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Abstract

In a model of two large asymmetric countries, we examine the effectiveness of the non-cooperative setting of tradable emission permits in reducing global pollution, under different rules of international taxation of capital earnings. Our key result is that, under certain conditions, the lowest Nash equilibrium level of global pollution is achieved when the policy-mix combines internationally, rather than nationally, tradable emission permits and either capital-tax exemptions or capital-tax credits.

JEL classification: F18, F21, H21.

Keywords: Emission Permits, Cross-border Pollution**,** Capital Tax Competition, Capital Tax Rules.

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1 Introduction

A long-standing policy debate is whether deeper economic integration in the form of higher degree of international capital mobility leads to a race to the bottom in environmental policies and to further environmental degradation. These concerns are amplified by the failure to reach International Environmental Agreements requiring universal emission targets that are binding for the participating countries.

Another issue of pivotal importance, related to international capital mobility, is that of international taxation of capital incomes. Countries, in order to attract internationally mobile capital, either impose low capital income taxes, i.e., race to the bottom in capital taxation, or tangle into international treaties to prevent double taxation and to limit tax avoidance and tax-base flight, between high and low-tax jurisdictions.[1] By and large, international double taxation treaties involve three possible rules or systems of taxing the earnings of internationally mobile capital. These are the so-called rules of (i) *capital tax-exemptions* or else *untaxed repatriated capital earnings*, (ii) *capital tax-credits*, and (iii) *capital tax-deductions*.[2]

For these reasons, one of the issues long gaining academic and policymaking prominence is that of the efficiency of non-cooperative policymaking in the presence of international capital mobility and pollution externalities. Nowadays, emission leakages are largely regulated via the issuance of emission permits tradable, either nationally, only within a country, or internationally across different countries and/or regions.[3] To the best of our knowledge, the policy implications of tradable emission permits under the alternative systems of taxation of repatriated capital earnings have not been examined.

Contribution of the paper: Given these realizations, first, we evaluate the effectiveness of nationally vs. internationally tradable emission permits in controlling pollution given the prevailing rule of international taxation of capital earnings. Second, we evaluate under which rule of capital income taxation each of the two regimes of tradable emission permits is more effective in reducing global pollution. The key result of the analysis is that the lowest Nash equilibrium level of global pollution is achieved when the policy-mix combines internationally tradable emission permits and either *capital-tax exemptions* or *capital-tax credits*.

Related Literature: A strand of the literature examines the effectiveness of non-cooperative gov-

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[1] Recently, October 2021,136 countries and jurisdictions, including all OECD and G20 member countries, agreed on a major reform of the international tax system by which Multinational Enterprises are subject to a global minimum corporate tax rate of 15 percent from 2023. This global minimum tax agreement does not seek to eliminate tax competition, but puts multilaterally agreed limitations on it. Only, four countries - Kenya, Nigeria, Pakistan and Sri Lanka - have not yet joined the agreement, see, OECD (2021).

[2] In order to reduce double taxation of foreign earned incomes, many EU countries, the UK and the US, have signed bilateral tax treaties and agreements by which foreign earned capital incomes are either fully or almost fully exempted from source-country based taxation, e.g., Davies (2003), Devereux et al. (2015).

[3] The latter type is the so-called Emission Trading System (ETS).Today, a growing number of such active ETSs are in use. For example, the the European ETS, the most renowned worldwide system of controlling CO_2 emissions, the US-SATS, an interstates system of controlling SO_2 emissions, the *Western Climate Initiative* (WCI) a multi-sector market based cap-and-trade Program among Western US States and Canadian Provinces to reduce GHG emissions. Other systems of market-based emission permits operate in China, Japan, N. Zealand, and S. Korea.

ernment policies in the presence of emission leakage, and/or terms of trade motives when economies are large in world capital markets.[4] Eichner and Runkel (2012) show that non-cooperative emission taxes are not efficient in a context with emission leakage, capital mobility and terms of trade externalities. Fell and Kaffine (2014), in a multi-jurisdictions model with capital mobility, capital retirement, and transboundary pollution, show that the welfare maximizing non-cooperative taxes generally differ from the welfare mixamizing taxes set by a centralized planner. Tsakiris et al. (2017) in a model of asymmetric regions demonstrate that non-cooperatively set intra-regionally or inter-regionally tradable emission permits, are always inefficient in a context with cross-border pollution and terms of trade motives. Eichner and Pethig (2019) in a model of symmetric countries with mobile capital and transboundary or local pollution show that when capital taxes-cum-emission caps are used, the non-cooperative policy combination calls for zero capital taxes, and emission caps which are inefficiently lower (set efficiently) to their socially optimal level when pollution is transboundary (local). When capital-cum-emission taxes are applied, the non-cooperative policy combination calls for capital subsidies (zero taxes), and emission taxes which are inefficiently lower (set efficiently) to their socially optimal rates when pollution is transboundary (local). Habla (2018), in a two period model with capital mobility shows that the welfare maximizing policy combination calls for environmental taxes combined with source-based capital subsidies in the first period and capital taxes in the second. Tsakiris et al. (2018), in a model with internationally mobile capital and cross border pollution, show that the decentralized setting of inter-regionally tradable emission permits is efficient when revenue finances the provision of public pollution abatement. The same result is reached by Landry (2021), who shows that the decentralized setting of interjurisdictionally tradable emission permits is efficient when revenue from permits sales is lump-sum distributed and governments "think globally on average", i.e., on average their revealed social cost of emissions equals the global social cost of emissions on average.[5]

Related to our study is also the literature on international capital taxation under different rules of taxing capital earnings. Janeba (1995) in a model of international capital mobility, and of non-cooperative capital income taxation shows that among the three systems of capital income taxation, *capital tax-credits* require the fewer restrictions for achieving Pareto improvement. Under *capital tax-exemptions*, Pareto improvement requires the harmonization of tax rates, while under *capital tax-deductions*, a "side" payment is in order for efficient allocation of capital to be achieved.[6] Haufler

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[4]A number of studies, not directly related to the present work, examines the welfare implications of tradable emission permits when countries are large in world commodity markets and capital is internationally immobile, e.g., see, among others, Copeland and Taylor (2005), Carbone et al. (2009).

[5]Within an imperfectly competitive framework, Richter et al. (2021) analyze a non-cooperative setting of emission taxes in the presence of mobile polluting firms.

