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Is International Cooperation Necessary for Climate Policy?

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Abstract

Most game theory models of international environmental policy have the benefits to a country being a function of a country's emissions whereas the costs are a function of global emissions. Obviously, the result is that the emissions of a country impose a negative externality on the rest of the world, and hence that international cooperation through an International Environmental Agreement (IEA) is necessary to solve the problem of climate policy. Here, international trade is added to the simple general equilibrium model of Azacis and Collie (2025). Since an increase in emissions will increase the output of a country, it will also increase exports thereby worsening the country's terms of trade but improving the terms of trade for the rest of the world. Hence, there will be a positive terms of trade externality in addition to the negative environmental externality with the overall externality turning out to be endogenous depending upon the quantity of emissions from the rest of the world. It is shown that the Nash equilibrium (NE) with environmental policies (tradeable permits or emissions taxes) is Pareto efficient when preferences are identical and there is no home consumption bias. In this case there are no potential gains from international cooperation through an IEA. When preferences are symmetric but with a home consumption bias, the NE with environmental policies will not be Pareto efficient and there will be potential gains from international cooperation through an IEA.

Keywords: emissions taxes; tradeable permits; terms of trade; international trade; externalities.

JEL Classification: C72; D62; F18; H23; Q58.

1. Introduction

International cooperation through international environmental agreements (IEAs) such as the Kyoto Protocol in 1997 and the Paris Agreement in 2015 has been seen as a key part of the solution to climate change. The extensive literature on modelling international cooperation in IEAs has generally started with a game-theory model where the benefits to a country are a function of national emissions whereas the costs (or damage) come from global emissions and, for simplicity, the functions are often assumed to be linear and/or quadratic.[1] Obviously, such a model immediately implies that there will be a negative externality from the emissions of a country and hence that international cooperation through an IEA is necessary to solve the problem of climate change.[2] Here, it will be shown that adding international trade to a model of global emissions makes the sign of the externality ambiguous.

The approach taken in this paper is to add international trade in consumption goods to the autarky model of Azacis and Collie (2025) by giving consumers preferences for many goods and having one good produced by each country.[3] The model is a highly stylised, static, general equilibrium model with a production function and a utility function, where global emissions affect productivity as in environmental macroeconomic models such as Golosov et al. (2014) and also in line with the observations of the WHO and WMO (2025).[4] Since an increase in emissions will increase the output of a country, it will also increase exports thereby

[1] An alternative, but basically equivalent, approach is to express the model in terms of abatement where the benefits to a country depend upon abatement in all countries but the costs only depend upon abatement in the country. The result is that a country's abatement has a positive externality on foreign countries and therefore there are gains from international cooperation through an IEA to increase abatement in all countries.

[2] For surveys of the literature on using game theory to model international cooperation in IEAs from the seminal article of Barrett (1994) onwards, see Barrett (2005), Caparrós (2016), and Harstad (2024).

[3] The economics of international trade and climate policy is surveyed by Farrokhi et al. (2026). Kiyono and Ishikawa (2013) and Eichner and Pethig (2015) consider environmental policy games with trade in fossil fuel and a homogeneous consumption good rather than trade in a number of consumption goods that is the subject of this paper.

[4] Environmental macroeconomic models are surveyed by Hassler et al. (2016) and van der Ploeg and Rezai (2026), but most of this literature does not consider strategic interactions between countries in the setting of environmental policy with a few exceptions such as Moro and Nispi Landi (2025).

worsening the country's terms of trade but improving the terms of trade for other countries. Hence, there will be a positive terms of trade externality from emissions as well as the negative environmental externality with the overall externality depending upon the relative sizes of these externalities. The sign of the overall externality turns out to be endogenous depending upon the quantity of emissions from foreign countries. When preferences are identical and there is no home consumption bias, the overall externality is equal to zero at the Nash equilibrium (NE) in environmental policies (tradeable permits or emissions taxes) and hence the NE is Pareto efficient. In this case, there are no potential gains from international cooperation through an IEA. When there is a home consumption bias, the NE in environmental policies will not be Pareto efficient and there will be potential gains from an international agreement through an IEA that decreases emissions and increases welfare for all countries. In this case, tradeable permits are superior to emissions taxes since welfare is higher for all countries in the NE in tradeable permits than in the NE in emissions taxes.

Section 2 analyses a two-country emissions game using a static general equilibrium model with international trade where the countries can have different technologies but both countries have identical preferences. Despite the asymmetries, it is shown that the NE with tradeable permits and the NE with emissions taxes are both Pareto efficient so there is no scope for international cooperation through an IEA. Section 3 extends the analysis to the case of many countries by assuming symmetry so that all countries have identical technology and symmetric preferences although with the possibility of a home consumption bias. When there is no home consumption bias, again the NE with tradeable permits and the NE with emissions taxes are Pareto efficient so there is no scope for international cooperation through an IEA. When there is a home consumption bias, the NE with tradeable permits and the NE with emissions taxes are no longer Pareto efficient and there are potential gains from international cooperation

through an IEA that reduces the emissions of all countries and thereby increases the welfare of all countries.

2. Two-Country Emissions Game with International Trade

Consider an open-economy variant of the of the global emissions externality game from Collie (2022) and Azacis and Collie (2025) with two countries. Rather than having one consumption good that is not traded it will be assumed that each country produces a distinct good and that consumers in each country consume some of both the available goods. As a result, assuming that both countries pursue a policy of free trade, there will be international trade in goods subject only to a real trade (transport) cost.[5] Each country has a labour endowment, and a constant returns to scale production function where the inputs are labour and emissions, which represents the use of the environment by firms in production.[6] The countries and goods are labelled $j=1,2$ with good j produced in country j by a perfectly competitive industry so it is implicitly assumed that country j has a comparative advantage in good j. The output of good j in country j is Y_j, the quantity of emissions in country j is E_j, and the labour endowment of country j is L_j. The aggregate production function for good j in country j is given by the modified Cobb-Douglas function:

$$Y_j = \exp\left[-\beta\left(E_1+E_2\right)\right] A_j L_j^{1-\alpha_j} E_j^{\alpha_j} \qquad j=1,2 \tag{1}$$

[5] The vast majority of countries still pursue a policy of fairly free trade according to World Trade Organisation (WTO) rules with one notable exception so the assumption of free trade seems fairly reasonable.

