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International Trade and Environmental Cooperation among Heterogeneous Countries

Soham Bakshi* and Amrita Ray Chaudhuri*,†

Abstract

We examine the impacts of trade liberalization and border tax adjustment (BTA) on the incentives of heterogeneous countries to cooperate when regulating emissions of a global pollutant. We consider an oligopoly model of trade between two countries, North and South, where production generates transboundary pollution and the pollution damage parameter is higher in the North. Each country imposes a pollution tax on its domestic firm, where the tax rate can be chosen either cooperatively or non-cooperatively. We analyze the sustainability of environmental cooperation between the countries within an infinitely repeated game framework using trigger strategies. While the North has a stronger incentive to cooperate than the South, we find that an increase in the degree of heterogeneity between the two countries in terms of their pollution damage parameter reduces the likelihood of cooperation between them. Trade liberalization increases both the global gains from cooperation as well as the likelihood of cooperation between the countries. Further, we consider the use of a border tax adjustment under non-cooperation, where the North imposes a tariff on imports of the polluting good from the South, and the tariff rate reflects the difference in pollution tax rates across the two countries. We find that imposing the BTA makes the North less likely to cooperate, while the South is more likely to cooperate provided the countries are sufficiently heterogeneous.

JEL classification: Q54; Q58; F18

Keywords: International environmental agreements; Transboundary pollution; International trade; Border tax adjustment

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1 Introduction

We examine countries' incentives to cooperate in regulating emissions of a transboundary pollutant, when the countries differ in terms of the damage they face from pollution. Such heterogeneity may arise due to differential vulnerability to pollution induced damages across countries, or may reflect income differential across countries. As observed in the empirical literature on economic growth and the environment, citizens of richer countries typically demand better environmental quality and experience a greater disutility from pollution than citizens of poorer countries. The presence of such heterogeneity leads to differential environmental policies across countries, which in turn influence international trade, and raises a set of questions not adequately addressed in the existing literature on international environmental cooperation, which mainly focuses on models with symmetric countries under autarky. In this paper, we address some of these issues involving international trade, transboundary pollution and environmental cooperation among heterogeneous countries. In particular, we analyze how the extent of heterogeneity and freer trade affect the sustainability of such cooperation. We also examine the role played by border tax adjustments (BTAs) in sustaining cooperation, where countries imposing a higher pollution tax on their domestic firms charge the BTA on imports of a polluting good from countries imposing a lower pollution tax.

These issues gain importance in light of the ongoing intergovernmental negotiations on climate change conducted under the aegis of the UNFCCC. Since the 1990s, while trade liberalization through regional and multilateral trade agreements have proliferated, intergovernmental negotiations to mitigate greenhouse gas emissions have floundered. Despite recognizing the need for more stringent environmental regulations, many developed countries have been reluctant to tighten their own regulations unless they are simultaneously matched by stricter regulations in developing countries. A main reason for this reluctance among developed countries has been the concern that their firms may lose international competitiveness if the stricter regulations are not matched by all other countries.¹ Moreover,

¹For example, this was cited as an important factor to justify the US' decision not to ratify the Kyoto

if stricter regulations in developed countries lead to the shifting of polluting production to developing countries with laxer regulations (i.e. “pollution leakage”), this would undermine the mitigation of transboundary pollutants at the global level.

One possible solution to these problems that has been recently proposed is the use of border tax adjustments based on differences in environmental regulations between a pair of trading countries (e.g. Böhringer et al., 2015, 2016; Eyland and Zaccour, 2012, 2014; Ghosh et al., 2012).² It is unclear as to whether BTAs based on environmental regulations would be consistent with extant WTO rules. While some have argued that exemptions under Article XX of the WTO allow the use of such BTAs (e.g. Zhang, 2010), others have suggested that this may not be the case and proposed a “carbon footprint tax” as a WTO compliant alternative to BTAs (MacAusland and Najjar, 2015).³

In this paper, we develop a theoretical framework which captures some of these issues underlying climate negotiations. Specifically, we consider an oligopoly model of trade in a polluting good between two countries, North and South, which differ in terms of their pollution damage parameter. The pollution damage parameter is assumed to be higher in the North. Production generates transboundary pollution, and each country imposes a pollution tax on its domestic firm, where the tax rate can be chosen either cooperatively or non-cooperatively. Since markets are imperfectly competitive, each country has an incentive to strategically distort its non-cooperative pollution tax in order to give its domestic firm a competitive advantage and capture rents from the other country (Barrett, 1994; Kennedy, 1994). We analyze the sustainability of environmental cooperation between the two countries within an infinitely repeated game framework, where cooperation is self-sustained through the use of trigger strategies.⁴

Protocol and Canada’s decision to withdraw from it.

²The Waxman-Markey Bill (American Clean Energy and Security Act of 2009) proposed a cap-and-trade system for the US and required importers to purchase “international reserve allowances” for goods from countries with laxer climate policies.

³For environmental exemptions under the WTO, see https://www.wto.org/english/tratop_e/envir_e/envt_rules_exceptions_e.htm

⁴Other papers on international environmental agreements that use a repeated game framework include Barrett (1999), Asheim et al. (2006), Asheim and Holtmark (2009), and Bencheikroun and Yildiz (2011).

Unlike most of the literature on international environmental agreements (IEAs), our model allows for both international trade in a polluting good and heterogeneity among countries. Consequently, we are able to analyze how inter-jurisdictional pollution leakage, facilitated by international trade, affects the incentives of heterogeneous countries to cooperate with each other in terms of their environmental policies. We find that, when the two countries choose their pollution tax rates cooperatively, they set it at the same level. As a result, there is no pollution leakage in the cooperative equilibrium. By contrast, the non-cooperative tax rate is higher in the North, which leads to production shifting from the North to the South and an increase in net exports of the polluting good from the latter to the former. Our analysis shows that a greater degree of cross-country heterogeneity with respect to the pollution damage parameter reduces the likelihood of cooperation between the countries. Second, we find that trade liberalization increases both the global gains from cooperation as well as the likelihood of cooperation between the countries. Third, imposition of a border tax adjustment by the North on imports of the polluting good from the South weakens the North's incentive to cooperate. As well, the BTA strengthens the South's incentive to cooperate provided the countries are sufficiently heterogeneous. Whether the BTA ultimately facilitates cooperation between the two countries depends, in part, on the rules associated with the use of BTAs.

