# POLLUTION AND CAPITAL TAX COMPETITION WITHIN A REGIONAL BLOCK

COSTAS HADJIYIANNIS
PANOS HATZIPANAYOTOU
MICHAEL S. MICHAEL

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## Abstract

The paper examines the interaction among taxes on factors income, environmental quality and welfare. We construct a two-country regional block model with capital mobility and cross-border pollution. Pollution in the two countries is simultaneously abated by the private sector, in response to a pollution tax and by the public sector utilizing income and pollution tax revenue. We demonstrate, among other things, that due to the existence of cross-border pollution in many cases the Nash optimal policy on capital income is a positive tax, even if taxes on the income of immobile factors are chosen optimally. This tax rate increases with the degree of cross-border pollution.

JEL classification: F15, F18, F22, H21.

Keywords: optimal income taxes, public pollution abatement, cross-border pollution, capital mobility.

*Costas Hadjiyiannis*
*Department of Economics*
*University of Cyprus*
*P.O. Box 20573*
*CY 1678, Nicosia*
*Cyprus*
*costash@ucy.ac.cy*

*Panos Hatzipanayotou*
*Department of International and European Economic Studies*
*Athens University of Economics and Business*
*76 Patission str.*
*Athens 104 34*
*Greece*
*hatzip@aueb.gr*

*Michael S. Michael*
*Department of Economics*
*University of Cyprus*
*P.O. Box 20537*
*CY 1678, Nicosia*
*Cyprus*
*m.s.michael@ucy.ac.cy*

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# 1 Introduction

International capital mobility is one of the key features of the recent wave of globalization. This was mainly facilitated by the deregulation of national capital markets in an effort to attract foreign capital. As a result one of the main concerns that have been raised both in policy debates and in the relevant theoretical literatures is the issue of tax competition. This refers to a race to the bottom in capital income taxes among countries, in an effort to attract foreign firms and capital.

The literature on tax competition largely examines the efficiency properties of source-based capital taxes. In this framework, countries or regions, choose their tax instruments non-cooperatively, accounting for capital mobility. Three important conclusions emerge from this literature. First, the Nash equilibrium taxes are such that capital tends to be under-taxed in the countries or regions involved. Moreover, when governments use this capital-tax revenue to finance the provision of local public goods, this under-taxation of capital leads to an under-provision of public goods.[1] Second, if additional distortionary taxes (e.g., commodity and/or other factor taxes) exist, then the under-taxation of capital may lead to over-taxation of other commodities and factors (e.g., Bucovetsky and Wilson (1991)).[2] Third, in many cases the Nash optimal policy is a capital income tax for the capital importing country and a capital income subsidy for the capital exporting country.[3] Finally, Bjorvatn and Schjelderup (2002) show that when we have an international public good with perfect spillovers then there is no capital tax competition.

An extensive literature has also emerged studying the interaction between capital mobility and the quality of the environment. This literature examines the properties of the Nash equilibrium pollution taxes and their impact on net pollution and welfare in the presence of cross-border pollution.[4,5]

[1] See Zodrow and Mieszkowski (1986), Gordon and Wilson (1986) and Wilson (1986).

[2] Other related, but not directly relevant, issues of this literature include the strategic choice of government expenditure as opposed to tax rates (e.g., Wildasin (1988), Hoyt (1993)), the taxation of mobile capital within the context of optimal income tax models (e.g., Huber (1999)), and fiscal competition among countries of unequal size within the context of imperfect competition (e.g. Haufler and Wooton (1999)).

[3] See for example DePater and Myers (1994), Hatzipanayotou, Hadjiyiannis, and Michael (2002) and Peralta and Van Ypersele (2003).

[4] Another strand of the literature examines the welfare and policy implications of cross-border pollution in the absence of capital mobility, e.g., Markusen (1975), Copeland and Taylor (1995), Ludema and Wooton (1997).

[5] Merrifield (1988) in a two-country general equilibrium model with international flows of goods, capital and pollution shows that higher pollution taxes may actually have an adverse effect on the levels of pollution emissions. Copeland (1994) shows that in the absence of cross-border pollution in a small open economy pollution policy reforms entail greater welfare gains when capital is internationally mobile

To the best of our knowledge, however, very few studies examine the interactions between taxes on factors' income, the quality of the environment and welfare. Chao and Yu (1997) examine the welfare effects of changes in capital income taxes and environmental standards in the context of a single economy with capital mobility and local pollution. They demonstrate, among other things, that the ranking of the weights of the government objectives determine the optimal capital tax/subsidy and the stringency of environmental standards. Rauscher (1997) examines this interaction in a single commodity, two-country model with capital mobility and cross-border pollution but from the point of view of a single country. He shows that the optimal policy for capital incomes is a tax (subsidy) for the capital importing (exporting) country. In addition he shows that capital moves to the country with less stringent environmental regulations and that global pollution may rise or fall. Kim and Wilson (1997) develop a model with many identical countries, capital mobility and local pollution, where governments use taxes on mobile and immobile factors' income to provide public goods. They find that public goods are underprovided and that countries engage in a race to the bottom in environmental standards. They argue that the race to the bottom is more important in terms of welfare than the underprovision of public goods.

Our goal is to analyze the interactions between income taxes, the quality of the environment and welfare but in a more general model of a two-country regional block with capital mobility, cross-border pollution and public pollution abatement.[6] In our analysis we assume that pollution taxes are exogenously given. Our model resembles the situation in the European Union (EU), where there are uniform minimum pollution taxes for mineral fuels including oil products, natural gas, electricity and coal. At the same time EU members are free to chose their capital and other income taxes as long as they do not discriminate between domestic and foreign capital. Within this framework, we examine the effects of capital and immobile factors' income taxes on public sector abatement activity and on net pollution. We, then, examine how the existence of cross-border pollution and public pollution abatement affect the Nash equilibrium capital income taxes. We find, among other things, that in many cases, the Nash optimal policy is a tax on capital income and that, under reasonable assumptions, this tax increases

than when it is not.

[6] Ample evidence from OECD statistics attest to the role undertaken by several governments in abating pollution. For example, in the early 1990s the share of public sector abatement of air pollution in the UK and the Netherlands was 30% and 50% respectively, while in the US was 6%. Moreover, Brett and Keen (2000) provide evidence for the US whereby environmental tax revenues are earmarked for environmental related public sector expenditures.

with the degree of cross-border pollution. We also show that when the two countries are identical in every respect and the degree of cross-border pollution is at its maximum, then the Nash optimal taxes on capital and immobile factors incomes are the same.

## 2 The Model

We develop a general equilibrium model of a two country Regional Block (RB). The two countries, we call Home and Foreign, are assumed to be small in world commodity markets and they trade freely with each other and the rest of the World.[7] Commodity prices are, therefore, constant and equal to the World prices. We assume that each country comprises of identical individuals. In both countries, production generates pollution that affects the utility of the residents in the two countries. In other words, pollution generated in one country affects negatively the utility of local residents and, through cross-border emissions, the utility of the other country's residents. We assume that capital is inter-RB mobile, but completely immobile between the RB and the rest of the World. Moreover, we designate Home as the capital-importing country and Foreign as the capital-exporting one. All other factors of production are assumed inter-RB and internationally immobile.

