Border adjustments supplementing nationally determined carbon pricing[*]

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Abstract

The Paris agreement can be seen as a first ambitious multilateral climate agreement post Kyoto. The aim of the convention is to cap global warming at +2°C. However, each country's measures are chosen individually and voluntarily and there will be no mechanism to force a country to comply with its own "nationally determined contributions". This bottom up approach builds on unilateral actions and yields some kind of carbon pricing, not necessarily identical across countries. As a consequence, these nationally determined climate policies have negative drawbacks in terms of carbon leakage and loss of competitiveness for firms producing in a more ambitiously regulating country. To restrict these negative effects, border adjustments (BAs) may be appropriate. Since there is a competitive disadvantage at home as well as abroad, BAs can either be imposed on imports or exports to supplement the existing domestic carbon pricing. In a game-theoretic model with imperfect competition, we look at the implications an import BA or a combination of im- and export BA has on domestic welfare and global emissions. We distinguish between Bertrand and Cournot competition and conclude that both BA types improve the competitiveness of domestic firms as well as the welfare of the unilaterally (or more ambitiously) regulating country independent of the underlying competition type.

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1 Motivation

Fighting climate change is an ongoing concern for policy makers all around the world. Its global character and the involvement of many parties leaves global climate agreements a very complicated issue. Moreover, since climate protection is a public good, there are free rider incentives. After years of multilateral negotiations, the parties finally succeeded in Paris to sign a first promising multilateral agreement post Kyoto. The signatories start to mitigate their CO_2 emissions to achieve the Paris goals through "nationally determined contributions"[1], which implicitly yields in pricing carbon. However, with this bottom-up approach, every country decides unilaterally how to achieve its emission reduction. Consequently, some countries will do more and some will do less, i.e. despite the multilateral action, there still is regulatory asymmetry that causes a competitive disadvantage for the firms in the (ambitiously) regulating countries that leads to the well-known caveats of unilateral climate policy. Furthermore, the initial carbon prices or at least the carbon price differentials between countries are relatively small. In our model, we consider an ambitious home country with climate policy whose firms compete with firms located in a foreign country that has no or at least a less ambitious climate policy. In the latter case, the regulatory asymmetry between the signatories is the carbon price differential.

With a nationally determined climate policy, domestic producers face climate measures which increase their operating costs. Since foreign producers in a non-regulating or less ambitious country do not face these higher costs, the regulation creates a competitive disadvantage for domestic firms. Consequently, domestic production will be replaced by imports so that the success of a nationally determined climate policy falls short of the intended extent. In the worst case, overall emissions may even increase if technologies abroad are less environmentally friendly than domestic ones. This phenomenon is known as carbon leakage (CL).

To tackle these problems and maybe even give an incentive to countries to join climate agreements by reducing the free rider incentive, border adjustments (BAs) are considered an option.[2] They can be applied on imports or on exports in order to level the playing field. In the former case, they work like an import tariff and in the latter like an export subsidy. Böhringer et al. (2012) compare several multi-sector, multi-region CGE models and conclude that BAs are suitable instruments in addition

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[1] The Paris agreement builds a turning point in climate protection. However, even before Paris, numerous countries implemented some kinds of carbon pricing unilaterally, either through a cap and trade system or taxing carbon directly.

[2] Anoulies (2015) finds that even the prospect of a possible implementation of BAs can induce more countries to join international environmental agreements. Furthermore, Helm and Schmidt (2015) as well as Karp and Zhao (2008) conclude that BAs can help countries into a climate coalition.

to unilateral climate policy because they reduce CL.[3] Moreover, Fischer and Fox (2012) as well as Veenendaal and Manders (2008) find that BAs on imports and on exports can partly restore competitiveness.

Dermailly and Quirion (2008b) find in their analysis on the european iron and steel sector that competitiveness losses are small. However, a nationally determined climate policy affects more than just competitiveness. It influences several factors, such as energy prices or income distribution. It might even cause the relocation of production plants to less regulating countries.[4] However, in our model, we focus on CL as a shift in production caused by competitiveness loss. Ritz (2009) refers to this as output leakage which he identifies as a crucial part of CL. However, implementing BAs has some real world issues. This is why Sakai and Barrett (2016) doubt the effectiveness of BAs as exclusive measure to fight CL.[5]

After all, neither CL nor restoring competitiveness should be considered as the only assessment criterion to evaluate the consequences of supplementing nationally determined carbon pricing by the introduction of a BA. It is the whole benefit of the regulating region which has to be considered. Therefore, for evaluating the efficacy of a BA, the impact on consumer and producer surplus as well as on global emissions (i.e. a proxy for damage) and public revenues are decisive. Since we analyze nationally determined measures, we have to take into account that usually, policy makers do not have global but national welfare in mind when taking decisions. Hence, we will analyze the impacts of BAs on global emissions and on national welfare in a partial equilibrium model. As usual in a game theoretic analysis, we focus on the main (direct) impact of a BA on national welfare. Thus, we abstract from indirect channels like changes in terms of trade or factor prices (income) whose impact can only be dealt with in a general equilibrium model. However, this shortcoming is not really decisive because an optimal choice changes at most gradually.

