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PRINCIPLES FOR PARETO EFFICIENT BORDER CARBON ADJUSTMENT

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Abstract: Border Carbon Adjustment Mechanisms (BCAMs) are becoming reality in the EU and elsewhere, and recur—in very different form—in U.S. legislative proposals. But they remain contentious, with features and differences that leave the underlying welfare rationale and implications unclear. Exploring these, this paper establishes two general principles for Pareto efficient BCAM design: regulatory measures should be recognized symmetrically with explicit carbon prices; and, whatever the ambition of mitigation in the BCA-imposing country, a general 'difference-in-differences' form of a BCAM is appropriate. These nest, as special cases, the very different approaches to BCAM design in Europe and the U.S.

Keywords: Environmental taxation; Carbon pricing; Border tax adjustment; International taxation

JEL classification: H21, H23, H87, F18

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1. Introduction

After many years of heated debate, Border Carbon Adjustment Mechanisms (BCAMs)—broadly, schemes that levy a charge on the carbon content embodied in imports that the importing country regards as in some sense underpriced or otherwise excessive—are fast becoming reality. The European Union has begun the transition to full adoption of a BCAM in 2030, with financial implications for affected companies starting in 2025; the UK is committed to adopt a BCAM in 2027; and Canada is in reflection stage after a public consultation. In the U.S., some form of BCAM is a recurrent feature of legislative proposals for climate action.[1] But the use and design of BCAMs remains highly contentious and politically charged, making it especially important to have a clear understanding of the welfare arguments for and against some form of BCAM.

There is indeed a sizable literature on many of the issues raised by the idea of border carbon adjustment, including: compatibility (or not) with WTO rules; practical issues of implementation; sectoral and trade impacts; the extent to which alternative instruments can replicate the effects of a BCAM; and the impact on developing countries.[2] Surprisingly little attention has been paid, however, to what would seem the most fundamental question underlying (almost) all of the others: Is there a coherent welfare rationale for some form of BCAM, and if so, precisely what is that form? Exceptions include a largely overlooked analysis in Gros (2009), focused on the effect on global welfare of a tariff on implicitly imported carbon, Kortum and Weisbach (2021), focused largely on the treatment of fossil fuels, and Keen and Kotsogiannis (2014), who show that a form of BCAM—which reduces in a special case to something approaching that now being put into place in Europe—is indeed Pareto efficient when climate policies in other countries are for some reason constrained at inefficient levels.[3] The aim in this short paper, building on Keen and Kotsogiannis (2014), is to explore two sets of issues that have considerable practical significance but whose implications for the desirability and design of BCAMs have either not been addressed or, at the least, remain incompletely articulated. Doing so leads to two general principles to guide the efficient design of BCAMs.

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[1] See, respectively European Parliament and Council of the European Union (2023), Government of the UK (2023), Government of Canada (2021); and, on recent U.S. proposals, Gangotra and Kennedy (2023) and Bistline et al. (2024).

[2] As an illustrative list, see respectively: Bullock (2018), Parry et al. (2021) and Tsakiris and Vlassis (2022); Kortum and Weisbach (2017) and Cosbey et al. (2019); Fischer, Morgenstern and Richardson (2015); Fischer and Fox (2012) and Böhringer, Rosendahl and Storrøsten (2017); and UNCTAD (2021) and Lowe (2021). Recent and relatively brief reviews are in Keen, Parry and Roaf (2022), Böhringer et al. (2022) and Clausing and Wolfram (2023).

[3] See in particular their Propositions 2 and 5. Kotsogiannis and Woodland (2013) extend these results to the case in which the externality enters production rather than consumer welfare.

The first set of issues relates to the common presumption in the formal analysis of BCAMs that mitigation (the reduction of emissions) is by carbon pricing.[4] In practice, however, it is becoming increasing clear that many countries with an intention to mitigate—including, not least, the U.S.—are instead relying on a wide range of other mitigation instruments (such as performance standards, subsidies and tax credits for investment in, or energy sourced by, renewables) that are often not equivalent to a direct price on emissions: the wide range of credits and subsidies made available in the U.S. by the Inflation Reduction Act of 2022 is the leading example. The question that then arises is whether some allowance should be made in calculating the BCAM for mitigation measures abroad other than explicit carbon pricing. The answer given by the EU and UK schemes is an uncompromising "No": both have made very clear that the charge due on imports will be reduced only to reflect explicit carbon prices paid abroad, so entirely ignoring any other form of mitigation.[5] In the U.S. the 2023 Market Choice Act, which proposed a U.S. carbon tax, would also adjust the import charge only for explicit carbon charges.[6] Canada, however, another carbon-pricing country, recognizes that the right answer is not obvious: "[a] key challenge [is] to...consider whether and how non-pricing regulatory instruments can be compared to explicit pricing measures," (Government of Canada, 2021).

In the U.S., a further issue arises. There, proposals that do not include a domestic carbon price do nonetheless include a form of BCAM—a form, however, that is structurally quite different from that considered in the analytical literature cited above and now being put in place in Europe. Instead of looking to differences in carbon pricing at home and abroad, this looks to differences in embodied emissions. The Foreign Pollution Fee Act of 2023,[7] for example, would apply a common charge—the level of which is unspecified, being left to the Secretary of Energy—to the difference in emission intensity between the U.S. and origin country. Unlike the EU and UK approach, such a form of BCAM would recognize mitigation efforts abroad through means other than carbon pricing, but would take no account of the financial burden that such pricing imposes in addition to the direct private cost of reducing emissions.

There are thus a variety of approaches to structuring BCAMs in the presence of mit-

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[4] For brevity, we take any explicit carbon pricing to be in the form of taxation rather than cap-and-trade; Pareto efficient BCAM design in the case of the latter is discussed in Keen and Kotsogiannis (2014).