Next we proceed to construct the model of Home while the model of Foreign follows analogously. The country's maximum value of production of private goods is denoted by the revenue function, $R(p, v, t, K)$, defined as:

$$R(p, v, t, K) = \max_{x,z,K}\{p^{'}x - tz : (x, z, K) \in \Phi(v, K)\}, \tag{1}$$

where $p$ is the vector of exogenously given world commodity prices, $\Phi(v, K)$ is the country's aggregate technology set and $v$ is the endowment vector of the immobile factors. Also, $K = \overline{K} + k^f$ where $\overline{K}$ is Home's domestic endowment of capital and $k^f$ is the amount of foreign capital employed in Home and, therefore, $K$ is the domestic supply of capital. The vector of net outputs is denoted by $x$, $t$ is the emissions tax rate, and $z$ is the amount of pollution generated by production, net of the amount abated by the private sector.[8] Since $p$ and $v$ are invariant for the rest of the analysis, the revenue function can

[7] Foreign's variables are denoted by an asterisk.

[8] For simplicity we assume only one type of pollutant generated in all sectors. A prime ($'$) denotes a transposed vector or matrix, and $p^{'}x - tz$ is the value of factor income. Finally, $\Phi(v, K)$ includes production technologies and abatement technologies in various private sectors, as they carry out some pollution abatement in response to the emission tax ($t$).

be written as $R(t, K)$. We assume that the $R(t, K)$ function is strictly concave in $K$ (i.e., $R_{KK} < 0$) and strictly convex in $t$ (i.e., $R_{tt} > 0$). Strict convexity in $t$ implies that pollution emissions by the private sector are reduced, as the pollution tax, $t$, increases. By the envelop theorem, $R_K$ is the marginal revenue product of capital and the level of pollution, $z$, generated by the private sector is given by[9]

$$z = -R_t(t, K). \tag{2}$$

We assume that in both countries pollution is capital intensive (i.e., $R_{tK} < 0$ and $R^*_{t^*K^*} < 0$). In addition to the pollution abatement carried-out by the private sector in response to the emissions tax, $(t)$, the government provides public pollution abatement financed by tax revenue. This is done by importing a pollution abatement good from the rest of the World at the price $P_g$. Therefore, net pollution, after accounting for private and public sector abatement activities and cross-border pollution is given by

$$r = z - g + \Theta(z^* - g^*), \tag{3}$$

where $\Theta \in [0, 1]$ is the degree of cross-border pollution, $g$ is the level of local public pollution abatement and $z^*$ and $g^*$ represent the level of pollution and the level of public abatement in Foreign, respectively.[10] We assume that the government imposes pollution taxes, at a rate $t$, capital income taxes, at a rate $\rho$ and taxes on the income of all other factors, at a rate $\mu$, and uses the tax revenues solely for the provision of public pollution abatement activity (i.e., $P_g g$).[11] Note that capital income taxes are the same for domestic and foreign capital as required by the EU. Assuming a balanced budget for the public sector, the government's budget constraint is given by

$$P_g g = \mu R(t, K) + (\rho - \mu) K R_K(t, K) - t R_t(t, K). \tag{4}$$

The relevant literature, by and large, assumes that lump-sum taxes and occasionally capital income taxes are used to finance the provision of public goods (in this case public

[9] Copeland (1994) and Turunen-Red and Woodland (1998) among others define pollution in the same way.

[10] Equation (3) implicitly assumes that there is only one pollutant in both countries.

[11] We assume that all tax revenue is earmarked for financing the public sector's pollution abatement activity. Alternatively, it could be assumed that only a fraction of this revenue is used for this purpose and the rest is used for other purposes by the government. This specification significantly complicates the analysis without adding much to the results.

pollution abatement). In reality, however, governments rely more on income taxes rather than on lump-sum taxes to finance public sector activities. For these reasons, this paper considers income taxes on capital and on all immobile factors.

Turning to the demand side, we assume that all households are identical and, as previously noted, utility is adversely affected by domestic and Foreign generated pollution transmitted across borders. Let $E(u, r)$ denote the minimum expenditure required to achieve a level of utility, $u$, given a level of net pollution, $r$. Therefore, $E_u$, normalized to equal one, denotes the inverse of the marginal utility of income. Similarly, $E_r$ is the marginal damage to consumers from pollution (as in Copeland (1994)). Alternatively, $E_r$ can be interpreted as the marginal willingness to pay for a reduction in pollution as in Chao and Yu (1999). $E_r$ is positive, since a higher level of pollution needs to be compensated with a higher level of consumption of private goods to maintain a given level of utility.

We complete Home's model by stating the households' budget constraint. It requires that private spending $E(u, r)$ must equal after tax factor income from the production of goods minus repatriated earnings of Foreign's capital employed in Home. The income-expenditure identity for Home can be written as:

$$E(u, r) = (1-\mu)R(t, K) + (\mu - \rho)KR_K(t, K) - (1-\rho)k^f R_K(t, K). \tag{5}$$

Similarly, the corresponding equations for Foreign are

$$\begin{aligned}
z^* &= -R^*_{t^*}(t^*, K^*) && (6)\\
r^* &= z^* - g^* + \Theta^*(z - g) && (7)\\
P^*_{g^*} g^* &= \mu^* R^*(t^*, K^*) + (\rho^* - \mu^*)K^* R^*_{K^*}(t^*, K^*) - t^* R^*_{t^*}(t^*, K^*) && (8)\\
E^*(u^*, r^*) &= (1-\mu^*)R^*(t^*, K^*) + (\mu^* - \rho^*)K^* R^*_{K^*}(t^*, K^*) \\
&\quad +(1-\rho)k^f R_K(t, K), && (9)
\end{aligned}$$

where $r^*$ is the level of total net pollution in Foreign, $P^*_{g^*}$ is the price of the imported pollution abatement good, $\Theta^*$ is the rate of cross-border pollution into that country and $K^*$ is the supply of capital in Foreign.[12] Note that by the assumptions of the model $dK = dk^f = -dK^*$.

[12] We assume that $P^*_{g^*}$ could be different from $P_g$. This is a more general set-up and does not exclude the case where the two are equal.

Finally, perfect capital mobility within the RB and no capital mobility between the RB and the rest of the World requires that the net return to capital in the two countries is equalized. Therefore, equilibrium in the RB's capital market requires that

$$(1-\rho)R_K(t,K) = (1-\rho^*)R^*_{K^*}(t^*,K^*). \tag{10}$$

The system of equations (2)-(10) contains nine endogenous variables, namely $u$, $u^*$, $g$, $g^*$, $z$, $z^*$, $r$, $r^*$ and $K$; six policy parameters, namely $(t,\mu,\rho)$ and $(t^*,\mu^*,\rho^*)$; and four exogenous parameters, namely $(P_g,\Theta)$ and $(P^*_{g^*},\Theta^*)$. Substituting equations (2) and (3) into (5) and equations (6) and (7) into (9), the original system reduces to a five-equations system, in terms of the unknowns ($u$, $u^*$, $g$, $g^*$, and $K$), which comprises of the modified equations (5), (9) and equations (4), (8), and (10). Some of the comparative statics of this system appear in Appendix A. For the rest of the analysis we assume that pollution taxes $t$ and $t^*$ are exogenously given.[13] This assumption is realistic for the EU case where minimum pollution taxes are set at the regional level and are not optimally chosen by member countries.