[6] Labour may be interpreted as a shorthand for a composite factor that also includes capital, land, natural resources, and any other factors of production. Also, emissions could be reinterpreted as energy as in the static global economy-climate model of Hassler et al. (2016) where one case that was considered was when the cost of producing oil was assumed to be zero.

where $A_j > 0$ is a technology parameter and $\alpha_j \in (0,1)$ is the share of emissions in production of good j in country j.[7] If $\alpha_j > \alpha_i$ then country j uses the environment more intensively in production than country i. The exponential function represents the externality effect of global emissions on production where the parameter $\beta > 0$ represents the size of this negative externality effect. It has been widely used in environmental macroeconomic models such as Golosov et al. (2014). Also, this global production externality is in line with the WHO and WMO (2025) report that finds a 2-3% decrease in labour productivity for every one degree increase in temperature above 20°C.

Since *a priori* there is no theoretical reason why consumer preferences should differ between countries, see Samuelson (1952) for a discussion, the preferences of the representative consumer for the two goods are assumed to be identical in the two countries and are represented by the Cobb-Douglas utility function:

$$U_j\left(x_{1j}, x_{2j}\right) = x_{1j}^{\phi_1} x_{2j}^{\phi_2} \qquad j = 1,2 \tag{2}$$

where x_{ij} is consumption of good i in country j and $\phi_i \in (0,1)$ is the share of good i in total expenditure in each country, and $\phi_1 + \phi_2 = 1$.

With a real 'iceberg' trade (or transport) cost as in Samuelson (1954), if one unit of good j is exported then only $1/\tau_j$ units are imported since $(\tau_j - 1)/\tau_j$ units 'melt' *en route*, where $\tau_j \geq 1$. Hence, if the world price of good j is p_j then the domestic price of good j in country j is p_j whereas the domestic price of the imported good in country j is $\tau_i p_i$, for $i \neq j$. The representative consumer receives all the labour income and all the revenue from

[7] See Azacis and Collie (2025) for the derivation of the aggregate production function from the profit-maximizing decisions of individual firms in the perfectly-competitive industry.

tradeable permits or emissions taxes. Therefore, since there are constant returns to scale, the income of the representative consumer in country j is given by the value of the country's output, $p_j Y_j$. As the representative consumer has Cobb-Douglas preferences, demand (consumption) for the domestically-produced good and the imported good in the two countries are:

$$x_{jj} = \frac{\phi_j p_j Y_j}{p_j} = \phi_j Y_j \qquad x_{ij} = \frac{\phi_i p_j Y_j}{\tau_i p_i} \qquad i \neq j \quad i, j = 1,2 \tag{3}$$

Hence, the exports of country j are equal to production of good j minus its consumption of good j that is $Y_j - x_{jj} = \left(1 - \phi_j\right) Y_j = \phi_i Y_j$. The imports of country i are equal to x_{ji}, its consumption of good j, but the amount that has to be exported by country j is $\tau_j x_{ji} = \phi_j p_i Y_i / p_j$ due to the real trade cost. Then, equating supply and demand for good j on the world market yields that: $\phi_i Y_j = \phi_j p_i Y_i / p_j$. Hence, using the aggregate production function (1), the equilibrium relative price of good j is:

$$\frac{p_j}{p_i} = \frac{\phi_j Y_i}{\phi_i Y_j} = \frac{\phi_j A_i L_i^{1-\alpha_i} E_i^{\alpha_i}}{\phi_i A_j L_j^{1-\alpha_j} E_j^{\alpha_j}} \qquad i \neq j \quad i, j = 1,2 \tag{4}$$

This relative price is the terms of trade of country j and it can be seen that an increase in emissions by country j worsens its terms of trade whereas an increase in emissions by country i improves the terms of trade of country j, which is the positive terms of trade externality. Substituting the equilibrium relative price into (3) yields consumption of the domestic and the imported goods in the two countries:

$$x_{jj} = \phi_j Y_j \qquad x_{ij} = \frac{\phi_j Y_i}{\tau_i} \qquad i \neq j \quad i, j = 1,2 \tag{5}$$

Substituting consumption of the goods (5) into the utility function of country j (2), and using the aggregate production function (1) yields the welfare of country j as a function of the quantity of emissions of the two countries:

$$W_j = \Lambda_j \exp\left[-\beta\left(E_1 + E_2\right)\right] E_1^{\phi_1\alpha_1} E_2^{\phi_2\alpha_2} \qquad \text{where } \Lambda_j = \phi_j \left(A_j L_j^{1-\alpha_j}\right)^{\phi_j} \left(\frac{A_i L_i^{1-\alpha_i}}{\tau_i}\right)^{\phi_i} > 0 \qquad (6)$$

The welfare of country j is log-concave and hence quasi-concave in its own emissions. Note that the welfare functions of the two countries are identical apart from the constant term Λ_j. This welfare function exhibits a negative environmental externality (through the exponential function) and a positive terms of trade externality (through the Cobb-Douglas function). The overall externality can be determined by differentiating the welfare of country j with respect to the quantity of emissions of country i, where $i \neq j$, which yields:

$$\frac{\partial W_j}{\partial E_i} = W_j \left(\frac{\phi_i\alpha_i - \beta E_i}{E_i}\right) > (<) 0 \qquad \text{if} \qquad E_i < (>) \tilde{E}_i \equiv \frac{\phi_i\alpha_i}{\beta} \qquad (7)$$

The overall externality effect of foreign emissions depends upon the quantity of emissions of the foreign country. When the quantity of emissions of the foreign country are sufficiently small, $E_i < \tilde{E}_i$, then the overall externality is positive as the positive terms of trade externality outweighs the negative environmental externality whereas the overall externality is negative when the quantity of emissions of the foreign country are sufficiently large, $E_i > \tilde{E}_i$, as the negative environmental externality outweighs the positive terms of trade externality.