[5] The EU regulation provides credit against the charge on the carbon content of imported products only for carbon price that has been effectively paid in the country of origin (European Parliament and Council of the European Union (2023), especially Articles 6.2 and 9), and the UK makes clear that "[t]he price applied by a BCAM will...be set on the basis of the explicit carbon price differential between the UK and the country where the products were produced," (Government of the UK, 2023).

[6] HR 6665 at https://www.govinfo.gov/content/pkg/BILLS-118hr6665ih/pdf/BILLS-118hr6665ih.pdf, Section 102.

[7] S 3198 at https://www.congress.gov/118/bills/s3198/BILLS-118s3198is.pdf.

igation measures other than direct emissions pricing (which for brevity we simply refer to as ‘regulatory’ measures)—each with some intuitive appeal, but with no clear analytical guidance as to which, if any, is the most appropriate in any given circumstances. The result cited earlier that constrained Pareto efficiency requires a (price-based) BCAM provides no answer, since it assumes that all countries use explicit carbon pricing. Relaxing this, the answers that emerge from the first general principle for BCAM design established below is clear-cut: the shadow prices for carbon associated with regulatory mitigation should be treated in just the same way as explicit carbon prices. Taking those shadow prices as metaphors for the strength of regulatory mitigation, the implication is that, in looking only to explicit prices, the approach of the EU and UK is misconceived. Moreover, there emerge within this encompassing principle circumstances in which it is the emissions-based approach of the Foreign Pollution Fee Act, not a price-based approach, that is constrained Pareto efficient, along with guidance as to what the proper fee then is.

The second set of issues arises from the presumption underlying previous results on the efficiency case for an appropriately designed BCAM that the BCA-imposing countries are completely free in the carbon price they set (or, transposed to the context here, in their mitigation policy more generally), and so set it at efficient levels. This too risks being significantly at odds with reality. Countries may, for instance, price carbon at a level which reflects not global harm but only that which they themselves suffer; and it is all too evident in Europe and elsewhere that political resistance to ambitious carbon pricing is strong. Even in the EU, the pioneer of BCAMs, the carbon price of around USD 70 per tonne (in February 2024), which is relatively aggressive by international standards, is well below the USD 120 per tonne that the Environmental Protection Agency (2023) gives as its lowest estimate of the social cost of carbon (for 2020). What becomes of the case for a BCAM in such circumstances? While one might expect some type of BCAM to remain desirable even with significant under-pricing (explicit or shadow), its precise form is not immediately apparent. What emerges below—the second general principle—is that constrained Pareto efficiency then requires a generalized form of BCAM which looks not to the difference between domestic and foreign (explicit or shadow) carbon prices, but to the difference in how far each deviates from the first best level: a ‘difference-in-differences’ BCAM. Conveniently, it will be seen too that in one not wholly unreasonable special case, this too reduces to the usual mechanical form of BCAM even when the carbon price in the importing country (explicit or shadow) is inefficient. By nesting as special cases the quite different forms of BCAM observed and proposed, this general characterization of Pareto efficient BCAMs makes clear the (also quite different) circumstances in which each can be given an efficiency rationale.

The welfare perspective adopted here is, almost entirely, that of constrained Pareto efficiency. Viewed not just as a benchmark for evaluation but as a guide to action, this perspective requires some degree of benevolence on the part of the unconstrained country, at least to the extent of preferring not to make others worse off. But without some regard for the well-being of others it is hard to understand why any country would ever introduce into its tariff structure the recognition of foreign mitigation policies that is the core element of any BCAM;[8] this will be seen when, for comparison, the case of self-interest is examined briefly[9] below.

Section 2 describes the model and analytical approach. Results are in Section 3, and conclusions drawn in Section 4. The formalities are straightforward but involved, and so are for the most part relegated to appendices.

2. Preliminaries

The model

The setting is of a competitive global economy with just two goods and two countries, each with a single representative consumer.[10] One good, taken as numeraire, is clean; the other is 'dirty' in the sense that its production generates harmful emissions.[11] The 'home' country—whose possible deployment of some form of BCAM is the focus of interest—is described in lower case letters, and the 'foreign' in upper case.

Preferences in the home country are described by expenditure function of the form $e(p_0, p, u) + p_0\theta k$, where p_0 denotes the price of the numeraire and p the (consumer and producer) price of the dirty good, while u indicates home welfare, k global emissions and $\theta > 0$ the damage they cause to the home country.[12] In what follows p_0 is set to unity and suppressed as an argument. The price of the dirty good is $p = w + t$,

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[8] One might argue that adopting a BCAM can serve a self-interested purpose by encouraging tighter mitigation abroad. But the direct force of any such incentive seems likely to be limited: even for the EU the proportion of emissions from the large-emitting countries embodied in imports is modest (Keen, Parry and Roaf, 2022), and the best targeted response is an offsetting export charge, not a generalized carbon price. Nordhaus (2015) is notably skeptical as to the effectiveness of BCAM as a sanction.

[9] This case is more familiar, having been examined, albeit from perspectives somewhat different from that here, by, for example, Markusen (1975) and Neary (1985).

[10] The additional considerations that arise with many countries and goods are much as in Keen and Wildasin (2004): the possibility, for example, of using tariff policy to engineer inter-country transfers when there are more goods than countries.

[11] We speak of these as emissions from burning fossil fuels, but other interpretations are of course possible; and it is straightforward to generalize the damage function introduced below to allow for local damage.

[12] These preferences imply that compensated demand for the dirty good is independent of damage, which avoids cumbersome feedback effects on tariff revenue along lines discussed in Keen and Kotsogiannis (2014).

with w being the world price and t the home tariff. For definiteness (but with no implications for the analytics), in the discussion we shall have it in mind that this is home's importable, so that $t > 0$ indicates an import tariff (while for the 'foreign,' upper case, country, $T > 0$ means an export subsidy). This dirty commodity may, but need not be, interpreted as the fossil fuel from whose use damage arises: we characterize and take up this special case later. Compensated demand for the dirty good is given by[13] $e_p(p, u)$, with standard concavity properties implying that $e_{pp}(p, u) \leq 0$. Preferences in the foreign country, analogously, are $E(P, U) + \Theta k$.