# 3 Capital Mobility, Income Taxes and Public Abatement

In this section we examine how changes in income taxes and capital mobility affect public sector pollution abatement in Home and Foreign. Using Appendix A and equations (4) and (8) it can be shown that:

$$\frac{dg}{d\rho} = \frac{\partial g}{\partial \rho} + \frac{\partial g}{\partial K}\frac{dK}{d\rho} = \frac{KR_K}{P_g} - \frac{tR_{tK} - \rho R_K - (\rho-\mu)KR_{KK}}{P_g}\frac{R_K}{H}, \tag{11}$$

$$\frac{dg^*}{d\rho} = \frac{\partial g^*}{\partial K}\frac{dK}{d\rho} = -\frac{(\rho^*-\mu^*)K^*R^*_{K^*K^*} + \rho^* R^*_{K^*} - t^* R^*_{t^*K^*}}{P^*_{g^*}}\frac{R_K}{H}, \tag{12}$$

where $H = (1-\rho)R_{KK} + (1-\rho^*)R^*_{K^*K^*} < 0$. From Appendix A we get $\frac{dK}{d\rho} = \frac{R_K}{H} < 0$, indicating that raising Home's capital income tax rate causes a capital outflow from

[13] Hadjiyiannis, Hatzipanayotou, and Michael (2002) examine the interaction among pollution taxes, capital mobility, cross-border pollution and public sector abatement activities.

the country and thus a capital inflow in Foreign.[14] Equation (11) indicates that the effect of raising $\rho$ on Home's public abatement $g$, is the combination of two revenue effects through the country's government budget constraint. The first, $(\partial g/\partial \rho)$, is a positive revenue effect indicating that the higher $\rho$, given $K$, leads to an increase in capital income tax revenue which in turn raises $g$. The second, $(\partial g/\partial K)(dK/d\rho)$, is an ambiguous tax revenue effect due to the inter-RB capital mobility. Through this effect the higher $\rho$, which reduces Home's $K$, affects tax revenues and thus the level of $g$, in a number of ways. First, since pollution is capital intensive, the decrease in capital leads to a decrease in the pollution tax revenue, $(-P_g^{-1}H^{-1}tR_{tK}R_K)$. Second, the decrease in capital reduces the amount of capital tax revenue since the tax applies to a smaller stock of Home's capital, $(P_g^{-1}H^{-1}\rho R_K^2)$. Third, the decrease in capital decreases income to all other factors, $(R - KR_K)$, and, therefore, the tax revenue from those incomes by $-P_g^{-1}H^{-1}\mu KR_{KK}R_K$.[15] These three effects combined lead to a reduction in $g$ due to the higher capital income tax $\rho$. However, a fourth effect, $P_g^{-1}H^{-1}\rho KR_{KK}K$, entails an increase in capital tax revenue, thus an increase in $g$. That is, the tax induced reduction in $K$ increases its domestic rate of return $R_K$, and, therefore, it raises government tax revenue and the provision of public abatement. Overall, an increase in $\rho$ entails an ambiguous effect on $g$.

By setting $(dg/d\rho) = 0$ in (11) we derive the tax rate $\rho$ that maximizes the public sector's abatement activity as:[16]

$$\widetilde{\rho} = R_K^{-1}[tR_{tK} - (1-\rho^*)KR^*_{K^*K^*} - (1-\mu)KR_{KK}]. \tag{13}$$

From equation (13) we derive the following proposition:

**Proposition 1** *Under the conditions of the model and for $t \approx 0$ (sufficient but not necessary condition), there exists a positive capital income tax rate that maximizes the public sector's pollution abatement activity.*

Equation (12) gives the effect of an increase in $\rho$ on Foreign's public sector's abatement activities, $g^*$. In this case, there is no direct effect, and thus the impact of an increase in Home's capital tax rate on Foreign's level of public abatement is entirely through the

[14] The expressions for $(\partial g/\partial \rho)$ and $(\partial g/\partial K)$ are given by differentiating equation (4) and $(\partial g^*/\partial K)$ by totally differentiating equation (8).

[15] This is because the decrease in capital makes all other factors relatively more abundant.

[16] This is equivalent to deriving the revenue maximizing capital income tax rate.

indirect revenue effect in Foreign due to capital mobility. The terms of this indirect revenue effect are the same four as those described above for Home. The only difference is that an increase in $\rho$ increases the capital stock, $K^*$, in Foreign and, therefore, these terms have the opposite signs. Clearly, in the absence of capital mobility, changes in Home capital income taxes do not affect Foreign's public pollution abatement (i.e., $dg^*/d\rho = 0$). With capital mobility, however, the overall effect of the higher $\rho$ on $g^*$ is again ambiguous. The following Proposition states sufficient conditions to resolve this ambiguity.

**Proposition 2** *Under the conditions of the model, sufficient but not necessary, conditions for an increase in Home's capital income tax rate to raise Foreign's public sector abatement (e.g.,* $\frac{dg^*}{d\rho} > 0$*) are*

*1)* $\rho^* \leq \mu^*$*, or*

*2)* $|\epsilon^*| \equiv \left| \frac{K^*}{R^*_{K^*}} R^*_{K^*K^*} \right| \leq 1.$

The intuition behind Proposition 2 is as follows. An increase in $\rho$ results in a capital inflow in Foreign. As a result of that the marginal revenue product of capital in that country falls, while the marginal revenue product of immobile factors increases. Therefore, tax revenues from capital incomes decrease and tax revenues from immobile factors increase. If the former effect is greater than the latter (i.e. $\rho^* \leq \mu^*$), overall revenues increase and $g^*$ increases. Alternatively, if the capital elasticity of the marginal revenue product in Foreign is small, then the capital inflow raises capital income tax revenue and thus $g^*$. Similar results hold for the effects of changes in Foreign's capital income tax $\rho^*$ on $g$ and $g^*$. Appendix A shows the corresponding effects for $\rho^*$.

Next we turn to the effects of changes in taxes on the income of immobile factors on the provision of public sector abatement. Using Appendix A we get that the effect of changes in these taxes on their own public sector abatement activities is given by

$$\frac{dg}{d\mu} = \frac{R - KR_K}{P_g} \tag{14}$$

$$\frac{dg^*}{d\mu^*} = \frac{R^* - K^* R^*_{K^*}}{P^*_{g^*}}. \tag{15}$$

The only impact of an increase in $\mu$ on $g$ is the positive direct effect.[17] In other words, an

[17] From Appendix A, $\frac{dK}{d\mu} = \frac{dK}{d\mu^*} = 0$. That is, capital does not respond to changes in the income tax rate of the immobile and inelastically supplied factors.

increase in $\mu$ transfers a larger part of non-capital income $(R - KR_K)$ to the government in the form of tax revenue. Also, since an increase in $\mu$ does not affect capital mobility it does not affect public abatement activities in Foreign and vice versa ($\frac{dg^*}{d\mu} = \frac{dg}{d\mu^*} = 0$).

# 4 Taxes, Net Pollution and Welfare

In this section we examine the effects of raising capital and non-capital income taxes $(\rho, \mu)$ and $(\rho^*, \mu^*)$ on net pollution in the two countries ($r$ and $r^*$) and on their respective levels of national welfare ($u$ and $u^*$). The main purpose of this section is to highlight the fact that income taxes have an impact on the environment and in setting these taxes governments should account for these externalities.