[6]Davies (2003) in a model of a tax treaty where countries are simultaneously source and host to foreign direct investment, concludes that for any given combination of double taxation relief system, an equilibrium exists with positive capital flows in both directions, and positive capital taxes by both countries. When countries are symmetric, *capital tax-credits* is the unique and efficient treaty equilibrium. With asymmetric countries, the treaty needs tax harmonization in order to yield improvements over the non-treaty equilibrium. A newer spin in the literature of international tax competition, of the choice of corporate income taxes, and of the scheme of taxing repatriated incomes, considers the case where international investment involves not only reallocation of real capital between capital-exporting and capital-importing countries, but also the change of ownership, e.g., international mergers and

and Lülfesmann (2015) show that non-cooperative capital income taxation leads to inefficiently low tax rates, and propose a two tier tax structure that mitigates capital tax competition. Mongrain and Wilson (2018), in a model of international capital tax competition with heterogeneous capital, examine the merits of preferential vs. non-preferential capital tax regimes.

2 The Model

We consider a model of a two asymmetric countries world, Home and Foreign, with international capital mobility. Each country produces a single consumption good which is freely traded.[7] Its production generates perfect cross-border pollution, e.g., CO_2 emissions, which equally affects negatively welfare of residents in the two countries. Commodity and factor markets in both countries are perfectly competitive.

2.1 Production and demand

The production side of each economy is represented by the Gross Domestic Product (GDP) function. Home's (GDP) function is given by $R(\tau, K) = \max\{py(K, \Psi) - \tau z : F(y, K, \Psi) \leq 0\}$. It captures the maximum value of the country's production given the producers' price p, the aggregate production possibilities set $F(y, K, \Psi)$, and the vector of all other factors in fixed supplies Ψ. Hereon, Ψ is omitted since it is fixed, and p, is omitted as the price of the single commodity, e.g., Janeba (1995) and Eichner and Pethig (2019). y is the amount of the tradable good produced, τ is the price of tradable emission permits, and z is the level of production generated pollution. For the purposes of our analysis, Home is assumed to be the capital importing country, $K = \overline{K} + k$, is the supply of capital in Home, $\overline{K}$ is the country's initial capital endowment, and $k > 0$ is the amount Foreign's capital operating in Home. The derivatives of the GDP function with respect to (w.r.t) capital, e.g., $\partial R / \partial K = R_K(\tau, K)$, denotes the marginal revenue product of capital, and its derivative w.r.t. τ, by the Envelope Theorem, is $\frac{\partial R}{\partial \tau} = R_\tau(\tau, K) = -z$. The GDP function is strictly concave in K, e.g., $R_{KK} = \frac{\partial R_K}{\partial K} < 0$, and strictly convex in τ, i.e., $R_{\tau\tau} = -\left(\frac{\partial z}{\partial \tau}\right) > 0$, implying that an increase in τ, denoting tighter environmental policy, reduces production and the levels of production generated pollution. Since a higher K increases pollution, then $R_{\tau K} < 0$. Similar definitions and properties hold for Foreign, assumed to be the capital-exporting country. $R^*(\tau^*, K^*)$ denotes the country's GDP function, and τ^* is the price of tradable emission permits issued by Foreign. $R^*_{K^*}(\tau^*, K^*)$ and $z^* = -R^*_{\tau^*}(\tau^*, K^*)$, respectively, denote its marginal revenue product of capital, and its level of production generated pollution. $K^* = \overline{K}^* - k$, is the supply of capital in Foreign and $\overline{K}^*$ is the country's initial capital endowment. $R^*_{K^*K^*} < 0$, $R^*_{\tau^*\tau^*} > 0$, and $R^*_{\tau^*K^*} < 0$. Hereon, an $(*)$ indexes Foreign's variables.

The demand side is captured by the minimum expenditure function. Home's expenditure func-

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acquisitions due to firms' multinational activity, e.g., Becker and Fuest (2010, 2011), Devereux et al. (2015).

[7]In the standard literature of international capital tax competition, the one-good model is the "work-horse" model due to its analytical simplicity and clarity of the results, e.g., see Bond and Samuelson (1989), Janeba (1995).

tion is denoted by $E\left(p,r,u\right)=\min_{x}\left\{px:U\left(x,r\right)\geq u\right\}$, and shows the minimum expenditure required to achieve a given utility level u, at given price p and pollution r. $U\left(x,r\right)$ is the utility function for a representative household, (x) is the quantity consumed of the tradable commodity, $U_x\left(x,r\right)>0$ and $U_r\left(x,r\right)<0$. Hereon, the consumer price p is omitted as noted above, hence $E\left(r,u\right)$. The partial derivatives $E_u\left(=\frac{\partial E}{\partial u}\right)$ and $E_r\left(=\frac{\partial E}{\partial r}\right)$, respectively, give the reciprocal of the marginal utility of income, and the household's marginal willingness to pay for reduction in pollution or the marginal environmental damage. E_r is positive since pollution affects households' utility negatively, e.g., see Copeland and Taylor (2005). Similarly, Foreign's expenditure function is given by $E^*\left(r^*,u^*\right)$, featuring similar properties.

2.2   The regimes of capital income taxation

Capital flows between the two asymmetric countries are affected by (i) the capital tax rates under the alternative regimes of international taxation of capital earnings, and (ii) the implemented environmental policies to control for the production generated cross-border pollution. Foreign earned capital incomes are fully repatriated to capital owners in the source, capital-exporting, country. Capital tax revenue by each country is lump-sum rebated to its representative household.

With *capital tax-exemptions (ex)*, the earnings of Foreign's capital employed in Home are completely exempted from its tax liability in the source country. The world capital market equilibrium is achieved when the net rate of return to capital is equated across the two countries. That is,

$$(ex):\quad (1-\rho)R_K\left(.\right)=(1-\rho^*)R^*_{K^*}\left(.\right), \tag{1}$$

where ρ and ρ^* are a capital tax or a subsidy in Home and Foreign.

Under a rule of *capital tax-credits (cr)*, Foreign extends tax credits to its capital employed in Home, up to the amount of taxes that the latter is liable under domestic taxation. This tax-regime entails the taxation of capital earnings at the highest of the two tax rates. The equilibrium condition of the world capital market is:

$$(cr):\quad \left\{1-\max(\rho,\rho^*\right\}R_K\left(.\right)=(1-\rho^*)R^*_{K^*}\left(.\right). \tag{2}$$

When $\rho<\rho^*$, the equilibrium condition (2) reduces to $R_K\left(.\right)=R^*_{K^*}\left(.\right)$. In this case, a reduction (an increase) in the capital tax by Home, the capital-importing country, simply transfers capital tax revenue to Foreign (from Foreign), without causing international capital movements. Similarly, as long as Foreign remains a net-capital exporter and $\rho<\rho^*$, then, changes in ρ^* simply redistribute income from the country's capital owners to the government, without affecting the country's domestic supply of capital, thus its domestic production. When $\rho>\rho^*$, the equilibrium condition (2) reduces to equilibrium condition (1). Then, changes in Home's capital tax affect the country's net rate of return to capital.