In our analysis, we consider a country that has engaged in climate protection by implementing some sort of carbon pricing while other countries are not that

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[3] There are several studies on a regional level which include different sectors with carbon pricing. They all show that CL will be reduced by applying BAs. For details, see Mathiesen and Mæstad (2004), Ponssard and Walker (2008), Dermailly and Quirion (2008a and 2008b), Meunier et al. (2014), Monjon and Quirion (2011).

[4] An analysis on plant relocation caused by climate policy is made by Mæstad (2001). He concludes that unilateral climate policy should, from a global economic efficiency perspective, always include trade measures that avoid this form of leakage. Furthermore, Veenendaal and Manders (2008) conclude that BAs reduce employment losses due to production replacement compared to a climate policy without BAs.

[5] They show that additional trade provisions, such as the principle of "best available technology" can reduce carbon emissions significantly. Nevertheless, the issues can be relaxed if the BA scheme just covers a few trade-exposed and carbon-intensive commodities as proposed in Droege (2011) and Lininger (2015). Another administrative issue is the compatibility of BAs with WTO regulations. However, its thorough analysis is beyond the scope of this paper (see for example Ismer and Neuhoff (2007)).

ambitious.[6] The difference in carbon prices yields a competitive advantage for firms in the foreign country and therefore part of the domestic production is shifted abroad.

Literature shows that the competition type is crucial for the magnitude of CL.[7] As we know from standard trade literature (Brander and Spencer (1985)), the underlying competition type also determines the optimal trade policy instruments. Since BAs cause similar effects as import tariffs or export subsidies, we want to examine whether these contrasting recommendations also apply to BAs under oligopolistic competition (i.e. Bertrand or Cournot). The question whether the optimal BA policy might be ambiguous due to different strategic incentives depending on the competition type has not been analyzed in detail yet. Thus, the overall purpose of this analysis is to find out whether the welfare of the (ambitiously) regulating country can be improved by BAs given some extent of carbon pricing and whether the results depend on the underlying competition type.

However, we have to take into account that trade measures do not only affect domestic but also foreign welfare. Naturally, foreign welfare improves with a nationally determined climate policy at the expense of the implementing country and deteriorates with a BA. However, for the evaluation of the consequences for the foreign country, the choice of the benchmark scenario is crucial. This is emphasized in Becker et al. (2013) and supported by the results of Yomogida and Tarui (2013). The former compare the situation without any climate policy with a unilateral climate policy consisting of a carbon tax supplemented by an import BA. Since a combined measure is compared to the situation pre climate policy, the foreign country is not necessarily worse off with a domestic tax plus import BA. In this case, the artificially created competitive advantage for the foreign country is taken back by the BA at the same time so that the foreign country finds itself in the same competitive situation as before. This is why we talk about restoring, rather than creating competition neutrality. Yomogida and Tarui (2013) compare two climate policies where the government can either implement an emission tax with or without BA on im- and exports. Not surprisingly, they find that the emission tax policy with BAs yields better national welfare and environmental quality than without BAs. Moreover, they find that BAs are not necessarily a beggar-thy-neighbor policy when the positive effects of global emission reduction and profit shifting due to unilateral carbon pricing outweigh the profit shifting due to BAs. Our benchmark scenario to compare our results to is the

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[6] Complementary, Eyland and Zaccour (2012) allow the foreign country to have active climate policy in their game-theoretic approach. They show that a partial import BA can set incentives for the foreign country to implement climate policy but they also conclude that there are undesired strategic effects which can set (wrong) incentives resulting in export subsidies which could not legally be justified under WTO-law.

[7] Due to stronger competitive pressure than in Cournot competition, CL is higher under Bertrand competition (see Fowlie (2009)) as well as under perfect competition (see Ritz (2009)).

situation post carbon pricing.

Moreover, there are design options of BAs that can attenuate the negative consequences on foreign welfare: Although Böhringer et al. (2012) warn that existing income inequalities might be exacerbated due to the redistributive effects of BAs, they suggest that this problem may be overcome if the revenues created by BAs are attributed back to the exporting countries. Moreover, Mattoo et al. (2009) conclude from their CGE model that the trade effects for non-regulating countries are weakened if BAs are applied symmetrically on im- and exports based on the carbon content in domestic production rather than the carbon content of imports.

Various authors took consequences on national and foreign welfare into account by regarding global welfare.[8] Gros and Egenhofer (2011) show that a BA on imports increases not only national but also global welfare because it implicitly introduces carbon pricing also to countries without any climate regulation. The (well-known) welfare loss caused by an import tariff is overcompensated by the welfare gain due to decreased global emissions.[9] Although Böhringer et al. (2010) find that in some cases, there are welfare losses in the non-regulating countries, global costs in achieving a given emission level can be slightly reduced. Moreover, they find that the main effects on global welfare, emissions and leakage are caused by the initial unilateral climate policy.

The paper is organized as follows: First, we introduce our model framework and explain how the BAs can be applied. With the equilibrium results, we then determine the emission levels to analyze the environmental efficacy of the BAs. We proceed with chapter **??**, where we analyze domestic welfare in order to find out which policy option is suitable to supplement a nationally determined climate policy. Finally, we briefly discuss our results to draw a conclusion in the end.