Production decisions are described by a revenue function

$$r(p, s) \equiv \max_{x_n, x, z}\{x_n + p\,x - s\,z : \; (x_n, x, z) \in f\}\,, \tag{1}$$

where x_n denotes output of the numeraire, x output of the dirty good, z emissions from the burning of carbon (the latter both assumed throughout to be strictly positive), s an explicit carbon tax charged on those emissions and $f(\cdot)$ the technologically feasible set. As standard properties,[14] $r(p, s)$ is convex and differentiable in p and $-s$, with $r_p = x$ and $r_s = -z$; for simplicity, we assume strict convexity, so that r_{pp}, r_{ss} and $r_{pp}r_{ss} - (r_{ps})^2$ are all strictly positive. It will be assumed too that $r_{sp} = -z_p < 0$, so that an increase in the price of the dirty good induces higher emissions.[15]

Countries may, however, choose to mitigate not by carbon taxation but instead, or also, by regulatory measures. Leading to some level of emissions $\bar{z}$, we take these to be characterized by a shadow price $\bar{s}$ such that $\bar{z} = -r_s(p, \bar{s})$. Production is then determined by whichever of the explicit price s and shadow price $\bar{s}$ is higher, so that output and emissions are given by

$$x = r_p(p, s^*) \quad ; \quad z = -r_s(p, s^*)\,, \tag{2}$$

where $s^* \equiv \max\{s, \bar{s}\}$; we refer to s^* as the 'binding' price, since it is this that determines production decisions. Under regulation, for instance, the binding price is the shadow price, and emissions are $\bar{z} = -r_s(p, \bar{s})$. Net private income from production, however, reflects financial payments that are made only of the explicit carbon price s, not of the shadow price $\bar{s}$. When a shadow price $\bar{s}$ is binding but an explicit price s is nevertheless in place, for example, net revenue is $r(p, \bar{s}) + \bar{s}\bar{z} - s\bar{z} = r(p, \bar{s}) - (\bar{s} - s)r_s(p, \bar{s})$: that is, while producers behave as if they faced a price of $\bar{s}$ the fact that they do not corresponds to their receiving a lump sum rebate of $\bar{s}\bar{z}$; they do, however, face a real cost on their

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[13] With obvious exceptions, subscripts indicate derivatives.

[14] See Dixit and Norman (1980) and Woodland (1982).

[15] Neary (2006) refers to z_p as an indicator of pollution intensity.

inputs of $s\bar{z}$. More generally, net income is given by the adjusted revenue function[16]

$$g(p,s^*,s) \equiv r(p,s^*) - (s^* - s)r_s(p,s^*)\,. \tag{3}$$

The description of the foreign country is analogous, though preferences and technologies may be quite different. Aggregate emissions, recalling (2), are thus

$$k\left(p,P,s^*,S^*\right) = -r_s\left(p,s^*\right) - R_S\left(P,S^*\right)\,, \tag{4}$$

and, denoting home's (compensated) net import demand by $m\left(p,s^*,u\right) \equiv e_p\left(p,u\right) - r_p\left(p,s^*\right)$, market clearing requires that

$$m\left(p,s^*,u\right) + M\left(P,S^*,U\right) = 0\,, \tag{5}$$

where, from the properties noted above, $m_p < 0, M_P < 0$.

To focus on the environmental concerns motivating the potential use of BCAMs, revenue raised by the tariff and any explicit carbon prices are assumed in our central case to be returned to the representative consumer as a lump sum; we shall though consider the implication of policymakers also having a distinct need to raise revenue. For now, using (2), the income-expenditure identity for the home country is then

$$e(p,u) + \theta k = g(p,s^*,s) - sr_s(p,s^*) + tm\left(p,s^*,u\right) - \alpha\,, \tag{6}$$

where α denotes a lump sum transfer to the foreign country; the identity for the foreign country is analogous, but with α entering positively.[17]

Constrained efficiency

It is assumed throughout that the foreign country is, for some reason—perhaps reflecting domestic political constraints or views on differential responsibilities to mitigate—wholly constrained in its tariff and mitigation policies: T, S and $\bar{S}$ are all taken as fixed at arbitrary levels. Since $Z = -R_S(P,\bar{S})$, fixity of the shadow price $\bar{S}$ serves to allow some responsiveness of emissions there to policies in the unconstrained country, through the impact, via world prices, on the foreign producer price $P = \omega + T$. The framework thus captures the looser impact of regulation relative to the absolute limits set directly by emissions standards or cap-and-trade schemes.

The home country, however, is not so constrained, and the aim in what follows is to characterize the Pareto efficient choice of the instruments at its disposal, conditional on the foreign country achieving welfare of at least $\bar{U}$. Throughout, we assume the home

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[16] This approach is similar to those of Neary and Roberts (1980) and Neary (1985).

[17] The combination of (5) and (6) ensures market clearing for the numeraire.

tariff t—and hence options regarding a possible BCAM—to be unconstrained. But we allow for the possibility that domestic mitigation policy (regulatory or explicit pricing) is fixed at some arbitrary level, reflecting possible constraints of the kind discussed in the introduction.

The various problems of constrained Pareto efficiency to be considered[18] are encompassed by the Lagrangean

$$\begin{aligned}
\mathcal{L} &= u + \phi(U - \bar{U}) \\
&+ \lambda\{e(p,u) + \theta k(p,P,s^*,S^*) - g(p,s^*,s) + s r_s(p,s^*) - t m(p,s^*,u) + \alpha\} \\
&+ \Lambda\{E(P,U) + \Theta k(p,P,s^*,S^*) - G(P,S^*,S) + S R_S(P,S^*) - T M(P,S^*,U) - \alpha\} \\
&+ \mu\{m(p,s^*,u) + M(P,S^*,U)\}, \qquad (7)
\end{aligned}$$

where ϕ is the multiplier on the constraint that foreign welfare be at least $\bar{U}$, λ and Λ those on the home and foreign income-expenditure identities respectively and μ that on market-clearing; bearing in mind too that aggregate emissions $k(p,P,s^*,S^*)$ are given by (4), while producer prices are given by $p = \omega + t$ and $P = \omega + T$.