The last rules of international taxation of capital earnings we consider is the *capital tax-deductions (de)*. Foreign, before applying its own capital income tax, allows for the complete

deduction of the income tax payments made by its capital employed in Home. That is, tax payments by Foreign's capital employed in Home are deducted as cost when calculating its gross tax liability in Foreign, the source country. A unit of Foreign's capital when employed in Home earns a net rate of return $(1 - \rho^*)(1 - \rho)R_K$, while when it is employed in Foreign, its net rate of return is $(1 - \rho^*)R_{K^*}^*$. The world capital market equilibrium condition is:

$$(de): \quad (1 - \rho^*)(1 - \rho)R_K = (1 - \rho^*)R_{K^*}^* \Longrightarrow (1 - \rho)R_K = R_{K^*}^*. \tag{3}$$

3   Nationally tradable emission permits and capital taxes

Let Z_n and Z_n^*, respectively, be the levels of emission permits issued by Home and Foreign's governments. Assuming that the issued levels of permits are binding, then, equilibrium in each country's permits market is achieved when the supply of and demand for nationally tradable emission permits are equal. That is:

$$Z_n = z = -R_{\tau_n}(\tau_n, K) \quad \text{and} \quad Z_n^* = z^* = -R_{\tau_n^*}^*(\tau_n^*, K^*), \tag{4}$$

where τ_n and τ_n^*, are the prices of the nationally tradable permits in the two countries. Cross-border pollution is perfect, i.e., a unit of production generated pollution in one country affects equally the welfare of residents in both. Overall pollution in each country is:[8]

$$r = Z_n + Z_n^*, \quad \text{and} \quad r^* = Z_n^* + Z_n. \tag{5}$$

Differentiating equations (5) with respect to Z_n and Z_n^*, the effects of changes in the levels of nationally tradable emission permits on the levels of pollution are $\frac{dr}{dZ_n} = \frac{dr^*}{dZ_n^*} = \frac{dr^*}{dZ_n} = \frac{dr}{dZ_n^*} = 1$.

The representative household's budget constraint in each country requires that spending on goods must equal income from production plus rebated government revenue from the sales of emission permits, minus (plus) the net payments to foreign (own) capital employed in Home. That is:

$$E(r, u) = R(\tau_n, K) + \tau_n Z_n - (1 - \rho)R_K k,$$

$$E^*(r^*, u^*) = R^*(\tau_n^*, K^*) + \tau_n^* Z_n^* + (1 - \rho)R_K k. \tag{6}$$

The two asymmetric countries world economy is described by the system of equations (4)-(6), and the relevant world capital market equilibrium condition, i.e., equations (1)-(3).

To obtain the Nash equilibrium levels of nationally tradable emission permits Z_n^N and Z_n^{*N}, and the Nash equilibrium capital tax rates ρ^N and ρ^{*N}, under the alternative regimes of international taxation of capital earnings, we set $\frac{du}{dZ_n} = \frac{du}{d\rho} = \frac{du^*}{dZ_n^*} = \frac{du^*}{d\rho^*} = 0$, in equations (A.2)-(A.5) in Appendix I. The superscript "N" indicates values at the Nash equilibrium.

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[8]A general specification for the case of cross-border pollution could be $r = Z_n + \theta Z_n^*$ and $r^* = Z_n^* + \theta^* Z_n$, where, $0 < \theta, \theta^* \leq 1$ denotes the rate of cross-border pollution from Foreign to Home and vice-versa. When $\theta = \theta^* = 1$ cross-border pollution is perfect, while when $\theta = \theta^* = 0$ pollution is local.

With *capital tax-exemptions*, the Nash equilibrium level of nationally tradable emission permits are chosen so that their Nash equilibrium price is equal to the marginal environmental damage of pollution. That is:

$$\tau_n^N = E_r \quad \text{and} \quad \tau_n^{*N} = E_{r*}^*. \tag{7}$$

Solving the reaction functions obtained by setting $\frac{du}{d\rho} = \frac{du^*}{d\rho^*} = 0$, given conditions (7), gives each country's Nash equilibrium capital tax rates as follows:

$$\rho^N = -k\widetilde{R}_{K^*K^*}^* \left(R_{K^*}^* - k\widetilde{R}_{KK}\right)\Omega^{-1}, \quad \text{and} \quad \rho^{*N} = k\widetilde{R}_{KK}\left(R_K + k\widetilde{R}_{K^*K^*}^*\right)\Omega^{-1}, \tag{8}$$

where $\Omega = \left(R_K R_{K^*}^* + k^2\widetilde{R}_{K^*K^*}^*\widetilde{R}_{KK}\right) > 0$, since $\widetilde{R}_{KK} < 0$, $\widetilde{R}_{K^*K^*}^* < 0$ by equations (A.1) in the Appendix I. Equations (8) indicate that under *capital tax-exemptions* Home's Nash equilibrium policy towards capital is a tax, while Foreign's Nash equilibrium policy requires a subsidy.[9] As shown by the Table 1 in Appendix II, the same result holds under the rule of *capital tax-credits*.

Under *capital tax-deductions*, the Nash equilibrium conditions are given by:

$$\rho^N = -k\widetilde{R}_{K^*K^*}^* R_K^{-1} > 0, \quad \text{and} \quad \rho^{*N} \in [0, \rho_{\max}^*], \tag{9}$$

$$\tau_n^N = E_r \quad \text{and} \quad \tau_n^{*N} = E_{r*}^* + (1 - \rho^N)k\widetilde{R}_{KK}R_{\tau_n^* K^*}^* \left(R_{\tau_n^*\tau_n^*}^* \widetilde{H}_{KK}\right)^{-1}. \tag{10}$$

Equations (9) and (10) indicate that at Nash equilibrium, Home, the capital-importing country, issues a level of nationally tradable permits so that their price equals the marginal environmental damage of pollution. Its optimal policy towards capital is a tax. For Foreign, however, we have $\tau_n^{*N} < E_{r*}^*$. That is, Foreign, at Nash equilibrium, strategically issues a level of nationally tradable permits higher than that under the rules of *capital tax-exemptions* and *capital tax-credits*. The reason for this strategic choice by Foreign is the following. Since ρ^* cannot be used to affect the allocation of capital between the two countries, Foreign, the capital exporting country, by issuing more permits, reduces their price, which results in a higher marginal revenue product of capital, i.e., $R_{K^*\tau_n^*} < 0$. This leads to a capital inflow in Foreign and capital outflow from Home. The emerging capital outflow from Home increases the reward of capital in that country, and payments to Foreign's capital still employed in Home rise. This constitutes a terms of trade gain for Foreign in capital markets, thus an incentive, at Nash equilibrium, to issue a higher level of nationally tradable emission permits.

