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Abstract

We develop a model of two small open asymmetric economies with two tradable and one non-tradable goods, capital mobility and consumption generated cross border pollution. We show that the Nash equilibrium calls for a consumption tax and capital tax (subsidy) when the consumption of the tradable (non-tradable) good pollutes. In this model, the consumption tax causes pollution leakages between the two countries which is partly offset by the capital tax or subsidy. Thus, the existence of non-tradable goods and international capital mobility induce the small countries to act strategically. In the absence of capital taxes, consumption taxes are lower to their rates when capital taxes are also present since are used strategically to mitigate the pollution leakage.

JEL classification: F15, F18, F20, H20, H21

Keywords: Pollution Leakage; Non-tradable Goods; Capital Mobility; Capital and Consumption Taxes; Consumption-generated Cross-border Pollution.

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1 Introduction

Many production and consumption activities generate cross-border pollutants, e.g., green gas emissions, which not only deteriorate the quality of environment in the emitting country, but also the environmental quality in other countries. It has been established that tax policies in a country which affect the levels of domestically generated production pollution, entail the so-called pollution leakage effects, e.g., increased levels of pollution in one country due to reduction of emissions in another as a result of the latter country's stricter environmental policies. Furthermore, these policy induced pollution leakage effects can be exacerbated in the presence of international capital mobility.

By and large, the pollution leakage effect has been examined in the framework of large open economies with production generated pollution, e.g., Kotsogiannis and Woodland (2013), Böhringer et al. (2014). Furthermore, this cross-country pollution leakage is exacerbated in the presence of international capital mobility, e.g., Eichner and Pethig (2019).[1]

The pollution leakage effects, however, have not been examined when the source of pollution emissions is an economy's consumption activity. Consumption generated environmental pollutants, such as carbon monoxide (CO), carbon dioxide (CO_2), and sulfur dioxide (SO_2) are generated from both indoors and outdoors residential consumption activities, e.g., burning woods, kerosene and coal, exhaust fumes from cars, and solid waste accumulation. OECD (2012) reports that about 90 percent of CO emissions is generated from such activities and about 70 percent of CO_2 emissions are due to energy consumption.[2]

We use a two country model with international capital mobility, where each country produces tradable and non-tradable goods. The countries are asymmetric small open economies, both in world good and capital markets. Thus, the prices of the tradable goods are determined in world commodity markets and are taken as given by the small open economies, while the prices of the non-tradable goods are endogenously determined. In regards to international capital mobility, we adopt the widely used Ogawa and Wildasin (2009) framework, where the net

[1] Other studies examining the production generated leakage effect, include Copeland and Taylor (2005), Ishikawa and Kiyono (2006), Böhringer et al. (2017), Holladay (2018), and Richter et al. (2021).

[2] The US Environmental Protection Agency (EPA, 2014) reports that in the US, close to 40% of greenhouse gasses are generated from households' residential activity. Earlier European Environmental Agency studies (EEA, 2005) show that the average ecological footprint of EU citizens in 2001 included 3.8 global hectare (ha) per person in Italy, 4.8 in Germany, 5.8 in France and 7.0 in Sweden. The global average was estimated at 2.2 global ha per person. In 2002, EU-25 contained 7 % of the world's population and its consumption generated 17 % of the world's ecological footprint. Hu and McKitrick (2016) report, among other factual evidence, that nearly 50 percent of volatile organic compounds (VOCs) and of nitrogen oxide emissions (NO_x) in the USA are due to motor vehicles use.

rate of return to capital in each economy is fixed and equals the world rate of return to capital. Consumption of the tradable or non-tradable commodities can be either a clean or a polluting activity. Capital and consumption taxes are the countries' policy instruments to control for consumption generated pollution. We derive the Nash equilibrium rates of consumption and capital taxes, either concurrently or the one in the absence of the other. We examine the efficiency of these policy instruments in the sense of achieving the welfare effects of the cooperative tax setting.

Contribution of the paper: The focal point of the paper is to heighten the issues of consumption generated pollution leakage, and of the existence of strategic interactions between small open economies. The mechanism via which these results emerge is quite different to the one in the related literature.[3] In our case, a small open economy's tax on consumption of the polluting good, while it does not affect world relative prices, it affects the domestic relative price of the non-tradable good. As a result, the rate of return to the internationally mobile capital changes, causing flows of the factor between the two countries. Changes in the supply of capital in the other country, changes the production of the non-tradable good affecting its price. The consumption of both the tradable and the non-tradable goods changes, causing the consumption generated pollution leakage effect.

The main results of the paper are as follows. The Nash equilibrium policies call for a consumption tax and a capital tax (subsidy) when the consumption of the tradable (non-tradable) good pollutes. The existence of international capital mobility and of the non-tradable goods induce the small open economies to act strategically, regardless of whether cross-border pollution is due to the consumption of the tradable or the non-tradable good. That is, a country via the use of its capital tax/subsidy can mitigate the consumption pollution leakage effect induced by the consumption tax. As a result, the capital tax/subsidy is non-zero, despite the use of consumption taxes to control for consumption generated pollution.[4] The Nash equilibrium capital tax/subsidy is efficient, while the consumption tax is inefficiently low, in the sense of being lower than the cooperative equilibrium consumption tax. When a capital tax/subsidy is not at

[3] In the relevant literature, the policy-induced strategic interaction arises because countries are large in world commodity and capital markets and the pollution leakage effects are production generated., e.g., Copeland and Taylor (2005), Ishikawa and Kiyono (2006), and Böhringer et al. (2017).

