon tax is allowed to be implemented; and reduced mitigation effectiveness at higher carbon tax levels. Both factors drive the carbon tax (required to fulfill the host country's NDC) and the OCP price point to higher levels.

Table 1 sums up the most important information related to the different price points for ICP and OCP. All figures express the fraction of the carbon tax that needs to be compensated to the host (for acceptance) that we seek. The figures in Table 1 give key numbers from the discussion, as our parametric assumptions correspond to those we already have used. The leftmost numbers column contains the results from the simplified case in section 2 (with no co-benefits, and $\lambda = 1$).

Table 1: Price points for ICP and OCP, different parameter combinations

Price point category	Mathematical formula for price point	Parametric assumptions*			
		$v_L = 0$, $\lambda = 1$	$v_L = t_H$, $\lambda = 1$	$v_L = 0$, $\lambda = ½$	$v_L = t_H$, $\lambda = ½$
ICP	$\frac{t_H - 2v_L}{2t_H}$	**½**	0	½	0
OCP	$\frac{1}{2t_H}\left[\frac{2t_L - t_H}{\lambda} + 2(t_H - v_L)\right]$	**1.5**	½	2	1

*The figures in bold type represent our BAU or benchmark cases in section 2.

ICP is either ½, our benchmark from section 2; or lower, possibly zero, when there are significant co-benefits. OCP varies from ½ to 2 depending on parametric alternatives. It can be either lower or higher than our section 2 benchmark, which is 1.5.

To conclude, when including only pure economic (DWL) losses, ICP is at most ½, and could be lower or even zero. OCP can be lower or higher than its benchmark level of 1.5, depending both on co-benefits and on possible inefficiency in mitigation beyond implementing t_H.

5. Implementing the pricing formulas: Some illustrative examples

In this section we consider a few examples of how our formulas can be applied in practical cases. The examples considered here are for Mexico, Chile, Ukraine, Romania and Bulgaria. We stress that the calculations do *not* represent normative assessments of GHG mitigation policies in the countries named; they are *only* illustrative numerical examples.

We base our calculations on the Enerdata data set MAC, which was set up to project mitigation implications of carbon taxes introduced at particular future dates.[10] Our calculations are based on the "Enerbase" simulations created by Enerdata, where it is assumed that no climate policy is applied up to 2025 in these countries under business as usual (and where LULUCF emissions are ignored).[11] In our application of Enerdata, we consider two different carbon taxes in 2025, namely \$10 and \$20 per ton of CO_2 e. We phase in the carbon tax linearly over time: in the \$10 case, for example, the tax is zero in 2020, \$2 in 2021, \$4 in 2022, etc.

The Enerdata framework is somewhat broader than the simple static framework considered in Sections 2-4. The most important difference is that with the Enerdata approach, the quantity of mitigation resulting from doubling the carbon tax is less than double that from the initially chosen carbon tax. This reflects a presumption that a significant amount of "low-hanging fruit" can be harvested as mitigation outcomes at relatively low carbon taxes. In the model framework laid out in Sections 2-4, by contrast, mitigation outcomes are proportional to the implemented carbon tax. Similarly, in the conceptual model in Sections 2-4, support payments tend to increase with the square of the carbon tax rate, since a higher carbon tax leads to a proportionally higher mitigation rate. Since mitigation in the Enerdata simulations increases by less than the carbon tax, support payments grow more slowly than the square of the tax rate.

Table 2 gives figures for mitigation effected in the five sample countries, due to imposing a carbon tax which increases linearly by year, from zero today up to either \$10 or \$20 per ton CO_2e by 2025. Column 5 gives mitigation in 2025, relative to the BAU emissions rate in the same year, due to imposing these two alternative tax levels by 2025. The rightmost column gives the cumulative

---

[10] For reference to Enerdata and the data sets referenced, see the following website: https://www.enerdata.net/.