Our paper contributes to a large literature on international environmental agreements (reviewed in Marrouch and Ray Chaudhuri, 2016). This literature mostly uses reduced form models, which abstract away from market structure, heterogeneity and trade flows between countries, by directly specifying the benefits and costs of identical countries as functions of their emission or abatement levels. To analyze the stability of self-enforcing IEAs, the dominant stream of the literature uses the internal and external stability criteria presented by d'Aspremont et al. (1983). Since they do not model international trade, the reduced form models cannot be used to analyze how trade liberalization, or the imposition of BTAs,

Like them, we assume that the use of trigger strategies is credible.

affects the incentives of countries to cooperate in terms of their environmental policies. The few papers which examine the stability of IEAs with heterogeneous countries (e.g. McGinty, 2007; Kolstad, 2010; Pavlova and de Zeeuw, 2013; Hagen and Eisenack, 2015), do not address these issues since they abstract away from international trade.

A smaller literature explicitly models international trade while examining the stability of IEAs involving identical countries. Using an oligopoly model of trade with identical countries where firms face abatement standards, Barrett (1997) shows that a threat by IEA signatory countries to impose trade sanctions on non-signatory countries, accompanied by a minimum participation clause, may lead to a stable global IEA.⁵ Using a similar setting where firms face emission taxes, Baksi and Ray Chaudhuri (2014) show that the global IEA is unstable under autarky, and that free trade may stabilize the global IEA. As markets become more competitive, it becomes more likely that the global IEA is stable. They further find that the imposition of a BTA destabilizes an otherwise stable global IEA. At the same time, if the global IEA is unstable under free trade, imposing a BTA may improve welfare. Eichner and Pethig (2013, 2014, 2015) use general equilibrium models of trade with perfect competition and identical countries, and inter alia find that large sub-coalitions are stable only when the gains from cooperation are small. Our paper is closest to Benckroun and Yildiz (2011), who use an oligopoly model of trade between two identical countries and a repeated game framework involving trigger strategies. They find that a move from autarky to free trade reduces the likelihood of cooperation between the countries. Unlike our paper, they consider emission standards, and do not analyze the impact of BTAs on cooperation.

We proceed further as follows. Section 2 presents our basic model without any BTA. Section 3 derives its equilibrium under full cooperation and non-cooperation in the one shot game. Section 4 presents the repeated game associated with the one shot game, and analyzes the incentives of the countries to cooperate in the absence of a BTA. In section 5, we analyze the impact of implementing a BTA on cooperation. The last section concludes.

⁵Nordhaus (2015) also finds that trade sanctions by members on non-members can induce the latter to join a “climate club” consisting of countries that set a common carbon price.

2 The basic model

Consider two countries, 1 and 2, with one firm in each country. Both firms are identical and produce a homogeneous good at constant marginal cost, c . The two countries have segmented markets. In each market, the firms compete in quantities *à la* Cournot. The firm in country i sells x_{ij} units of the good in country j , with $i, j = 1, 2$. Inverse demand in each country is given by

$$p(Q_i) = p(0) - Q_i,$$

where $p(0) - c \equiv a > 0$, and $Q_i \equiv \sum_{j=1}^2 x_{ji}$ is total quantity sold and consumed in country i .

A by-product of production in this industry is a perfectly transboundary pollutant such as carbon dioxide. With appropriate definition of units it is assumed that, for every unit of output they produce, the firms emit one unit of pollution.⁶ The social cost of pollution is increasing and convex in the level of emissions affecting a country. Pollution damage in country i , D_i , is given by

$$D_i = \frac{1}{2}\beta_i \left[\sum_{i=1}^2 X_i \right]^2, \quad (1)$$

where β_i denotes the pollution damage parameter in country $i = 1, 2$. Note that total production undertaken in country i is $X_i \equiv \sum_{j=1}^2 x_{ij}$, and total global production is $\sum_{i=1}^2 X_i = \sum_{i=1}^2 Q_i$. We assume that $\beta_1 > \beta_2 > 0$, i.e. pollution damage is higher in country 1 (the “North”) than in country 2 (the “South”) for any given amount of global pollution. The environmental policy in country i is a tax imposed on the domestic firm at the rate t_i per unit of emission. Given our assumption of constant emission-output ratio, a tax per unit of emission is equivalent to a tax per unit of output produced of the polluting good. Moreover, each country imposes a tariff τ per unit of import from the other country.

Given the above setting, consumer surplus and producer surplus in country i are respec-

⁶Thus we are assuming a constant emission intensity of output. Emissions can be reduced through a reduction in output, with forgone profit being the abatement cost for a firm. We do not model abatement as a separate choice variable for the firms.

tively given by $CS_i = \frac{1}{2}Q_i^2$ and $\pi_i = (p(Q_i) - c)x_{ii} + (p(Q_j) - c)x_{ij} - t_i X_i - \tau x_{ij}$. Country i 's emission tax revenue is $ER_i = t_i X_i$, and its tariff revenue is $TR_i = \tau x_{ji}$, with $j \neq i$. In the basic model, welfare of country i is defined as

$$W_i = CS_i + \pi_i + ER_i + TR_i - D_i \quad (2)$$

While in the basic model there is no BTA, we extend this model in Section 5 by introducing a BTA. In the next two sections, we present a one-shot game and the corresponding repeated game and derive the equilibriums in the absence of BTAs.

3 One-shot game

In the one-shot game, we consider two alternative scenarios – full cooperation and non-cooperation – which act as building blocks for our analysis. Superscripts c and nc are used to denote the fully cooperative and non-cooperative equilibriums, respectively. The one-shot game consists of two stages. In the first stage, each country chooses its pollution tax rate either cooperatively or non-cooperatively depending on the scenario. In the second stage, each firm takes the policies set by the countries and the output decisions of the other firm as given, and chooses its own output. To obtain the subgame perfect Nash equilibrium, the model is solved using backward induction.

The second stage is common across the two scenarios, full cooperation and non-cooperation. The firm in country i chooses the output it sells at home and in the foreign market so as to maximize its own profit, i.e.

$$\underset{x_{ii}, x_{ij}}{Max} \quad \pi_i = (a - x_{ji} - x_{ii})x_{ii} + (a - x_{jj} - x_{ij})x_{ij} - t_i(x_{ii} + x_{ij}) - \tau x_{ij}$$

Simultaneously solving the first order conditions (FOCs) for the above profit maximization

problem, the equilibrium quantities are obtained as

$$x_{ii} = \frac{a - 2t_i + t_j + \tau}{3} \quad (3)$$

$$x_{ij} = \frac{a - 2(t_i + \tau) + t_j}{3} \quad (4)$$

where $j \neq i$. The second order conditions (SOCs) are satisfied as we have $\frac{\partial^2 \pi_i}{\partial x_{ii}^2} < 0$, $\frac{\partial^2 \pi_i}{\partial x_{ij}^2} < 0$ and $\frac{\partial^2 \pi_i}{\partial x_{ii}^2} \frac{\partial^2 \pi_i}{\partial x_{ij}^2} - \left(\frac{\partial^2 \pi_i}{\partial x_{ii} \partial x_{ij}} \right)^2 > 0$.