Before analysing the NE in environmental policies, the first-best outcome can be derived by maximising world welfare $W = W_1 + W_2$ with respect to E_1 and E_2, which yields the first order conditions:

$$\frac{\partial W}{\partial E_j}=\frac{\partial W_1}{\partial E_j}+\frac{\partial W_2}{\partial E_j}=W_1\left(\frac{\phi_j\alpha_j-\beta E_j}{E_j}\right)+W_2\left(\frac{\phi_j\alpha_j-\beta E_j}{E_j}\right)=W\left(\frac{\phi_j\alpha_j-\beta E_j}{E_j}\right)=0 \qquad (8)$$

Hence, at the unique first-best outcome, the quantity of emissions in the two countries are: $E_1^{FB}=\phi_1\alpha_1/\beta$ and $E_2^{FB}=\phi_2\alpha_2/\beta$, which depend upon the technology, preferences and the externality. Therefore, if $\phi_j\alpha_j>\phi_i\alpha_i$ then the quantity of emissions in country j will be larger than in country i. Substituting the first-best quantity of emissions into (6) yields the welfare of each country in the first-best outcome:

$$W_j^{FB}=\Lambda_j\exp\left[-\left(\phi_1\alpha_1+\phi_2\alpha_1\right)\right]\left(\frac{\phi_1\alpha_1}{\beta}\right)^{\phi_1\alpha_1}\left(\frac{\phi_2\alpha_2}{\beta}\right)^{\phi_2\alpha_2} \qquad j=1,2 \qquad (9)$$

Since the welfare functions of the two countries are identical apart from the constant term, these emissions maximise the welfare of each country as well as maximising world welfare, and $W_1^{FB}/W_2^{FB}=\Lambda_1/\Lambda_2$.

2.1. Nash Equilibrium with Tradeable Permits

Suppose that each country has its own closed emissions trading system then each country can set the quantity of tradeable permits to determine the quantity of emissions in the country.[8] In the Nash equilibrium (NE) with tradeable permits, each country sets the quantity of emissions to maximise its welfare given the quantities of emissions chosen by the other country. Differentiating the welfare of country j (6) with respect to its own emissions E_j yields the first-order condition:

[8] According to the World Bank (2026), 29% of global emissions are now subject to direct carbon pricing with emissions trading systems accounting for 24% and emissions taxes for 4-5%, and government revenues from direct carbon pricing exceeds US$107billion. In addition, according to the OECD (2025), fuel excise taxes cover 24% of emissions.

$$\frac{\partial W_j}{\partial E_j} = W_j\left(\frac{\phi_j\alpha_j - \beta E_j}{E_j}\right) = 0 \tag{10}$$

Hence, the quantity of emissions and the welfare of each country in the NE (denoted by a subscript N) with tradeable permits (denoted by a superscript T) are:

$$E_{Nj}^T = \frac{\phi_j\alpha_j}{\beta} \qquad W_{Nj}^T = \Lambda_j \exp\left[-\left(\phi_1\alpha_1 + \phi_2\alpha_1\right)\right]\left(\frac{\phi_1\alpha_1}{\beta}\right)^{\phi_1\alpha_1}\left(\frac{\phi_2\alpha_2}{\beta}\right)^{\phi_2\alpha_2} \qquad j = 1,2 \tag{11}$$

Note that setting $E_j = E_{Nj}^T = \phi_j\alpha_j/\beta$ is a dominant strategy for both countries, and that $E_{Nj}^T = \tilde{E}_j$ from (7). Each country sets the quantity of emissions to deal with the domestic environmental externality, where domestic firms ignore the negative effect of their emissions on domestic welfare, and with the negative terms of trade effect, where increasing emissions by increasing output and exports worsens the country's terms of trade. Comparing the NE with tradeable permits and the first-best outcome leads to the following:

Proposition 1: *In the NE with tradeable permits, the quantity of emissions and welfare in each country are the same as in the first-best outcome.*

Proof: From (8) and (11), $E_{Nj}^T = E_j^{FB} = \phi_j\alpha_j/\beta$ for $j = 1,2$. Hence, from (9) and (11), $W_{Nj}^T = W_j^{FB}$ for $j = 1,2$.■

The NE with tradeable permits is Pareto efficient and there are no potential gains from international cooperation. In this case, the negative environmental externality is exactly offset by the positive terms of trade externality so that the overall externality is zero, since $\tilde{E}_i = E_{Nj}^T$, in the NE with tradeable permits. Free trade has resulted in the interests of both countries becoming perfectly aligned.

The best-reply functions of the two countries and their iso-welfare loci are shown in **Figure 1**. The best-reply function of country one (two) R_1^T $\left(R_2^T\right)$ is vertical (horizontal) because setting $E_{Nj}^T = \phi_j \alpha_j / \beta$ is a dominant strategy for both countries. The iso-welfare loci are the same for both countries, although the levels of welfare may differ, as the welfare function (6) is the same for both countries apart from the constant term. Hence, it can be seen that the NE and the first-best outcome (FB) coincide as the overall externality is equal to zero at the NE.