Proposition 1 *When pollution is regulated via nationally tradable emission permits, then, at Nash equilibrium: (i) the capital importing country, under all tax rules for capital earnings, chooses a level of permits so that their price equals the marginal environmental damage. The equilibrium policy towards capital is a tax. (ii) The capital exporting country, under capital tax-exemption and capital tax-credits, chooses a level of permits so that their price equals the marginal environmental*

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[9] Reasonably assuming $\rho^N < 1$ requires that $\left(R_K + k\widetilde{R}_{K^*K^*}^*\right)R_{K^*}^* > 0$. Thus, we must have $\left(R_K + k\widetilde{R}_{K^*K^*}^*\right) > 0$, which by equation (8) gives $\rho^{*N} < 0$.

damage, and the equilibrium policy towards capital calls for a subsidy. Under capital tax-deductions, it chooses a level of permits so that their price is lower than the marginal environmental damage, and the equilibrium policy towards capital calls either for a zero subsidy or for a tax.

The above results are summarized in the Table 1 in Appendix II.

4   Internationally tradable emission permits and capital taxes

Now, each country issues emission permits, Z and Z^*, which are tradable across them. Producers can raise production emissions above the levels Z or Z^* set by their own country, simply by purchasing permits from the other country. Revenue from permits sales accrue lump-sum to the representative household of the country of issuance. The equilibrium condition for the internationally tradable emission permits market which determines their common price, τ, is given by:

$$Z + Z^* = z + z^* = -R_\tau(\tau, K) - R_\tau^*(\tau, K^*). \tag{11}$$

Aggregate pollution in each country is defined as:

$$r = r^* = z + z^* = -R_\tau(\tau, K) - R_\tau^*(\tau, K^*). \tag{12}$$

The budget constraints of the representative households for Home and Foreign, respectively, are given by:

$$E(r, u) = R(\tau, K) + \tau Z - (1 - \rho)R_K k,$$

$$E^*(r^*, u^*) = R^*(\tau, K^*) + \tau Z^* + (1 - \rho)R_K k. \tag{13}$$

Setting $\frac{du}{dZ} = \frac{du}{d\rho} = \frac{du^*}{dZ^*} = \frac{du^*}{d\rho^*} = 0$ in equations (A.8)-(A.11) in Appendix I, we obtain the Nash equilibrium levels of internationally tradable emission permits issued by each country, and the capital tax rates under the alternative rules of international taxation of capital earnings.

Under capital tax-exemptions or capital tax-credits, it is shown that the Nash equilibrium level of internationally tradable emission permits is such that:

$$\tau^N = \overline{e} - \frac{\left(\rho^N R_K - \rho^{*N} R_{K^*}^*\right)}{2}\frac{dk}{dZ}, \tag{14}$$

where $\overline{e} = \frac{E_r + E_{r^*}^*}{2}$ is the average marginal environmental damage of pollution in the two countries. The term $-\frac{\left(\rho^N R_K - \rho^{*N} R_{K^*}^*\right)}{2}\frac{dk}{dZ}$ captures the net effect on both countries' welfare of capital flows induced by changes in the level of emission permits, and it arises due to the existence of capital taxes.[10] Hereon, for brevity, we refer to this effect as the *capital induced global welfare effect of emission permits.* Solving the reaction functions (A.12), obtained by setting $\frac{du}{d\rho} = \frac{du^*}{d\rho^*} = 0$, gives

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[10]This term emerges from the addition of the last right-hand-side terms, at Nash equilibrium, in equations (A.8) and (A.10).

each country's Nash equilibrium capital tax rates as follows:

$$\rho^N = -kR^*_{K^*K^*}\left(R^*_{K^*} - kR_{KK}\right)\Phi^{-1} > 0, \text{ and } \rho^{*N} = kR_{KK}\left(R_K + kR^*_{K^*K^*}\right)\Phi^{-1} < 0, \quad (15)$$

where $\Phi = \left(R_K R^*_{K^*} + k^2 R^*_{K^*K^*}R_{KK}\right) > 0$. Equations (15) indicate that at Nash equilibrium, with *capital tax-exemptions*, the optimal policy towards capital is a tax for Home, the capital-importing country, and a subsidy for Foreign, the capital-exporting country. As shown by the Table 2 in Appendix II, the same result emerges under the rule of *capital tax-credits*. To facilitate the analysis we make the following Assumption:

Assumption At the initial equilibrium, the responses of pollution levels to changes in capital supply are the same in the two countries, i.e., $R_{\tau K} = R^*_{\tau K^*}$.[11]

By this Assumption, $\frac{dk}{dZ} = \frac{dk}{dZ^*} = -\frac{\left(\rho^N - \rho^{*N}\right)R_{\tau K}}{H_{KK}H_{\tau\tau}} < 0$. Since $\frac{dk}{dZ} < 0$ and $\left(\rho^N R_K - \rho^{*N}R^*_{K^*}\right) > 0$, equation (14) indicates that at Nash equilibrium the price of internationally tradable emission permits is higher than the average marginal environmental damage of pollution in the two countries, i.e., $\tau^N > \bar{e}$. In this case, an increase in emission permits reduces the supply of capital in Home, the capital-importing country.[12] Intuitively, an increase in emission permits, reduces their price and this causes the reward to capital to increase in both countries. Since at Nash equilibrium capital is taxed in Home and subsidized in Foreign, then, the effect on net payments on capital in Foreign is higher than that in Home, i.e., $\left|\left(1 - \rho^{*N}\right)R^*_{\tau K^*}\right| > \left|\left(1 - \rho^N\right)R_{\tau K}\right|$. As a result, an increase in emission permits causes a capital outflow from Home into Foreign. The capital outflow entails a negative welfare effect for Home. There are two reasons for this effect, (i) the marginal revenue product of capital in the country increases, and thus net payments to Foreign's capital remaining in the country are higher, and (ii) capital tax revenue decreases. The capital inflow in Foreign entails an ambiguous welfare effect. That is, a positive one due to the higher net payments received by its remaining capital employed in Home, and a negative one due to subsidy payments to repatriated capital. However, the effect of such capital flows on the two countries' aggregate welfare as a result of higher volume of internationally tradable permits issued, is negative, i.e., $\left(\rho^N R_K - \rho^{*N}R^*_{K^*}\right)\frac{dk}{dZ} < 0$. Therefore, based of the resulting changes in the two countries' welfare levels due to the induced capital flows, it is to the countries' common interest to issue a relatively small number of internationally tradable emission permits, resulting in a higher permits price, hence $\tau^N > \bar{e}$. The same result holds under the rule of *capital tax-credits*, as shown by the Table 2 in Appendix II.