The first stage of the game differs across the two scenarios, full cooperation and non-cooperation. Under full cooperation, the countries maximize their joint welfare. The optimization problem is then given by $\underset{t_1}{Max}(W_1 + W_2)$ and $\underset{t_2}{Max}(W_1 + W_2)$, where W_i is defined in (2). Simultaneously solving the two FOCs, we find that equilibrium tax rates in the cooperative equilibrium are equal in each country and given by $t_1^c = t_2^c = t^c$, where

$$t^c = \frac{a}{2\Omega} (4\beta_1 + 4\beta_2 - 1) - \frac{\tau}{2} \quad (5)$$

and $\Omega \equiv 2\beta_1 + 2\beta_2 + 1$. Moreover, the SOCs are satisfied since $\frac{\partial^2 (W_1 + W_2)}{\partial t_i^2} < 0$ for $i = 1, 2$. We note that $\frac{\partial t^c}{\partial \tau} = -\frac{1}{2} < 0$, implying that trade liberalization, in the form of bilateral tariff reductions, results in a higher cooperative emission tax rate. This is because trade liberalization increases global production for given t_i and t_j , which follows from (3) and (4), thereby increasing marginal damage from pollution. Further, $\frac{\partial t^c}{\partial \beta_1} = \frac{\partial t^c}{\partial \beta_2} = \frac{3a}{\Omega^2} > 0$, i.e. a higher pollution damage parameter in either country results in a higher cooperative emission tax rate.

Substituting (5) in (3) and (4), the equilibrium output levels under full cooperation are obtained as

$$x_{11}^c = x_{22}^c = \frac{a + \tau\Omega}{2\Omega} \quad (6)$$

$$x_{12}^c = x_{21}^c = \frac{a - \tau\Omega}{2\Omega} \quad (7)$$

Thus domestic sales increase, while exports decrease, in the tariff level. Note that exports are positive, i.e. $x_{12}^c = x_{21}^c > 0$, if and only if $\tau < \frac{a}{\Omega}$. Throughout the paper, we assume that the tariff rate τ is sufficiently small (i.e. close to zero) and less than the prohibitive rate of tariff. Equations (6) and (7) imply that net export of each country is zero, as $Q_i^c = X_i^c$.⁷ Using (2), the welfare level for country i under full cooperation is given by

$$W_i^c = \frac{a^2 (1 + 4\beta_j)}{2\Omega^2},$$

with $W_2^c - W_1^c = \frac{2a^2}{\Omega^2} (\beta_1 - \beta_2) > 0$. The global production and welfare levels are respectively given by $X^c \equiv X_1^c + X_2^c = \frac{2a}{\Omega}$ and $W^c \equiv W_1^c + W_2^c = \frac{a^2}{\Omega}$, which are independent of the tariff rate. This is because, in the cooperative equilibrium, any decrease in tariff τ is offset by an increase in the tax rate t^c , such that global production and welfare remain unchanged at their efficient levels.

On the other hand, in the non-cooperative scenario, each country chooses its pollution tax rate to maximize its own welfare, taking as given the other country's tax rate. The optimization problem is now given by $\underset{t_i}{Max} W_i$, for $i = 1, 2$, where W_i is given by (2). The FOC for country i gives its reaction function $t_i(t_j)$, with $\frac{dt_i}{dt_j} = -\frac{4\beta_i+1}{4\beta_i+7} < 0$. Thus pollution taxes are strategic substitutes in the non-cooperative equilibrium. Simultaneously solving the two countries' FOCs, the non-cooperative equilibrium taxes are obtained as

$$t_i^{nc} = \frac{1}{4\Psi} [4a(3\beta_i - \beta_j - 1) + \tau(5 - 8\beta_i + 4\beta_j)], \quad (8)$$

where $\Psi \equiv \beta_1 + \beta_2 + 2$ and $i, j = 1, 2$ with $i \neq j$. The SOC's are satisfied since $\frac{\partial^2 W_i}{\partial t_i^2} < 0$. Moreover, the reaction functions of the two countries yield a stable equilibrium. Substituting

⁷Net export of the polluting good by country i is defined as its production minus consumption of that good, i.e. $X_i - Q_i$.

(8) in (3) and (4), the output levels in the non-cooperative equilibrium are given by

$$x_{ii}^{nc} = \frac{1}{4\Psi} [a(4 - 8\beta_i + 8\beta_j) + \tau(1 + 8\beta_i - 4\beta_j)] \quad (9)$$

$$x_{ij}^{nc} = \frac{1}{4\Psi} [a(4 - 8\beta_i + 8\beta_j) - \tau(7 - 4\beta_i + 8\beta_j)] \quad (10)$$

We assume that parameter values are such that these quantities are positive. The global production level is given by $X^{nc} = \frac{4a-3\tau}{\Psi}$, which is decreasing in the tariff level τ .⁸ Thus, changes in the tariff level are not fully offset by adjustments of the non-cooperatively set tax rates, so that trade liberalization increases global production and pollution damage under non-cooperation, unlike under full cooperation. Moreover, we have

$$Q_1^{nc} - X_1^{nc} = X_2^{nc} - Q_2^{nc} = \frac{1}{\Psi} (4a - 3\tau) (\beta_1 - \beta_2) > 0 \quad (11)$$

which shows that the North – the country with the higher pollution damage parameter – is a net importer and the South a net exporter of the polluting good in the non-cooperative equilibrium.