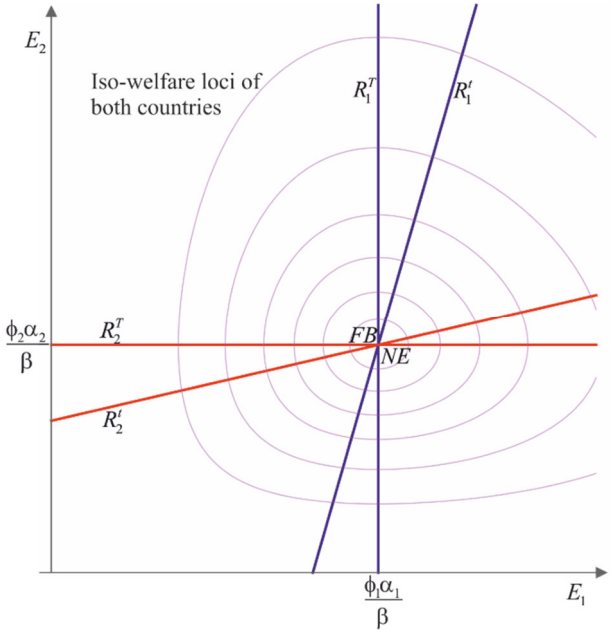


***Figure 1**: Best-reply functions and iso-welfare loci*

2.2 Nash Equilibrium with Emissions Taxes

As in Azacis and Collie (2025), the NE with emissions taxes can be obtained by having each country set the quantity of emissions subject to a unilateral equivalence constraint that implies that the other country keeps their emissions tax constant. This yields the NE with emissions taxes in terms of the quantities of emissions rather than in terms of the emissions taxes, which allows the quantity of emissions in the NE with tradeable permits to be compared with that in the NE with emissions taxes. As industries are perfectly competitive and there are

constant returns to scale, the unilateral equivalence constraint of the other country is obtained by equating its emissions tax, t_i, with the marginal product of emissions in its industry. Differentiating the aggregate production function of country i with respect to its emissions, E_i, while treating the exponential function as a constant since the perfectly-competitive firms ignore the environmental externality, and equating to its emissions tax, yields:

$$t_i = \frac{\partial Y_i}{\partial E_i} = \exp\left[-\beta\left(E_1 + E_2\right)\right]\alpha_i A_i L_i^{1-\alpha_i} E_i^{\alpha_i - 1} \tag{12}$$

Note that this emissions tax is expressed in terms of good i. Totally differentiating the unilateral equivalence constraint while keeping the emissions tax constant yields:

$$\left.\frac{dE_i}{dE_j}\right|_{t_i=\bar{t}} = -\frac{\partial t_i}{\partial E_j} \Big/ \frac{\partial t_i}{\partial E_i} = \frac{-\beta E_i}{1-\alpha_i+\beta E_i} < 0 \tag{13}$$

Hence, if country j increases its quantity of emissions whilst the other country keeps their emissions tax constant then the other country will reduce their quantity of emissions. The unilateral equivalence constraint facing country one is shown in **Figure 2** for a number of

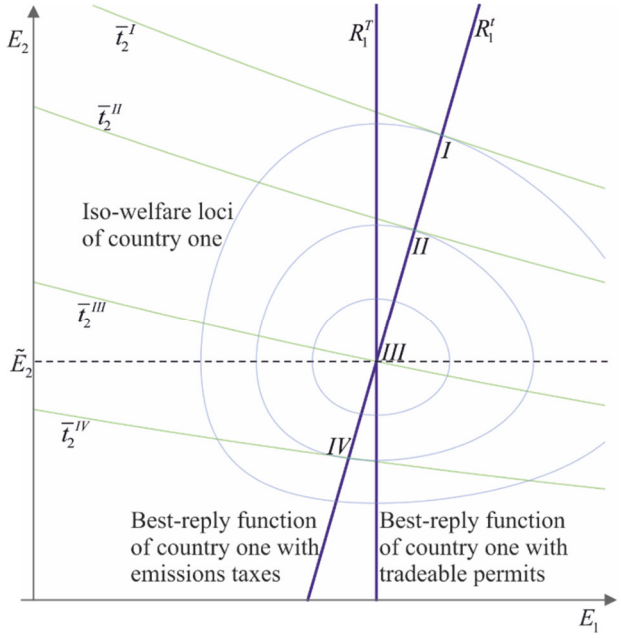


Figure 2: *Derivation of best-reply function with emissions taxes*

emissions tax rates of country two, $\bar{t}_2^{I} < \bar{t}_2^{II} < \bar{t}_2^{III} < \bar{t}_2^{IV}$. The best-reply function of country one when country two uses an emissions tax is derived by maximising the welfare of country one given the unilateral equivalence constraints that yields the maxima at I, II, III and IV, where in each case the unilateral equivalence constraint is tangential to the iso-welfare locus. The best-reply function shifts outwards (inwards) when the overall externality is negative (positive) as $E_2 > (<) \tilde{E}_2$ thereby leading the best-reply function to swivel clockwise around III, the first-best outcome.

Maximising the welfare of country j subject to the unilateral equivalence constraint yields the first-order condition:

$$\frac{dW_j}{dE_j} = \frac{\partial W_j}{\partial E_j} + \frac{\partial W_j}{\partial E_i}\frac{dE_i}{dE_j}\bigg|_{t_i=\bar{t}} = \frac{W_j\left\{\phi_j\alpha_j\left(1-\alpha_i\right) - \left(1-\alpha_i+\phi_i\alpha_i\right)\beta E_j + \phi_j\alpha_j\beta E_i\right\}}{E_j\left(1-\alpha_i+\beta E_i\right)} = 0 \quad (14)$$

Setting the expression in curly brackets equal to zero implicitly defines the best-reply function of country j, which is linear and upward sloping. Solving the two simultaneous equations yields the quantity of emissions in the NE with emissions taxes in each country: $E_{Nj}^{t} = \phi_j\alpha_j/\beta$, where the superscript t denotes the NE with emissions taxes. Then, substituting the quantity of emissions into welfare (6) yields welfare in the NE with emissions taxes, W_{Nj}^{t}. Comparing the NE with emissions taxes and the NE with tradeable permits leads to the following:

Proposition 2: *In the NE with emissions taxes, the quantity of emissions and welfare are the same as in the NE in tradeable permits.*

Proof: From (11), $E_{Nj}^{t} = E_{Nj}^{T} = \phi_j\alpha_j/\beta$ and hence $W_{Nj}^{t} = W_{Nj}^{T}$.■

Hence, emissions taxes and tradeable permits are strategically equivalent in the terminology of Kiyono and Ishikawa (2004). **Figure 1** shows the best-reply functions with

emissions taxes of the two countries, R_1^t and R_2^t, and the iso-welfare loci that are the same for both countries although the levels of welfare are different. The best-reply functions with emissions taxes and with tradeable permits intersect at the same point that is the NE with tradeable permits and with emissions taxes. Propositions 1 and 3 together imply the following:

Corollary 1: *The quantity of emissions and welfare in the NE with emissions taxes are the same as in the first-best outcome.*

The NE with emissions taxes is Pareto efficient and there are no potential gains from international cooperation. It does not matter whether countries use tradeable permits or emissions taxes the NE is Pareto efficient because with international trade the interests of both countries are perfectly aligned.