[4] This result is in contrast to standard literature results, by which, the Nash equilibrium capital taxes are zero when economies are small, and a second policy instrument, e.g., environmental standards or pollution/production taxes, is used to control for production generated pollution. For example, see Oates and Schwab (1988) for the case of small open economies. When, however, economies are large in world capital markets, Petchey (2015), Eichner and Pethig (2018, 2019) show that the non-cooperative equilibrium policy calls for non-zero capital taxes.

a government's disposal, the inefficiently low Nash equilibrium consumption tax becomes even lower, since in this case the consumption tax is used strategically to mitigate the pollution leakage. In the absence of non-tradable goods, the Nash equilibrium policy calls for a consumption tax and zero capital tax.

Relevant literature: The environmental literature has examined the Nash equilibrium taxes and their efficiency in a variety of models with local or transboundary pollution, related to production or consumption activities, or to the use of capital. Ogawa and Wildasin (2009), show that when pollution is transboundary and related to the use of capital, the Nash equilibrium policy calls for capital taxes, and these capital taxes are efficient. However, the efficiency of the Nash equilibrium capital taxes ceases to exist in cases where the total supply of capital is variable, e.g., Eichner and Runkel (2012). Fell and Kaffine (2014) in a model with many heterogenous jurisdictions, capital mobility and inter-jurisdictional pollution show that in the presence of "capital retirement" the decentralized policy outcome generally differs from the solution of a centralized planner's social welfare-maximizing problem. A related strand of the literature examines the Nash equilibrium tax policies when pollution is related to production and capital is internationally mobile. For example, Tsakiris et al. (2017) show that the non-cooperatively setting of intra-regionally or inter-regionally tradable emission permits are always inefficient. Eichner and Pethig (2019) show that when the countries are symmetric, the Nash equilibrium policies call for an emission tax and a capital subsidy (zero tax) if pollution is transboundary (local). Habla (2018) in a two period model, assuming that fossil energy and capital are complements in production and pollution is transboundary, shows that along with a tax on fossil energy, capital must be subsidize in the first period and taxed in the second.

Some recent studies examine the impact of environmental policies on production generated emission leakages in the presence on non-tradable goods. For example, Böhringer et al. (2017) show that output-based rebating of carbon tax payments combined with a consumption tax on emission-intensive and trade-exposed (EITE) industries, can be equivalent to border carbon adjustments. Kaushal and Rosendhal (2020), extending the Böhringer et al. (2017), demonstrate unambiguously global welfare improving effects of a consumption tax imposed on the EITE industries. Holladay et al. (2018) show that the pollution leakage effect emerges only when the non-tradable good becomes partially tradable due to the lowering of trade frictions.

In models of perfect competition, studies that examine optimal tax policies under consumption pollution externalities propose that for small open economies, the first-best policy combination requires an emission or a consumption tax to control for the consumption pollution externality, and free trade, e.g., Gulati and Roy (2008), Copeland (2011) and Chao et al. (2012). In the absence of non-tradable goods, when pollution is generated from consumption activities, and regardless of whether it is local or transboundary, international capital mobility alone does not alter the Nash equilibrium policies. That is, a consumption tax, free trade and a zero capital tax remains a country's Nash equilibrium policy mix. However, Tsakiris et al. (2019) show that when pollution generated from the consumption of one unit of domestically produced importable differs from that of consumption of one unit of imports, then, the first-best policy requires border tax adjustment (BTA) measures, such as tariffs or import subsidies, in addition to consumption taxes on all polluting goods. In models of imperfect competition, Ishikawa and Okubo (2011), examine the effects of emission taxes and tariffs in the presence of consumption generated pollution, when a domestic and a foreign firms produce imperfect substitute goods, and the consumption of the foreign produced one is more polluting than that of the domestically produced. Cheng (2022) in presence of monopolistic competition examines how trade liberalization and a consumption tax affect firm locations across countries and consumption-generated cross-border emissions.

The rest of the paper is organized as follows. Section 2, develops the model. Section 3, considers the case where consumption of the tradable good is polluting. We derive the Nash equilibrium taxes and we examine their efficiency relative to the cooperative case. We provide the results in the general case and in special cases where pollution is local, pollution is perfectly transboundary and countries are symmetric. Section 4 pursues the same analysis for the case where the consumption of the non-tradable good is polluting. The final section offers some concluding remarks.

2 The Model

Consider a simple general equilibrium model of two asymmetric countries, Home and Foreign, with consumption generated cross-border pollution and capital mobility between them.[5] Hereon, an asterisk ($*$) denotes the variables of Foreign. Each country produces three goods; two tradables, good 1 and good 2, and a non-tradable, good 3. A representative consumer residing in

[5] A good part of the literature on environmental taxation assumes that countries are homogenous or symmetric, e.g., Habla (2018), Eichner and Pethig (2019). Here, like in Ogawa and Wildasin (2009), countries are assumed heterogenous.

each country derives utility from the consumption of the three commodities and clean environment. Good 1 is treated as the numeraire commodity whose production and consumption are clean activities. The consumption of the tradable good 2 and that of the non-tradable good 3 in both countries may generate transboundary pollution emissions which affect negatively the utility of households in both countries. Home and Foreign are assumed small open economies in world commodity and capital markets, thus, policies by either country do not affect world commodity prices, and the world rate of return to capital. Without loss of generality, we assume that the world price of the numeraire good 1 is equal to unity. The prices of the non-tradable goods are determined in each country's respective market. There is a fixed capital endowment in each country. Capital is freely mobile between them. A country's net rate of return to capital is fixed and equal to the rate of return to capital in the other country.[6] All other factors of production are inelastically supplied and cross-country immobile. All commodity and factor markets are perfectly competitive. To control for consumption generated pollution, each country's government imposes a source based specific capital tax or subsidy and a specific tax on consumption of the polluting good. Capital and consumption tax revenues are lump-sum rebated to the country's representative consumer.