Under *capital tax-deductions* the Nash equilibrium conditions are given by:

$$\rho^N = -kR^*_{K^*K^*}R_K^{-1} > 0, \text{ and } \rho^{*N} \in [0, \rho^*_{\max}], \quad (16)$$

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[11]It is important to emphasize that this assumption makes no inference to symmetric countries. It merely states that, while the absolute levels of their principal magnitudes can differ at the initial equilibrium position, their responses to changes in parameter values are the same, e,g., Keen (1989), Kotsogiannis et al. (2005).

[12]This result is in complete contrast to that under nationally tradable permits, where, by equations (A.1), $dk/dZ_n > 0$.

$$\tau^N = \overline{e} - \frac{\rho^N R_K}{2} \frac{dk}{dZ}. \tag{17}$$

Equations (16) and (17) show that under *capital tax-deductions*, at Nash equilibrium, we also have that $\tau^N > \overline{e}$. Similarly to the other two rules of capital income taxation, the term $\left(-\frac{\rho^N R_K}{2}\frac{dk}{dZ} > 0\right)$ captures *the capital induced global welfare effect of emission permits*.

Proposition 2 *When pollution is regulated via internationally tradable emission permits, then, at Nash equilibrium: (i) under all three rules of capital income taxation, the permits price is higher than the average marginal environmental damage in the two countries, i.e., $\tau^N > \overline{e}$, (ii) for the capital-importing country, under all rules of international taxation of capital earnings, the optimal policy towards capital is a tax, and (iii) for the capital-exporting country, the optimal policy towards capital is a subsidy under the rules of capital tax-exemptions and capital tax-credits, and either a zero subsidy or a tax under capital tax-deductions.*

5   Pollution-ranking

In this section we evaluate, first, the effectiveness of nationally vs internationally tradable emission permits in controlling transboundary pollution given the prevailing regime of international taxation of capital earnings. Second, the effectiveness, pollution-wise, of each of the three rules of international taxation of capital earnings within each of the two alternative regimes of tradable emission permits. For the validity of these comparisons, in all cases, the analysis is conducted in the neighborhood of the same initial equilibrium conditions.[13]

First, we examine the effectiveness of nationally and internationally tradable emission permits in reducing global pollution, under the alternative rules of international taxation of capital earnings. Consider the case where governments control the production generated cross-border pollution via the issuance of nationally tradable emission permits. Under the rules of *capital tax-exemptions* and *capital tax-credits,* both the capital-importing and the capital-exporting countries choose a Nash equilibrium level of emission permits so that their price equals the marginal environmental damage of pollution, i.e., $\tau_n^N = E_r$ and $\tau_n^{*N} = E_{r*}^*$, see Tables 1 and 2 in Appendix II. When production generated cross-border pollution is controlled via internationally tradable emission permits, and capital earnings are taxed according to the rule of *capital tax-exemptions* or *capital tax-credits,* both the capital-importing and the capital-exporting countries choose a Nash equilibrium level of emission permits so that their price is always higher than the average, across countries, marginal environmental damage of pollution, i.e., $\tau^N > (E_r + E_{r*}^*)/2$.[14] This is so, because of the *capital*

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induced global welfare effect of emission permits, i.e., $-\frac{\left(\rho^N R_K - \rho^{*N} R_{K*}^*\right)}{2}\frac{dk}{dZ} > 0$. As a result, the price of internationally tradable emission permits is either higher than both prices of nationally tradable emission permits by the two countries, or it is in between them, but closer to the higher price of nationally tradable emission permits.

To examine whether the level of global pollution is lower or higher under internationally vs. nationally tradable emission permits we consider the following cases. First, let τ^N be larger than both τ_n^N and τ_n^{*N}. This implies that the average volume of internationally tradable emission permits issued by the two countries is smaller relative to the volume of nationally tradable permits issued by each one of them. Thus, the level of total permits and global pollution is lower with internationally vs. nationally tradable emission permits. This result emerges when (i) the *capital induced global welfare effect of emission permits* is sufficiently large, regardless of the difference between E_r^N and E_{r*}^{*N}, and (ii) either the marginal environmental damages in the two countries are the same, or their difference is sufficiently small, regardless of the size of the *capital induced global welfare effect of emission permits*. Second, let $\tau_n^N < \tau^N < \tau_n^{*N}$ or $\tau_n^{*N} < \tau^N < \tau_n^N$, then, at first glance, it is unclear whether the level of emission permits issued combined by the two countries, thus the level of global pollution, under a regime of internationally vs. nationally tradable emission permits is higher or lower. However, it is still very likely that the total number of permits issued by the two countries jointly is lower, and thus, the level of global pollution is also lower under the regime of internationally rather than that under the regime of nationally tradable emission permits. For example, consider the case where $\tau_n^N < \tau^N \lesssim \tau_n^{*N}$, implying that, relative to the average number of internationally tradable emission permits issued by the two countries jointly, Home issues a larger number of nationally tradable emission permits while Foreign issues a slightly smaller number of them. In such a case, the combined number of internationally tradable emission permits issued by the two countries is smaller than the combined number of nationally tradable permits issued. As a result, the level of global pollution in the former case is lower relative to that in the latter.

Under the rule of *capital tax-deductions*, with nationally tradable emission permits, the capital-importing country issues a number of permits leading to $\tau^N = E_r$, while the capital-exporting country issues relatively more emission permits leading to a laxer environmental policy, thus, $\tau^N < E_{r*}^*$. When permits are internationally tradable, at Nash equilibrium both countries issue a number of permits that results in a price that is higher than the average marginal environmental damage of pollution, of the two countries i.e., $\tau^N > \left(E_r + E_{r*}^*\right)/2$. A similar analysis to that under the rules of *capital tax-exemptions* and *capital tax-credits* also applies in the case of *capital tax-deductions*.

Proposition 3 *Under all rules of international taxation of capital earnings, sufficient but not necessary conditions for the Nash equilibrium level of global pollution to be lower in the regime of internationally tradable emission permits relative to that in the regime of nationally tradable emission permits, are: (i) the net effect on both countries' welfare of capital flows induced by*

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permits, the value of each variable is the same in the neighborhood of the initial equilibrium, ensures that each country's value of the marginal environmental damage of pollution is the same across the two regimes of tradable emission permits.

changes in the level of emission permits is sufficiently large, and (ii) the difference between the marginal environmental damages in the two countries is sufficiently small.