2 Modeling climate and trade policy

In our analysis, we consider two countries, A and B, where each country has firms that supply the domestic market and firms that supply the export market. These firms compete on many markets. On each market, one domestic and one foreign firm offer (near) substitutes in demand. We assume that each of these duopolies is alike. Hence, the analysis of the home and the foreign market can be simplified to that of a representative duopoly of one domestic and one foreign firm. The demand is

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[8] For an analysis in terms of global efficiency, see Keen and Kotsogiannis (2014) or Mattoo et al. (2009). Moreover, Vlassis (2013) finds that harmonizing environmental policies can be Pareto-improving.

[9] This only holds if the country implementing the BA is big enough to influence the world market price as is known from standard international trade literature (see for example Krugman et al. (2012), p. 225 ff.).

considered to be a linear function of both prices: $x_i = 1 - \alpha p_i + \beta p_j$ in country A and $y_i = 1 - \alpha q_i + \beta q_j$ in country B. Note that the indices indicate where the good is produced whereas x and y denote the place of consumption. We assume that the effect of the own price exceeds the effect of the competing price so that $\alpha > \beta > 0$. Furthermore, country A has already engaged in climate protection before by having implemented some form of carbon pricing where the carbon price is t.[10]

We use a two-stage model where the home country A decides about BAs in the first stage and in the second stage, firms in A compete in Bertrand or Cournot competition with firms situated in B whose government does not apply any kind of climate policy. For better understanding, the model structure with demand and operating costs is illustrated in figure **??**.[11]

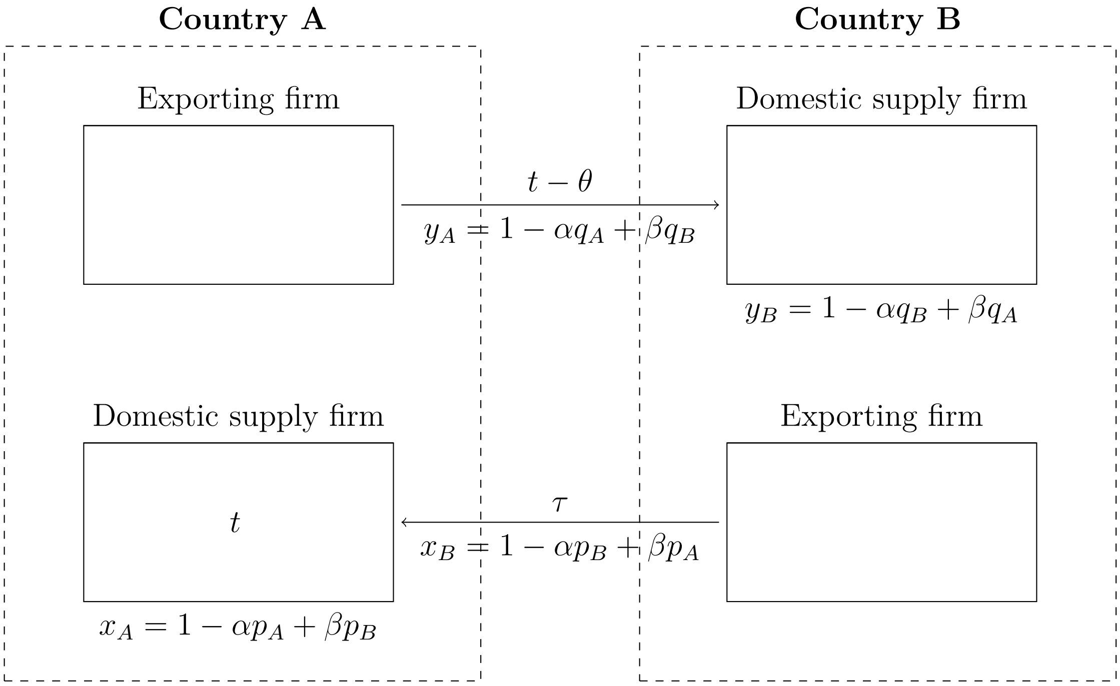

Figure 1: Trade structure

2.1 Costs and policies

With domestic carbon pricing, operating costs vary with the place of production and the place of consumption. The government in country A can choose one of three options. In our status quo benchmark (SQ), it does not apply any BA but

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[10] In the remainder of this paper, we will always talk about the carbon price t which represents the situation where the competing country has a carbon price of zero. However, we bear in mind that the results are also valid in the post Paris situation with a carbon price differential t between regulating countries.

[11] We thank an anonymous reviewer for suggesting this illustration.

there is a carbon price t, so that domestic production costs are higher compared to those in non- or less regulating countries, i.e. domestic firms have a competitive disadvantage. Alternatively, the domestic government can either apply an import BA (IBA) with an import carbon price τ or it can combine an import with an export BA, implemented at the same rate.[12] We will refer to this as *complete BA* (CBA) where the carbon price for imports is θ and the net carbon price for exports is $t - \theta$. In order not to discriminate foreign firms, i.e. not to oppose WTO-rules, any BA must not exceed the domestic regulations. Consequently, t is the maximum amount for both adjustments. Moreover, partial adjustments are possible, i.e. $0 \leqslant \tau, \theta \leqslant t$. The marginal production costs c are assumed to be constant and identical in both countries in order to examine the impact of the BAs only. Firms in both countries are carbon-price takers which makes the model applicable for carbon pricing in form of a carbon tax or some sort of cap and trade system. Table (**??**) gives an overview over the different operating costs that arise for each firm in each market. The variable c_i or ς_i denotes the place of consumption whereas the index indicates the place of production. Hence, goods that are sold on the A market ($x_A; x_B$) cause costs c_i and goods that are sold on the B market ($y_A; y_B$) cause costs ς_i.