[11] The other relevant simulation alternative from Enerdata, called "Enerblue", assumes that certain climate policies have already been implemented by the host countries which reduces the mitigation scope from using carbon taxation, and this reduces the needed support. This alternative is not invoked in our calculations, but might have been the better alternative if the host countries in question had already started to implement (or were expected to implement) their NDCs before support would be received. They would also give lower overall payouts to hosts as the induced mitigation amounts are smaller.

amount of mitigation up to 2025, from gradually increasing the carbon tax over this period (in the $10 case, this annual tax will be zero in 2020, $2 in 2021, $4 in 2022, etc.).

Table 2: Emissions and mitigation due to alternative carbon tax rates imposed gradually from 2021 to 2025, in five selected countries, under the Enerbase simulation alternatives

(Million tons CO_2 e)

Country	Tax rate imposed by 2025	BAU emissions in 2025	Emissions in 2025 with carbon tax	Mitigation in 2025	Cumulative mitigation by 2025
Mexico	$10	678	662	16	35
	$20	678	654	24	53
Chile	$10	117.1	114.2	2.9	6.4
	$20	117.1	112.9	4.2	8.4
Ukraine	$10	289	276	13	29
	$20	289	271	18	40
Romania	$10	103.4	100.3	3.1	6.8
	$20	103.4	99.1	4.3	9.5
Bulgaria	$10	53.8	51.6	2.2	4.8
	$20	53.8	50.4	3.4	7.5

We next calculate the amounts of carbon tax implementation support implied by our two derived cost prices, the ICP and the OCP, using these figures as our alternative cases. A formula similar to (6) (based on the compensation parameter α times the applied carbon tax times the induced mitigation) can then be used to calculate the tax implementation support in any given year, including the last year, 2025. Given and our baseline price point values, $\alpha_1 = ½$ (for the ICP) and $\alpha_2 = 1.5$ (for the OCP), we arrive in Table 3 at a set of figures for tax implementation support in 2025.

Table 3: Tax implementation support payments in 2025 under the ICP and OCP, by host country and carbon tax alternative, in the numerical alternatives from Table 2

(US$ Million)

Country	ICP		OCP	
	Tax = $10	Tax = $20	Tax = $10	Tax = $20
Mexico	80	240	240	720
Chile	15	42	44	126
Ukraine	65	180	195	540
Romania	16	43	46	129
Bulgaria	11	34	33	102

To calculate the needed externally provided aggregate payments over the period 2021-2025, we simply scale up the figures in Table 3 by a factor 2.2 (the sum of squared p values from 2021 to 2025, relative to the last squared p value = 100). This gives Table 4 for total payments for the entire support period 2021-2025.

Table 4: Tax implementation support payments under the ICP and OCP, by host country and carbon tax alternative, for 2021-2025

(US$ Million)

Country	ICP		OCP	
	Tax = \$10	Tax = \$20	Tax = \$10	Tax = \$20
Mexico	176	532	528	1584
Chile	33	92	99	276
Ukraine	143	396	428	1188
Romania	35	95	105	285
Bulgaria	24	75	72	225

These calculations are based on several strong assumptions. First, we use "baseline" values of our assessed cost compensation parameters, $\alpha = ½$ for the ICP, and $\alpha = 1.5$ for the OCP. These baseline values ignore co-benefits, which tend to reduce them. In addition, our applied compensation formulas ignore the other (implementation, revenue, distributional, political economy) issues noted in the introduction and considered further in section 6. For that reason, these figures can most likely be considered as lower bounds for the amounts required to compensate host countries for carbon tax implementation.

6. Practical issues related to implementing externally supported carbon price increases

Our compensation formulas, (9) or (15) for the ICP, and (14) or (23) for the OCP, are theoretical conclusions which ignore obstacles to and practical complications with actual implementation of carbon taxes. They are however far from conclusive. Several issues make the problem of deriving "correct" compensation rules for carbon tax implementation more challenging in practice:

a) The net fiscal impact for the receiving country government

b) Competitiveness issues for energy-intensive sectors in the receiving country

c) Distributional impacts

d) Political economy issues, making carbon pricing reform politically difficult to implement

e) Other technical and practical barriers to carbon tax implementation.