Using (8), we have $\frac{\partial t_i^{nc}}{\partial \beta_i} = \frac{1}{4\Psi^2} (7 + 4\beta_j) (4a - 3\tau) > 0$ and $\frac{\partial t_i^{nc}}{\partial \beta_j} = -\frac{1}{4\Psi^2} (1 + 4\beta_i) (4a - 3\tau) < 0$. In other words, the pollution tax rate in each country increases in its own pollution damage parameter, and decreases in the other country's pollution damage parameter, consistent with free-riding behaviour in the non-cooperative equilibrium. Moreover, we have $t_1^{nc} - t_2^{nc} = \frac{1}{\Psi} (4a - 3\tau) (\beta_1 - \beta_2) > 0$, i.e. the pollution tax rate is higher in the North, which explains the equilibrium pattern of trade given by (11). The welfare level for country i in the non-cooperative equilibrium is given by

$$W_i^{nc} = \frac{4a - 3\tau}{8\Psi^2} [4a(1 + \beta_j + 2\beta_j^2 - 3\beta_i - 2\beta_i^2) + \tau(3 - 4\beta_j - 8\beta_j^2 + 16\beta_i + 8\beta_i^2)]$$

In the neighbourhood of free trade, welfare is higher in the South as $\lim_{\tau \rightarrow 0} (W_2^{nc} - W_1^{nc}) =$

⁸Note that $X^{nc} = \frac{4a-3\tau}{\Psi} > 0$ implies $\tau < \frac{4}{3}a$, which is assumed to hold.

$\frac{8a^2}{2\Psi^2} (\beta_1 - \beta_2) (\beta_1 + \beta_2 + 1) > 0$. Global welfare in the non-cooperative equilibrium is given by

$$W^{nc} \equiv W_1^{nc} + W_2^{nc} = \frac{4a - 3\tau}{4\Psi^2} [4a(1 - \beta_1 - \beta_2) + 3\tau\Omega],$$

which is concave in τ , with $\frac{\partial W^{nc}}{\partial \tau} = \frac{9}{2\Psi^2} (2a(\beta_1 + \beta_2) - \tau\Omega) \geq 0$ if and only if $\tau \leq \hat{\tau} \equiv \frac{2a}{\Omega} (\beta_1 + \beta_2)$.

Comparing the fully cooperative and the non-cooperative equilibria, we have

$$\lim_{\tau \rightarrow 0} (t^c - t_i^{nc}) = \frac{a}{2\Omega\Psi} [5\beta_i + 13\beta_j - 8(\beta_i^2 - \beta_j^2)] \quad (12)$$

$$\lim_{\tau \rightarrow 0} (W_i^c - W_i^{nc}) = \frac{a^2 (\beta_i + \beta_j)}{2\Omega^2\Psi^2} [41\beta_i - 23\beta_j + 4(\beta_i + \beta_j)(20\beta_i - 11\beta_j) + 32(\beta_i - \beta_j)(\beta_i + \beta_j)^2] \quad (13)$$

Since the markets are imperfectly competitive, each country has an incentive to inefficiently lower its non-cooperative pollution tax in order to give its domestic firm a competitive advantage and capture rents from the other country. Hence, in the interior equilibrium near free trade, we have $t_2^{nc} < t_1^{nc} < t^c$. While the North is always better off under cooperation, the same is true for the South provided the difference between β_1 and β_2 is not too large.⁹ Global production and pollution are higher under non-cooperation than under cooperation if and only if $\tau \leq \hat{\tau}$, since

$$X^{nc} - X^c = \frac{3}{\Omega\Psi} [2a(\beta_1 + \beta_2) - \tau\Omega] \quad (14)$$

Moreover, global welfare is unambiguously higher under cooperation as

$$W^c - W^{nc} = \frac{9}{4\Omega\Psi^2} [2a(\beta_1 + \beta_2) - \tau\Omega]^2 > 0 \quad (15)$$

Next we determine the effect of trade liberalization on the gains from cooperation. The environmental gains from cooperation are defined as the reduction in global pollu-

⁹For example, when $\beta_2 = 0.1$, we find that $\lim_{\tau \rightarrow 0} (W_2^c - W_2^{nc}) \geq 0$ if and only if $\beta_1 \leq 0.17$.

tion achieved when moving from the non-cooperative to the cooperative equilibrium, i.e. $(X^{nc} - X^c)$. Similarly, the welfare gains from cooperation are defined as the difference $(W^c - W^{nc})$.

PROPOSITION 1: *In the neighbourhood of free trade, bilateral tariff reductions increase the global environmental and welfare gains from cooperation.*

PROOF: Using (14) and (15), we have $\frac{\partial(X^{nc}-X^c)}{\partial\tau} < 0$ and $\lim_{\tau \rightarrow 0} \frac{\partial(W^c-W^{nc})}{\partial\tau} < 0$.

Proposition 1 follows from the fact that global production and pollution are independent of the tariff level under full cooperation, $\frac{\partial X^c}{\partial\tau} = 0$, and decreasing in the tariff level under non-cooperation, $\frac{\partial X^{nc}}{\partial\tau} < 0$. Moreover, global welfare is independent of the tariff level under full cooperation, $\frac{\partial W^c}{\partial\tau} = 0$, and concave in τ under non-cooperation with $\lim_{\tau \rightarrow 0} \left(\frac{\partial W^{nc}}{\partial\tau}\right) > 0$. While trade liberalization makes cooperation more desirable from an environmental and global welfare standpoint, whether such cooperation can be sustained in the long run is what we turn to analyze next.

4 Repeated game

To examine the sustainability of cooperation between the heterogeneous countries, in this section we consider a supergame where the one shot game described in the previous section is repeated infinitely. According to the well known folk theorem, the cooperative equilibrium may be sustained by trigger strategies as long as the players' discount rates are sufficiently small, i.e. the players are sufficiently patient. A trigger strategy typically entails adopting the cooperative solution unless defection is observed. Defection by any one player in any period triggers a permanent breakdown of cooperation, and the players choose the non-cooperative solution in every period subsequent to the period when defection is observed. In every period, each player weighs the one period benefit of defecting against the present value of future losses from the breakdown of cooperation. If the latter is greater than the

former for each player in every period, cooperation is self sustainable.

In the context of our model, the trigger strategy is applicable as follows. In every period, each country decides whether to set its tax at the cooperative level, t^c , or to defect from the cooperative outcome. In the case where one country unilaterally defects while the other plays the cooperative strategy, it is assumed that the cooperating country sets its tax rate at t^c in the period when defection happens. Thus, if country i defects, its optimization problem is given by $\underset{t_i}{Max} W_i|_{t_j=t^c}$. Solving the relevant FOC, the tax rate chosen by the defecting country, t_i^d , is obtained as

$$t_i^d = \frac{a(16\beta_i\beta_j - 20\beta_j + 16\beta_i^2 - 7) + \tau\Omega(11 - 4\beta_i)}{2\Omega(7 + 4\beta_i)}$$

The SOC is satisfied as $\frac{\partial^2 W_i|_{t_j=t^c}}{\partial t_i^2} < 0$.