## 4.1 Income Taxes and Net Pollution

We begin the analysis of this section by examining the effects of higher taxes on immobile factors' incomes ($\mu$ and $\mu^*$) on net pollution in Home and Foreign ($r$ and $r^*$). Recalling that $\frac{dK}{d\mu} = \frac{dK}{d\mu^*} = 0$ and $\frac{dg^*}{d\mu} = \frac{dg}{d\mu^*} = 0$, equations (3)and (14) yield:

$$\frac{dr}{d\mu} = -\frac{dg}{d\mu} = -\frac{R - KR_K}{P_g}, \tag{16}$$

and equations (3) and (15) yield:

$$\frac{dr}{d\mu^*} = -\Theta\frac{dg^*}{d\mu^*} = -\Theta\frac{R^* - K^* R^*_{K^*}}{P^*_{g^*}}. \tag{17}$$

Similarly, equations (7) and (14) yield:

$$\frac{dr^*}{d\mu} = -\Theta^*\frac{dg}{d\mu} = -\Theta^*\frac{R - KR_K}{P_g}, \tag{18}$$

and equations (7) and (15) yield:

$$\frac{dr^*}{d\mu^*} = -\frac{dg^*}{d\mu^*} = -\frac{R^* - K^* R^*_{K^*}}{P^*_{g^*}}. \tag{19}$$

Equations (16) and (18) indicate that a higher $\mu$, lowers net pollution both in Home and Foreign. Intuitively, in Home, an increase in $\mu$ transfers income from immobile factors to the government which uses it to finance more public pollution abatement, lowering net pollution. In the presence of cross-border pollution, lower net pollution in Home causes lower net pollution in Foreign. In the case where $\Theta^* = 0$, a higher tax $\mu$ has no effect on Foreign's $r^*$. A similar reasoning applies to the effect of a higher $(\mu^*)$ on $r$ and $r^*$ as captured by equations (17) and (19). A final note is in order regarding the interaction between taxes on immobile factors income and the quality of the environment. This interaction exists due to the assumption that tax revenues from immobile factors income are used for public pollution abatement. Alternatively, if we assume lump-sum distribution of these tax revenues to consumers these interactions cease to exist.

Next we derive the effects of higher capital income taxes ($\rho$ and $\rho^*$) on net pollution in the two countries. From equations (3), (7), (11) and (12) the effect of a higher capital tax $\rho$ on net pollution in Home is given by:

$$\begin{aligned}\frac{dr}{d\rho} &= (\Theta R^*_{t^*K^*} - R_{tK})\frac{dK}{d\rho} - \frac{dg}{d\rho} - \Theta\frac{dg^*}{d\rho} \\ &= \Delta^{-1}R_K\{-P^*_{g^*}R_{tK}[P_g - t] + \Theta P_g R^*_{t^*K^*}[P^*_{g^*} - t^*] \\ &\quad +\Theta P_g R^*_{K^*}[\rho^* + (\rho^* - \mu^*)\varepsilon^*] \\ &\quad -R_K P^*_{g^*}\rho - P^*_{g^*}K[(1-\mu)R_{KK} + (1-\rho^*)R^*_{K^*K^*}]\} \qquad (20)\end{aligned}$$

where, $\Delta = HP^*_{g^*}P_g$ and is negative. Equation (20) indicates that the effect of the higher $\rho$ on $r$ emerges through its impact on capital mobility and on the provision of public pollution abatement in the two countries. As depicted by the above equation, this effect is generally ambiguous. Equation (39) of Appendix A demonstrates the analogous ambiguous effect of the higher $\rho$ on net pollution, $r^*$, in Foreign.

From equations (20), (11) and (12) note that in the absence of capital mobility $dr/d\rho < 0$ since the impact of capital income taxes on net pollution is only through the direct effect on public pollution abatement, i.e. $\partial g/\partial\rho$.

Setting $(dr/d\rho) = 0$ gives the net pollution minimizing rate of the capital income tax as:

$$\begin{aligned}\widehat{\rho} &= (P^*_g R_K)^{-1}\{-P^*_{g^*}R_{tK}(P_g - t) + \Theta P_g R^*_{t^*K^*}(P^*_g - t^*) \\ &\quad +\Theta P_g R^*_{K^*}[\rho^* + (\rho^* - \mu^*)\varepsilon^*] \\ &\quad -P^*_g K[(1-\mu)R_{KK} + (1-\rho^*)R^*_{K^*K^*}]\}. \qquad (21)\end{aligned}$$

One could argue that the value of analyzing $\widehat{\rho}$ is limited since governments hardly ever use income taxes as environmental policy instruments. However, $\widehat{\rho}$, is of some interest since it represents the choice of a government that is solely interested in minimizing net pollution. Equation (21) indicates that if $\Theta = 0$, then the net pollution minimizing capital income tax rate is positive provided that $P_g \geq t$. If, on the other hand, $\Theta > 0$, then the sufficient but not necessary conditions for $\widehat{\rho} > 0$ are: i) $P_g \geq t$, $P^*_{g^*} \leq t^*$, and $\rho^* \leq \mu^*$ or ii) $P_g = P^*_{g^*}$, $R_{tK} = R^*_{t^*K^*}$ , $t = t^*$, $\rho^* \leq \mu^*$ and $P_g \geq t$.[18] The following proposition states these results.

**Proposition 3** *The net pollution minimizing capital income tax rate, $\widehat{\rho}$, is positive if*

*1) $\Theta = 0$ and $P_g \geq t$ or*

*2) $\Theta > 0$, $P_g \geq t$, $P^*_{g^*} \leq t^*$, and $\rho^* \leq \mu^*$ or*

*3) $\Theta > 0$,$P_g = P^*_{g^*}$, $R_{tK} = R^*_{t^*K^*}$, $t = t^*$, $\rho^* \leq \mu^*$ and $P_g \geq t$.*

From proposition 3, it is clear that if the two countries are identical in every respect and $P_g = t$, then the conditions in part 3 of the proposition are satisfied.[19] Therefore, in this case there exists a positive net pollution minimizing capital income tax rate.

## 4.2 Income Taxes and Welfare

In this section we examine the welfare implications of small changes in income taxes in the two countries. We first analyze the situation in Home and we then infer the analogous results for Foreign. Before, however, getting into the actual welfare analysis of this section, it is worth noting some benchmark results useful for the analysis to follow. Differentiating (5), and recalling that by assumption $dt = dt^* = 0$, we get

$$\begin{aligned} du = &-[E_r(\Theta R^*_{t^*K^*} - R_{tK}) - (\mu - \rho)KR_{KK} + (1-\rho)k^f R_{KK}]dK \\ &- [(K - k^f)R_K]d\rho - (R - KR_K)d\mu + E_r dg + \Theta E_r dg^*. \end{aligned} \tag{22}$$

From equation (22) we get that an increase in Home's public pollution abatement ($dg > 0$) increases welfare by $E_r$, the marginal benefit of reducing pollution. Similarly an increase in Foreign's public abatement ($dg^* > 0$) increases welfare by $\Theta E_r$, reflecting the fact that

[18] It is reasonable to assume that $P_g = P^*_{g^*}$ since both countries import this good, possibly at the same World price. Also, $t = t^*$ includes the case with no pollution taxes and thus it is not necessarily a symmetry condition.

[19] As we will see in section 5.3 when the two countries are identical and $P_g = t$ we get $\rho^N \leq \mu$.

one unit of pollution in Foreign results in the transfer of $\Theta$ units of pollution in Home. Capital mobility affects welfare in two ways: (i) through the induced change in the level of gross pollution in Home and Foreign. Since pollution is assumed to be capital intensive, gross pollution rises in Home, the capital importing country, and falls in Foreign, the capital exporting one. As a result, capital mobility through the term $-E_r(\Theta R^*_{t^*k^*} - R_{tk})$ entails an ambiguous impact on Home's welfare, and (ii) through changes in the rate of return to capital and other factors of production. Changes in factor returns affect government tax revenue (i.e., $(\mu - \rho)KR_{KK}$) and net repatriated capital earnings to Foreign (i.e., $-(1-\rho)k^f R_{KK}$), thus affecting Home's private real incomes. Both effects are ambiguous, therefore rendering an ambiguous overall impact on domestic welfare.