3. The Design of Pareto Efficient BCAMs

The analysis addresses the issues raised above by looking in turn at a series of cases. It begins with the simplest: that in which distributional concerns are eliminated by supposing the cross-country transfer α to be efficiently chosen. After extending this to look briefly at the case in which policy is driven not only by environmental concerns but also by a need for revenue, we then characterize constrained efficient policies when the transfer α is fixed at some arbitrary level (possibly zero), so that issues of cross-country equity arise. This latter serves to raise the question, prominent in the policy debate, of how imports from lower income countries—poorer, with less historical responsibility and/or higher mitigation costs—should be treated in the design of BCAMs. Finally, and by way of contrast, we address briefly the better-understood case in which policy in the unconstrained country is wholly self-interested.

Efficient BCA in the absence of distributional concerns

We start with the case in which mitigation policy in the potentially BCA-imposing country (as well as that abroad) is constrained at some arbitrary level, perhaps for reasons of the kind touched on in the Introduction, then turn to that in which it too, along with tariff policy, can be freely chosen.

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[18] Other than that in which revenue is a distinct concern.

Constrained mitigation policy

In this case the problem is thus to choose the home tariff t, world prices w (to ensure market clearing) and the transfer α to maximize u subject also to $U = \bar{U}$. For clarity—and again temporarily—we take $T = 0$.

For this case, denoting the aggregate damage from a unit of emissions by $\theta^A \equiv \theta + \Theta$:

Proposition 1. *Whatever its domestic mitigation policy* s^**, and given* $T = 0$*, when international transfers are freely available, constrained Pareto efficiency requires a tariff in the home country of*

$$t = (s^* - \theta^A)\left(\frac{r_{sp}(p, s^*)}{m_p(p, s^*, u)}\right) - (S^* - \theta^A)\left(\frac{R_{SP}(P, S^*)}{M_P(P, S^*, U)}\right). \tag{8}$$

Proof: The circumstances are as in Proposition 5 below, with the addition that the cross-country transfer α is freely chosen, implying from (7) that $\lambda = \Lambda$; the result then follows from (17) below. □

Two lessons follow from Proposition 1.[19] First, it is only s^* and S^* that enter the rule in (8): all that matters is what the binding price is, not whether it is implemented by explicit carbon pricing or by regulation. We return to the significance of this later, the point being established more completely by considering also, below, the Pareto efficient choice of home mitigation policy.

The second and perhaps more striking implication of Proposition 1 is that the appropriate BCAM looks not to the difference between home and foreign (explicit or shadow) prices, $s^* - S^*$, but to the difference between how far each deviates from the first best level θ^A: a kind of 'difference-in-differences' BCAM. These differences (and we will have in mind that binding prices are below first-best, so that emissions are underpriced in both countries) are weighted by (positive) terms reflecting behavioral responses that we look at shortly.[20] Loosely speaking, the BCAM of Proposition 1 thus weighs the effects of a higher home tariff in (a) increasing the domestic producer price and thereby adversely expanding home production and so aggravating the welfare loss from domestic emissions that are underpriced by an amount $\theta^A - s^* > 0$ against that of (b) reducing the producer price abroad and so beneficially reducing under-priced foreign emissions. It is only if the (behaviourally-weighted) under-pricing abroad is

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[19] Since (8) applies whatever the direction of trade in the dirty good, it also illustrates a principle for BCAM design that is well-recognized in theory but widely neglected in practice: that the case for remission on exports mirrors that for charging on imports.

[20] Gros (2009), it should be noted, makes a similar observation in passing (around his equation (30)), for the carbon tax case.

greater than that at home that a positive tariff is appropriate.

A more precise intuition follows on noting that—as shown in Appendix A—the 'difference-in-differences' BCAM in (8) implies that

$$-t\frac{dm}{dt} = (\theta^A - S^*)\Big(-\frac{dZ}{dt}\Big) - (\theta^A - s^*)\frac{dz}{dt}, \tag{9}$$

where the derivatives are conditional on the levels of welfare and binding prices. On the left of (9) is the marginal welfare loss from the distortionary impact of the tariff itself (as a positive number), which in the absence of environmental concerns, would call for the tariff to be set to zero. On the right is the marginal gain from the reduction in underpriced emissions abroad ($-dZ/dt > 0$) reduced by the marginal loss from the increase in under-priced domestic emissions ($dz/dt > 0$). The 'difference-in-differences' BCAM simply equates these marginal welfare costs and benefits—-from traditional production inefficiency and environmental harm—of increasing the home tariff.

Returning to (8), the home weight in the generalized BCAM of Proposition 1 can be written in perhaps more transparent elasticity form as

$$\frac{r_{sp}(p,s^*)}{m_p(p,s^*,u)} = \Big(\frac{z}{x}\Big)\frac{\epsilon(z,p)}{\epsilon(e_p,p)\left(\frac{e_p}{x}\right) + \epsilon(x,p)}, \tag{10}$$

where $\epsilon(c,d)$ denotes the (absolute value of) the elasticity of c with respect to d. Assuming domestic emissions to be under-priced, so that $s^* < \theta^A$, the charge on imports is thus lower: the greater is the emissions intensity (dirtiness) of production at home (z/x), the more responsive are home emissions to a tariff-induced increase in the price of the dirty good and the less price responsive are domestic compensated demand and production (hence the smaller the impact of the tariff on the foreign producer price)—all factors that point to environmental benefits from a high tariff that are modest relative to the associated non-environmental distortions. Conversely, the import charge is greater the more strongly the same conditions apply abroad.

In general, the generalized Pareto-efficient BCAM in Proposition 1 looks to differences across countries in both binding prices and emissions intensity, mediated by behavioral responses in consumption and productions. There are circumstances, however, in which it reduces to simpler forms, and ones directly related to practical policy actions and proposals along the lines of those described in the Introduction.