2.1 Production and Demand

Our methodology, for convenience and simplicity, is based on duality theory following Copeland (1994, 2011). The Gross Domestic Product (GDP) and minimum expenditure functions represent the countries' production and demand conditions.

Production of all three goods is a clean and untaxed activity. The GDP function represents the maximum value of domestic production at the given producer prices and factor supplies. $R(1,\ p_2,\ p_3,\ K,\ \Omega) = \left\{ \sum_{j=1}^{3} p_j x_j (1,\ p_2,\ p_3,\ K_j,\ \Omega_j) \right\}$, $j = 1,\ 2,\ 3$, denotes Home's GDP function, 1 and p_2 indicate, respectively, the producer prices of the tradable goods 1 and 2, which are equal to the world prices of these goods. The producer price of the non-tradable good, p_3, is determined by the market clearing condition in the country's respective market. $K = \overline{K} + k$, is Home's supply of capital, where $\overline{K}$ denotes the country's capital endowment, $k > 0 (< 0)$ if Home is a capital importing (exporting) country, and Ω is the vector of endowments of all other

[6] This is a simplifying assumption, widely used in the literature of international capital mobility. For example, Ogawa and Wildasin (2009), among numerous other studies, apply this assumption in the context of a multi-jurisdictional federal economy where capital is freely mobile among the jurisdictions and it is in fixed supply in the federal economy. Moreover, they assume that each of the jurisdictions is small in the world capital markets, implying that the net rate of return to capital is exogenously fixed.

inelastically supplied and immobile factors. x_j is the output of the j^{th} commodity, K_j and Ω_j are respectively the amounts of capital and of all other factors employed in its production. By the properties of the GDP function, i.e., envelope theorem, its derivative with respect to price p_j denotes the supply function of the j^{th} good, i.e., $R_j\left(=\partial R/\partial p_j\right)$. The derivative with respect to K is the marginal revenue product of capital, i.e., $R_K\left(=\partial R/\partial K\right)$. The $R\left(.\right)$ function is strictly concave in factor supplies, i.e., $R_{KK}\left(=\partial R_K/\partial K\right)<0$, and strictly convex in prices, i.e., $R_{22}\ \left(=\partial R_2/\partial p_2\right)>0$ and $R_{33}\ \left(=\partial R_3/\partial p_3\right)>0$. Similarly, Foreign's (GDP) function is given by $R^*\left(1,\ p_2,\ p_3^*,\ K^*,\ \Omega^*\right)$, where $K^*=\overline{K}^*-k$, and $\overline{K}^*$denotes capital endowment in Foreign.[7]

A country's representative consumer derives utility from the consumption of the three goods and clean environment. Demand conditions and preferences in the two countries are captured by the *minimum expenditure function.* Home's minimum expenditure function is denoted as $E\left(1,\ \pi_2,\ \pi_3,\ z,\ u\right)$. It captures the minimum expenditure on consumption of goods required to attain a given level of utility u, given the level of overall consumption generated pollution in the country, z, to be defined soon below. $\pi_j\left(=p_j+\tau_j\right)$ denotes the consumer prices of j^{th} good, and τ_j is the consumption tax on the consumption of the j^{th} polluting good. Given the assumptions of the model, $d\pi_2=d\tau_2$ and $d\pi_3=dp_3+d\tau_3$. By the properties the $E\left(.\right)$ function, i.e., Shephard's Lemma, the derivative $E_j\left(=\partial E/\partial \pi_j\right)$ denotes the compensated (Hicksian) demand for j^{th} the good, $E_u\left(=\partial E/\partial u\right)$ is the reciprocal of the marginal utility of income, which for convenience is set equal to one, and $E_z\ \left(=\partial E/\partial z\right)$ is the *marginal willingness to pay for pollution reduction* or alternatively is the *marginal damage of pollution.* E_z measures the increase in income required to keep utility constant when emissions increases by a unit. The $E\left(.\right)$ function is strictly concave in consumer prices, i.e., $E_{jj}\left(=\partial E_j/\partial \pi_j\right)$ are negative, and $E_{23}=E_{32}$ is positive (negative) depending on whether goods 2 and 3 are substitutes (complements) in consumption. For simplicity, we assume that all income effects fall on the non-polluting tradable good, i.e., $E_{2u}=E_{3u}=0$, and that the polluting goods and clean environment are independent in consumption, i.e., $E_{2z}=E_{3z}=0$.[8] Similarly, Foreign's minimum expenditure function is

[7] For the properties of the GDP function, see among others, Keen and Kotsogiannis (2014), Lapan and Sikdar (2017).

[8] The assumption that goods and clean environment are independent is consumption is frequently adopted in the relevant literature, e.g., Copeland (2011). An expenditure function associated with quasi-linear preferences and separability of z, yielding the above properties, is $E\left(1,\ \pi_2,\ \pi_3,\ z,\ u\right)=\sum_{j=1}^{3}\pi_j c_j+u-f\left(z\right)$, where c_j's, $j=1,2,3$, are the levels of consumption of the three commodities, and $f'\left(z\right)>0$. Bandyopadhyay et al. (2013), and Lapan and Sikdar (2017), provide similar examples of the minimum expenditure functions in the presence of pollution.

given by $E^*(1,\ \pi_2^*,\ \pi_3^*,\ z^*,\ u^*)$, where $\pi_j^* = p_j^* + \tau_j^*$, $d\pi_2^* = d\tau_2^*$ and $d\pi_3^* = dp_3^* + d\tau_3^*$.