Next, we examine the pollution ranking of the alternative rules of international taxation of capital earnings within each of the two regimes of tradable emission permits. Consider the case where governments control the production generated cross-border pollution via the issuance of nationally tradable emission permits. As indicated by Table 1 in Appendix II, under the rules of *capital tax-exemptions* and *capital tax-credits,* both the capital-importing and the capital-exporting countries choose a Nash equilibrium level of emission permits so that their price equals the marginal environmental damage of pollution, i.e., $\tau^N = E_r$ and $\tau^{*N} = E_{r*}^*$, and set their capital income taxes at the same rate, i.e., $\rho_{ex}^N = \rho_{cr}^N$ and $\rho_{ex}^{*N} = \rho_{cr}^{*N}$. Thus, within the regime of nationally tradable emission permits, under the rules of *capital tax-exemptions* and *capital tax-credits* the level of global pollution is the same. Under the rule of *capital tax-deductions,* the capital-importing country's Nash equilibrium level of nationally tradable emission permits is such than $\tau^N = E_r$, while the capital-exporting country's Nash equilibrium level of nationally tradable permits is such that $\tau^{*N} < E_{r*}^*$. Therefore, with nationally tradable emission permits, under *capital tax-deductions,* the Nash equilibrium level of emission permits issued by the two countries jointly is higher, and thus, global pollution is higher compared to that under *capital tax-exemptions* and *capital tax-credits.* By this reasoning, pollution-wise, the rule of *capital tax-deductions* is inferior to the other two rules.[15]

When pollution is controlled via internationally tradable emission permits, under *capital tax-exemptions* and *capital tax-credits* the Nash equilibrium level of emission permits leads to the same level of global pollution. Under *capital tax-deductions*, however, the Nash equilibrium level of emission permits leads to a higher level of global pollution.[16]

Proposition 4 *Within the regime of either nationally or internationally tradable emission permits, the Nash equilibrium level of global pollution under capital tax-exemptions is the same as that under capital tax-credits, and it is lower than that under capital tax-deductions.*

Based on Propositions 3 and 4 we state the following Corollary.

Corollary 1 *The lowest Nash equilibrium level of global pollution is achieved when the policy-mix combines internationally tradable emission permits and either capital-tax exemptions or capital-tax credits.*

6 Concluding Remarks

Our paper examines the efficiency of non-cooperative policymaking in controlling cross-border pollution under different rules of international taxation of capital earnings. According to our results,

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[15]This result still holds when, under *capital tax-deductions*, the capital-exporting country adopts a capital income tax, since such a tax cannot affect the distribution of capital between the two countries.

[16]A formal proof of this result is provided in Appendix I by the Proof of Proposition 4.

under certain conditions, global pollution is lower, first, when emission permits are internationally rather than nationally tradable. Second, within the regime of either nationally or internationally tradable emission permits, the Nash equilibrium level of global pollution under *capital tax-exemptions* is the same as that under capital tax-credits, and it is lower than that under *capital tax-deductions*. Therefore, a policy recommendation for a way to mitigate global pollution levels is to link national emission permits markets to an international permits market, and to adopt either *tax-exemptions* or *tax-credits* rules of taxing capital earnings.

APPENDIX I

Nationally tradable emission permits and capital taxes

Totally differentiating the equilibrium conditions (1)-(5), we obtain the following comparative statics results:

$$
\begin{bmatrix}
H_{KK} & (1-\rho)R_{K\tau} & -(1-\rho^*)R^*_{K^*_{\tau^*}} \\
R_{\tau_n K} & R_{\tau_n \tau_n} & 0 \\
-R^*_{\tau^*_n K^*} & 0 & R^*_{\tau^*_n \tau^*_n}
\end{bmatrix}
\begin{bmatrix}
dk \\
d\tau_n \\
d\tau^*_n
\end{bmatrix}
=
\begin{bmatrix}
0 \\
-1 \\
0
\end{bmatrix}
dZ_n +
\begin{bmatrix}
0 \\
0 \\
-1
\end{bmatrix}
dZ^*_n
$$

$$
+
\begin{bmatrix}
R_K \\
0 \\
0
\end{bmatrix}
d\rho +
\begin{bmatrix}
-R^*_{K^*} \\
0 \\
0
\end{bmatrix}
d\rho^*. \tag{A.1}
$$

The determinant of the left-hand-side matrix is $\Delta_n = R_{\tau_n \tau_n} R^*_{\tau^*_n \tau^*_n} \widetilde{H}_{KK} < 0$. Under *capital tax-exemptions* or *tax-credits* we have:

$H_{KK} = [(1-\rho)R_{KK} + (1-\rho^*)R^*_{K^*K^*}] < 0$, $\widetilde{H}_{KK} = \left[(1-\rho)\widetilde{R}_{KK} + (1-\rho^*)\widetilde{R}^*_{K^*K^*}\right] < 0$,

$\widetilde{R}_{KK} = R_{KK} - R_{\tau_n K} R^{-1}_{\tau_n \tau_n} R_{K\tau_n} < 0$, $\widetilde{R}^*_{K^*K^*} = R^*_{K^*K^*} - R^*_{\tau^*_n K^*} R^{*-1}_{\tau^*_n \tau^*_n} R^*_{K^*\tau^*_n} < 0$,

$\frac{d\tau_n}{d\rho} = -R_{\tau_n K} R_K \left(R_{\tau_n \tau_n} \widetilde{H}_{KK}\right)^{-1} < 0$, $\frac{d\tau_n}{d\rho^*} = R_{\tau_n K} R^*_{K^*} \left(R_{\tau_n \tau_n} \widetilde{H}_{KK}\right)^{-1} > 0$,

$\frac{d\tau^*_n}{d\rho} = R^*_{\tau^*_n K^*} R_K \left(R^*_{\tau^*_n \tau^*_n} \widetilde{H}_{KK}\right)^{-1} > 0$, $\frac{d\tau^*_n}{d\rho^*} = -R^*_{\tau^*_n K^*} R^*_{K^*} \left(R^*_{\tau^*_n \tau^*_n} \widetilde{H}_{KK}\right)^{-1} < 0$,

$\frac{dk}{dZ^*_n} = -(1-\rho^*)R^*_{K^*\tau^*_n} \left(R^*_{\tau^*_n \tau^*_n} \widetilde{H}_{KK}\right)^{-1} < 0$, $\frac{dk}{dZ_n} = (1-\rho)R_{K\tau_n} \left(R_{\tau_n \tau_n} \widetilde{H}_{KK}\right)^{-1} > 0$,

$\frac{dk}{d\rho^*} = -R^*_{K^*} \widetilde{H}^{-1}_{KK} > 0$, $\frac{d\tau_n}{dZ_n} = -\left[(1-\rho)R_{KK} + (1-\rho^*)\widetilde{R}^*_{K^*K^*}\right] \left(R_{\tau_n \tau_n} \widetilde{H}_{KK}\right)^{-1} < 0$,

$\frac{d\tau_n}{dZ^*_n} = R_{\tau_n K}(1-\rho^*)R^*_{\tau^*_n K^*} \Delta^{-1}_n < 0$, $\frac{d\tau^*_n}{dZ_n} = R^*_{\tau^*_n K^*}(1-\rho^*)R_{\tau_n K} \Delta^{-1}_n < 0$,

$\frac{d\tau^*_n}{dZ^*_n} = -\left[(1-\rho)\widetilde{R}_{KK} + (1-\rho^*)R^*_{K^*K^*}\right] \left(R^*_{\tau^*_n \tau^*_n} \widetilde{H}_{KK}\right)^{-1} < 0$, $\frac{dk}{d\rho} = R_K \widetilde{H}^{-1}_{KK} < 0$.