To see this, suppose that there are fixed coefficients in the production of the dirty good in the sense that emissions are simply proportional to output, so that $z = -r_s(p,s) = br_p(p,s) = bx$ for some constant $b > 0$. The most compelling instance of this is that in which the non-numeraire good is fossil fuel, though one can conceive too of other goods for which abatement technologies are severely limited. This proves a particularly instructive special case. It implies (since then $r_{ps} = -br_{pp}$) that the home weight in (8) of Proposition 1 becomes

$$\frac{r_{sp}(p, s^*)}{m_p(p, s^*, u)} = \frac{b}{1 - (e_{pp}/r_{pp})}, \tag{11}$$

and of course similarly abroad. The weights are thus strictly less than unity so long as there is some price responsiveness in compensated demand. Through the first term in (8), the Pareto efficient BCAM thus does not fully equalize the treatment of imports and domestic production: it leaves domestic producers at some competitive disadvantage.[21] By the same token, however, it also gives less than full credit for the binding price paid by exporters abroad.

Pursuing this special case of fixed emission intensities, suppose further that compensated demand for the dirty good is completely inelastic, so that $e_{pp} = E_{PP} = 0$. The general CBAM of Proposition 1 then becomes

$$t = (s^* - \theta^A)b - (S^* - \theta^A)B. \tag{12}$$

From this, the alternative forms of BCAM based either on only differences in binding prices (along similar lines to the EU and UK, though there of course not only for explicit prices) or on only differences in technology (as in the U.S. Foreign Pollution Fee Act) emerge as distinct special cases of the generalized BCAM of Proposition 1:

Proposition 2. *Under the conditions of Proposition 1, suppose further that, in both countries, emissions intensities are technological constants and that compensated demands are perfectly inelastic. Then:*

(a) If technologies in each country are the same, constrained Pareto efficiency requires a tariff in the home country of

$$t = (s^* - S^*)B. \tag{13}$$

(b) If binding prices in each country are the same, at say s', constrained Pareto efficienc yrequires a tariff in the home country of

$$t = \tilde{s}(B - b), \tag{14}$$

where $\tilde{s} \equiv \theta^A - s'$.

Part (a) shows that even when mitigation policy in the home country is set at an arbitrary level, if technologies are the same at home and abroad then the efficient

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[21] This is similar to a result of Kortum and Weisbach (2021) to the effect that constrained Pareto efficiency requires a tax on the home extraction of fossil fuels that is less than fully rebated on export.

BCAM has the key feature of those adopted and proposed in Europe, but extended also to regulatory measures: it charges an amount equal to the excess of the home over the foreign price—explicit or shadow, efficiently set or not—multiplied by a mechanical indicator of carbon content.

Part (b) shows, in contrast, that—again whatever the forms and levels of mitigation policies in the two countries—a BCAM based only on differences in emissions intensity, as under the U.S. Foreign Pollution Fee Act, is appropriate. (And this is so, even if the foreign country mitigates by explicit carbon taxation.) The result also indicates the correspondingly appropriate fee (which the proposal leaves open): a charge equal to the amount by which the common binding price falls short of the first best carbon price.[22]

While showing that both can be rationalized on efficiency grounds, the juxtaposition of parts (a) and (b) of Proposition 2 highlights the differing circumstances in which BCAMs based on differences in binding prices and those based on differences in emissions intensities are warranted. The former, loosely peaking, is appropriate when technologies are sufficiently similar that the key difference that the BCAM needs to adjust for is the ambition of mitigation efforts, as reflected in binding prices. The latter is appropriate when mitigation efforts are broadly similar, but emissions intensities differ.

Unconstrained mitigation policy

None of the results above assumes mitigation policy in the BCA-imposing country to be in any sense optimal. If, however, that mitigation policy is unconstrained then it straightforward to see that efficiency requires that s^* be set at the first best level of θ^A. It then follows from Proposition 1 that:

Proposition 3. *Under the conditions of Proposition 1, if mitigation in the home country is efficient—whether achieved by price or regulation—then* $s^* = \theta^A$*, and constrained efficiency requires a tariff in the home country of*

$$t = (s^* - S^*)\left(\frac{R_{SP}(P, S^*)}{M_P(P, S^*, U)}\right). \tag{15}$$

Proof: Appendix B. □

The appropriate BCAM is thus again the difference in binding prices multiplied by

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[22] Identical binding prices are of course consistent with differing emissions intensities if technologies differ.

a term reflecting induced emission responses abroad.[23] This resembles the result in Proposition 2: the key difference is that the result there requires identical technologies while Proposition 3 instead requires efficient mitigation in the BCA-imposing country.

Taken together, Propositions 1 and 3 make clear that—whatever the nature of the mitigation measures taken at home and abroad—the Pareto efficient BCAM treats explicit carbon prices and regulatory shadow prices associated with mitigation policies in exactly the same way, taking account only of whichever is binding on production decisions. In this broad sense, it is thus the approach typically found in draft U.S. legislation, which gives credit for non-price mitigation abroad, that is in line with constrained Pareto efficiency, not that in the EU Directive and rules proposed in the U.K., which gives credit only for explicit carbon prices. Indeed there is no trace in these results of the 'leveling the playing field' argument for imposing a financial charge on imports to match that on domestic production. Such a charge—in line with the 'destination principle' that is the worldwide standard for commodity taxation—serves production efficiency by tilting consumption and hence production towards firms with lower private marginal costs; in the climate context, however, the wider efficiency perspective requires balancing such concerns against environmental harm.

When revenue matters

An obvious difference between carbon pricing and direct regulatory measures, such as non-tradable performance standards, is that the former collects tax revenue while the latter do not, a potentially significant difference when policy makers have not only environmental concerns but also a need to finance valued public expenditures. In that case, one might expect the appropriate form of BCAM to differ between the two approaches; here we look briefly[24] at precisely how.