To compare the NE emissions taxes in the two countries, note that the emissions tax of each country is expressed in terms of the good that it produces (12). The emissions tax of country 1 is in terms of good 1 whereas the emissions tax of country 2 is in terms of good 2 but can be expressed in terms of good 1 as $t_2\left(p_2/p_1\right)$. Hence, using the terms of trade (4) and the quantity of emissions in the NE, the NE emissions tax of country 1 relative to that of country 2 in terms of the same good is:

$$\frac{t_1 p_1}{t_2 p_2} = \frac{\exp\left[-\beta\left(E_1+E_2\right)\right]\alpha_1 A_1 L_1^{1-\alpha_1} E_1^{\alpha_1-1}}{\exp\left[-\beta\left(E_1+E_2\right)\right]\alpha_2 A_2 L_2^{1-\alpha_2} E_2^{\alpha_2-1}} \frac{\phi_1 A_2 L_2^{1-\alpha_2} E_2^{\alpha_2}}{\phi_2 A_1 L_1^{1-\alpha_1} E_1^{\alpha_1}} = \frac{\phi_1 \alpha_1 E_{N2}^t}{\phi_2 \alpha_2 E_{N1}^t} = 1 \qquad (15)$$

Despite the asymmetries in the model, the emissions taxes in the NE with emissions taxes are the same in the two countries, which is not surprising as the NE with emissions taxes is Pareto efficient. This also implies that the optimal emissions taxes in the first-best outcome will be the same in both countries, and that the price of tradeable permits in the NE with tradeable permits will be the same in both countries.

3. Multi-Country Emissions Game with International Trade

The two-country model can be extended to the case of many countries by assuming that there are $J \geq 2$ identical countries with the same labour endowment, the same technology, the same real trade cost, and the same symmetric preferences although with the addition of a home consumption bias. The countries and goods are labelled $j = 1,\ldots,J$ with good j produced in country j by a perfectly competitive industry. The output of good j in country j is Y_j, and the quantity of emissions in country j is E_j. Since the technology is assumed to be identical in all countries, $A_j = A > 0$, $L_j = L > 0$, and $\alpha_j = \alpha \in (0,1)$ for $j = 1,\ldots,J$. Hence. the aggregate production function for good j in country j is now given by the modified Cobb-Douglas function:

$$Y_j = \exp\left[-\beta \sum_{i=1}^{J} E_i\right] A L^{1-\alpha} E_j^{\alpha} \qquad i, j = 1,\ldots,J \tag{16}$$

The preferences of the representative consumer in country j for the J goods are given by the Cobb-Douglas utility function:

$$U_j(\mathbf{x}_j) = x_{jj}^{\frac{1+\gamma}{J+\gamma}} \prod_{i \neq j} x_{ij}^{\frac{1}{J+\gamma}} \qquad i, j = 1,\ldots,J \tag{17}$$

where x_{ij} is consumption of good i in country j, $\mathbf{x}_j = (x_{1j},\ldots,x_{Jj})'$, and $\gamma \geq 0$ represents the home consumption bias in preferences so expenditure on the domestic good is $1+\gamma$ times expenditure on an imported good.[9] If $\gamma = 0$ then the exponent on all goods is the same so preferences are identical in all countries and there is no home consumption bias whereas if γ

[9] One might question the rationale for a home consumption bias that is modelled as an exogenous bias in preferences rather than being the result of trade costs, but trade costs do not affect expenditure shares with Cobb-Douglas preferences.

goes to infinity then only the domestically-produced good is consumed in the country as in Azacis and Collie (2025).

Since the real trade cost is assumed to be the same for all the goods, $\tau_j = \tau \geq 0$ for $j = 1,\ldots,J$, the domestic price of good j in country j is equal to the world price p_j, whereas the domestic price of imported goods in country j is τp_i, for $i \neq j$. The representative consumer receives all the labour income and all the revenue from tradeable permits or emissions taxes. Hence, the income of the representative consumer in country j is given by the value of the country's output, $p_j Y_j$. Since the representative consumer has Cobb-Douglas preferences, demand (consumption) for the domestic and imported goods in country j are:

$$x_{jj} = \frac{(1+\gamma)Y_j}{J+\gamma} \qquad x_{ij} = \frac{p_j Y_j}{\tau p_i (J+\gamma)} \qquad i \neq j \tag{18}$$

If consumption of an imported good in country j is x_{ij} then country i must export τx_{ij} due to the real trade cost. To determine the equilibrium relative price, equate demand and supply for all the goods in the world market, which for good j yields:

$$x_{jj} + \sum_{i \neq j} \tau x_{ji} = \frac{(1+\gamma)Y_j}{J+\gamma} + \sum_{i \neq j} \frac{p_i Y_i}{p_j (J+\gamma)} = Y_j \qquad i, j = 1,\ldots,J \tag{19}$$

Some routine, but tedious algebra, yields that the equilibrium relative price of good j is $p_j / p_i = Y_i / Y_j = \left(E_i / E_j\right)^{\alpha}$, where the final expression is obtained using (16). This relative price is the terms of trade of country j and it can be seen that an increase in emissions by country j worsens its terms of trade whereas an increase in emissions by country i improves the terms of trade of country j, which is the positive terms of trade externality. Substituting the equilibrium relative price into (18) yields consumption of the domestic and the imported goods in country j:

$$x_{jj} = \frac{(1+\gamma)Y_j}{J+\gamma} \qquad x_{ij} = \frac{Y_j}{\tau(J+\gamma)}\left(\frac{E_i}{E_j}\right)^{\alpha} \tag{20}$$