		SQ	IBA	CBA
produced and consumed in A (x_A)	c_A	$c+t$	$c+t$	$c+t$
imports from B to A (x_B)	c_B	c	$c+\tau$	$c+\theta$
exports from A to B (y_A)	ς_A	$c+t$	$c+t$	$c+t-\theta$
produced and consumed in B (y_B)	ς_B	c	c	c

Table 1: Operating costs

The purpose of BAs is leveling the playing field between domestic and foreign competitors. Thereby, an IBA restores import neutrality whereas the CBA on im- and exports restores competition neutrality by harmonizing production costs across countries.[13] Comparing competitors cost on the domestic market in the CBA scenario leads to $(c + t) - (c + \theta)$, while on the foreign market, costs are $(c + t - \theta) - c$. Consequently, we have the same cost differential $t - \theta$ on either market, i.e. both, the interior and the exterior competitive disadvantage, are handled in the same manner. By this means, the burden of the regulation shifts from domestic production to

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[12] We do not consider the implementation of an export BA as exclusive adjusting measure since this would counteract the initial ambitious climate policy of nationally determined carbon pricing. Since we assume that climate protection is still a policy goal with high priority, this scenario can be neglected.

[13] For alternative concepts of competition neutrality, see Sheldon (2011) or Sheldon and McCorriston (2012).

domestic consumption[14] without a change in the magnitude of the regulation base.

2.2 Profits (2nd stage)

As usual, to solve a two-stage game, we use backward induction and start with the second stage, i.e. with maximizing profits of the firms in both countries. The first letter in the profit index gives the place of production whereas the second letter marks the place of consumption. Consequently, profits created on the home market for the domestic firm and its foreign competitor are

$$\pi_{AA} = (p_A - c_A)x_A \qquad \text{and} \qquad \pi_{BA} = (p_B - c_B)x_B. \tag{1}$$

Profits on the foreign market for the exporting firm of country A and its competitor in country B are

$$\pi_{AB} = (q_A - \varsigma_A)y_A \qquad \text{and} \qquad \pi_{BB} = (q_B - \varsigma_B)y_B. \tag{2}$$

Equilibrium prices and quantities are straightforward. Details can be found in the appendix in sections (**??**) for Betrand and (**??**) for Cournot competition.

2.3 Emissions and environmental damages

Based on the equilibrium quantities, we can derive the emissions caused by production. We assume that emissions are proportional to domestic and foreign production, i.e. $x_A + x_B + y_A + y_B$. Total emissions under Bertrand competition[15] are

$$D^B = 4 - \frac{(\alpha - \beta)[4 + \alpha(c_A + c_B + \varsigma_A + \varsigma_B)]}{2\alpha - \beta}. \tag{3}$$

Respectively, total emissions under Cournot competition are

$$D^C = \frac{4(\alpha + \beta) - (\alpha^2 - \beta^2)(c_A + c_B + \varsigma_A + \varsigma_B)}{2\alpha + \beta}. \tag{4}$$

By comparison we find that emissions under Bertrand competition are higher than under Cournot competition because $4 - (\alpha - \beta)(c_A + c_B + \varsigma_A + \varsigma_B) > 0$. This inequality is true because it represents a positive served demand with prices equal to marginal

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[14] The consumption-based approach has several advantages compared to the production based approach which have already been discussed in the literature. See for example Peters (2008) or Steininger et al. (2014).

[15] Throughout the whole paper, we will refer to results of Bertrand (Cournot) competition with superscript B (C).

costs. Since the marginal costs are the lowest prices possible, this served demand is always positive. This result fits the intuition since Bertrand competition is stronger and therefore yields lower prices with higher production. Due to the assumptions of the model, this directly translates into higher emissions.

Considering equations (**??**) and (**??**), it becomes obvious that global damage decreases with the sum of effective marginal costs ($c_A + c_B + \varsigma_A + \varsigma_B$), independent of the competition type. Hence, the three regimes can be put into a ranking according to their impact on global emissions: $D_{SQ}(t > 0, \tau = \theta = 0) = D_{CBA}(\theta = t) > D_{IBA}(\tau = t)$ which leads to the following proposition.

Proposition 1 *Environmental efficacy of BAs*
Given a domestic carbon price and symmetric emission intensity in both countries:

i) Applying a supplementary IBA exclusively supports the home country's climate policy by further reducing global emissions.

ii) A supplementary CBA that is applied to imports and exports at the same rate neither improves nor deteriorates the global emission level. It rather shifts emissions back from the non-regulating to the regulating country (i.e. reduces CL).

Proof.

i) As the (negative) sum of all effective marginal costs $c_A + c_B + \varsigma_A + \varsigma_B = 4c + 2t + \tau$ determines the impact on total emissions in either case (Bertrand and Cournot), an import BA softens CL and improves the efficacy of climate policy ($\frac{\partial D}{\partial \tau} < 0$).

ii) For the CBA, the sum of all effective marginal costs is in either case (Bertrand and Cournot) reduced to $c_A + c_B + \varsigma_A + \varsigma_B = 4c + 2t$ and consequently does not change with θ ($\frac{\partial D}{\partial \theta} = 0$). If both BAs are applied at the same rate, the partial effects on im- and exports add up to zero for both competition types.