If one of the countries defects in a given period, it is assumed that both countries play the non-cooperative strategy, t^{nc} , from the subsequent period onwards. When deciding whether to cooperate or defect in a given period, each country compares its one period gain from defecting against the present value of losses arising from the fact that both countries choose non-cooperation subsequent to a defection. The one period gain from defection for country i is given by

$$G_i \equiv W_i|_{t_i=t_i^d, t_j=t^c} - W_i^c$$

The loss in each future period is given by

$$L_i \equiv W_i^c - W_i^{nc}$$

Thus, country i has an incentive to defect if and only if $G_i > \frac{\theta_i}{1-\theta_i} L_i$, where $\theta_i \in [0, 1]$ represents the discount factor of country i . Self-enforcing cooperation is sustainable if and only if the current gain from defection is less than the discounted life-time cost of defection for each country, i.e. $G_i \leq \frac{\theta_i}{1-\theta_i} L_i$ for $i = 1, 2$. Let $\hat{\theta}_i(\beta_1, \beta_2, \tau)$ represent the threshold value

of the discount factor for country i such that

$$G_i = \frac{\hat{\theta}_i}{1 - \hat{\theta}_i} L_i$$

Thus, for $\theta_i \geq \hat{\theta}_i$, country i chooses to implement the cooperative tax rate, and for $\theta_i < \hat{\theta}_i$, country i chooses to unilaterally defect. Note that if $\hat{\theta}_i > 1$, country i unilaterally defects for any value of its discount factor $\theta_i \in [0, 1]$.

For analytical tractability, henceforth we assume $\beta_2 = 0.1$.¹⁰ For $\beta_2 = 0.1$ and $\tau \rightarrow 0$, the quantities given by (6), (7), (9) and (10) are strictly positive in all cases (i.e. the fully cooperative equilibrium, non-cooperative equilibrium, and if either country defects) only if $\beta_1 < 0.41$.¹¹ Hence, for the remainder of this section, we restrict our attention to $\beta_1 \in (0.1, 0.41)$ and tariff rates that are close to zero. This ensures that production and trade takes place in equilibrium.

When $\beta_2 = 0.1$, the above-mentioned threshold values of the discount factors for the two countries are given by

$$\hat{\theta}_1|_{\tau \rightarrow 0} = \frac{16(10\beta_1 + 21)^2(5\beta_1 + 1)^2}{(650\beta_1 + 400\beta_1^2 + 21)(1678\beta_1 + 2360\beta_1^2 + 800\beta_1^3 + 105)} \quad (16)$$

$$\hat{\theta}_2|_{\tau \rightarrow 0} = \frac{20(10\beta_1 + 21)^2(20\beta_1 + 1)^2}{(6430\beta_1 + 5400\beta_1^2 + 789)(250\beta_1 - 400\beta_1^2 + 69)} \quad (17)$$

For $\beta_1 \in (0.1, 0.41)$, we find that $\hat{\theta}_1|_{\tau \rightarrow 0} < \hat{\theta}_2|_{\tau \rightarrow 0}$.¹² Thus the North, which suffers more from pollution, is more likely to cooperate as it cooperates for a greater range of θ values than the South. Since it takes participation by both countries for self-enforcing cooperation between them, any factor that causes a decrease (respectively increase) in the higher of the two discount factor thresholds, i.e. $\max\{\hat{\theta}_1, \hat{\theta}_2\}$, is said to increase (respectively decrease)

¹⁰Our results remain qualitatively unchanged for other values of β_2 .

¹¹Fractions have been approximated to the second decimal place.

¹²When $\beta_1 = \beta_2 = 0.1$, we have $\hat{\theta}_1|_{\tau \rightarrow 0} = \hat{\theta}_2|_{\tau \rightarrow 0} = 0.65$. As β_1 increases with β_2 remaining unchanged, $\hat{\theta}_1|_{\tau \rightarrow 0}$ decreases while $\hat{\theta}_2|_{\tau \rightarrow 0}$ increases. When $\beta_1 = 0.41$, we have $\hat{\theta}_1|_{\tau \rightarrow 0} = 0.21$. Moreover, $\hat{\theta}_2|_{\tau \rightarrow 0} \leq 1$ if and only if $\beta_1 \leq 0.17$. Thus, if $\beta_1 > 0.17$, using (13) and (17) we have $\lim_{\tau \rightarrow 0} (W_2^c - W_2^{nc}) < 0$ and $\hat{\theta}_2|_{\tau \rightarrow 0} > 1$, and the South is unwilling to cooperate for any value of its discount factor.

the likelihood of sustainable cooperation.

We begin by examining how the likelihood of cooperation is affected by the degree of asymmetry between the countries.

PROPOSITION 2: *In the neighbourhood of free trade, a greater degree of asymmetry between the countries, as denoted by a higher β_1 given $\beta_2 = 0.1$, decreases the likelihood that cooperation is sustained between them.*

PROOF: Using (16) and (17), for $\beta_1 \in (0.1, 0.41)$, we have $\hat{\theta}_1|_{\tau \rightarrow 0} < \hat{\theta}_2|_{\tau \rightarrow 0}$, $\frac{\partial \hat{\theta}_1}{\partial \beta_1}|_{\tau \rightarrow 0} < 0$ and $\frac{\partial \hat{\theta}_2}{\partial \beta_1}|_{\tau \rightarrow 0} > 0$.

Proposition 2 shows that the greater the heterogeneity between the North and the South in terms of their pollution damage parameter, the less (respectively, more) is the likelihood of cooperation by the South (respectively, North). An implication is that if asymmetry across the countries were reduced, for e.g. through economic growth or greater awareness of environmental damages in the South, which increases demand for environmental quality in that country, this would increase the likelihood of sustainable cooperation between them in terms of their pollution pricing policies.

Next, we examine the effect of trade liberalization on the likelihood of sustaining cooperation.