Substituting consumption of the goods (20) into the utility function of country j (17), and using the aggregate production function (16) yields the welfare of country j as a function of the quantity of emissions of all the countries:

$$W_j = \Lambda \exp\left[-\beta \sum_{i=1}^{J} E_i\right]\left(E_j^{1+\gamma}\prod_{i\neq j} E_i\right)^{\frac{\alpha}{J+\gamma}} \qquad \text{where } \Lambda = \frac{(1+\gamma)^{\frac{1+\gamma}{J+\gamma}} AL^{1-\alpha}}{(J+\gamma)\tau^{\frac{J-1}{J+\gamma}}} > 0 \tag{21}$$

The welfare of country j is log-concave and hence quasi-concave in its own emissions. Note that if there is no home consumption bias, $\gamma = 0$, then the welfare function is identical for all countries, but that if $\gamma > 0$ then it is not identical for all countries but it is symmetric. This welfare function exhibits a negative environmental externality (through the exponential function) and a positive terms of trade externality (through the Cobb-Douglas function), and the overall effect can be determined by differentiating the welfare of country j with respect to the quantity of emissions of country i, where $i \neq j$, which yields:

$$\frac{\partial W_j}{\partial E_i} = W_j\left(\frac{\alpha - \beta(J+\gamma)E_i}{(J+\gamma)E_i}\right) > (<) 0 \qquad \text{if} \qquad E_i < (>)\, \tilde{E} \equiv \frac{\alpha}{\beta(J+\gamma)} \tag{22}$$

The overall externality effect of foreign emissions depends upon the quantity of emissions of the foreign country. When the quantity of emissions of the foreign country are sufficiently small, $E_i < \tilde{E}$, then the overall externality is positive as the positive terms of trade externality outweighs the negative environmental externality whereas the overall externality is negative when the quantity of emissions of the foreign country are sufficiently large, $E_i > \tilde{E}$, as the negative environmental externality outweighs the positive terms of trade externality.

Since all countries are identical, the (symmetric) first-best outcome can be derived by setting $E_i = E_j = E$, which yields that the welfare of each country is $W = \Lambda \exp\left[-\beta JE\right] E^{\alpha}$, and then maximising welfare with respect to E. This yields that the first-best quantity of emissions in each country and the welfare of each country are:

$$E^{FB} = \frac{\alpha}{\beta J} \qquad W^{FB} = \Lambda \exp\left[-\alpha\right]\left(\frac{\alpha}{\beta J}\right)^{\alpha} \tag{23}$$

Note that the first-best quantity of emissions does not depend upon the home consumption bias parameter, γ, and that total world emissions, that are equal to α/β, do not depend upon the number of countries.

3.1 Nash Equilibrium with Tradeable Permits

In the Nash equilibrium (NE) with tradeable permits, each country sets the quantity of emissions to maximise its welfare given the quantities of emissions chosen by the other countries. Differentiating the welfare of country j (21) with respect to its own emissions E_j yields the first-order condition:

$$\frac{\partial W_j}{\partial E_j} = W_j\left(\frac{\alpha(1+\gamma) - \beta(J+\gamma)E_j}{(J+\gamma)E_j}\right) = 0 \tag{24}$$

Hence, the quantity of emissions and the welfare of each country in the NE (denoted by a subscript N) with tradeable permits (denoted by a superscript T) are:

$$E_N^T = \frac{\alpha(1+\gamma)}{\beta(J+\gamma)} \qquad W_N^T = \Lambda \exp\left[-\frac{\alpha(1+\gamma)J}{J+\gamma}\right]\left(\frac{\alpha(1+\gamma)}{\beta(J+\gamma)}\right)^{\alpha} \tag{25}$$

Note that setting $E_j = E_N^T$ is a dominant strategy for all countries, and that $E_N^T = \tilde{E}$ if $\gamma = 0$ whereas $E_N^T > \tilde{E}$ if $\gamma > 0$ from (22). Each country sets the quantity of emissions to deal

with the domestic environmental externality, where domestic firms ignore the negative effect of their emissions on domestic welfare, and with the negative terms of trade effect, where increasing emissions by increasing output and exports worsens the country's terms of trade. The NE quantity of emissions is increasing in the home consumption bias parameter, γ, as this increases consumption of the domestically-produced good and reduces the negative terms of trade effect.

Comparing the NE with tradeable permits and the first-best outcome when there is no home consumption bias in preferences, $\gamma = 0$, leads to the following:

Proposition 3: *When there is no home consumption bias, $\gamma = 0$, the quantity of emissions and welfare in the NE with tradeable permits are the same as in the first-best outcome.*

Proof: If $\gamma = 0$ then $E_N^T = E^{FB} = \alpha/(\beta J)$ and $W_N^T = W^{FB} = \Lambda \exp[-\alpha](\alpha/(\beta J))^{\alpha}$ from (23) and (25).■

The NE with tradeable permits is Pareto efficient and there are no potential gains from international cooperation. In this case, the negative environmental externality is exactly offset by the positive terms of trade externality so that the overall externality is zero, since $E_N^T = \tilde{E}$, at the NE with tradeable permits.

Comparing the NE with tradeable permits and the first-best outcome when there is a home consumption bias, $\gamma > 0$, leads to the following:

Proposition 4: *When there is a home consumption bias, $\gamma > 0$, the quantity of emissions is higher and welfare is lower in the NE with tradeable permits than in the first-best outcome.*

Proof: If $\gamma > 0$ then the quantity of emissions and welfare in the NE with tradeable permits relative to those in the first-best outcome are:

$$\frac{E_N^T}{E^{FB}} = \frac{J(1+\gamma)}{J+\gamma} > 1 \qquad \Omega_T \equiv \frac{W_N^T}{W^{FB}} = \exp\left[-\frac{\alpha\gamma(J-1)}{J+\gamma}\right]\left(\frac{(1+\gamma)J}{J+\gamma}\right)^{\alpha} \tag{26}$$

Taking the log of Ω_T and differentiating with respect to γ yields:

$$\frac{\partial \ln \Omega_T}{\partial \gamma} = -\frac{\alpha\gamma(J-1)^2}{(1+\gamma)(J+\gamma)^2} < 0 \tag{27}$$

Since $\Omega_T = 1$ when $\gamma = 0$ and Ω_T is decreasing in γ, $W_N^T < W^{FB}$ for $\gamma > 0$. ■

In this case, at the NE with tradeable permits, emissions of each country are higher than at the first-best outcome. The overall externality is negative as the negative environmental externality outweighs the positive terms of trade externality, since $E_N^T > \tilde{E}$, and there is scope for international cooperation to decrease emissions and increase the welfare of all countries.