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This result is rather intuitive: the regime which burdens imports and domestic production naturally performs best with respect to global emissions since with this regime, the broadest production volume is regulated, i.e. emissions abatement is the highest. The CBA is emission neutral since under symmetric conditions[16], the increase in emissions caused by the export BA equals the decrease in emissions thanks to the IBA.

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[16] By symmetric conditions, we refer to the same emission intensity in both countries. We will abstract from this assumption in section **??**.

3 Optimal BA to supplement domestic carbon pricing (1^{st} stage)

After the Paris agreement, there is some national carbon pricing but there is still no uniform global carbon price, resulting in the already explained negative drawbacks. The purpose of this paper is not to find the optimal carbon price but the optimal supplementing policy to counteract these drawbacks. Consequently, we assume t to be fixed and relatively small since it can be interpreted as either the initial carbon price in a bottom-up approach or as the carbon price differential. Since we consider a nationally determined policy, we assume the regulator to make a decision about BAs based on their impact on national welfare rather than on global welfare. Domestic welfare

$$W_A = PS_A + CS_A + T_A - D \tag{5}$$

consists of country A's producer surplus PS_A, consumer surplus CS_A, public revenues T_A and damage approximated by global emissions D. We normalize marginal damage to unity since including marginal damage as a parameter does not change our results.

3.1 Import BA (IBA)

First, we consider an IBA as exclusive adjusting measure. The IBA can be applied as partial or full IBA or not at all, i.e. $\tau \in [0, t]$. We can calculate the impact on country A's welfare by summing up the positive welfare effects (**??**) and the negative effect on CS (**??**) to

$$\frac{\partial W_A^B}{\partial \tau} = \Gamma \begin{bmatrix} 2\alpha^2\beta(p_A - c - t) + \\ \alpha\beta x_A + 2\alpha^2 x_B \end{bmatrix} + \frac{\alpha}{2\alpha - \beta}\left[\frac{\alpha\beta t - \tau(2\alpha^2 - \beta^2)}{2\alpha + \beta} + \alpha - \beta\right] > 0 \tag{6}$$

and for Cournot competition with the positive welfare effects (**??**) and the negative effect on CS (**??**), we obtain

$$\frac{\partial W_A^C}{\partial \tau} = \Gamma \begin{bmatrix} 2\alpha\beta^2 x_A + \frac{x_A}{\alpha}\beta(\alpha^2 - \beta^2) + \\ x_B(2\alpha^2 + \beta^2) \end{bmatrix} + \frac{\alpha^2 - \beta^2}{2\alpha + \beta}\left[\frac{\beta t - 2\alpha\tau}{2\alpha - \beta} + 1\right] > 0, \tag{7}$$

where Γ is an abbreviation for $\Gamma = \frac{1}{4\alpha^2 - \beta^2}$.

Proposition 2 *IBA supplementing a nationally determined carbon price*
Independent of the competition type, a full IBA improves national welfare.

Proof. Obviously, the first terms in large brackets in (**??**) and (**??**) are positive.[17]

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[17] Note that the first term of (**??**) is positive as the equilibrium price p_A always exceeds firms' operating costs $(c + t)$.

Furthermore, since $2\alpha^2 - \beta^2 > \alpha\beta\frac{1-t}{1-\tau}$, the second term in (**??**) is positive and since $2\alpha > \beta\frac{1-t}{1-\tau}$, the second term in (**??**) is positive for all $\tau \leqslant t$. Thus, national welfare is increasing with an IBA and it should be applied to its maximum extent as a full IBA, i.e. $\tau^* = t$. ∎

3.2 Complete BA (CBA)

Next, we will evaluate the welfare consequences in case of an implementation of both instruments at the same rate in a CBA θ. We calculate the impact on welfare and rearrange to

$$\frac{\partial W_A^B}{\partial \theta} = \Gamma \begin{bmatrix} \alpha\beta\left[\alpha(p_A - c - t) + \alpha(p_A - c) - \beta(q_A - c)\right] \\ +\alpha\beta x_A + 2\alpha^2 x_B + 2\alpha^3(t - \theta) \end{bmatrix} - \theta\Gamma\alpha(2\alpha^2 - \beta^2) \tag{8}$$

for Bertrand and for Cournot, we have

$$\frac{\partial W_A^C}{\partial \theta} = \Gamma \begin{bmatrix} \beta t(\alpha^2 - \beta^2) + 2\alpha\beta^2 x_A + 2\alpha(\alpha^2 - \beta^2)(t - \theta) \\ +\beta^2 y_A + \frac{x_A}{\alpha}\beta(\alpha^2 - \beta^2) + x_B(2\alpha^2 + \beta^2) \end{bmatrix} - \theta\Gamma(\alpha^2 - \beta^2)2\alpha. \tag{9}$$

Obviously, the impact on domestic welfare stems from changes in producer surplus, consumer surplus and public revenues only. We already discussed in section **??** that a change in the CBA θ leaves global emissions unaltered as the decrease through an import BA will be completely offset by the emission increase caused by the export BA.