PROPOSITION 3: *In the neighbourhood of free trade, bilateral tariff reductions increase the likelihood that cooperation is sustained between the heterogeneous countries.*

PROOF: Using (16) and (17), for $\beta_1 \in (0.1, 0.41)$, we have $\hat{\theta}_1|_{\tau \rightarrow 0} < \hat{\theta}_2|_{\tau \rightarrow 0}$, $\frac{\partial \hat{\theta}_1}{\partial \tau}|_{\tau \rightarrow 0} < 0$ and $\frac{\partial \hat{\theta}_2}{\partial \tau}|_{\tau \rightarrow 0} > 0$.¹³

Thus, trade liberalization reduces (respectively, expands) the range of the discount factor for which the North (respectively, South) cooperates. Since $\hat{\theta}_1|_{\tau \rightarrow 0} < \hat{\theta}_2|_{\tau \rightarrow 0}$, it follows that

¹³To compute the effect of a marginal change in τ on $\hat{\theta}_i$ in the neighbourhood of free trade, i.e. $\frac{\partial \hat{\theta}_i}{\partial \tau}|_{\tau \rightarrow 0}$, we first take the derivative of $\hat{\theta}_i(\beta_1, \beta_2, \tau)$ with respect to τ and then evaluate the resulting expression, which is a function of β_1 , β_2 and τ , at $\tau = 0$, $\beta_2 = 0.1$ and $\beta_1 \in (0.1, 0.41)$.

bilateral tariff reductions in the neighbourhood of free trade increases the likelihood that environmental cooperation is sustained between the North and the South.¹⁴ Propositions 1 and 3 highlight an optimistic result relative to the general conclusion in the IEA literature. Assuming symmetric countries, the literature finds that conditions under which larger coalitions become sustainable are typically associated with lower gains from cooperation. Propositions 1 and 3 together show that trade liberalization not only makes cooperation more likely between heterogeneous countries, but also increases the environmental and welfare gains from cooperation.

5 Border tax adjustment

The previous section showed that the South is less likely to cooperate than the North. In this section, we examine whether (the threat of) imposing a border tax adjustment by the North in the non-cooperative equilibrium can induce more cooperation from the South. To this end, we extend our basic model by allowing the countries to implement a BTA. The BTA takes the form of a “carbon tariff” that is imposed by the country with the higher pollution (e.g. carbon) tax on imports of the polluting good from the other country. The carbon tariff rate is set proportional to the carbon tax differential across the two trading countries. In the fully cooperative equilibrium, both countries set the same tax rate, t^c , and the BTA plays no role. Within the repeated game framework, in the period where one of the countries defects from full cooperation, the BTA also plays no role since the cooperating country, setting the higher tax, does not observe the other country defecting within that period. Therefore, the fully cooperative equilibrium and the equilibrium where one country unilaterally defects remain as described in the previous sections.

The BTA does play a key role in the non-cooperative equilibrium, so we describe the

¹⁴For the case of two identical countries, Bencheekroun and Yildiz (2011) find that the increase in the benefit of defection due to trade liberalization dominates the increase in the life-time cost of defection. Hence, trade liberalization raises the threshold discount factor, which is the same for identical countries, and makes cooperation between them less likely to be sustainable. In our model, trade liberalization raises (lowers) the threshold discount factor for the North (South).

non-cooperative equilibrium again, this time allowing for the BTA. Since $\beta_1 > \beta_2$, the non-cooperative pollution tax rate is higher in the North. Hence, the North imposes a BTA at the rate of $\delta(t_1 - t_2)$ per unit of import from the South, where δ is a parameter. We assume that $\delta = 1$, i.e. the carbon tariff rate accounts for the full differential in the carbon tax rates across the two countries.¹⁵ Since the pollution tax rate is lower in the South, it does not impose any BTA on imports from the North in the non-cooperative equilibrium. For simplicity, in this section we assume that the general tariff rate, τ , is zero.

In the non-cooperative equilibrium with the BTA, producer surplus for the North remains the same as that specified in Section 2, i.e. $\Pi_1 = \pi_1$. The producer surplus for the South changes to $\Pi_2 = (p(Q_2) - c)x_{22} + (p(Q_1) - c)x_{21} - t_2X_2 - \delta(t_1 - t_2)x_{21}$. North's revenue from the BTA is given by $BR_1 = \delta(t_1 - t_2)x_{21}$. Since $\tau = 0$, neither country collects any tariff revenue. Welfare of the North and the South are then given by

$$W_1^{BTA} = CS_1 + \Pi_1 + ER_1 + BR_1 - D_1$$

$$W_2^{BTA} = CS_2 + \Pi_2 + ER_2 - D_2$$

The sequence of moves in the game, as described previously, remains unchanged. Setting $\delta = 1$ and solving the two firms' profit maximization problems in the second stage, the non-cooperative equilibrium quantities are obtained as

$$\begin{aligned} x_{11}^{nc,BTA} &= x_{21}^{nc,BTA} = \frac{a - t_1}{3} \\ x_{12}^{nc,BTA} &= \frac{a - 2t_1 + t_2}{3} \\ x_{22}^{nc,BTA} &= \frac{a + t_1 - 2t_2}{3} \end{aligned}$$

The SOC's are satisfied as we have $\frac{\partial^2 \Pi_i}{\partial x_{ii}^2} < 0$, $\frac{\partial^2 \Pi_i}{\partial x_{ij}^2} < 0$ and $\frac{\partial^2 \Pi_i}{\partial x_{ii}^2} \frac{\partial^2 \Pi_i}{\partial x_{ij}^2} - \left(\frac{\partial^2 \Pi_i}{\partial x_{ii} \partial x_{ij}} \right)^2 > 0$ for $i, j = 1, 2$. Substituting the above quantities in W_i^{BTA} and then maximizing with respect

¹⁵When there is no BTA, as in the analysis in the previous sections, $\delta = 0$.

to t_i gives the first stage reaction function of country i , $t_i(t_j)$. From the North's reaction function we have $\frac{dt_1}{dt_2} = \frac{2-3\beta_1}{9\beta_1+10}$, which is positive for sufficiently small values of β_1 that ensure the equilibrium quantities are positive. Moreover, the South's reaction function gives $\frac{dt_2}{dt_1} = -\frac{3(\beta_2+1)}{\beta_2+3} < 0$. Simultaneously solving the two countries' FOCs, the non-cooperative equilibrium tax rates are obtained as

$$t_1^{nc,BTA} = \frac{a(-3 + 36\beta_1 + 7\beta_2)}{2(18 + 9\beta_1 + 8\beta_2)} \quad (18)$$

$$t_2^{nc,BTA} = \frac{a(3 - 36\beta_1 + 43\beta_2)}{2(18 + 9\beta_1 + 8\beta_2)} \quad (19)$$

The associated SOC's are satisfied, since $\frac{\partial^2 W_i^{BTA}}{\partial t_i^2} < 0$ for $i = 1, 2$. Moreover, the reaction functions of the two countries yield a stable equilibrium.