Suppose then that the marginal value of public funds in the home country is $1 + v$, with $v > 0$, meaning that, at the margin, a dollar transferred from the public sector conveys a social gain of v. For this case, it is shown in Appendix C that:

Proposition 4. *Under the conditions of Proposition 1, but now valuing home revenue from the tariff and any carbon tax by the marginal value of public funds* $1 + v$*, constrained Pareto*

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[23] This generalizes Proposition 3 of Keen and Kotsogiannis (2014), replacing explicit prices there by binding prices.

[24] The brevity is partly because the starkness of the difference between the two is some way from reality: many prominent mitigation measures involving other than the direct pricing of emissions—such as the tax credits of the 2022 Inflation Reduction Act of 2022—also have revenue consequences. Dealing with that, however, would require adding additional structure to the simple setting above.

efficiency requires—whatever the mitigation policy is there[25]*—that the home tariff be*

$$t = \frac{1}{(1+v)}\left\{ \left(s^* + vs - \theta^A\right)\left(\frac{r_{sp}}{m_p}\right) - \left(S^* - \theta^A\right)\left(\frac{R_{SP}}{M_P}\right)\right\} + \frac{v}{1+v}\left(\epsilon(m,p)\frac{dlnp}{dt}\right)^{-1}. \tag{16}$$

Comparing this with (8) of Proposition 1, there are three adjustments to be made. First, the 'difference-in-differences' BCAM term is scaled down by the factor $1+v$: intuitively, the core rationale for the BCAM is to prevent emissions reductions at home being offset by increased emissions abroad—but that is less of a concern when domestic emissions contribute valuable revenue. Second, the domestic under-pricing is taken to be reduced by vs: this reflects the adverse distortionary impact of the carbon tax in reducing the wider domestic tax base.[26] Third, an additional term appears that is essentially a familiar Ramsey-type inverse elasticity capturing the pure revenue-raising role of the tariff that would remain even in the absence of environmental concerns. This last points to higher tariff if the dirty good is the importable, and to a lower export subsidy if it is the exportable; the latter case carries echoes of the feature of the EU BCAM, otherwise hard to rationalize as a matter of principle, that no carbon rebates are provided to exports.[27]

Cross-country distributional concerns

To allow for distributional concerns, we now relax the assumption that the international transfer α is freely available, and denote by σ the ratio Λ/λ: thus $\sigma > 1$, for example, means that welfare is increased by a transfer from the unconstrained home to the constrained foreign country. This case thus captures the concern which, as noted at the outset, has been prominent in the BCAM debate, as to the proper treatment of imports from lower income countries: the U.S. Market Choice Act, for instance, would exclude least developed countries.[28] In the absence of income effects for the dirty good and normalizing $e_u = E_U$, it is easily seen[29] that $\sigma = \phi$, so that σ can also be thought of, somewhat loosely, as the welfare weight attached to the foreign country.

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[25] Because of the value attached to tax revenue, carbon taxation is readily shown to welfare-dominate regulatory measures in this setting (given a stability condition, $e_u - te_{pu}$, along the lines of Hatta (1977) and Neary (2006)).

[26] This becomes clearer on supposing taxation to be the binding instrument: with $s^* = s$ the part of the BCAM relating to domestic underpricing becomes $s - \theta^A/(1+v)$, which corresponds to the result of Sandmo (1975) that when environmental taxes distort they are optimally set with an environmental component correspondingly below the Pigovian level.

[27] Strikingly, the U.S. Market Choice Act would remit on exports.

[28] Section 1994.

[29] This follows from the first order conditions on u and U from (7): with $e_{pu} = E_{PU} = 0$, these are $1 + \lambda e_u = 0$ and $\phi + \Lambda E_U = 0$. Non-zero income effects complicate the link with ϕ by introducing feedback effect from international transfers to tariff revenues and producer prices.

Taking again the case in which the home country's mitigation policy is fixed at some arbitrary level, and now allowing also for $T \neq 0$, efficient tariff and BCAM designed is characterized in:

Proposition 5. *Whatever its domestic mitigation policy s^*, constrained Pareto efficiency requires a tariff in the home country of*

$$t = \sigma T - (\sigma - 1)\left(\frac{M}{M_P}\right) + \underbrace{(s^* - \theta^{AA})\left(\frac{r_{sp}}{m_p}\right) - (\sigma S^* - \theta^{AA})\left(\frac{R_{SP}}{M_P}\right)}_{BCA\ term}, \tag{17}$$

where $\theta^{AA} \equiv \theta + \sigma\Theta$.

Proof: Appendix D.

There are thus two additional terms, and some recasting of the BCAM, relative to the special case in Proposition 1. The first of these, σT, reflects the possibility of a direct transfer, albeit distortionary, between the two countries. Suppose for instance that $T < 0$, meaning that the foreign country sets an export tax. If $\sigma = 1$, so that distributional concerns vanish, constrained efficiency would require (absent environmental concerns) setting $t = T < 0$, meaning an import subsidy that exactly offsets that export tax, and eliminates the production inefficiency that it otherwise causes abroad. If, on the other hand, $\sigma > 1$, capturing the case in which the foreign country is of relatively low income, then Pareto efficiency calls for a home import subsidy that more than offsets foreign's export tax: the rationale is that this effectively transfers revenue from the higher income country (through the subsidy it offers) to the lower income country (through the additional export tax revenue it collects from consequently increased demand for those exports), more than offsetting, in welfare terms, the induced production inefficiency. The second additional term comes into play only when $\sigma \neq 1$. With $\sigma > 1$, it calls (given $M, M_P < 0$), all else equal, for $t < 0$: an import subsidy in the home country. The intuition is simply that by this means the high income home country engineers a terms of trade effect that favors the low income country.