Next, note that an increase in the capital tax rate, $\rho$, reduces capital income available for consumption of private goods net of repatriated earnings by $(K - k^f)R_K$ and thus it reduces welfare. Similarly, an increase in the non-capital income tax rate, $\mu$, reduces income available for consumption by $(R - KR_K)$ and thus it reduces welfare.

We now proceed to a more detailed examination of the effects of income taxes $(\mu, \rho)$ and $(\mu^*, \rho^*)$ on their national welfare levels. From the system of equations in Appendix A we get the following:

$$\frac{du}{d\mu} = \frac{S_g(R - KR_K)}{P_g}, \tag{23}$$

where $S_g = E_r - P_g$. We define the public abatement good as under-provided (over-provided) when $S_g$ is positive (negative). The public abatement good is optimally provided when $S_g = 0$. Similarly we get

$$\frac{du^*}{d\mu^*} = \frac{S^*_{g^*}(R^* - K^*R^*_{K^*})}{P^*_{g^*}}, \tag{24}$$

where $S^*_{g^*} = E^*_{r^*} - P^*_{g^*}$. Equations (23) and (24) indicate that an increase in the tax on income of the immobile factors simply redistributes funds between these factors and the government. The marginal benefit of this is the marginal utility of pollution clean-up, i.e., $E_r$ in Home and $E^*_{r^*}$ in Foreign. The marginal cost is the value of private goods forgone, $P_g$ in Home and $P^*_{g^*}$ in Foreign.

In examining the welfare effects of capital taxes we first derive the impact of an increase in $\rho$ on Home's welfare as:

$$\begin{aligned}
\frac{du}{d\rho} &\equiv A = \frac{\partial u}{\partial \rho} + E_r \frac{dg}{d\rho} + \frac{\partial u}{\partial K}\frac{dK}{d\rho} + \Theta E_r \frac{\partial g^*}{\partial K}\frac{dK}{d\rho} \\
&= \Delta^{-1} R_K P^*_{g^*} E_r R_{tK}[P_g - t] - \Delta^{-1}\Theta R_K P_g E_r R^*_{t^*K^*}[P^*_{g^*} - t^*] \\
&\quad +\Delta^{-1} R_K P^*_{g^*} K[(1-\mu)R_{KK} + (1-\rho^*)R^*_{K^*K^*}][E_r - P_g] \\
&\quad +\Delta^{-1} k^f R_K P_g P^*_{g^*}(1-\rho^*)R^*_{K^*K^*} + \Delta^{-1} R^2_K P^*_{g^*} E_r \rho \\
&\quad -\Delta^{-1}\Theta R_K P_g E_r[(\rho^* - \mu^*)K^* R^*_{K^*K^*} + \rho^* R^*_{K^*}]. \qquad (25)
\end{aligned}$$

Equation (25) indicates that a higher capital income tax $\rho$ affects Home's welfare through three channels. First it entails a direct negative effect $(\frac{\partial u}{\partial \rho})$, as noted by the discussion of equation (22). A second effect, we call domestic public abatement effect, i.e., $E_r(\frac{dg}{d\rho})$, exerts a positive impact on welfare under the conditions of Proposition 1. The last effect, we call the capital mobility effect, i.e., $[\frac{\partial u}{\partial K} + \Theta E_r \frac{\partial g^*}{\partial K}]\frac{dK}{d\rho}$, comprises two terms; a direct capital-mobility effect, i.e.,$\frac{\partial u}{\partial K}\frac{dK}{d\rho}$, and an indirect one due to cross-border pollution and public abatement in Foreign, i.e., $\Theta E_r \frac{\partial g^*}{\partial K}\frac{dK}{d\rho}$. This latter effect exerts an ambiguous impact on Home's welfare.[20] Therefore, the overall effect of the higher $\rho$ on Home's welfare is ambiguous.

Similarly, the effect of an increase in Foreign's capital tax, $\rho^*$, on its own welfare is given by

$$\begin{aligned}
\frac{du^*}{d\rho^*} &\equiv A^* = \frac{\partial u^*}{\partial \rho^*} + E^*_{r^*} \frac{dg^*}{d\rho^*} + \frac{\partial u^*}{\partial K}\frac{dK}{d\rho^*} + \Theta^* E^*_{r^*} \frac{\partial g}{\partial K}\frac{dK}{d\rho^*} \\
&= \Delta^{-1} R^*_{K^*} P_g E^*_{r^*} R^*_{t^*K^*}[P^*_{g^*} - t^*] - \Delta^{-1}\Theta^* R^*_{K^*} P^*_{g^*} E^*_{r^*} R_{tK}[P_g - t] \\
&\quad +\Delta^{-1} R^*_{K^*} P_g K^*[(1-\mu^*)R^*_{K^*K^*} + (1-\rho)R_{KK}][E^*_{r^*} - P^*_{g^*}] \\
&\quad -\Delta^{-1} k^f R^*_{K^*} P_g P^*_{g^*}(1-\rho)R_{KK} + \Delta^{-1} R^{*2}_{K^*} P_g E^*_{r^*} \rho^* \\
&\quad -\Delta^{-1}\Theta^* R^*_{K^*} P^*_{g^*} E^*_{r^*}[(\rho - \mu)K R_{KK} + \rho R_K]. \qquad (26)
\end{aligned}$$

The interpretation of equation (26) is analogous to that of equation (25).

[20] There is an extensive literature on the welfare implications of capital income taxes (e.g. Huber (1999)). However, most of this literature ignores public pollution abatement and cross-border pollution. In that case, equation (25), reduces to $\frac{du}{d\rho} = \frac{\partial u}{\partial \rho} + \frac{\partial u}{\partial K}\frac{dK}{d\rho}$.

## 5 Nash Equilibrium Income Taxes

In this section we derive the equilibrium taxes on capital and non-capital incomes (i.e., $\mu$, $\rho$, $\mu^*$ and $\rho^*$), assuming that Home and Foreign choose these tax rates simultaneously. We first derive the Nash equilibrium tax rates on immobile factors' income. Setting $(du/d\mu) = 0$ in equation (23) and $(du^*/d\mu^*) = 0$ in equation (24) we get that the Nash equilibrium income tax rates $\mu^N$ and $\mu^{*N}$ require that $S_g = S^*_{g^*} = 0$.[21] In other words, the Nash equilibrium tax rates $\mu^N$ and $\mu^{*N}$ lead to the optimal provision of public pollution abatement from the local point of view. Note that the tax revenue generated by $\mu^N$ and $\mu^{*N}$ simply represents a transfer of income from immobile factors to the government, which uses it solely for the provision of public pollution abatement.