Proposition 3 *CBA supplementing a nationally determined carbon price*

i) Independent of the competition type, a full CBA combining export and import BA improves national welfare as long as carbon prices are rather small, i.e. $\theta^* = t$.

ii) For relatively high carbon prices t, a partial CBA becomes optimal ($t > \theta^* > 0$). However, no CBA is not an appropriate option.

Proof.

i) For both equations, (**??**) and (**??**), the first term in large brackets is positive. For Bertrand, the term is positive since the equilibrium price must always exceed operating costs, i.e. $p_A - c - t > 0$ and the price of domestic products within the home country always exceeds the export price ($p_A > q_A$) since we have a competitive disadvantage on the foreign market in combination with strategic complementarity of prices. For Cournot, it is obvious. Thus, there is only one negative term in each equation which depends on θ. In case of a small t, θ is even smaller since $\theta \leqslant t$. Consequently, for a small t, welfare is strongly increasing in θ and we get the corner solution of a full BA $\theta^* = t$.

ii) Furthermore, figure (**??**) shows the marginal impact of a CBA on national welfare with an unconstrained optimum at θ^*_{high}. However, as a WTO compatible CBA requires $\theta \leqslant t$, there are two options. Either t_{high} exceeds θ^*_{high} or t_{low} falls short before θ^*_{high}. In the latter case, the constrained optimum yields $\theta^*_{low} = t_{low}$. Thus, for low carbon prices, a full CBA is optimal while for high carbon prices, a partial CBA becomes optimal. Additionally, $\frac{\partial W_A}{\partial \theta}|_{\theta=0} > 0$ in either case. Thus, not to apply any CBA is not an appropriate option.

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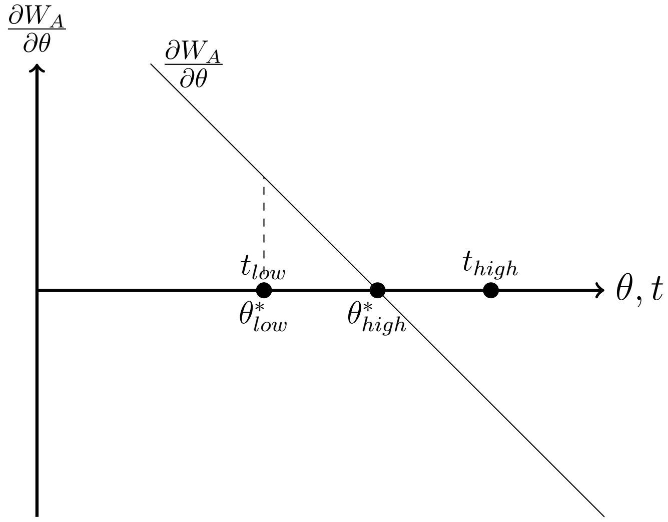

Figure 2: Marginal impact of CBA on national welfare

A full CBA restores competitiveness at home and abroad by harmonizing operating costs across countries without increasing global emissions. Countries that apply similar carbon pricing choose a full CBA whereas only extreme outliers (pioneers) choose a partial CBA. With a high t, the initial loss in CS is strong and even exacerbated by θ.[18] With the IBA, there is the additional effect of decreasing global damage whereas this positive welfare effect is missing for the CBA. This is why the initial carbon price t determines the optimal extent of the CBA while the optimal extent of the IBA is independent of t.

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[18] This is similar to an over-internalization (cf. Ebert 1991/92, Ebert and v.d. Hagen 1998).

4 Discussion and conclusion

As we have shown, a country that ambitiously protects climate can improve the competitiveness of its own industry by introducing BAs without counteracting the initial goal of climate protection. However, perfectly symmetric countries are not a realistic assumption. Therefore, our results require a robustness check. We will now discuss three main asymmetries: i) different emission intensities, ii) different marginal damages across countries and iii) different trade structures (i.e. industrialized countries are net carbon importers). First, we assume country B to apply a technology that is more emission intensive than the one of country A which already had incentives to invest in emissions abatement due to carbon pricing. In order to implement this in the model, the damage function can be modified to $D = (x_A + y_A)(1 - \lambda) + (x_B + y_B)(1 + \lambda)$, where λ represents the asymmetry in the pollution coefficient. Under symmetric conditions ($\lambda = 0$), we already explained that the CBA is emission neutral, i.e. the net effect on global damage is zero because the global production level remains constant. With asymmetric emission intensities however, global damage is decreasing with either type of BA which in turn increases (national and global) welfare. While the global production remains unchanged, a CBA shifts “dirty” foreign production to “clean” domestic firms. Hence, there is an additional welfare increasing factor which weakens the influence of the initial carbon price t and supports a more excessive use of a CBA. Since an IBA also increases clean production while cutting dirty production, global emissions decrease in both BA scenarios for both competition types. Consequently, asymmetric emission intensities even amplify our results.