Under *capital tax-deductions* the above expressions still hold except for $\frac{d\tau_n}{d\rho^*} = \frac{d\tau^*_n}{d\rho^*} = \frac{dk}{d\rho^*} = 0$. Changes in the levels of welfare due to changes in the amount of internationally tradable emission permits and in capital taxes are obtained by differentiating equations (6), using equations (5), (A.1)

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and the capital market equilibrium conditions. Doing so, we obtain:

$$E_u \frac{du}{dZ_n} = -(E_r - \tau_n) + [\rho R_K - (1-\rho)k R_{KK}] \frac{dk}{dZ_n} - (1-\rho)k R_{K\tau_n} \frac{d\tau_n}{dZ_n} \quad \text{and} \quad \text{(A.2)}$$

$$E_u \frac{du}{d\rho} = -(1-\rho)k R_{K\tau_n} \frac{d\tau_n}{d\rho} + k R_K + [\rho R_K - (1-\rho)k R_{KK}] \frac{dk}{d\rho}, \quad \text{(A.3)}$$

$$E_{u^*}^* \frac{du^*}{dZ_n^*} = -(E_{r^*}^* - \tau_n^*) + [-\rho^* R_{K^*}^* + (1-\rho)k R_{KK}] \frac{dk}{dZ_n^*} + (1-\rho)k R_{K\tau_n} \frac{d\tau_n}{dZ_n^*}, \quad \text{(A.4)}$$

$$E_{u^*}^* \frac{du^*}{d\rho^*} = [-\rho^* R_{K^*}^* + (1-\rho)k R_{KK}] \frac{dk}{d\rho^*} + (1-\rho)k R_{K\tau_n} \frac{d\tau_n}{d\rho^*}. \quad \text{(A.5)}$$

Setting $\frac{du}{d\rho} = \frac{du^*}{d\rho^*} = 0$, we obtain each country's capital tax reaction function as follows:

$$\rho(\rho^*) = -(1-\rho^*)k \widetilde{R}_{K^*K^*}^* R_K^{-1} \quad \text{and} \quad \rho^*(\rho) = (1-\rho)k \widetilde{R}_{KK} R_{K^*}^{*-1}. \quad \text{(A.6)}$$

Internationally tradable emission permits and capital taxes

Totally differentiating the equilibrium conditions (11), (12), and (1)-(3), we obtain the following comparative statics results:

$$\begin{bmatrix} H_{KK} & (1-\rho)R_{K\tau} - (1-\rho^*)R_{K^*\tau}^* \\ 0 & -H_{\tau\tau} \end{bmatrix} \begin{bmatrix} dk \\ d\tau \end{bmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix} dZ + \begin{bmatrix} 0 \\ 1 \end{bmatrix} dZ^*$$

$$+ \begin{bmatrix} R_K \\ 0 \end{bmatrix} d\rho + \begin{bmatrix} -R_{K^*}^* \\ 0 \end{bmatrix} d\rho^*. \quad \text{(A.7)}$$

The determinant of the left-hand-side matrix is $\Delta_\tau = -H_{KK} H_{\tau\tau} > 0$, and

$H_{\tau\tau} = R_{\tau\tau} + R_{\tau\tau}^* > 0$, $\frac{d\tau}{dZ} = \frac{d\tau}{dZ^*} = H_{KK}\Delta_\tau^{-1} < 0$.

Under capital tax-exemptions or capital tax-credits:

$H_{KK} = [(1-\rho)R_{KK} + (1-\rho^*)R_{K^*K^*}^*] < 0$, $\frac{dk}{d\rho} = -R_K H_{\tau\tau}\Delta_\tau^{-1} < 0$,

$\frac{dk}{d\rho^*} = R_{K^*}^* H_{\tau\tau}\Delta_\tau^{-1} > 0$, $\frac{d\tau}{d\rho} = \frac{d\tau}{d\rho^*} = 0$, $dr = dr^* = -(R_{\tau\tau} + R_{\tau\tau}^*)(\frac{d\tau}{dZ}dZ + \frac{d\tau}{dZ^*}dZ^*)$,

$\frac{dk}{dZ} = \frac{dk}{dZ^*} = (\rho - \rho^*)R_{K\tau}\Delta_\tau^{-1} = \frac{(\rho-\rho^*)R_{K\tau}}{[(1-\rho)R_{KK}+(1-\rho^*)R_{K^*K^*}^*]H_{\tau\tau}} < 0$.

Under capital tax-deductions:

$H_{KK} = [(1-\rho)R_{KK} + R_{K^*K^*}^*] < 0$, $\frac{dk}{dZ} = \frac{dk}{dZ^*} = \rho R_{K\tau}\Delta_\tau^{-1} = \frac{\rho R_{K\tau}}{[(1-\rho)R_{KK}+R_{K^*K^*}^*]H_{\tau\tau}} < 0$,

$\frac{dk}{d\rho} = -R_K H_{\tau\tau}\Delta_\tau^{-1} < 0$, $\frac{dk}{d\rho^*} = 0$, $\frac{d\tau}{d\rho} = \frac{d\tau}{d\rho^*} = 0$, $dr = dr^* = -(R_{\tau\tau} + R_{\tau\tau}^*)(\frac{d\tau}{dZ}dZ + \frac{d\tau}{dZ^*}dZ^*)$.