To proceed with the derivation of the Nash optimal capital income taxes, we first derive the reaction functions for these taxes by setting $(du/d\rho) = 0$ in equation (25) and $(du^*/d\rho^*) = 0$ in equation (26). Since, $\mu$ and $\mu^*$ are chosen optimally, as described above, we account for the fact that public pollution abatement is optimally provided in both countries (i.e., $S_g = S^*_{g^*} = 0$). These reaction functions are given by

$$\begin{aligned}\rho &= -R_K^{-1} R_{tK}[P_g - t] + \Theta R_K^{-1} P_{g^*}^{*-1} P_g R^*_{t^*K^*}[P^*_{g^*} - t^*] \\ &\quad -k^f R_K^{-1}(1-\rho^*) R^*_{K^*K^*} \\ &\quad +\Theta P_g R_K^{-1} P_{g^*}^{*-1}[(\rho^* - \mu^*) K^* R^*_{K^*K^*} + \rho^* R^*_{K^*}] \qquad (27)\end{aligned}$$

$$\begin{aligned}\rho^* &= -R_{K^*}^{*-1} R^*_{t^*K^*}[P^*_{g^*} - t^*] + \Theta^* R_{K^*}^{*-1} P^*_{g^*} P_g^{-1} R_{tK}[P_g - t] \\ &\quad +k^f R_{K^*}^{*-1}(1-\rho) R_{KK} \\ &\quad +\Theta^* R_{K^*}^{*-1} P^*_{g^*} P_g^{-1}[(\rho - \mu) K R_{KK} + \rho R_K]. \qquad (28)\end{aligned}$$

The Nash equilibrium tax rates are the solutions to the system of equations (27) and (28). Appendix B describes how these Nash tax rates are derived. The general solutions for $\rho^N$ and $\rho^{*N}$ are very complicated and are not presented here. In general, even if taxes on immobile factor incomes are chosen optimally (resulting in $S_g = S^*_{g^*} = 0$) and $P_g = t$ and $P^*_{g^*} = t^*$ the Nash capital income tax rates are not zero.[22] We proceed by examining

[21] $S_g = S^*_{g^*} = 0$ is the Samuelson rule for the optimal provision of public goods. In other words, this condition equates the marginal willingness to pay for the public good, ($E_r$ for Home and $E^*_{r^*}$ for Foreign) with the marginal cost of providing it ($P_g$ for Home and $P^*_{g^*}$ for Foreign).

[22] Hadjiyiannis, Hatzipanayotou, and Michael (2002), in the absence of capital income taxes, show that

some special cases.

### 5.1 $k^f = 0$ and $\Theta = \Theta^* = 0$

In this benchmark case, the only interaction between Home and Foreign is the one emanating from the RB's capital market. In this case we assume that the two countries have identical factor endowments and technologies and as a result, no foreign capital is employed in Home, i.e., $k^f = 0$.[23] At the same time, there is no cross-border pollution since $\Theta = \Theta^* = 0$. Therefore, from equations (27) and (28) we get that the Nash capital income tax rates, $\rho^N$ and $\rho^{N*}$ are

$$\rho^N = -R_K^{-1} R_{tK}[P_g - t] \tag{29}$$

$$\rho^{N*} = -R_{K^*}^{*-1} R_{t^*K^*}^*[P_{g^*}^* - t^*]. \tag{30}$$

Since there are no interactions between the two countries their choice of capital income tax does not depend directly on the tax choice of the other country. Each country's optimal capital income tax rate is positive, if the price of the imported public abatement good exceeds its own pollution tax rate. That is, $\rho^N > 0$, if $P_g > t$ in Home and $\rho^{*^N} > 0$, if $P_{g^*}^* > t^*$ in Foreign.[24]

### 5.2 $k^f = 0$ and $\Theta > 0$, $\Theta^* = 0$ or $\Theta = 0$, $\Theta^* > 0$

First we allow for cross-border pollution from Foreign to Home but not the other way around, i.e., $\Theta > 0$ and $\Theta^* = 0$. We continue to assume that the two countries have identical factor endowments and technologies and thus no foreign capital is employed in Home, i.e., $k^f = 0$. Foreign's Nash capital income tax rate is that given by equation (30).

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in general Nash pollution taxes can be greater or smaller than the cost of public pollution abatement. However, in the special case where the two countries are identical and lump-sum taxes are chosen optimally, then $P_g = t^N$ and $P_{g^*}^* = t^{*N}$.

[23] In this case, preferences could be different since prices are exogenously given because of free trade with the rest of the World.

[24] Note that in this case, where $\Theta = \Theta^* = 0$ and $k^f = 0$, if pollution tax rates ($t$ and $t^*$) are optimally set, then one possible equilibrium is $P_g = t^N$, $P_{g^*}^* = t^{*N}$ and $\rho^N = \rho^{*^N} = 0$ (see Hadjiyiannis, Hatzipanayotou, and Michael (2002)). Kim and Wilson (1997) also find that Nash capital income taxes are zero in the absence of cross-border pollution and when countries are identical.

On the other hand, equations (27) and (28) give Home's Nash capital tax rate as follows:

$$\rho^N = -R_K^{-1}R_{tK}[P_g - t] - \Theta P_g R_K^{-1} P_{g^*}^{*-1}(\epsilon^* R^*_{t^*K^*}[P^*_{g^*} - t^*] + \mu^* K^* R^*_{K^*K^*}). \qquad (31)$$

The Nash capital income tax in equation (31) is higher than that in equation (29) if $P^*_{g^*} \leq t^*$ (sufficient but not necessary condition), and it could be lower if $P^*_{g^*} > t^*$. Similarly, if we allow for one-way cross-border pollution from Home to Foreign, Home's Nash tax is the one given by equation (29) and Foreign's is given by:

$$\rho^{N*} = -R_{K^*}^{*-1}R^*_{t^*K^*}[P^*_{g^*} - t^*] - \Theta^* R_{K^*}^{*-1} P^*_{g^*} P_g^{-1}(\epsilon R_{tK}[P_g - t] + \mu K R_{KK}). \qquad (32)$$

From equation (32) note that the Nash capital tax is higher than that in equation (30) if $P_g \leq t$ (sufficient but not necessary condition). If, however, $P_g > t$, then it is possible for that rate to be lower. From the above analysis we conclude that in this case if in each country the pollution tax is equal to the cost of the public pollution abatement good, the Nash capital income policy for the country suffering from cross-border pollution is a positive tax. Intuitively, in the presence of cross-border pollution the Nash optimal policy calls for a tax on capital to reduce net pollution. The following Proposition summarizes the results when the two countries have identical factor endowments and technologies and no or one-way cross-border pollution.

**Proposition 4** *Under the conditions of the model:*

*1) if* $k^f = 0$ *and* $\Theta = \Theta^* = 0$, *then* $\rho^N \geq 0$ *if* $P_g \geq t$, *and* $\rho^{*^N} \geq 0$ *if* $P^*_{g^*} \geq t^*$,

*2) if* $k^f = 0$, $\Theta^* = 0$ *and* $\Theta > 0$, *then Foreign's Nash capital income tax rate is the same as in (1);* $\rho^N$ *is greater than the rate under (1) if* $P^*_{g^*} \leq t^*$. *Also,* $\rho^N > 0$ *if* $P_g = t$ *and* $P^*_{g^*} = t^*$.

*3) if* $k^f = 0$, $\Theta = 0$ *and* $\Theta^* > 0$, *then Home's Nash capital income tax rate is the same as in (1);* $\rho^{*^N}$ *is greater than the rate under (1) if* $P_g \leq t$. *Also,* $\rho^{*^N} > 0$ *if* $P_g = t$ *and* $P^*_{g^*} = t^*$.

## 5.3 $k^f = 0$, $\Theta > 0$ and $\Theta^* > 0$

In this case, we allow for two-way cross-border pollution while continuing to assume that the two countries have identical endowments and technologies and, therefore, $k^f = 0$.