The consumption of good 1 in each country is a clean activity, while the consumption of the tradable good 2 and that of the non-tradable good 3 in both countries generate transboundary pollution emissions. The overall levels of pollution in Home and Foreign are respectively given as follows:

$$z = a_2[E_2(.) + \beta E_2^*(.)] + a_3[E_3(.) + \beta E_3^*(.)] \quad \text{and} \tag{1}$$

$$z^* = a_2[E_2^*(.) + \beta^* E_2(.)] + a_3[E_3^*(.) + \beta^* E_3(.)], \tag{2}$$

where $\alpha_j\,(> 0)$ is the rate of emissions per unit of consumption of the j^{th} good, $0 \leq \beta \leq 1$ is the rate of cross-border pollution, i.e., the environmental spillover, from Foreign to Home and takes values between zero and one. When $\beta = 0$, pollution is local and $\beta = 1$, transboundary pollution is perfect or complete. Equivalently, $0 \leq \beta^* \leq 1$ is the rate of cross-border pollution from Home to Foreign.

Equilibrium in capital markets requires that the net rate of return to capital, i.e., the factor's marginal revenue product minus the specific capital tax, is equated across the two countries, and it is also equal to the fixed world rate of return to capita $(\overline{r})$. Thus, we have:

$$R_K(1, p_2,\ p_3,\ K) - \rho = R_K^*(1, p_2,\ p_3^*,\ K^*) - \rho^* = \overline{r}, \tag{3}$$

where ρ and ρ^* are the capital tax rates in the two countries. The market clearing conditions in the two countries' non-tradable goods markets requires that the demand for equals the supply of the good, and is given by the following conditions:

$$E_3(1, \pi_2,\ \pi_3,\ z,\ u) = R_3(1, p_2,\ p_3,\ K) \quad \text{and} \tag{4}$$

$$E_3^*(1, \pi_2^*,\ \pi_3^*,\ z^*,\ u^*) = R_3^*(1, p_2,\ p_3^*,\ K^*). \tag{5}$$

The model closes with the representative consumer's budget constraint in each country, i.e., the *expenditure-income identities*. This identity requires that each representative consumer's expenditure on consumption must equal income from production plus lump-sum rebated tax revenues by the government, minus (plus) capital payments to foreign (domestic) capital employed locally (abroad). That is:

$$E\left(1,\pi_2,\ \pi_3,\ z,\ u\right) \;=\; R\left(1,p_2,\ p_3,\ K\right)+\tau_2 E_2\left(.\right)+\tau_3 E_3\left(.\right)-\left(R_K(.)-\rho\right)k, \qquad (6)$$

$$E^*\left(1,\pi_2^*,\pi_3^*,z^*,u^*\right) \;=\; R^*\left(1,p_2,p_3^*,K^*\right)+\tau_2^* E_2^*\left(.\right)+\tau_3^* E_3^*\left(.\right)+\left(R_K(.)-\rho\right)k. \qquad (7)$$

The two-economies system consists of equations (1)-(7), in terms of z, z^*, K, K^*, p_3, p_3^*, u, and u^*. The policy instruments are ρ, ρ^*, τ_j and τ_j^*.

3 Nash equilibrium taxes when the consumption of the tradable good is polluting

We start the analysis by assuming that the consumption of the tradable good 2 is polluting while the consumption of the non-tradable good 3 is a clean activity.[9] A tax is imposed on the consumption of the polluting good 2. That is, $\alpha_2 > 0$, $\alpha_2^* > 0$ and $\alpha_3 = \alpha_3^* = 0$.[10] Totally differentiating the system of equations (1)-(7), and substituting the expressions for dz and dz^* into the differentiated representative consumers' budget constraints, we obtain the matrix system (A.1) in the Appendix. We derive the two countries' Nash (non-cooperative) equilibrium policy when both instruments, i.e., the capital and consumption taxes, are available to policy makers, and we evaluate their efficiency *vis-a-vis* the corresponding cooperative tax rates. We present the Nash equilibrium policy choices of Home, and similar results hold for Foreign.

3.1 Nash equilibrium capital and consumption taxes

To obtain the Nash equilibrium consumption tax on the polluting good 2, and the Nash equilibrium capital tax, in this two country model, we set $\frac{du}{d\rho} = \frac{du}{d\tau_2} = 0$ and $\frac{du^*}{d\rho^*} = \frac{du^*}{d\tau_2^*} = 0$.For Home, using equations (A.1), the effects of an increase in capital and consumption taxes on welfare are

[9] Tradable goods whose consumption generates pollution could be certain manufacturing products such as automobiles and electric appliances. In terms of polluting consumption activity of non-tradable goods, e.g., the European Environmental Agency (EEA, 2015) reports "*.... Household chemicals continue to affect -the quality of surface, ground and marine waters (p. 122) ... power plants and households contribute to Europe's air pollution (p. 125) .... Another important source of particulate matter and polycyclic aromatic hydrocarbons is coal and wood burning for heating, in households as well as in commercial and institutional facilities. Low-level household emissions can significantly affect the concentrations close to the ground. Emissions of benzo(a)pyrene increased by 21% between 2003 and 2012, driven by the increase (24%) in emissions from domestic combustion in Europe. (p. 125)...*"

[10] It is well known and can be easily shown that the Nash equilibrium consumption tax on the non- polluting good is zero, i.e., $\tau_3 = \tau_3^* = 0$.