Some of these implications are benign and favorable for setting and implementing a high carbon tax level. In particular, the positive fiscal impacts of carbon taxation for a host country government can be more favorable in cases where the country's tax system seriously distorts the economy. Easily-earned revenues from carbon taxation can then substitute for distortive taxes and improve the allocation; an argument which should increase the country's willingness to impose comprehensive carbon taxes.

The income distribution impacts of carbon taxation are often benign in low-income countries, since most fossil fuels tend to be consumed by these countries' higher-income groups; see Dorband et al. 2019 for empirical support. While higher carbon taxation still erodes part of the public's buying power, also among low-income groups, these groups can in most cases (at least in principle) be compensated through transfers of a moderate share of the government's increased carbon tax revenue. The ability and willingness to implement such transfers is then important for determining the overall impacts of these taxes. A widespread problem here is that many governments lack this ability or willingness, making it a greater problem than it otherwise could be.

Competitiveness and political economy concerns, and technical and practical barriers, typically make it more difficult or costly to implement fossil fuel taxes in low-income countries. They often lead to less mitigation impact of a given carbon price rise than what is found from simple models (thus reducing the host country's reward based on our derived compensation formulas), and (often more importantly) lead to high resistance against imposing meaningful carbon taxes, among the public and in governments of host countries.

It is difficult (without going into country-specific detail) to assess the rate at which our derived cost prices need to be "marked up" to ensure government preference for donor-supported carbon taxes. We will not introduce any particular formula to embed these factors in pricing principles for external support programs, leaving this to individual-country evaluation.

7. Conclusions

We have in this paper derived "price points" for the "incremental cost price" (ICP), and the "opportunity cost price" (OCP), to be applied to donor-supported programs for carbon tax implementation in low-income ("host") countries. When not taking into account co-benefits of climate mitigation for hosts, the most plausible (economics-based) price points are ½ for the ICP, and 1.5 for the OCP. The reason why the OCP price point is higher is that it requires larger overall mitigation effort from the host, and this pushes the host's mitigation costs, and the corresponding deadweight loss to the host economy, to higher levels.

The presence of co-benefits from own domestic climate policy reduces the price points because real (net) mitigation costs are reduced; and the resulting increased tax revenue should also make the tax easier to bear for the host government. But several factors also work to make such taxes more burdensome and complicated to implement, and are reasons why almost no low-income countries have so far adopted carbon taxes. In practice, implementation of such programs must be done through bargaining between the host and the program sponsor.

An issue not discussed in this paper is the possibility of strategic behavior of host countries in anticipation of donor-funded carbon tax implementation programs. Expectation of such (future) funding possibilities may reduce hosts' interest to aim for ambitious NDC mitigation targets, and instead make countries wait to implement their own carbon taxes. But note that such a rule, for a given cost to the donor and given value to the host, only would shift a given total carbon tax from the donor-sponsored tax to the tax imposed by the host, so that the sum of the two taxes would be fixed. The cost to the donor would then be the same, for a given total tax imposed in the host country. This would also not solve the basic incentive problem versus the host, namely, to set a "correct" own carbon tax prior to any donor-sponsored compensation rule.

Finally, while we have discussed the host country's achieving its own NDC target through an own imposed and comprehensive national carbon tax, a "starting-point" national carbon tax is not central for our argument. One could in principle think of other mechanisms than a national carbon tax for implementing the NDCs of host countries; both market-based mechanisms (such as cap-and-trade or feebate schemes) and non-market based (such as renewable investment support, or government emissions standards). All the results derived above should hold qualitatively also when other instruments than comprehensive carbon taxes are used for NDC implementation.

The success of such programs could be crucial for the achievement of sufficient climate policy progress at the global level in the years to come.