Regarding the consequences on foreign welfare, even the non- or less regulating countries have environmental benefits from global emission reductions. This beneficial effect is even amplified if we take into account the second asymmetry: different marginal damage. Non-OECD countries possibly suffer more from climate change, i.e. have higher marginal damage from emissions. Thus, the positive environmental effect on foreign welfare is even stronger. On the other hand, with lower marginal damage from emissions, the beneficial effect of BAs for OECD countries is weakened. Since a CBA is emission neutral, marginal damage from emissions does not influence national welfare in this scenario. However, the extent of the optimal IBA depends on marginal damage from emissions. Countries with very low marginal damage or those that might even benefit from climate change do not engage in climate protection (i.e. $t = 0$) and obviously, there is no need for BAs. In contrast, countries with high marginal damage regulate ambitiously and apply a full BA since the beneficial effect from emission reduction is high. Countries with medium marginal damage implement a climate policy and partial BAs. Since BAs are relevant only for countries which have already adopted a climate policy (i.e. carbon pricing in some form), they have at least medium marginal damage from emissions. Hence, taking into account asymmetric marginal damage only alters the extent of an optimal IBA but not the decision whether to implement it or not.

Domestic consumption is burdened in both scenarios. Considering that most Annex B countries are net importers of carbon (Peters and Hertwich(2008)), consumer surplus becomes a dominant welfare factor (relative to producer surplus, public revenues and environmental damage) for these countries. In that case, the negative welfare effect on CS ((**??**) and (**??**), respectively) becomes too strong to leave the overall effect (**??** and **??**, respectively) positive for all values of $\tau, \theta \leqslant t$. Thus, an IBA or CBA is less favorable under an asymmetric trade structure and a partial BA becomes more attractive.

Our results are applicable to different kinds of carbon pricing. For a carbon tax, the intuition is straightforward and furthermore, we can easily transfer our results to a situation with a cap and trade system. If permits are auctioned completely, the effects of a cap and trade system are identical to those of a carbon tax. Furthermore, for a permit market with partial auctioning, the effects are at least similar. The only difference in the latter case would be that less foreign profit can be shifted to domestic public revenues through an IBA.

In our model, we focussed on the national perspective of a climate policy as agreed on in the Paris convention. However, climate change as a global problem can only be tackled efficiently with an internationally coordinated policy. Keen and Kotsogiannis (2014) show that BAs help decentralizing different carbon prices efficiently while Gros and Egenhofer (2011) are interested in global welfare implications of a BA supplementing a unilateral climate policy. However, their results are not applicable for governments in a bottom up post Paris process as long as there is no binding climate agreement for all countries.

Nevertheless, we have shown that regardless of the underlying competition type, both BAs as a supplementing policy for existing carbon pricing can improve national welfare. Either an IBA or a CBA focussed on both, exports and imports, can increase competitiveness of the firms in the regulating countries. Furthermore, neither of the two options deteriorates the ecological efficiency of the initial chosen climate policy since both options reduce CL via the competitiveness channel. With the IBA, we even reach a further emission reduction by reduced output. Consequently, BAs to supplement carbon pricing are appropriate tools to increase national welfare, even after the success of Paris.

5 Appendix

5.1 Equilibrium analysis (2^{nd} stage)

5.1.1 Bertrand competition

First, the presented model will be solved assuming price competition. We maximize profits with respect to the domestic and foreign prices. For simplicity, we introduce $\Gamma = \frac{1}{4\alpha^2-\beta^2}$ and get the equilibrium prices

$$\begin{pmatrix} p_A & q_A \\ p_B & q_B \end{pmatrix} = \Gamma \begin{pmatrix} 2\alpha & \beta \\ \beta & 2\alpha \end{pmatrix} \begin{pmatrix} 1+\alpha c_A & 1+\alpha \varsigma_A \\ 1+\alpha c_B & 1+\alpha \varsigma_B \end{pmatrix} \tag{10}$$

and the equilibrium quantities

$$\begin{pmatrix} x_A & y_A \\ x_B & y_A \end{pmatrix} = \begin{pmatrix} 1 & 1 \\ 1 & 1 \end{pmatrix} - \Gamma \begin{pmatrix} 2\alpha^2-\beta^2 & -\alpha\beta \\ -\alpha\beta & 2\alpha^2-\beta^2 \end{pmatrix} \begin{pmatrix} 1+\alpha c_A & 1+\alpha \varsigma_A \\ 1+\alpha c_B & 1+\alpha \varsigma_B \end{pmatrix}. \tag{11}$$

5.1.2 Cournot competition

To solve stage two under Cournot competition, we need the inverse demand functions within the home and the foreign country

$$\begin{pmatrix} p_A & q_A \\ p_B & q_B \end{pmatrix} = \frac{\begin{pmatrix} \alpha & \beta \\ \beta & \alpha \end{pmatrix} \begin{pmatrix} 1-x_A & 1-y_A \\ 1-x_B & 1-y_B \end{pmatrix}}{\alpha^2-\beta^2}. \tag{12}$$

Maximizing profits, the equilibrium quantities can be derived for the four firms that serve the domestic and the foreign market

$$\begin{pmatrix} x_A & y_A \\ x_B & y_B \end{pmatrix} = \Gamma(\alpha+\beta) \begin{pmatrix} 2\alpha & -\beta \\ -\beta & 2\alpha \end{pmatrix} \begin{pmatrix} 1-c_A(\alpha-\beta) & 1-\varsigma_A(\alpha-\beta) \\ 1-c_B(\alpha-\beta) & 1-\varsigma_B(\alpha-\beta) \end{pmatrix}. \tag{13}$$