given by:

$$\Delta\frac{du}{d\rho} = Z_{33}Z_{33}^{*}\left[-\rho + (\alpha_2 E_z - \tau_2)E_{23}Z_{33}^{-1}R_{3K} - \alpha_2\beta E_z E_{23}^{*}Z_{33}^{*-1}R_{3K}^{*}\right] \quad \text{and} \tag{8}$$

$$\Delta\frac{du}{d\tau_2} = \left\{\begin{array}{c} (\alpha_2 E_z - \tau_2)[-E_{22}\Delta + E_{23}E_{32}(HZ_{33}^{*} + R_{K3}^{*}R_{3K}^{*})] \\ +E_{23}R_{3K}Z_{33}^{*}(\rho + \alpha_2\beta E_z E_{23}^{*}Z_{33}^{*^{-1}}R_{3K}^{*}) \end{array}\right\}, \tag{9}$$

where $H = R_{KK} + R_{K^*K^*}^{*}(< 0)$, $Z_{33} = E_{33} - R_{33}\,(< 0)$ and $Z_{33}^{*} = E_{33}^{*} - R_{33}^{*}\,(< 0)$. The determinant of the left-hand-side coefficients matrix of equations (A.1), given in the Appendix, is $\Delta = Z_{33}Z_{33}^{*}\left(\widetilde{R}_{KK} + \widetilde{R}_{K^*K^*}^{*}\right)$ and is negative, $\widetilde{R}_{KK} = R_{KK} + R_{K3}Z_{33}^{-1}R_{K3}(< 0)$ and $\widetilde{R}_{K^*K^*}^{*} = R_{K^*K^*}^{*} + R_{K^*3}^{*}Z_{33}^{*^{-1}}R_{K^*3}^{*}\,(< 0)$.

For simplicity and without loss of generality, the following Assumption is maintained throughout the analysis.

Assumption The tradable good 2 and the non-tradable good 3 are substitutes in consumption, i.e., $E_{23} > 0$ and $E_{23}^{*} > 0$. An inflow of capital increases the production of the non-tradable good 3, i.e., $R_{K3} > 0$ and $R_{3K}^{*} > 0$.[11]

Similar results for Foreign are derived using equations (A.4) and (A.6) in the Appendix.

Using $\frac{du}{d\rho} = \frac{du}{d\tau_2} = 0$, the Nash equilibrium capital and consumption tax rates for Home are given as follows:

$$\rho^N = -\alpha_2\beta E_z E_{23}^{*}Z_{33}^{*^{-1}}R_{3K}^{*}, \tag{10}$$

$$\tau_2^N = \alpha_2 E_z. \tag{11}$$

Equations (10) and (11) show that the Nash equilibrium calls for (i) a capital tax, and (ii) a consumption tax on the polluting good, equal to the marginal willingness to pay for pollution reduction per unit of consumption of good 2, or alternatively, a consumption tax equal to the pollution damage caused by a unit of consumption of good 2.[12]

[11] When only two goods exist, then these are always substitutes in consumption. In our model with three goods, it is possible that goods 2 and 3 are complements in consumption. R_{jK} represents output changes due to changes in the supply of capital, keeping all other things constant. In the short-run, a capital inflow in a sector increases its output, i.e., $R_{jK} > 0$. In the international trade theory, however, in the long-run, a capital inflow may reduce a sector's output. Along this line, a j^{th} good is called capital (non-capital) intensive when the increase in the capital supply increases (decreases) its production i.e., $R_{jK} > (<)0$, e.g., Kotsogiannis and Woodland (2013). The results for other cases, e.g., complementarity of tradable and non-tradable goods in consumption, and/or $R_{3K} < 0$, are reported briefly without further discussion.

[12] Eichner and Pethig (2019) show that when the cross border pollution is generated from production and countries are symmetric, the Nash equilibrium policy calls for an emission tax and a capital subsidy. They assume that capital is the only factor of production used in the production of an intermediate good. The

Intuitively, the increase in Home's consumption tax reduces the consumption of the polluting good 2 and increases the consumption of the non-tradable good 3, since the two goods are substitutes in consumption, i.e., $E_{32} > 0$. The price of good 3 increases, resulting to an increase in Home's marginal revenue product of capital since $R_{K3} > 0$. The higher marginal revenue product of capital in Home induces a capital inflow from Foreign. In Foreign, the stock of capital falls, and so does the production of the non-tradable good since $R^*_{3K} > 0$. In the latter country, the price of the non-tradable good rises, thus, consumption of good 3 falls and that of the polluting good 2 rises, since the two commodities are substitutes in consumption, i.e., $E^*_{23} > 0$. Higher consumption of good 2 in Foreign increases pollution and this causes a *pollution leakage effect* from Foreign to Home (spillback) due to the transboundary nature of consumption pollution of good 2. Thus, the higher consumption tax by Home increases the leakage of pollution from abroad. To reduce this inflow of pollution, Home's government taxes capital in order to reduce the inflow of capital from Foreign. Based on this reasoning, when both policy instruments are available, Home's optimal policy choice is a capital tax, i.e., $\rho^N > 0$, and a consumption tax τ_2^N equal to the marginal willingness to pay for pollution reduction per unit of consumption of good 2.[13]

When pollution is local, i.e., pollution generated by Home does not affect the welfare of Foreign and vice versa, i.e., $\beta = \beta^* = 0$, then, the Nash equilibrium policy calls for zero capital tax and a consumption tax on the polluting good equal to the damage caused by the consumption of a unit of this good, i.e., $\tau_2^N = \alpha_2 E_z$. The same Nash equilibrium results, i.e., $\rho^N = 0$ and $\tau_2^N = \alpha_2 E_z$, emerge in the presence of cross border pollution but in the absence of non-tradable goods. In this case, when Home increases the consumption tax on the polluting good, the domestic marginal revenue product of capital does not change, thus there are no capital flows between the two countries. Pollution in Foreign remains unaffected, i.e., there is no pollution leakage effect (spillback).

In the present framework of tradable and non-tradable goods, and of international capital mobility, when Home imposes consumption taxes to control for locally generated consumption pollution, it affects consumption and consumption generated pollution in Foreign. Since pol-

emission of pollutants is proportional to the use of the intermediate good in the production of the final good. Thus, they implicitly assume that an increase in capital, indirectly through the increase in the intermediate good, increases the production of the final good.