References

Acemoglu, Daron, U. Akcigit, D. Henley and W. Kerr. 2016. Transition to Clean Technology. *Journal of Political Economy*, 124, 52-104.

Aghion, Phippe, A. Dechezleprêtre, D. Hemous, R. Martin and J. Van Reenen. 2016. Carbon Taxes, Path Dependency and Directed Technical Change: Evidence from the Auto Industry. *Journal of Political Economy*, 124, 1-51.

Andersson, J. J. 2019. Carbon Taxes and CO2 Emissions: Sweden as a Case Study. *American Economic Journal: Economic Policy*, 11 no 4, 1-30.

Cramton, Peter, D. J. C. MacKay, A. Oxenfelts and Steven Stoft. 2017. *Global Carbon Pricing. The Path to Climate Cooperation*. Cambridge, MA.: MIT Press.

Dagoumas, A. S. and T. S. Barker. 2010. Pathways to a Low-Carbon Economy for the UK with the Macro-econometric E3MG Model. *Energy Policy*, 38, 3067-3077.

Devarajan, Shantayanan, Delfin Go, Sherman Robinson and Karen Thierfelder. 2009. Tax policy to reduce carbon emissions in South Africa. Policy Research Working Paper WPS4933. Washington D.C.: The World Bank.

Dorband, Ira Irina, Michael Jakob, Matthias Kalkuhl and Jan Christoph Steckel. 2019. Poverty and Distributional Effects of Carbon Pricing in Low- and Middle-Income Countries – A Global Comparative Analysis. *World Development*, 115, 246-257.

Edwards, T. Huw and John P. Hutton. 2001. Allocation of Carbon Permits in a Country: A General Equilibrium Analysis of the United Kingdom. Report, University of Warwick/University of York.

Goulder, Lawrence H. (ed.). 2002. *Environmental Policy Making in Economies with Prior Tax Distortions.* Cheltenham, UK: Edward Elgar Publishers.

Jorgenson, Dale W., R J. Goettle, M. S. Ho and P. J. Wilcoxen. 2018. The Welfare Consequences of Taxing Carbon. *Climate Change Economics*, 9 no. 1.

Mundaca, B. Gabriela and Jon Strand. 2020. Unconditional and Conditional NDCs Under the Paris Agreement. Unpublished.

Orlov, Anton and Harald Grethe. 2012. Carbon Taxation and Market Structure: A CGE analysis for Russia. *Energy Policy*, 51, 696-707.

Pollitt, Hector, Seng-Joon Park, Sucheol Lee and Kazuhiro Ueta. 2014. An Economic and Environmental Assessment of Future Electricity Generation Mixes in Japan – an Assessment Using the E3MG Macro-econometric Model. *Energy Policy*, 67, 243-254.

Rausch, Sebastian and John Reilly. 2012. Carbon Tax Revenue and the Budget Deficit: A Win-Win-Win Solution? MIT Joint Program on the Science and Policy of Global Change. Joint Program Report Series Report 228.

Steckel, Jan Christoph, Michael Jakob, Christian Flachsland, Ulrike Kornek, Kai Lessmann and Ottmar Edenhofer. 2016. From Climate Finance Toward Sustainable Development Finance. *WIREs Climate Change*, 2016. doi: 10.1002/wcc.437

Strand, Jon. 2020. Transformational Climate Finance: Donors' Willingness to Support Deep and Transformational Greenhouse Gas Emissions Reductions in Lower-Income Countries. Policy Research Working Paper WPS9251, World Bank, May 18, 2020.

Stretton, Stephen. 2020. Supporting Price-Based Mitigation Policies in Developing Countries through Results-Based Payments for Verified Emissions Reductions. TCAF Blueprint Paper. Unpublished, September 2020.

Tvinnereim, Eivind and Michael Mehling. 2018. Carbon Pricing and Deep Decarbonization. *Energy Policy*, 121, 185-189.

World Bank. 2017. *Carbon Tax Guide. A Handbook for Policy Makers*. World Bank: Partnership for Market Readiness.