For tractability and to facilitate comparison with the results in the previous sections, we again set $\beta_2 = 0.1$. Substituting the relevant tax rates, we find that the equilibrium quantities are strictly positive in all cases (i.e. the fully cooperative equilibrium, non-cooperative equilibrium with BTA, and if either country defects) for $\beta_1 \in (0.1, 0.41)$. Moreover, from (18) and (19), we have $t_1^{nc,BTA} - t_2^{nc,BTA} = \frac{12a(15\beta_1-2)}{45\beta_1+94} > 0$ if and only if $\beta_1 > 0.13$. Accordingly, in this section, we restrict attention to the range of β_1 values given by $\beta_1 \in (0.13, 0.41)$. This ensures that the North imposes a BTA on imports from the South in the non-cooperative equilibrium, as the pollution tax rate is higher in the former country.¹⁶

Comparing the cooperative equilibrium and the non-cooperative equilibrium with BTA, we find that $t_1^{nc,BTA} > t^c|_{\tau \rightarrow 0}$ for $\beta_1 \in (0.13, 0.41)$, while $t_2^{nc,BTA} \geq t^c|_{\tau \rightarrow 0}$ if and only if $\beta_1 \leq 0.17$. Thus the North raises its non-cooperative pollution tax above the efficient level, as this enables it to raise the BTA rate on imports from the South and earn more revenue from that source. The same consideration with respect to the BTA simultaneously dampens the South's rent capture motive to lower its tax in the non-cooperative equilibrium.¹⁷ Global

¹⁶In the non-cooperative equilibrium with BTA, North's net import of the polluting good from South is given by $Q_1^{nc,BTA} - X_1^{nc,BTA} = X_2^{nc,BTA} - Q_2^{nc,BTA} = \frac{1}{3}(t_1^{nc,BTA} - t_2^{nc,BTA})$.

¹⁷Recall that, in the absence of the BTA, the non-cooperative tax rate is lower than its efficient level in

production and pollution are lower under full cooperation, i.e. $X^c \leq X^{nc,BTA}$, if and only if $\beta_1 \geq 0.24$. However, global welfare is higher under full cooperation, $W^c > W^{nc,BTA}$, for all $\beta_1 \in (0.13, 0.41)$. For individual countries, we have $W_1^c \geq W_1^{nc,BTA}$ if and only if $\beta_1 \geq 0.23$, and $W_2^c \geq W_2^{nc,BTA}$ if and only if $\beta_1 \leq 0.24$.

By changing their welfare levels in the non-cooperative equilibrium, imposition of the BTA by the North changes the loss functions, L_i , for both countries when cooperation breaks down. This, in turn, changes the discount factor thresholds that determine their decisions regarding cooperation. In the presence of the BTA, the modified thresholds for the North and the South are respectively given by

$$\hat{\theta}_1^{BTA} = \frac{16(1 + 5\beta_1)^2(94 + 45\beta_1)^2}{\left(\begin{array}{c} 395091 - 877350\beta_1 + 6660500\beta_1^2 \\ +17897000\beta_1^3 + 14170000\beta_1^4 + 3600000\beta_1^5 \end{array} \right)} \quad (20)$$

$$\hat{\theta}_2^{BTA} = \frac{20(1 + 20\beta_1)^2(94 + 45\beta_1)^2}{\left(\begin{array}{c} -320301 + 14919570\beta_1 \\ +63876800\beta_1^2 + 33891000\beta_1^3 - 10440000\beta_1^4 \end{array} \right)} \quad (21)$$

Country i chooses to cooperate if and only if its discount factor θ_i exceeds the threshold value $\hat{\theta}_i^{BTA}$. Within the range of $\beta_1 \in (0.13, 0.41)$, we find that $\hat{\theta}_1^{BTA}$ is non-monotonic and concave in β_1 , while $\hat{\theta}_2^{BTA}$ monotonically increases in β_1 . Moreover, $\hat{\theta}_1^{BTA} \leq 1$ if and only if $\beta_1 \geq 0.23$, and $\hat{\theta}_2^{BTA} \leq 1$ if and only if $\beta_1 \leq 0.24$.¹⁸

Comparison of each country's discount factor threshold with and without the BTA, allows us to infer how imposition of the BTA affects its incentive to cooperate with the other country over multiple periods. The following result holds.

PROPOSITION 4: *Imposition of the BTA by the North on imports from the South makes it less*

both the countries. From (12), we have $\lim_{\tau \rightarrow 0} (t^c - t_i^{nc}) > 0$ for $\beta_2 = 0.1$ and $\beta_1 \in (0.1, 0.41)$.

¹⁸For the different equilibriums - full cooperation, non-cooperation without BTA, and non-cooperation with BTA - Figures 1 to 5 show pollution, welfare and the threshold discount factors as functions of β_1 . These figures are drawn assuming $\beta_2 = 0.1$, $a = 1$ and $\tau = 0$.

likely that the North cooperates. As well, the BTA makes the South more likely to cooperate if and only if the countries are sufficiently heterogeneous in terms of their pollution damage parameter.

PROOF: Using (16), (17), (20) and (21), we have (i) $\hat{\theta}_1^{BTA} > \hat{\theta}_1|_{\tau \rightarrow 0}$ for all $\beta_1 \in (0.13, 0.41)$, and (ii) $\hat{\theta}_2^{BTA} \leq \hat{\theta}_2|_{\tau \rightarrow 0}$ if and only if $\beta_1 \geq 0.16$.

Imposition of the BTA in the non-cooperative equilibrium provides the North with additional revenue as well as levels the playing field for its firm in the domestic market. Consequently, the ability to impose a BTA makes the North less keen to cooperate with the South. For the South, the restriction imposed by the BTA on its ability to export to, and earn rents from, the North in the non-cooperative equilibrium weakens its incentive to defect from the cooperative equilibrium. At the same time, when β_1 is sufficiently small i.e. $\beta_1 < 0.24$, global pollution is less in the non-cooperative equilibrium with BTA than in the cooperative equilibrium, which weakens the countries' incentives to cooperatively raise their tax. The net effect of these opposing tendencies is that the BTA makes the South more willing to cooperate only when β_1 is sufficiently large.

Overall, whether the BTA engenders more cooperation between the two countries depends on the rules governing its usage. These rules may permit the North to impose the BTA on imports from the South only if the South defects from the cooperative equilibrium ("regime 1"). Alternatively, the relevant rules may allow the North to unilaterally defect from the cooperative equilibrium and impose the BTA ("regime 2"). Which regime prevails in practice will depend on how the rules governing the use of BTAs are formulated at multilateral organizations such as the WTO.