[13]The Nash equilibrium policy on capital is also a tax, when the polluting and the non-tradable goods are complements in consumption, i.e., $E_{32} < 0$ and $R_{K3} < 0$. If however, $E_{32} < (>) 0$ and $R_{K3} > (<) 0$, then the Nash equilibrium policy for capital is a subsidy.

lution is transboundary, pollution leakage effects emerge affecting negatively Home's welfare. To deal with this pollution leakage effect, Home taxes capital.[14] The relevant literature show that in Nash equilibrium countries refrain from taxing capital when economies are small, and a second policy instrument, e.g., environmental standards or pollution/production taxes, is used to control for production generated pollution, e.g., Oates and Schwab (1988), Copeland (1994). However, when countries are large economies, capital taxes are non-zero, e.g., Petchey (2015), Eichner and Pethig (2018, 2019). This implies that large open economies choose capital taxes strategically. In the current framework strategic interaction arises between small open economies. Thus, both small open economies act strategically by choosing positive capital taxes so as to mitigate the pollution leakage.

3.1.1 The efficiency of the Nash equilibrium

Having derived Home's Nash equilibrium tax rates ρ^N and τ_2^N, we examine their efficiency vis-a-vis the corresponding cooperative equilibrium tax rates, say ρ^C and τ_2^C. These are the tax rates chosen by Home to maximize Home's and Foreign's joint welfare, and are derived using the first-order-conditions $\frac{du}{d\rho} + \frac{du^*}{d\rho} = 0$ and $\frac{du}{d\tau_2} + \frac{du^*}{d\tau_2} = 0$. Similarly, Foreign's cooperative tax rates $\left(\rho^{*C},\, \tau_2^{*C}\right)$ are derived from the first-order-conditions $\frac{du}{d\rho^*} + \frac{du^*}{d\rho^*} = 0$ and $\frac{du}{d\tau_2^*} + \frac{du^*}{d\tau_2^*} = 0$. In order to compare the Nash equilibrium tax rates with the cooperative ones, we evaluate the slope of these joint welfare functions at the Nash equilibrium. Since at Nash equilibrium $\frac{du}{d\rho} = \frac{du}{d\tau_2} = 0$ and $\frac{du^*}{d\rho^*} = \frac{du^*}{d\tau_2^*} = 0$, it suffices to examine the sign of the terms $\frac{du^*}{d\rho}$ and $\frac{du^*}{d\tau_2}$. Substituting into equations (A.2) and (A.3) in the Appendix the Nash equilibrium values from equations (10) and (11) we obtain:

$$\frac{du^*}{d\tau_2} \mid_{\rho^N, \tau_2^N} = -\alpha_2 \beta^* E_z^* \widetilde{E}_{22} > 0 \qquad \text{and} \qquad \frac{du^*}{d\rho} \mid_{\rho^N, \tau_2^N} = -\frac{du^*}{d\rho^*} \mid_{\rho^{*N}, \tau_2^{*N}} = 0, \tag{12}$$

where $\widetilde{E}_{22} = E_{22} - E_{23} Z_{33}^{-1} E_{32} < 0$ using the properties of the expenditure and GDP functions.[15] From equations (12) it is evident that in the case of consumption taxes, the slope of the joint welfare function at the Nash equilibrium is positive. This implies that the Nash equilibrium

[14] For example, consider the case where the tradable good whose consumption pollutes is the use of cars for leisure purposes, and the non-tradable whose consumption is not polluting is housing. Under our assumption that these two goods are substitutes in consumption, i.e., $E_{23} > 0$, and the inflow of capital increases the stock of houses, i.e., $R_{3K} > 0$, then the Nash equilibrium policy is a consumption tax on the use of cars and a tax on capital.

[15] This can written as $\widetilde{E}_{22} = E_{22} - E_{23} Z_{33}^{-1} E_{32} = Z_{33}^{-1}(E_{22} Z_{33} - E_{23} E_{32}) = Z_{33}^{-1}(E_{22} E_{33} - E_{22} R_{33} - E_{23} E_{32}) = Z_{33}^{-1}(E_{22} E_{33} - E_{23} E_{32} - E_{22} R_{33})$ which is negative using the properties of the Hicksian demand and the output supply functions.

consumption tax is lower than the cooperative consumption tax rate, i.e., $\tau_2^N < \tau_2^C$. Intuitively, in Home, the higher consumption tax on the polluting good reduces its consumption, directly and indirectly through the change in the demand for the non-tradable good. As a result, there is lower consumption generated pollution in Home, thus, a lower pollution leakage effect (spillover) to Foreign, affecting positively that country's welfare. This positive effect on Foreign's welfare is not accounted for by Home when it chooses its consumption tax policy non-cooperatively. Thus, the Nash equilibrium consumption tax is lower than the cooperative one. When pollution is local, i.e., $\beta = \beta^* = 0$, the Nash equilibrium consumption tax is efficient.

For the capital tax, however, the slope of the joint welfare function at the Nash equilibrium is zero. This implies that the Nash equilibrium capital tax coincides with the cooperative equilibrium one, i.e., $\rho^N = \rho^C$, thus it is efficient. That is, when both countries chooses their capital taxes non-cooperatively, a further increase of the capital tax by one country does not affect the welfare of the other. This result holds regardless of whether pollution is local or is transboundary. Similarly, we can examine the efficiency of Foreign's Nash equilibrium tax rates ρ^{*N} and τ_2^{*N} by using equations (A.5) and (A.7) from the Appendix.

Based on the result of this subsection, we state the following Proposition.