From equations (27) and (28) we get that the Nash equilibrium income tax rates are:

$$\begin{aligned}\rho^N &= -\Omega^{-1}R_{tK}[1-\Theta\Theta^*(1+\epsilon^*)][P_g-t]-\Omega^{-1}\Theta P_g P_{g^*}^{*-1}\epsilon^* R^*_{t^*K^*}[P^*_{g^*}-t^*] \\ &\quad -\Theta\Omega^{-1}[\Theta^*(1+\epsilon^*)\mu K R_{KK}+P_g P_{g^*}^{*-1}\mu^* K^* R^*_{K^*K^*}] \end{aligned} \tag{33}$$

$$\begin{aligned}\rho^{*N} &= -\Omega^{*-1}R^*_{t^*K^*}[1-\Theta\Theta^*(1+\epsilon)][P^*_{g^*}-t^*]-\Omega^{*-1}\Theta^* P_g P_{g^*}^{*-1}\epsilon R_{tK}[P_g-t] \\ &\quad -\Theta^*\Omega^{*-1}[\Theta(1+\epsilon)\mu^* K^* R^*_{K^*K^*}+P_g P_{g^*}^{*-1}\mu K R_{KK}] \end{aligned} \tag{34}$$

where $\Omega = R_K[1-\Theta\Theta^*(1+\epsilon^*)(1+\epsilon)]$ and $\Omega^* = R^*_{K^*}[1-\Theta\Theta^*(1+\epsilon^*)(1+\epsilon)]$ and are both positive by the stability of the Nash equilibrium. The sufficient, but not necessary, conditions for $\rho^N > 0$ are $P_g \geq t$, $P^*_{g^*} \leq t^*$ and $|\epsilon^*| \leq 1$. Similarly, the sufficient conditions for $\rho^{*N} > 0$ are $P^*_{g^*} \geq t^*$, $P_g \leq t$ and $|\epsilon| \leq 1$.

An interesting special case arises when the two countries are identical in all respects, that is, in addition to identical endowments and technologies, preferences are also identical, $P_g = P^*_{g^*}$, $t = t^*$ and $\Theta = \Theta^*$.[25] In this case, the Nash capital income tax is given by:

$$\rho^N = -\Omega^{-1}R_{tK}[1-\Theta\Theta^*+\Theta\epsilon(1-\Theta^*)][P_g-t]-\frac{\Theta\mu\epsilon(1+\Theta^*(1+\epsilon))}{1-\Theta\Theta^*(1+\epsilon)^2} \tag{35}$$

From equation (35) we get that $\rho^N = \rho^{*N} = \mu = \mu^*$ when $\Theta = \Theta^* = 1$.[26] Note that this Nash optimal tax rate is lower than the net pollution minimizing capital income rate given by (21).[27] If, however, $\Theta = \Theta^* \neq 1$ and $P_g = t$, we get that the Nash capital income taxes are positive and are given by:

$$\rho^N = \rho^{*N} = \frac{-\Theta\mu\epsilon}{1-\Theta(1+\epsilon)}. \tag{36}$$

Note that under the same assumptions the Nash taxes in the benchmark case in section 5.1, where $\Theta = \Theta^* = 0$, are $\rho^N = \rho^{*^N} = 0$. Equation (36) shows that there is a

[25] To facilitate the derivation of results to follow we refrain from substituting $\Theta = \Theta^*$ in equation (35).

[26] Bjorvatn and Schjelderup (2002) in a model with identical countries, tax competition and international public goods find that when international spillovers are perfect (in our case $\Theta = 1$), there is no incentive for tax competition. This is true in our model too since in this case mobile and immobile factors are taxed at the same rate.

[27] Setting $\Theta = 1$ and $\rho^N = \rho^{*N} = \mu = \mu^*$ in equation (20) we get that $\frac{dr}{d\rho} < 0$ implying that $\widehat{\rho} > \mu$. In addition, note that the Nash capital income tax rates in sections 5.1 and 5.2 are also lower than the net pollution minimizing rate.

monotonic relationship between $\Theta$ and $\rho^N$ with the value of $\rho^N$ going from 0 to $\mu$, as $\Theta$ increases from 0 to 1. In other words, as the rate of cross-border pollution increases simultaneously in both countries, the Nash capital income tax rates also increase. On the other hand, equation (35) shows that starting from $\Theta = \Theta^*$ and assuming that $P_g = t$, an increase in $\Theta$, while $\Theta^*$ is kept constant, increases the Home's capital income tax, i.e., $(\partial\rho^N/\partial\Theta) > 0$.[28] The following proposition summarizes these results:

**Proposition 5** *When the two countries are identical in every respect and* $\Theta = \Theta^*$ *then*

*1)* $\rho^N = \rho^{*N} = \mu = \mu^*$ *if* $\Theta = \Theta^* = 1$

*2)* $\rho^N = \rho^{*N} = \frac{-\Theta\mu\epsilon}{1-\Theta(1+\epsilon)} > 0$ *if* $P_g = t$ *and a simultaneous increase in* $\Theta$ *and* $\Theta^*$ *increases* $\rho^N$ *and* $\rho^{*N}$*.*

*3) If* $P_g = t$*, an increase in* $\Theta$*, with* $\Theta^*$ *constant, increases* $\rho^N$ *(*$(\partial\rho^N/\partial\Theta) > 0$*).*[29]

## 5.4 $k^f > 0$, and $\Theta = \Theta^* = 0$

In this case we study the Nash capital tax rates in the presence of capital mobility between non-identical countries but in the absence of cross-border pollution. These are given by:

$$\rho^N = \frac{-R^*_{K^*}R_{tK}[P_g - t] - k^f R^*_{K^*K^*}R^*_{t^*K^*}[P^*_{g^*} - t^*] - k^f R^*_{K^*K^*}(R^*_{K^*} - k^f R_{KK})}{R_K R^*_{K^*} + (k^f)^2 R_{KK}R^*_{K^*K^*}} \quad (37)$$

$$\rho^{*N} = \frac{-R_K R^*_{t^*K^*}[P^*_{g^*} - t^*] + k^f R_{KK}R_{tK}[P_g - t] + k^f R_{KK}(R_K + k^f R^*_{K^*K^*})}{R_K R^*_{K^*} + (k^f)^2 R_{KK}R^*_{K^*K^*}} \quad (38)$$

From equations (37) and (38) we observe that in the absence of pollution, i.e., $R_{tK} = R^*_{t^*K^*} = 0$, or when $P_g = t$ and $P^*_{g^*} = t^*$, we get the standard results that $\rho^N > 0$ and $\rho^{*N} < 0$.[30] The presence of local pollution and public pollution abatement increase $\rho^{*N}$ when $P_g > t$ and $P^*_{g^*} > t^*$. In other words, the Nash optimal policy for Foreign can be a lower subsidy or even a tax.[31] However, the presence of local pollution and public pollution abatement have an ambiguous effect on $\rho^N$. The Nash optimal policy

[28] Note that this is a partial equilibrium result since we assume that all other variables remain constant when $\Theta$ changes.

[29] Rauscher (1997) finds the same result but from the point of view of a single country. The present analysis shows that this is not a general result.

[30] In this case equations (37) and (38) reduce to the corresponding equations in Hatzipanayotou, Hadjiyiannis, and Michael (2002). They show that if $0 < \rho^N < 1$ then $\rho^{*N} < 0$. DePater and Myers (1994) and Peralta and Van Ypersele (2003) also demonstrate that $\rho^N > 0$ and $\rho^{*N} < 0$.

[31] Note that the first two terms in the numerator of equation (38) are positive.

for Home can be a lower or higher capital income tax or even a subsidy.[32] The following Proposition summarizes these results:

**Proposition 6** *In the absence of cross-border pollution, i.e.,* $\Theta = \Theta^* = 0$*, and if* $P_g > t$ *and* $P^*_{g^*} > t^*$ *then the presence of local pollution and public pollution abatement increase* $\rho^{*N}$ *and have an ambiguous effect on* $\rho^N$*.*

Therefore, in the presence of local pollution and public pollution abatement it is even possible to have a reversal of the standard results. In other words, it is possible to have a capital income subsidy for the capital importing country and a capital income tax for the capital exporting country.