World Bank. 2019a. *Transformative Climate Finance Framework: Options to Enhance International Climate Finance Flows for Transformative Climate Action*. Washington D. C.: The World Bank.

World Bank. 2019b. *State and Trends of Carbon Pricing 2019*. Washington D.C.: The World Bank.

World Bank. 2020a. TCAF Discussion Note: Corresponding Adjustments. Unpublished.

World Bank. 2020b. Core Parameters for TCAF Operations. Unpublished.

Yusuf, Arief Anshory and Budy P. Resosudarmo. 2007. On the Distributional Effect of Carbon Tax in Developing Countries: The Case of Indonesia. Working Papers in Economics and Development Studies 200705, Department of Economics, Padjadjaran University.

Appendix 1: Total carbon tax *t** given

We here briefly discuss an alternative case for ICP to that treated in section 3.1, where the host already has an own carbon tax t_L, and the support is given to a carbon tax increase *that raises a total carbon tax of the L country to a level* $t^* = t_H + t_L$. The total carbon tax implemented in the L country, t^*, is there viewed as given by the L country. This means that the carbon tax increase support, $t_H = t^* - t_L$, is now a function of the L country's choice of t_L, and is greater when this choice is lower. In both cases we assume that the "support price" (the "incremental cost price") is a constant multiple α_6 of the increase in the carbon tax rate times the reduction in carbon emissions induced by this tax increase.

The welfare level of the L country is:

$$W_{L5} = \frac{1}{2\gamma}[(1-p-v_L)^2 - (t^* - v_L)^2] + \alpha_5 \frac{(t^* - t_L)^2}{\gamma}. \tag{A1}$$

(A1) yields basically the same conditions on α as from (6), for ICP. In particular, given $t_L = v_L$, (A1) also yields $\alpha_5 \geq ½$ for the supported carbon tax to be adopted by the host country.

The main differences from the case discussed in section 2 are that the DWL to the host country's economy (the second expression in the square bracket) is now independent of t_L (as the overall carbon tax, which determines the deadweight loss, is now fixed), and that support payments received by the host now depend negatively on t_L.

This provides an extra incentive for the host country to set a low t_L. Thus, when the host is made aware of the possibility of the carbon tax support program before determining its own carbon tax t_L, and is inclined to act strategically to this information, from (A1) the host country has incentive to set t_L lower than would have been optimal without external support.

This case is considered simply to demonstrate the adverse incentives that it would give for the host country; not necessarily to emphasize the practical relevance of this case which is less clear.

Appendix 2: Empirical estimates of economic losses due to carbon taxation

A set of estimates of losses resulting from the imposition of carbon taxation, for a variety of countries (both hosts and donors), are reproduced in this appendix, taken from the overview section (appendix 4b) of World Bank 2017, and displayed in Table A1 below; plus another study, Jorgenson et al 2018. These studies give estimates of economic costs related to carbon tax implementation, defined in similar ways as in our models for price point definition. We present the results so as to facilitate comparisons between these estimates and our calculations.

Such comparisons are not necessarily straightforward, for several reasons.

The first is co-benefits, assumed by us but generally not considered in the cited studies. Some co-benefits are probably always present but still ignored. This omission likely leads to excessive net cost calculations in the cited studies, since there are then beneficial impacts of the carbon tax, through the capture of co-benefits of the carbon tax policy, not accounted for nor corrected for (with a starting point of zero carbon taxation in the respective host country).

Second, non-competitive behavior in the host countries can alter welfare calculations. We have throughout assumed perfectly competitive behavior. Non-competitive behavior leads to distortions that can be magnified or lessened by carbon taxation, and complicates the welfare calculations.