Proposition 1 *Consider the case where only the consumption of the tradable good is polluting, and a consumption and a capital tax are at the government's disposal to control for consumption generated pollution. The Nash equilibrium calls for (i) a consumption tax on the polluting good, and (ii) a capital tax. The Nash equilibrium consumption tax is inefficiently low while the capital tax is efficient.*

3.2 Nash equilibrium capital taxes when consumption taxes are zero

Next, we examine the Nash equilibrium capital taxes when governments cannot use consumption taxes. Using equations (8) and (A.6) in the Appendix, and setting $(du/d\rho) = 0$ and $(du^*/d\rho^*) = 0$, when consumption taxes are zero, the Nash equilibrium capital tax for Home is obtained as follows:

$$\rho^N = \alpha_2 E_z [E_{23} Z_{33}^{-1} R_{3K} - \beta E_{23}^* {Z_{33}^*}^{-1} R_{3K}^*]. \tag{13}$$

Equation (13) shows that in this case, the Nash equilibrium policy on capital can be either a tax or a subsidy. Now there are two terms, capturing the effect of a Home capital tax on Home and Foreign pollution, and these two effects are of opposite signs. Comparing equation (13) to

(10) indicates that when consumption taxes are absent, as opposed to both instruments being available, an additional term emerges, i.e., the first right-hand-side term. This is because the government has at its disposal only a capital tax to meet the two policy objectives, i.e., to control for domestically generated pollution and for the pollution leakage effect due to international capital mobility. Under the assumption that $E_{23} > 0$, $E^*_{23} > 0$, and $R^*_{3K} > 0, R_{3K} > 0$, the first right-hand-side term is negative (effect on Home pollution) while the second (effect on Foreign pollution) is positive. The Nash equilibrium policy on capital is either a capital subsidy or a lower capital tax compared to when both policy instruments are available. The intuition of this results is as follows. When the consumption tax is zero, the consumption of good 2 and pollution are larger relative to the case of non-zero consumption taxes. If the government reduces the capital tax, then, the net rate of return to the factor increases, causing a capital inflow. Production of the non-tradable good increases, reducing its price and increasing its consumption. Since $E_{23} > 0$, the consumption of the polluting good falls, reducing pollution. Thus, Home reduces the capital tax or even subsidizes capital in order to reduce pollution generated from local consumption.[16]

When pollution is local, i.e., $\beta = 0$, the Nash equilibrium policy is a capital subsidy. Thus, with zero consumption taxes, the Nash equilibrium policy requires a capital subsidy to lower consumption generated local pollution.

Consider the special case where countries are symmetric. That is, $E_{23} = E^*_{23}$, $R^*_{3K} = R_{3K}$, and $Z_{33} = Z^*_{33}$. The Nash equilibrium capital tax in equation (13) becomes $\rho^N = \alpha_2 E_z[(1 - \beta)E_{23}Z_{33}^{-1}R_{3K}]$. If cross border pollution is perfect, i.e., $\beta = 1$, then, the Nash equilibrium policy on capital calls for a zero tax.[17] The positive effect of an increase in capital tax on Home's welfare through the decrease in pollution generated in Foreign is exactly offset by the negative effect on its welfare through the increase in pollution generated in Home. If, however, cross border pollution is not perfect, i.e., $\beta < 1$, then, the Nash equilibrium policy on capital is a subsidy.[18] At this point it is worth emphasizing that if countries are symmetric and $\beta < 1$, the Nash equilibrium policy on capital when both policy instruments are available is the opposite to the one when only the policy on capital is available. Since $E_{23} > 0$ and $R_{3K} > 0$, then, when both policy instruments are available, the Nash equilibrium policy on capital is a tax, i.e.,

[16] The same results emerge in the case where the non-tradable and the polluting goods are complements in consumption and $R_{3K} < 0$.

[17] The same conclusion is reached by Eichner and Pethig (2019) who show that the optimal capital taxes are zero when countries are large and symmetric, pollution is perfect, i.e., $\beta = 1$, but pollution is production generated.

[18] The Nash equilibrium policy on capital is a tax if either $E_{23} < 0$ and $R^*_{3K} > 0$, or $E_{23} > 0$ and $R^*_{3K} < 0$.

equation (10), while when only the policy on capital is available, the Nash equilibrium policy is a capital subsidy, i.e., see equation (13).

We now examine the efficiency of the Nash equilibrium capital tax $\left(\rho^N, \rho^{*N}\right)$ vis-a-vis the corresponding cooperative equilibrium tax rates $\left(\rho^C, \rho^{*C}\right)$ when $\tau_2 = \tau_2^* = 0$. Using the same procedure as before and equations (A.2) and (A.7) in the Appendix, we can easily show that $\frac{du^*}{d\rho} = -\frac{du^*}{d\rho^*} = 0$ and $\frac{du}{d\rho^*} = -\frac{du}{d\rho} = 0$. Thus, the slope of the two joint welfare functions at the Nash equilibrium is zero, which means that the Nash (non-cooperative) equilibrium is efficient. That is, when both countries set their capital taxes (subsidies) at their Nash equilibrium levels, a further increase in one country's capital tax (subsidy) does not affect the other's welfare, rendering the Nash equilibrium efficient. Thus, the result of Ogawa and Wildasin (2009), who show that when pollution is related to capital, the Nash equilibrium capital taxes are efficient, holds also in our model where non-tradable goods exist and pollution is generated from consumption.