# 6 Conclusions

To date the literature on the interaction between taxes on factors income and environmental quality remains thin, despite voluminous parallel literatures on tax competition and on the impact of international capital mobility on the quality of the environment. This paper contributes in that direction by examining the impact of these income taxes on net pollution and welfare and by deriving their Nash optimal rates. We construct a model of a regional block comprising two non-identical countries with capital mobility, cross-border pollution and public sector abatement of pollution. Governments take pollution taxes as given and finance their public pollution abatement activities using pollution and income tax revenue.

Within this framework we demonstrate, among other things, that there exists a capital income tax rate which maximizes each country's public sector pollution abatement activity. For a small emissions tax this capital income tax is positive. We also derive the capital income tax that minimizes net pollution and show that when the two countries are identical this rate is positive. In addition, we find that an increase in a country's tax rate on immobile factors' income unambiguously raises public sector abatement activity and thus it reduces net pollution, since it simply entails a transfer of non-capital income to the government.

Assuming that the two countries act non-cooperatively, we show that the Nash equilibrium tax rates on immobile factors' income require optimal provision of public sector

[32] Note that the first term in the numerator of equation (37) is positive, while the second is negative.

pollution abatement. We show that, under reasonable assumptions, the presence of local pollution and public pollution abatement reduce the Nash capital income subsidy of the capital exporting country and have an ambiguous effect on the Nash capital income tax of the capital importing country. In fact, it is possible for the standard result of the tax competition literature to be reversed, i.e. it is possible to have a Nash capital income subsidy for the capital importing country and a capital income tax for the capital exporting country. In the presence of cross-border pollution we find that, in many cases, the optimal capital income policy is a positive tax for both the capital importing and the capital exporting countries. Moreover, we find that in most cases the Nash capital income tax rate is lower than the net pollution minimizing rate.

When the two countries are identical in every respect we show that the capital income tax rate is not greater than the Nash tax rate on immobile factors income and is increasing in the degree of cross-border pollution. In addition, when the degree of cross-border pollution is at its maximum, then the Nash taxes on mobile and immobile factors' income are the same. Also, in the absence of cross-border pollution and when pollution taxes are equal to the cost of the public pollution abatement good, the Nash capital income taxes are zero. Thus, the Nash capital income taxes are set to account for the existence of cross-border pollution.

# Appendix A: The Model

$$\begin{bmatrix} 1 & 0 & U_K & -E_r & -\Theta E_r \\ 0 & 1 & U_K^* & -\Theta^* E_{r^*}^* & -E_{r^*}^* \\ 0 & 0 & H & 0 & 0 \\ 0 & 0 & tR_{tK} - \rho R_K - (\rho - \mu) K R_{KK} & P_g & 0 \\ 0 & 0 & (\rho^* - \mu^*) K^* R_{K^*K^*}^* + \rho^* R_{K^*}^* - t^* R_{t^*K^*}^* & 0 & P_{g^*}^* \end{bmatrix} \begin{bmatrix} du \\ du^* \\ dK \\ dg \\ dg^* \end{bmatrix} =$$

$$\begin{bmatrix} (k^f - K) R_K \\ -k^f R_K \\ R_K \\ K R_K \\ 0 \end{bmatrix} d\rho + \begin{bmatrix} 0 \\ -K^* R_{K^*}^* \\ -R_{K^*}^* \\ 0 \\ K^* R_{K^*}^* \end{bmatrix} d\rho^*$$

$$+ \begin{bmatrix} K R_K - R \\ 0 \\ 0 \\ R - K R_K \\ 0 \end{bmatrix} d\mu + \begin{bmatrix} 0 \\ K^* R_{K^*}^* - R^* \\ 0 \\ 0 \\ R^* - K^* R_{K^*}^* \end{bmatrix} d\mu^*$$

where $U_K = E_r(\Theta R_{t^*K^*}^* - R_{tK}) - (\mu - \rho) K R_{KK} + (1 - \rho) k^f R_{KK}$ and $U_K^* = E_{r^*}^*(R_{t^*K^*}^* - \Theta^* R_{tK}) + (\mu^* - \rho^*) K^* R_{K^*K^*}^* - (1 - \rho) k^f R_{KK}$.

$$\frac{dg^*}{d\rho^*} = \frac{\partial g^*}{\partial \rho^*} + \frac{\partial g^*}{\partial K} \frac{dK}{d\rho^*} = \frac{K^* R_{K^*}^*}{P_{g^*}^*} + \frac{t^* R_{t^*K^*}^* - \rho^* R_{K^*}^* - (\rho^* - \mu^*) K^* R_{K^*K^*}^*}{P_{g^*}^*} \frac{-R_{K^*}^*}{H}$$

$$\frac{dg}{d\rho^*} = \frac{\partial g}{\partial K} \frac{dK}{d\rho^*} = -\frac{tR_{tK} - \rho R_K - (\rho - \mu) K R_{KK}}{P_g} \frac{-R_{K^*}^*}{H}.$$

$$\begin{aligned} \frac{dr^*}{d\rho} &= (R_{t^*K^*}^* - \Theta^* R_{tK}) \frac{dK}{d\rho} - \frac{dg^*}{d\rho} - \Theta^* \frac{dg}{d\rho} \\ &= \Delta^{-1} R_K \{ P_g R_{t^*K^*}^* [P_{g^*}^* - t^*] - \Theta^* P_{g^*}^* R_{tK} [P_g - t] \\ &\quad + P_g [\rho^* R_{K^*}^* (1 + \epsilon^*) - \mu^* K^* R_{K^*K^*}^*] \\ &\quad - \Theta^* P_{g^*}^* [(1 - \mu) K R_{KK} + (1 - \rho^*) K R_{K^*K^*}^* + \rho R_K] \} \end{aligned} \quad (39)$$

## Appendix B: Nash Capital Income Taxes

Rewriting equations (27) and (28) in a matrix form we get:

$$\begin{bmatrix} A_1 & A_2 \\ A_2^* & A_1^* \end{bmatrix} \begin{bmatrix} \rho \\ \rho^* \end{bmatrix} = \begin{bmatrix} A_3 \\ A_3^* \end{bmatrix}$$

where:

$A_1 = -P^*_{g^*} R_K$

$A_1^* = -P_g R^*_{K^*}$

$A_2 = P^*_{g^*} R^*_{K^*K^*} k^f + (1+\varepsilon^*)\Theta P_g R^*_{K^*}$

$A_2^* = -P_g R_{KK} k^f + (1+\varepsilon)\Theta^* P^*_{g^*} R_K$

$A_3 = P^*_{g^*} R_{tK}(P_g - t) + k^f P^*_{g^*} R^*_{K^*K^*} - \Theta P_g [R^*_{t^*K^*}(P^*_g - t^*) - \mu^* K^* R^*_{K^*K^*}]$

$A_3^* = P_g R^*_{t^*K^*}(P^*_g - t^*) - k^f P_g R_{KK} - \Theta^* P^*_{g^*} [R_{tK}(P_g - t) - \mu K R_{KK}]$

Then, the values for the Nash capital income tax rates can be computed as follows:

$\rho = \frac{A_1^* A_3 - A_3^* A_2}{A_1 A_1^* - A_2 A_2^*}$ and $\rho^* = \frac{A_1 A_3^* - A_3 A_2^*}{A_1 A_1^* - A_2 A_2^*}$

Note that by the stability of the Nash equilibrium $A_1 A_1^* - A_2 A_2^* > 0$.

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