Using the equilibrium quantities, the equilibrium prices are determined. Equilibrium prices are

$$\begin{pmatrix} p_A \\ p_B \\ q_A \\ q_B \end{pmatrix} = \frac{\Gamma}{\alpha^2-\beta^2} \begin{pmatrix} 1 & c_A(2\alpha^2-\beta^2)+\alpha\beta c_B \\ 1 & c_B(2\alpha^2-\beta^2)+\alpha\beta c_A \\ 1 & \varsigma_A(2\alpha^2-\beta^2)+\alpha\beta \varsigma_B \\ 1 & \varsigma_B(2\alpha^2-\beta^2)+\alpha\beta \varsigma_A \end{pmatrix} \begin{pmatrix} (\alpha+\beta)(2\alpha^2-\beta^2) \\ \alpha^2-\beta^2 \end{pmatrix}. \tag{14}$$

5.2 Welfare

5.2.1 General Prerequisites

First, we want to give some general prerequisites that hold for both competition types. We start with producer surplus which consists of profits from both firms situated in country A, i.e. π_{AA} and π_{AB} and add the revenues from carbon pricing

$$PS_A + T_A = \underbrace{(p_A - c_A)x_A}_{\text{profit from domestic sales}} + \underbrace{(q_A - \varsigma_A)y_A}_{\text{profit from exports}} + \underbrace{tx_A + (t-\theta)y_A}_{\substack{\text{revenues carbon pricing}\\ \text{from domestic production}}} + \underbrace{\tau x_B}_{\substack{\text{revenues}\\ \text{import BA}}} . \tag{15}$$

As revenues from carbon pricing levied on domestic production are costs of country A's firms, they cancel out to zero and (**??**) can be simplified to

$$PS_A + T_A = (p_A - c)x_A + (q_A - c)y_A + \tau x_B. \tag{16}$$

For domestic consumer surplus, we take into account domestic demand for both products (x_A and x_B)

$$CS_A = \frac{1}{2}(p_A^0 - p_A)x_A + \frac{1}{2}(p_B^0 - p_B)x_B \tag{17}$$

where p_i^0 is the axis intercept of the inverse demand function ($i = A, B$). The consumer surplus can be simplified to

$$CS_A = \frac{x_A^2 + x_B^2}{2\alpha}. \tag{18}$$

5.2.2 Import BA

To determine the impacts of the import BA on producer surplus and public revenues, we differentiate (**??**) with respect to τ. With equilibrium prices (**??**) and quantities (**??**), we can determine the derivatives for Bertrand competition

$$\frac{\partial(PS_A^B + T_A^B - D)}{\partial\tau} = \Gamma\alpha \begin{bmatrix} 2\alpha\beta(p_A - c - t) \\ +\alpha\beta t - \tau(2\alpha^2 - \beta^2) + (\alpha - \beta)(2\alpha + \beta) \end{bmatrix} + x_B > 0 \tag{19}$$

and with equilibrium quantities (**??**) and prices (**??**) for Cournot competition

$$\frac{\partial(PS_A^C + T_A^C - D)}{\partial\tau} = \Gamma\left[(\alpha^2 - \beta^2)[2\alpha(1-\tau) - \beta(1-t)] + 2\alpha x_A\right] + x_B > 0. \tag{20}$$

Both effects are positive as shown in the proof of proposition **??**. In order to compute the effect on consumer surplus, we use equation (**??**) with the equilibrium quantities

(**??**), to get the impact in Bertrand competition

$$\frac{\partial CS_A^B}{\partial \tau} = \Gamma\left[\alpha\beta x_A - (2\alpha^2 - \beta^2)x_B\right] < 0 \tag{21}$$

which decreases with τ as $x_A - x_B = -\frac{2}{3}\alpha t \leqslant 0$ and $\alpha\beta < 2\alpha^2 - \beta^2$. In Cournot competition, we obtain

$$\frac{\partial CS_A^C}{\partial \tau} = \frac{\Gamma}{\alpha}(\alpha^2 - \beta^2)(x_A\beta - 2\alpha x_B) < 0 \tag{22}$$

which decreases with τ as $x_A \leqslant x_B$ and $\beta < 2\alpha$.

5.2.3 Complete BA

For the CBA, we differentiate (**??**) with respect to θ to get the impact on domestic producer surplus and public revenues. With equilibrium prices (**??**) and quantities (**??**) we get the impact in Bertrand competition

$$\frac{\partial(PS_A^B + T_A^B)}{\partial \theta} = \Gamma\left[\alpha^2\beta[2(p_A - c) - t] + \alpha[2\alpha^2(t-\theta) - (q_A - c)\beta^2] - \theta(2\alpha^2 - \beta^2)\alpha\right] + x_B \tag{23}$$

and with equilibrium quantities (**??**) and prices (**??**) for Cournot competition

$$\frac{\partial(PS_A^C + T_A^C)}{\partial \theta} = \Gamma\left[\beta t(\alpha^2 - \beta^2) + 2\alpha\beta x_A + 2\alpha(\alpha^2 - \beta^2)(t-\theta) + \beta^2 y_A - \theta(\alpha^2 - \beta^2)2\alpha\right] + x_B. \tag{24}$$

Since an additional export BA does not influence consumer surplus in A, $\frac{\partial CS_A}{\partial \theta} = \frac{\partial CS_A}{\partial \tau}$.

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