Third, the countries' tax systems lead to distortions which can be complex and depend on the initial levels and economic impacts of different tax categories. When revenues from a carbon tax can be used to reduce other distortionary taxes, welfare losses can be reduced, or welfare can even increase when imposing a carbon tax. The DWL from carbon taxation stems from such tax distortions. When a particularly serious distortion can be reduced, based on the carbon tax revenue, economic welfare can increase as a result of the carbon tax, leading to a "strong double dividend" from carbon taxation.[12] For example, Orlov and Grethe 2012 find, in a CGE model exercise for the Russian economy (the Russian Federation case in Table A1), impacts of carbon taxation which

---

[12] Most economists tend to assume that "strong double dividends," which imply both environmental improvements and welfare improvements apart from the environment, cannot occur when implementing environmental taxation policies; see Goulder 2002. Such dividends would usually require a high level of tax system distortions. The view is that the distortions which lead to such effects can be removed independent of the use of environmental taxation (and thus "before" any environmental taxes are imposed). This however does not preclude that double dividends will actually occur when an actual tax system leads to serious distortions, and environmental taxation is in practice the main remedy to counter them.

in some cases yield a "double dividend" with negative net economic costs of carbon taxation, given that all carbon tax revenues are used to reduce the labor tax which is highly distortive in Russia, assuming perfect competition in the entire Russian economy. When instead oligopolistic behavior is assumed among producers, they find that economic costs of carbon taxation can be large positive, potentially at the level of the imposed carbon tax. The U.K. example is similar; and even the Jorgenson et al 2018 study, which is the second U.S. case in Table A1, has similar elements. The capital tax is there assumed to be highly distortive, so that hardly any economic cost is suffered when this tax is reduced as a carbon tax is imposed.

Fourth, our welfare calculations cannot be directly compared to calculations from computable general equilibrium (CGE) models, focusing on GDP impacts which often tend to be higher than those found by us. Adding to this problem is that calculations based on theoretical models for actual economies are always imprecise. It can be difficult to see exactly what types and sizes of errors are present and how these affect the final welfare calculations.

With these caveats in mind, consider the calculated welfare impacts of carbon taxation presented in Table A1, based on 6 econometric studies using CGE models, three from potential host countries, and three from potential donors. Our own model-calculated DWL figures per ton CO_2 e mitigation that will result from carbon taxation (equivalent to an ICP price point value $\alpha = ½$) are given in the rightmost column. These calculations can be compared to the net economic costs found from the different model exercises in Table A1 (one from each of Indonesia, Russia, South Africa and the United Kingdom, and two from the United States). Our own DWL cost calculations are unambiguously higher than those from the studies for Indonesia, the United Kingdom, and both the U.S. studies; lower than those from the South Africa study; while comparison with the Russia study is ambiguous.[13] A range of further studies, also cited in World Bank (2017) (albeit all from donor countries and based on hybrid and not CGE models), which include Dagoumas and

---

[13] The higher calculated welfare losses in the South Africa study, from Devarajan et al 2009, could have several backgrounds. The study itself points to high labor market distortions which could be magnified by a comprehensive carbon tax refunded as lump-sum payments to the public. When tax revenues can instead be used to counter the labor market distortions, the authors argue that the economic costs to the South African economy from imposing this carbon tax would be negligible. On the other hand, it could be the case that heavily fossil-fuel dependent economies, such as South Africa (and perhaps also Russia in our sample), will bear somewhat higher economic costs from carbon tax implementation. This is an issue which needs further exploration.

Barker 2010 for the United Kingdom, and Pollitt et al. 2014 for Japan, also give lower economic costs per ton of CO_2 emissions reduced than our model gives.