The appropriate BCAM term itself alters in two ways. The first is that the damage level taken as reference in calculating the difference terms is no longer the simple sum $\theta^A = \theta + \Theta$ but instead an adjusted aggregate $\theta^{AA} = \theta + \sigma\Theta$, the adjustment being to attach greater weight to the damage suffered by the low income country. The second is that additional credit is given to mitigation efforts in the low income country, these being treated as if the binding price were not S^* but σS^*. The implications are especially clear in the circumstances of Proposition 2 (a)—identical, constant emissions intensities and inelastic compensated demand—as the BCAM term then becomes

$$(s^* - \sigma S^*)B\,. \tag{18}$$

The appropriate BCAM thus takes the form of applying the difference in binding prices to embodied emissions, with additional credit being given for mitigation efforts in low income countries.[30]

Self-interest

The focus so far on Pareto efficiency does not presume that the unconstrained country must somehow entirely set aside its own self-interest. The implication of Proposition 5, for example, is that if (17) does not hold then the home country could change its tariff policy to make itself better off—with the added feature that it could do so without making the foreign country any worse off, even without any international transfers.

It may of course be, however, that the unconstrained country simply attaches no weight to the well-being of the other country, in which case it will be able to do even better for itself than by following Proposition 5. This is the special case of the general structure above in which $\phi = 0$. Simplifying for clarity by supposing that there are fixed emissions intensities in both countries, it follows immediately from Proposition 5 that:

Proposition 6. *If wholly self-interested, the unconstrained country, whatever its domestic mitigation policy—and assuming there to be fixed emissions intensities in both countries*[31]*—will set a tariff of*

$$t = M(M_P)^{-1} + \theta B - (\theta - s^*)b\,. \tag{19}$$

Pure self-interest thus calls, beyond a standard optimal tariff, for charging the carbon content of imports at a rate which reflects the damage that production abroad causes at home, reducing this to the extent that damage from production at home is underpriced.[32] Comparing with the corresponding Pareto efficient BCAM in (12), and with the EU- and U.S.-style special cases of Proposition 2, the key difference (beyond account being taken only of damage at home, not globally) is that no credit is given for mitigation costs abroad, S^*B.

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[30] For completeness: it is straightforward to show—by the same steps as proving Proposition 3 (Appendix B)—that when mitigation policy is freely variable Pareto efficiency requires, as one would expect, that $s^* = \theta^{AA}$.

[31] We naturally assume too that the home country cannot transfer resources to itself.

[32] The final term corresponds to the result of Neary (2006), implicitly setting $B = 0$: imports should be subsidised if damage is underpriced domestically.

4. Concluding Remarks

The adoption of BCAMs opens a new frontier in efforts to use of tax-like tools to address climate change—efforts that so far have been, to put it mildly, disappointing. Understanding how they are to be best designed is thus of some importance. In that spirit, the results here suggest two principles for the desirability and structure of Pareto efficient BCAMs.

The first, and conceptually more straightforward, is that efficiency arguments for a BCAM and results on its appropriate structure apply with perfect symmetry to explicit carbon prices and shadow prices associated with mitigating regulatory measures. In this sense—interpreted, if not literally, at least as signaling a need to reflect all forms of mitigation adopted abroad—it is the proposals in the U.S., not the actions in the EU and UK, that emerge as the more defensible on efficiency grounds.

The second principle is that a generalized 'difference-in-differences' form of BCAM is required for Pareto efficiency: whatever the ambition and nature of the mitigation policies adopted, in the BCA-imposing country or abroad, efficiency calls for a BCAM based not on the difference between (explicit or shadow) prices at home and abroad but on the difference between how far each deviates from the first-best level.

Taken together, these two principles provide a unifying framework within which alternative forms of BCAM can be evaluated and, potentially, designed. An approach based on applying the difference in prices across countries to embodied imports, for instance—as in the EU and proposed for the UK, but, importantly, extended to allow for shadow prices—is constrained Pareto efficient if differences in technology are negligible; and this is so whatever the level of ambition of domestic mitigation policies. The very different approach of applying a single charge to differences in the carbon content of domestic and foreign products, on the other hand—as in the Foreign Pollution Fee proposed in the U.S.—is constrained efficient if mitigation efforts abroad are comparable to those in the BCA-imposing country, with guidance also emerging here as to the appropriate level of that charge (as the excess of marginal climate damage over the common shadow price). Not the least benefit of encompassing these very different approaches within a common framework, may, in due course, be in seeing how best to link the variety of BCAM schemes towards which the world may well be headed.

The analysis above is of course subject to many limitations. It abstracts, for instance, from considerations of imperfect competition and (within-country) firm heterogeneity, and from the diversity and complexity, in design and coverage, of the mitigation instruments used in practice. It sets aside too the slew of informational and other potential obstacles to implementation of any form of BCAM, including in relation to explicit carbon prices[33] but no doubt still greater in terms of other forms of mitigation. These problems, however, are by no means evidently insoluble. And the place to begin the design of BCAMs and address the practical problems they pose is surely with clarity on the principles it is intended to apply.

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[33] This requires taking some view, for example, as to when a coal tax or routine excise of fuels is to be counted as a carbon tax.

Appendices

Appendix A. Derivation of equation (9)

Multiplying (8) of Proposition 1 by $m_p(dp/dt) = dm/dt$ and recalling that $r_{sp} = -z_p$ gives

$$t m_p \frac{dp}{dt} = -\left(s^* - \theta^A\right)\frac{dz}{dt} - \left(S^* - \theta^A\right) R_{SP}\left(\frac{m_p}{M_P}\right)\frac{dp}{dt}\,. \tag{A.1}$$

For the second term on the right of (A.1), note from the market-clearing condition (5) that

$$\frac{dP}{dt} = \frac{d\omega}{dt} = -\Big(\frac{m_p}{m_p + M_P}\Big)\,, \tag{A.2}$$

and hence, since $p = w + t$,

$$\frac{dp}{dt} = \frac{d\omega}{dt} + 1 = \frac{M_P}{m_p + M_P}\,. \tag{A.3}$$

Substituting (A.3) into that second term gives

$$-\left(S^* - \theta^A\right) R_{SP}\left(\frac{m_p}{M_P}\right)\left(\frac{M_P}{m_p + M_P}\right) = \left(S^* - \theta^A\right) R_{SP}\left(\frac{dP}{dt}\right)\,, \tag{A.4}$$

use also having been made of (A.2). Recalling that $R_{SP} = -Z_P$, rearranging gives equation (9). □

Appendix B. Proof of Proposition 3

Since (15) is immediate given $s^* = \theta^A$, it suffices to verify that s^* will indeed be set equal to θ^A whether the unconstrained country uses explicit pricing or regulation.