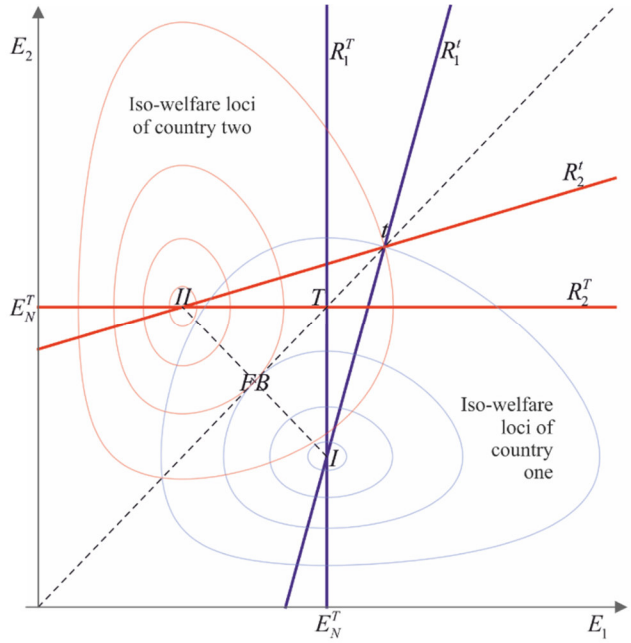


***Figure 3**: Best-reply functions with home consumption bias*

The two-country case with a home consumption bias, $\gamma > 0$, is shown in **Figure 3**, with the best-reply functions of the two countries and their iso-welfare loci. Again, the best-reply function of country one (two) R_1^T $\left(R_2^T\right)$ is vertical (horizontal) because setting E_N^T is a

dominant strategy for both countries, and the NE with tradeable permits is at the intersection T. The iso-welfare loci are no longer the same for both countries as the welfare function (21) is not the same for both countries when $\gamma > 0$. The welfare of country one (two) is maximized at I (II), and all the points on the line between I and II are Pareto efficient with the symmetric first-best outcome at the midpoint of the line. Hence, it can be seen that moving from the NE with tradeable permits (T) to the first-best outcome (FB) by reducing the quantity of emissions of both countries will increase their welfare so there are potential gains from international cooperation through an IEA.

3.2 Nash Equilibrium with Emissions Taxes

As in Section 2.2, the NE with emissions taxes can be obtained by having each country set the quantity of emissions subject to unilateral equivalence constraints that imply that the other countries keep their emissions taxes constant. This yields the NE with emissions taxes in terms of the quantities of emissions rather than in terms of the emissions taxes, which allows the quantity of emissions in the NE with tradeable permits to be compared with that in the NE with emissions taxes. Since the game is symmetric, all countries will set the same quantity of emissions in the NE with emissions taxes so the game can be analysed by considering the quantity of emissions chosen by country j, E_j, while all the other countries each set the same quantity of emissions, E_{-j}. As industries are perfectly competitive and there are constant returns to scale, the unilateral equivalence constraint of all the other countries is obtained by equating their emissions taxes, t_{-j}, with the marginal product of emissions in their industries. Differentiating the aggregate production function of country $-j$ with respect to its emissions, E_{-j}, while treating the exponential function as a constant since the perfectly-competitive firms ignore the environmental externality, and equating to its emissions tax, yields:

$$t_{-j} = \frac{\partial Y_{-j}}{\partial E_{-j}} = \exp\left[-\beta\left(E_j + (J-1)E_{-j}\right)\right]\alpha A L^{1-\alpha} E_{-j}^{\alpha-1} \tag{28}$$

Totally differentiating the unilateral equivalence constraint while keeping the emissions tax constant yields:

$$\left.\frac{dE_{-j}}{dE_j}\right|_{t_{-j}=\bar{t}} = \frac{-\beta E_{-j}}{1-\alpha+\beta(J-1)E_{-i}} < 0 \tag{29}$$

Hence, if country j increases its quantity of emissions whilst the other countries keep their emissions taxes constant then the other countries will reduce their quantity of emissions. Country j sets its quantity of emissions to maximise its welfare (21) subject to the unilateral equivalence constraint (28), which yields the first-order condition:

$$\begin{aligned}\frac{dW_j}{dE_j} &= \frac{\partial W_j}{\partial E_j} + \frac{\partial W_j}{\partial E_{-j}}\left.\frac{dE_{-j}}{dE_j}\right|_{t_{-j}=\bar{t}} \\ &= \frac{W_j\left\{\alpha(1-\alpha)(1+\gamma)+\alpha\beta(1+\gamma)(J-1)E_{-j}-\beta\left(J+\gamma-\alpha(1+\gamma)\right)E_j\right\}}{E_j\left(1-\alpha+\beta(J-1)E_{-j}\right)(J+\gamma)} = 0\end{aligned} \tag{30}$$