Changes in the levels of welfare due to changes in internationally tradable emission permits and in capital taxes are obtained by differentiating equations (13), using equations (12) and (A.7) as follows:

$$E_u \frac{du}{dZ} = \tau - E_r \frac{dr}{dZ} + [(Z-z) - (1-\rho)k R_{K\tau}] \frac{d\tau}{dZ} + [-(1-\rho)k R_{KK} + \rho R_K] \frac{dk}{dZ}, \quad \text{(A.8)}$$

$$E_u \frac{du}{d\rho} = k R_K - E_r \frac{dr}{d\rho} + [(Z-z) - (1-\rho)k R_{K\tau}] \frac{d\tau}{d\rho} + [-(1-\rho)k R_{KK} + \rho R_K] \frac{dk}{d\rho}, \quad \text{(A.9)}$$

$$E_{u*}^* \frac{du^*}{dZ^*} = \tau - E_{r*}^* \frac{dr^*}{dZ^*} + \left[(Z^* - z^*) + (1 - \rho)kR_{K\tau}\right] \frac{d\tau}{dZ^*} + \left[(1 - \rho)kR_{KK} - \rho^* R_{K*}^*\right] \frac{dk}{dZ^*}, \quad \text{(A.10)}$$

$$E_{u*}^* \frac{du^*}{d\rho^*} = -E_{r*}^* \frac{dr^*}{d\rho^*} + \left[(Z^* - z^*) + (1 - \rho)kR_{K\tau}\right] \frac{d\tau}{d\rho^*} + \left[(1 - \rho)(R_K + kR_{KK}) - R_{K*}^*\right] \frac{dk}{d\rho^*}. \quad \text{(A.11)}$$

Setting $\frac{du}{d\rho} = \frac{du^*}{d\rho^*} = 0$, we obtain each country's capital tax reaction function as follows:

$$\rho(\rho^*) = -(1 - \rho^*)kR_{K*K*}^* R_K^{-1} \text{ and } \rho^*(\rho) = (1 - \rho)kR_{KK}R_{K*}^{*-1}. \quad \text{(A.12)}$$

Proof of Proposition 4

The following analysis proves the pollution-wise superiority of capital tax-exemptions and capital tax-credits over capital tax-deductions, under internationally tradable permits. For this, under the assumption that the analysis is carried out in the neighborhood of the same initial equilibrium conditions, it suffices to show that the permits price under capital tax-credits and capital tax-exemptions, i.e., $\tau_{ex}^N(= \tau_{cr}^N)$ in equation (14), is higher to the permits price under capital tax-deductions, i.e., τ_{de}^N in equation (17).

The first term on the right-hand-side of the two equations, i.e., $\bar{e}$, cancels out since it is the same. For $\tau_{ex}^N > \tau_{de}^N$ the following condition must hold:

$$\left(\frac{\rho_{ex}^N R_K - \rho^{*N} R_{K*}^*}{2}\right)\left(-\frac{dk}{dZ}\right)_{ex} > \left(\frac{\rho_{de}^N R_K}{2}\right)\left(-\frac{dk}{dZ}\right)_{de}, \quad \text{(A.13)}$$

where the relevant expressions for $\left(-\frac{dk}{dZ}\right)_{ex}$, $\left(-\frac{dk}{dZ}\right)_{de}$ are given in equations (A.7). At Nash equilibrium, using equations (A.12) we get $\rho_{ex}^N = \rho_{cr}^N = -(1 - \rho^{*N})kR_{K*K*}^* R_K^{-1}$, and using equation (16) we get $\rho_{de}^N = -kR_{K*K*}^* R_K^{-1}$. Since $\rho^{*N} < 0$, then, $0 < \rho_{de}^N < \rho_{ex}^N = \rho_{cr}^N < 1$. Given that $\left(\rho_{ex}^N R_K - \rho^{*N} R_{K*}^*\right) > \rho_{de}^N R_K$, for $\tau_{ex}^N > \tau_{de}^N$ it suffices to show that $\left(-\frac{dk}{dZ}\right)_{ex} > \left(-\frac{dk}{dZ}\right)_{de}$, for which the following condition holds:

$$-\frac{(\rho_{ex} - \rho^*)R_{K\tau}}{\left[(1 - \rho_{ex})R_{KK} + (1 - \rho^*)R_{K*K*}^*\right]H_{\tau\tau}} > -\frac{\rho_{de}R_{K\tau}}{\left[(1 - \rho_{de})R_{KK} + R_{K*K*}^*\right]H_{\tau\tau}}. \quad \text{(A.14)}$$

The above condition reduces to:

$$\frac{(\rho_{ex} - \rho^*)}{\left[(1 - \rho_{ex})R_{KK} + (1 - \rho^*)R_{K*K*}^*\right]} > \frac{\rho_{de}}{\left[(1 - \rho_{de})R_{KK} + R_{K*K*}^*\right]}.$$

Following suitable algebraic calculations we obtain:

$$\rho_{ex} - \rho^* > \rho_{de} - \rho^* \rho_{de}.$$

Since $0 < \rho_{de}^N < \rho_{ex}^N = \rho_{cr}^N < 1$, the above inequality holds. Thus, $\tau_{ex}^N > \tau_{de}^N$ indicating that, in our framework, pollution-wise, *capital tax-exemptions* and *capital tax-credits* are superior to *capital tax-deductions*, under internationally tradable emission permits.

Appendix II

Table 1	Nationally Tradable Emission Permits
capital tax-exemptions *capital tax-credits*	Home: $\tau_n^N = E_r, \ \ \rho^N = -k\widetilde{R}_{K^*K^*}^* \left(R_{K^*}^* - k\widetilde{R}_{KK}\right)\Omega^{-1} > 0.$ Foreign: $\tau_n^{*N} = E_{r*}^*, \ \ \rho^{*N} = k\widetilde{R}_{KK}\left(R_K + k\widetilde{R}_{K^*K^*}^*\right)\Omega^{-1} < 0.$
capital tax-deductions	Home: $\tau_n^N = E_r, \ \ \ \rho^N = -k\widetilde{R}_{K^*K^*}^* R_K^{-1} > 0.$ Foreign: $\tau_n^{*N} = E_{r*}^* + (1-\rho^N)k\widetilde{R}_{KK}R_{\tau_n^*K^*}^* \left(R_{\tau_n^*\tau_n^*}^*\widetilde{H}_{KK}\right)^{-1} < E_{r*}^*,$ $\rho^{*N} \in [0, \rho_{\max}^*].$

Table 2	Internationally Tradable Emission Permits
capital tax-exemptions *capital tax-credits*	Home: $\rho^N = -kR_{K^*K^*}^*\left(R_{K^*}^* - kR_{KK}\right)\Phi^{-1} > 0.$ Foreign: $\rho^{*N} = kR_{KK}\left(R_K + kR_{K^*K^*}^*\right)\Phi^{-1} < 0.$ $\tau^N = \frac{E_r + E_{r*}^*}{2} - \frac{\left(\rho^N R_K - \rho^{*N} R_{K^*}^*\right)}{2}\frac{dk}{dZ} > \frac{E_r + E_{r*}^*}{2}.$
capital tax-deductions	Home: $\ \ \rho^N = -kR_{K^*K^*}^* R_K^{-1} > 0.$ Foreign: $\ \ \ \ \rho^{*N} \in [0, \rho_{\max}^*].$ $\tau^N = \frac{E_r + E_{r*}^*}{2} - \frac{\rho^N R_K}{2}\frac{dk}{dZ} > \frac{E_r + E_{r*}^*}{2}.$

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