Table A1: Estimates of economic costs of carbon tax implementation, various host and donor countries[14]

Country	Carbon tax rate US$	Induced mitigation, Million tons CO_2	Cost share of GDP, % (range)	Use of tax revenue	Net economic cost per ton CO_2 ER	Model-calculated DWL per ton CO_2 ER
Indonesia	42	80	0.02, 0.03	Reduce distorting taxes	\$3-4	\$21
Russian Federation	16	172	-0.23, 0.30	Increase govt revenue	(\$-11) - \$15	\$8
South Africa	17	60	0.5	Lump-sum payments to HHs	\$30	\$8.5
United Kingdom	67	100	-0.18, 0.06	Reduce other taxes	(\$-50) - \$17	\$33.5
United States	22	950	0.02	Reduce other taxes	\$4.5	\$11
United States	50	1500		Reduce capital or labor tax	\$2 – \$14	\$25

Overall, it seems fair to say that our calculations do not undervalue the welfare costs of comprehensive carbon price implementation. As a general conclusion, economic losses due to carbon taxation are smaller when carbon tax revenues are applied to reducing other distortive taxes, than when revenues are returned to the public as lump-sum transfers. This puts emphasis on the third complicating point which makes it difficult to compare theoretical and actual individual-country welfare calculations. (Tax system distortions can seriously complicate our welfare impact calculations, often making welfare calculations highly dependent on the manner in which carbon tax revenues are spent.)

---

[14] The studies cited in the table are for Indonesia, Yusuf 2007; for Russia, Orlov and Grethe 2012; for South Africa, Devarajan et al 2009; for the UK, Edwards and Hutton 2001; while for the US, Rausch and Reilly 2012, and Jorgenson et al 2018 (where we are in this table considering the \$50 tax alternative, and capital and labor tax reduction as the alternatives for use of the tax revenues).

We will look more carefully at one of these studies, Jorgenson et al. 2018, which compares three different alternatives for spending of revenues raised by additional carbon taxes for the United States, with very different results, presented in Table A2 below. A carbon tax, starting at either \$25 or \$50 per ton of CO_2e from 2020 on, is assumed to increase by either 1% or 5% per year up to 2050, creating 4 carbon tax paths. Three separate cost estimates calculated from this study are presented in Table A2, assuming that a) the tax revenues are returned to the public in lump-sum fashion, b) capital taxes are reduced, or c) labor taxes are reduced. The authors find that the lump-sum return alternative gives relatively high welfare costs of implementing a carbon tax, in the same range as the carbon tax receipts, while alternatives b and c give far lower social costs, and b the lowest cost, close to zero. The two latter effects are due to distortive impacts of capital and labor taxation, which are diminished when carbon tax revenues are applied for reducing these tax rates. When carbon tax revenue is returned to the public as lump-sum transfers, the calculated deadweight loss of carbon taxation is greater than the DWL figures found from our model. For the policy considered in Table A2, their calculated economic cost per ton of CO_2 e emissions reduction is then \$41, compared to our DWL of \$25 per ton of CO_2 e.

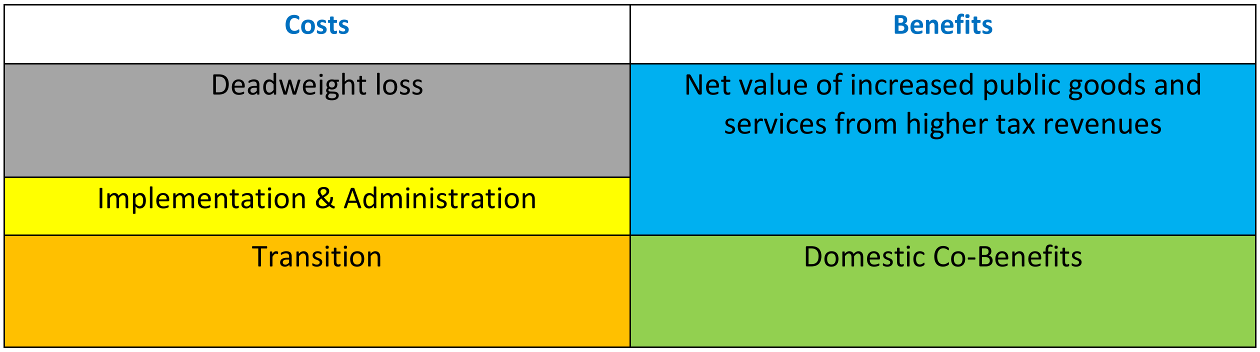
Table A2: Estimated economic costs of carbon tax per ton CO_2 e mitigated, under different assumptions about use of carbon tax revenue, United States, 2020-2050