Take first the case in which explicit pricing is used at the margin. Then s^* becomes s everywhere in the Lagrangean (7) and $g(p, s^*, s)$ in (3) becomes simply $r(p, s)$. The first order condition on s is then, after canceling terms in r_s, dividing by λ (=Λ, transfers being freely chosen) and collecting terms in r_{ss}

$$(s - \theta^A) r_{ss} + \Big(t - \frac{\mu}{\lambda}\Big) r_{ps} = 0\,. \tag{B.1}$$

From (D.4) in Appendix D below (with σ there set to unity, and so $\theta^{AA} = \theta^A$),

$$t - \frac{\mu}{\lambda} = (s - \theta^A)\frac{r_{sp}}{m_p}\,, \tag{B.2}$$

substituting which into (B.1) and collecting terms gives

$$(s-\theta^A)\left[r_{ss}+\frac{(r_{sp})^2}{m_p}\right]=0\,. \tag{B.3}$$

Since $m_p = e_{pp} - r_{pp} < 0$, the term in square brackets can be written as $[r_{ss}e_{pp} - (r_{pp}r_{ss} - (r_{sp})^2)]/m_p$; concavity of the expenditure function and strict convexity of $r(p,s)$ imply that $r_{ss}e_{pp} \leq 0$ and $r_{pp}r_{ss} - (r_{sp})^2 > 0$, and it then follows from (B.3) that $s = \theta^A$.

Turning to the case in which the home country uses regulation at the margin, so that s^* in (7) becomes $\bar{s}$, noting that then

$$g_{s^*}(p.\bar{s},s) = -(\bar{s}-s)r_{ss}(p,\bar{s})\,, \tag{B.4}$$

it is readily seen that the first order condition on $\bar{s}$ takes the same form as (B.1) but with s replaced by $\bar{s}$. It follows that efficiency in this case requires $\bar{s} = \theta^A$ as claimed. ☐

Appendix C. Proof of Proposition 4

The Lagrangean for the problem described in the text is given by

$$\begin{aligned}
\mathcal{L} \;&=\; u+\phi(U-\bar{U}) \\
&+\; \lambda\{e(p,u)+\theta k-g(p,s^*,s)+(1+v)sr_s(p,s^*)-t(1+v)m_p(p,s^*,u) \\
&+\; E(P,U)+\Theta k-G(P,S^*,S)+SR_S(P,S^*)\} \\
&+\; \mu\left(m_p\left(p,s^*,u\right)+M_P\left(P,S^*,U\right)\right).
\end{aligned} \tag{C.1}$$

The first order condition on ω is

$$\begin{aligned}
&\lambda\{e_p-\theta(r_{sp}+R_{SP})-g_p+(1+v)sr_{sp}-(1+v)tm_p+E_P-\Theta(r_{sp}+R_{SP})-G_P+SR_{SP}\} \\
&+\mu(m_p+M_P)=0\,.
\end{aligned} \tag{C.2}$$

Using (5) to cancel terms, and using also (D.2) from Appendix D below and its foreign analogue, this becomes, on collecting terms,

$$\lambda\Big\{\left(s^*+vs-\theta^A\right)r_{sp}+\left(S^*-\theta^A\right)R_{SP}-(1+v)tm_p\Big\}+\mu(m_p+M_P)=0\,. \tag{C.3}$$

The first order condition on t, using (D.2) and collecting terms, is

$$\lambda\Big\{\left(s^*+vs-\theta^A\right)r_{sp}-v\,m-(1+v)\,tm_p\Big\}+\mu m_p=0\,. \tag{C.4}$$

Solving (C.4) for μ, substituting into (C.3) and noting from (A.3) that

$$\frac{m(m_p + M_P)}{m_p M_P} = \left(\epsilon(m,p)\frac{dlnp}{dt}\right)^{-1}, \tag{C.5}$$

the result simplifies to (16) of Proposition 4. ☐

Appendix D. Proof of Proposition 5

From (7), the first order condition on ω is

$$\lambda\{m + (s^* - \theta)r_{sp} - \theta R_{SP} - tm_p\} + \Lambda\{M + (S^* - \Theta)\,R_{SP} - \Theta r_{sp} - TM_P\} \\ + \mu(m_p + M_P) = 0\,, \tag{D.1}$$

use having been made of $m \equiv e_p - r_p$ and $M = E_P - R_P$ together with the implication of (3) that

$$g_p = r_p - (s^* - s)r_{sp}\,, \tag{D.2}$$

(and similarly abroad). Dividing by λ, recalling that $\theta^{AA} \equiv \theta + \sigma\Theta$, and collecting terms in r_{sp} and R_{SP}, (D.1) becomes

$$m + (s^* - \theta^{AA})r_{sp} - tm_p + \sigma M + (\sigma S^* - \theta^{AA})R_{SP} - \sigma TM_P + \frac{\mu}{\lambda}(m_p + M_P) = 0\,. \tag{D.3}$$

The first order condition on t, again using (D.2), dividing by λ and collecting terms in r_{sp} is

$$(s^* - \theta^{AA})r_{sp} - tm_p + \left(\frac{\mu}{\lambda}\right)m_p = 0\,. \tag{D.4}$$

Solving (D.4) for μ/λ and substituting into (D.3), equation (17) of Proposition 5 follows after some simplification, dividing by M_P and recalling from (5) that $m = -M$. ☐

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