Setting the expression in curly brackets equal to zero implicitly defines the best-reply function of country j, which is linear and upward sloping. Imposing symmetry so that $E_j = E_{-j}$ yields the quantity of emissions in the NE with emissions taxes:

$$E_N^t = \begin{cases} \dfrac{\alpha(1-\alpha)(1+\gamma)}{\beta\Delta} & \alpha < \tilde{\alpha} \equiv \dfrac{J+\gamma}{(1+\gamma)J} \\ \infty & \alpha \geq \tilde{\alpha} \end{cases} \tag{31}$$

where $\Delta \equiv \gamma + (1-\alpha-\alpha\gamma)J > 0$ if $\alpha < \tilde{\alpha}$. When $\alpha \geq \tilde{\alpha}$ the best-reply functions do not intersect in the positive quadrant so all countries setting a zero emissions tax and an infinite

quantity of emissions is a NE.[10] Hence, substituting (31) into (21) yields welfare in the NE with emissions taxes is:

$$W_N^t = \begin{cases} \Lambda \exp\left[-\dfrac{\alpha(1-\alpha)(1+\gamma)J}{\Delta}\right]\left(\dfrac{\alpha(1-\alpha)(1+\gamma)}{\beta\Delta}\right)^{\alpha} & \alpha < \tilde{\alpha} \\ 0 & \alpha \geq \tilde{\alpha} \end{cases} \tag{32}$$

If $\alpha \geq \tilde{\alpha}$ then the quantity of emissions goes to infinity and the welfare of the countries goes to zero. Comparing the NE with emissions taxes with the NE with tradeable permits when there is no home consumption bias, $\gamma = 0$, and noting that $\tilde{\alpha} = 1$ when $\gamma = 0$, yields the following:

Proposition 5: *When there is no home consumption bias, $\gamma = 0$, the quantity of emissions and welfare in the NE with emissions taxes are the same as in the NE with tradeable permits.*

Proof: If $\gamma = 0$ then $E_N^t = E_N^t = \alpha/(\beta J)$ and $W_N^t = W_N^T = \Lambda \exp[-\alpha](\alpha/(\beta J))^{\alpha}$ from (25), (31) and (32).■

Hence, when there is no home consumption bias, emissions taxes and tradeable permits are strategically equivalent. Propositions 3 and 5 together imply the following:

Corollary 2: *When there is no home consumption bias, $\gamma = 0$, the quantity of emissions and welfare in the NE with emissions taxes are the same as in the first-best outcome.*

Once again, when there is no home consumption bias, the NE with emissions taxes is Pareto efficient and there are no potential gains from international cooperation. It does not matter whether countries use tradeable permits or emissions taxes, the NE is Pareto efficient.

[10] Alternatively, rather than assuming that the quantity of emissions are unbounded, it could be assumed that there was some finite limit to the quantity of emissions in each country. Then, the NE quantity of emissions would always be finite and NE welfare would be positive.

Comparing the NE with emissions taxes and the NE with tradeable permits when there is a home consumption bias, $\gamma > 0$, yields the following proposition:

Proposition 6: *When there is a home consumption bias, $\gamma > 0$, the quantity of emissions is higher and welfare is lower in the NE with emissions taxes than in the NE with tradeable permits.*

Proof: If $\gamma > 0$, and $\alpha < \tilde{\alpha}$, then the quantity of emissions and welfare in the NE with emissions taxes relative to the NE with tradeable permits are:

$$\begin{aligned} &\frac{E_N^t}{E_N^T} = \frac{(1-\alpha)(J+\gamma)}{\Delta} > 1 \\ &\Omega_t \equiv \frac{W_N^t}{W_N^T} = \exp\left[\frac{-\alpha^2\gamma(1+\gamma)(J-1)J}{(J+\gamma)\Delta}\right]\left(\frac{(1-\alpha)(J+\gamma)}{\Delta}\right)^{\alpha} \end{aligned} \tag{33}$$

Taking the log of Ω_t and differentiating with respect to γ yields:

$$\frac{\partial \ln \Omega_t}{\partial \gamma} = -\frac{\alpha^2\gamma J(J-1)^2(J+\gamma+\Delta)}{(J+\gamma)^2\Delta^2} < 0 \tag{34}$$

Since $\Omega_t = 1$ when $\gamma = 0$ and Ω_t is decreasing in γ, $W_N^t < W_N^T$ for $\gamma > 0$.

If $\gamma > 0$, and $\alpha \geq \tilde{\alpha}$, then the proof is obvious.■

Hence, when there is a home consumption bias, emissions taxes and tradeable permits are not strategically equivalent. The two-country case is shown in **Figure 3** that shows the best-reply functions of the two countries with emissions taxes, R_1^t and R_1^t, and the iso-welfare loci of the two countries.[11] The two best-reply functions with emissions taxes intersect each other

[11] The best-reply functions with emissions taxes can be obtained from (30) or derived as in **Figure 2**.

at the NE with emissions taxes, t, where the quantity of emissions of each country is higher than in the NE with tradeable permits, T. Proposition 4 and 6 together imply the following:

Corollary 3: *When there is a home consumption bias, $\gamma > 0$, the quantity of emissions is higher and welfare is lower in the NE with emissions taxes than in the first-best outcome.*

Once again, when there is a home consumption bias, the NE with emissions taxes is not Pareto efficient and there are potential gains from international cooperation to reduce the quantity of emissions and increase welfare.

4. Conclusions

In contrast to the rest of the literature, it has been shown that with international trade there is a positive terms of trade externality as well as the negative environmental externality from emissions, and that the sign of the overall externality is endogenous depending upon the quantity of emissions from foreign countries. When the quantity of emissions from foreign countries is sufficiently large then the overall externality is negative whereas the overall externality is positive when the quantity of emissions from foreign countries is sufficiently small. When preferences are identical, and there is no home consumption bias, the negative environmental externality is cancelled out by the positive terms of trade externality in the NE so that the overall externality is zero and as a result the NE with environmental policies (tradeable permits or emissions taxes) is Pareto efficient. Hence, there are no potential gains from international cooperation through an IEA as free trade has resulted in the interests of the countries being perfectly aligned.

When there is a home consumption bias, the negative environmental externality outweighs the positive terms of trade externality in the NE so that the overall externality is negative and as a result the NE with environmental policies is not Pareto efficient. Hence, there are potential gains from cooperation through an IEA that decreases the quantity of emissions

and increases the welfare of all countries. In this case, which is in line with the rest of the literature, international cooperation through an IEA can be modelled in an infinitely-repeated game or in a coalition-formation game as in the autarky model of Azacis and Collie (2025).

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