Tax schedule (base = 2020)	Tax by 2050	Cost, lump-sum compensation per ton CO_2 ER	Cost, capital tax reduced per ton CO_2 ER	Cost, labor tax reduced per ton CO_2 ER	Annual emissions reduction, million tons CO_2	Calculated DWL per ton CO_2 ER, our model
\$25 + 1%	\$33.70	\$37	\$0.2	\$11	1200	\$12.50
\$25 + 5%	\$108	\$38	\$1	\$13	1300	\$13.50
\$50 + 1%	\$67	\$41	\$2	\$14	1500	\$25
\$50 + 5%	\$216	\$44	\$4	\$17	1600	\$27

Appendix 3: A short primer on carbon pricing

From the perspective of a lower-income host country, the primary benefits of a carbon tax are the net societal gain from increased public goods and services provided by tax revenues, and local co-benefits such as reduced air pollution from burning fossil fuels, as shown in Figure A1.[15] A domestic carbon tax will typically have too limited mitigation impact on the global climate to generate benefits for the host country from slowing global warming, and therefore climate benefits are not included in Figure A1. If domestic carbon tax implementation in one country leads to implementation of carbon taxes or other mitigation policies in numerous other countries, climate risk mitigation benefits might accrue, but this case is not considered here.

Figure A1: Host-country costs and benefits of a carbon tax – a stylized representation



Costs	Benefits
Deadweight loss	Net value of increased public goods and services from higher tax revenues
Implementation & Administration	
Transition	Domestic Co-Benefits

A carbon tax also has costs: Aside from the transfer from households and enterprises to the government, which we do not include in the diagram, there is a “deadweight loss” for the economy as a whole, as any commodity taxation creates allocative inefficiencies that reduce to some extent the level of production and consumption in the economy. In addition, in actual practice there are transaction costs in tax implementation and tax administration including the cost of lawmaking, tax collection and enforcement, and recycling of tax revenues. Finally, there are transition costs resulting from structural changes in the economy induced by the tax, including costs of premature capital obsolescence and costs for some members of the labor force to shift from declining to expanding sectors.

---

[15] The net value of increased public goods and services from higher tax revenues could be negative if, for example, a country had a bloated or corrupt public sector. We ignore that possibility here.

Following this scheme, a country would increase its overall economic well-being if it implemented a carbon tax at a tax rate where the benefits are equal to or greater than the costs. This is the situation depicted in Figure A1. To implement a carbon tax at a higher rate, a country would need to be compensated by other nations for the cost-benefit differential, as shown in Figure A2. The motive for such compensation would be to increase global climate benefits.

In the real world few developing countries have implemented a carbon tax, and those that have at very low tax rates - substantially below \$10/t CO_2e. At such low tax rates, domestic benefits may well exceed domestic costs: transition costs will be low as the main impact will be efficiency gains, costs for tax implementation and administration are typically marginal, and deadweight losses are small at low tax rates.

Figure A2: International donor contributions to balance costs and benefits of a host-country carbon tax

Costs	Benefits
Deadweight loss	International donor financing
Implementation & Administration	Net value of increased public goods and services from higher tax revenues
Transition	Domestic Co-Benefits

Acronyms used in the paper:

BAU = business as usual
CGE = computable general equilibrium
CO_2 = carbon dioxide
CO_2 e = carbon dioxide equivalent emissions
DWL = deadweight loss
ER = emissions reduction
EU-ETS = European Union Emissions Trading Scheme
GDP = gross domestic product
GHG = greenhouse gas
H = high-income
HH = household
ICP = incremental cost price
L = low-income
MAC = marginal abatement curve
NDC = nationally determined contribution (of the host country toward the Paris Agreement)
OCP = opportunity cost price
PA = Paris Agreement
UNFCCC = United Nation Framework Convention on Climate Change