The first regime involves the use of the BTA solely as a penalty for non-cooperation. The relevant multilateral trading rules, under this regime, would deny approval to a country to impose a BTA on imports from its trading partner if the former unilaterally defects while the latter is willing to set the cooperative pollution tax. In the context of our model, since

the North cannot unilaterally defect from the cooperative equilibrium and impose the BTA under regime 1, and since the South would face a BTA if it defects unilaterally,¹⁹ the relevant threshold values that determine cooperation between the two countries are $\hat{\theta}_1|_{\tau \rightarrow 0}$ for the North and $\hat{\theta}_2^{BTA}$ for the South. If the countries are nearly symmetric, i.e. $\beta_1 \in (0.13, 0.16)$, we have $\hat{\theta}_1|_{\tau \rightarrow 0} < \hat{\theta}_2|_{\tau \rightarrow 0} < \hat{\theta}_2^{BTA} < 1$. Then, if the South does not cooperate in the absence of the BTA because its discount factor θ_2 is less than the threshold $\hat{\theta}_2|_{\tau \rightarrow 0}$, the threat of the BTA cannot induce additional cooperation from the South as $\hat{\theta}_2|_{\tau \rightarrow 0} < \hat{\theta}_2^{BTA}$. On the other hand, if the South's discount factor is $\theta_2 > \hat{\theta}_2|_{\tau \rightarrow 0}$, the South cooperates in the absence of the BTA and hence the BTA cannot be imposed by the North under regime 1. Thus, the BTA does not affect the likelihood of cooperation between the countries when they are nearly symmetric. For intermediate levels of asymmetry, i.e. $\beta_1 \in (0.17, 0.24)$, we have $\hat{\theta}_1|_{\tau \rightarrow 0} < \hat{\theta}_2^{BTA} < 1 < \hat{\theta}_2|_{\tau \rightarrow 0}$, which indicates that the South defects in the absence of the BTA but may cooperate in its presence (specifically, the South cooperates if $\theta_2 > \hat{\theta}_2^{BTA}$). Hence, the threat of the BTA increases the likelihood of sustainable cooperation between the countries in this case. Finally, if the countries are too asymmetric i.e. $\beta_1 > 0.24$, sustainable cooperation between them is not possible with or without the BTA, as both $\hat{\theta}_2|_{\tau \rightarrow 0}$ and $\hat{\theta}_2^{BTA}$ exceed 1 in such a case.

The second regime involves unrestricted use of BTAs – the relevant multilateral trading rules do not impose any restriction on the use of BTAs by countries. Under this regime, the BTA may be used as a disguised means of protection by the North, especially if trade agreements constrain the ability of countries to use more traditional trade policy instruments.²⁰ Under regime 2, the relevant threshold values that determine cooperation between the two countries are $\hat{\theta}_1^{BTA}$ for the North and $\hat{\theta}_2^{BTA}$ for the South. In the absence of a BTA, sustainable cooperation is possible between the countries if and only if $\beta_1 \in (0.1, 0.17)$, as we

¹⁹Note that in the non-cooperative equilibrium we have $W_1^{nc, BTA} > W_1^{nc}$, i.e. the North gets a higher level of welfare by imposing the BTA than by not imposing it.

²⁰For $\tau = 0$ and $\beta_1 \in (0.13, 0.41)$, we have $X_2^{nc} - Q_2^{nc} > X_2^{nc, BTA} - Q_2^{nc, BTA}$, i.e. imposition of the BTA reduces the South's net exports to the North in the non-cooperative equilibrium. Recall that the BTA motivates the North to inefficiently raise its non-cooperative pollution tax above the cooperative level, so that it can charge a higher BTA rate.

then have $\hat{\theta}_1|_{\tau \rightarrow 0} < \hat{\theta}_2|_{\tau \rightarrow 0} < 1$. However, when the North can unilaterally defect and impose a BTA, sustainable cooperation is possible if and only if $\beta_1 \in (0.23, 0.24)$, as we then have $\hat{\theta}_1^{BTA} < \hat{\theta}_2^{BTA} < 1$. Thus, the unrestricted use of BTAs makes cooperation less likely between nearly symmetric countries but can make cooperation more likely between more asymmetric countries.

Under regime 1, the BTA increases the likelihood of cooperation for $\beta_1 \in (0.17, 0.24)$, and does not affect the likelihood of cooperation for other values of β_1 . By contrast, under regime 2, the BTA is detrimental for cooperation for $\beta_1 \in (0.13, 0.17)$, and increases the likelihood of cooperation for $\beta_1 \in (0.23, 0.24)$. Under either regime, when the threat of the BTA changes the sustainable equilibrium from non-cooperation to cooperation, this reduces global pollution and improves global welfare (welfare improves in the North, while it worsens in the South if $\beta_1 > 0.17$). Our results suggest that, in order to promote environmental cooperation between heterogeneous countries, the use of BTAs may need to be restricted so that they are used solely as a means of penalizing defection by a country from the cooperative outcome, and not as a disguised means of protection.

6 Conclusion

This paper examines the role of trade liberalization and border tax adjustments on the incentives of heterogeneous countries to cooperate with each other in the pricing of a global pollutant. Using an oligopoly model of trade between two countries that differ in terms of their pollution damage parameter, we show that an increase in the degree of heterogeneity between the countries reduces the likelihood that cooperation is sustained between them. Moreover, freer trade in the form of bilateral tariff reductions increases both the gains from cooperation as well as the likelihood of cooperation. By contrast, trade restrictions in the form of border tax adjustments can foster or hinder cooperation, depending on the degree of heterogeneity between the countries and the rules governing the use of BTAs.

Our analysis shows that, when cooperation between countries is not possible (e.g. if the countries are very heterogeneous), global pollution is lower and global welfare is higher in the non-cooperative equilibrium with the BTA relative to their values in the non-cooperative equilibrium without BTA. This suggests that a BTA may serve as a second best alternative to cooperation when cooperation cannot be sustained between countries. While the paper has analyzed one form of heterogeneity across countries, i.e. differences in pollution damage parameters, it would be interesting to consider other policy relevant differences between countries as well. Whether trade policy instruments such as tariffs and BTAs can be used to foster environmental cooperation between countries that differ in terms of size, market structure, or emission intensity of output is left as work for the future.

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Figure 1: Global Pollution ($\beta_2=0.1$, $a=1$, $\tau=0$)

Figure 2: Global Welfare ($\beta_2=0.1, a=1, \tau=0$)

Figure 3: North's Welfare ($\beta_2=0.1, a=1, \tau=0$)

Figure 4: South's Welfare ($\beta_2=0.1, a=1, \tau=0$)

Figure 5: Threshold discount factors w/o and w/ BTA ($\beta_2=0.1$, $a=1$, $\tau=0$)