3.3 Nash equilibrium consumption taxes when the capital taxes are zero

Now, it is only a consumption tax that is available to control for pollution generated from the consumption of the tradable good 2. Using equation (9) when $\rho = \rho^* = 0$, for Home, we get:

$$\Delta \frac{du}{d\tau_2} = [\tau_2 - \alpha_2 E_z]\Phi_2 + B_2, \tag{14}$$

where $B_2 = \alpha_2 \beta E_z E_{23}^* Z_{33}^{*^{-1}} R_{3K}^* R_{K3} Z_{33}^{-1} E_{32} Z_{33} Z_{33}^* > 0$, and as shown in the Appendix, $\Phi_2 = \Delta E_{22} - E_{23} Z_{33}^{-1} E_{32}(R_{KK} + \widetilde{R}_{K^*K^*}^*) Z_{33} Z_{33}^* > 0$, regardless of the signs of E_{23} and R_{K3}. Setting $\frac{du}{d\tau_2} = 0$, and $\frac{du^*}{d\tau_2^*} = 0$, we get the Nash equilibrium consumption tax for Home, when capital taxes are zero, as follows:

$$\tau_2^N = \alpha_2 E_z - (B_2/\Phi_2). \tag{15}$$

Thus, when capital taxes cannot be used by the governments, the Nash equilibrium consumption tax on the polluting good is lower than the pollution damage caused by a unit of consumption of this good, i.e., $\tau_2^N < \alpha_2 E_z$.[19] Intuitively, in this case, the decrease of the consumption tax, increases the consumption of good 2 and reduces the demand for the non-tradable good since they are substitutes in consumption. The price of the non-tradable good and the return to capital fall, thus, causing an outflow of capital from Home into Foreign. The inflow of capital

[19] Note that this result holds regardless of the signs of E_{23} and R_{K3}.

into Foreign increases the production of the non-tradable good in that country, which reduces its price and increasing its consumption. Consumption of the polluting good 2 in Foreign and thus pollution and cross-border pollution fall. Thus, Home's optimal consumption tax should be lower than the pollution damage caused by a unit of consumption of good 2 in order to reduce the leakage of cross border pollution from Foreign i.e., reduce the spillback. Thus, when a capital tax/subsidy is not at a government's disposal, the Nash equilibrium consumption tax is lower than its rate when both instruments are available, since it is used strategically to mitigate the pollution leakage. Similar results hold for Foreign.

This result ascertains that small open economies can act strategically in policy making. That is, they engage in a race to the bottom in setting consumption taxes, in order to mitigate the pollution leakage effect. In the relevant literature where cross-border pollution is production generated and countries are assumed to be large in world capital markets, the Nash equilibrium production or emission taxes are lower to their cooperative equilibrium rates, e.g., Eichner and Pethig (2019), Tsakiris et al. (2017).

In terms of the efficiency of the Nash equilibrium consumption taxes $\left(\tau_2^N, \tau_2^{*N}\right)$ vis-a-vis the corresponding cooperative equilibrium tax rates $\left(\tau_2^C, \tau_2^{*C}\right)$ when $\rho = \rho^* = 0$, we follow the same procedure as before. That is, in order to examine whether the Nash equilibrium consumption taxes are efficient, it suffices to examine the sign of the terms $\frac{du^*}{d\tau_2}$ and $\frac{du}{d\tau_2^*}$. Using equation (A.3) in the Appendix when $\rho^* = 0$, for Home, we get:

$$\Delta \frac{du^*}{d\tau_2} = -E_{23}^*[\tau_2^* - \alpha_2 E_z^*][E_{32} R_{3K} R_{3K}^*] - \alpha_2 \beta^* E_z^* \Phi_2, \tag{16}$$

which evaluated at Nash equilibrium becomes,

$$\Delta \frac{du^*}{d\tau_2} = -\alpha_2 \beta^* E_z^* \Phi_2 + [B_2^*/\Phi_2^*][E_{23}^* E_{32} R_{3K} R_{3K}^*]. \tag{17}$$

Equation (17) shows that the effect of an increase of Home's consumption tax on Foreign's welfare is ambiguous.[20] At Nash equilibrium the slope of the joint welfare function can be positive or negative, meaning that the Nash equilibrium consumption tax can be inefficiently low or high. Intuitively, an increase in Home's consumption tax affects Foreign welfare through two channels. First, the increase in Home's consumption tax reduces the consumption of its polluting good, directly and indirectly through the change in the price of the non-tradable good.

[20] Similar results are obtained for Foreign's consumption tax rate τ_2^*.

Cross-border pollution falls, affecting positively Foreign's welfare. This effect is shown by the first right-hand-side term in equation (17). Second, it affects Foreign's welfare negatively, as shown by the second right-hand-side term of the equation. This effect is caused by the policy induced capital movements and changes in the price of the non-tradable goods, given that tax policies are not at their first best optimum levels. Intuitively, when both policy instruments are available, the Nash equilibrium policy for Foreign is a consumption and a capital tax. Since now the capital tax in Foreign is zero, this implies that Foreign's capital stock is higher and that of Home's is lower and thus, production of good 3 is lower in the latter country. Thus, when the consumption tax increases and the consumption of good 2 decreases, the demand for good 3 increases, causing its price to increase. Since the production of good 3 is low, this will cause higher increase in its price, higher reduction in its consumption and higher increase in the consumption of good 2 and pollution, affecting negatively Foreign's welfare. Based on the discussion of the previous two subsections, we state the following Proposition:

Proposition 2 *Consider the case where only the consumption of the tradable good is polluting. Relative to the case where both instruments are available, (i) when a capital tax is the only available instrument, the Nash equilibrium calls for a lower capital tax or even a capital subsidy, which is efficient, and (ii) when a consumption tax is the only available instrument, the Nash equilibrium calls for a lower consumption tax. This consumption tax can be inefficiently low or high.*

4 Nash equilibrium taxes when the consumption of the non-tradable good is polluting

In this section we analyze the case where the consumption of the tradable goods 1 and 2 is a clean activity while the consumption of the non-tradable good 3 pollutes, i.e., $\alpha_2 = \alpha_2^* = 0$, $\alpha_3 > 0$ and $\alpha_3^* > 0$. A tax is imposed on the consumption of the polluting non-tradable good 3.[21] Totally differentiating the system of equations (1)-(7), and substituting the expressions for dz and dz^* into the differentiated representative consumers' budget constraints, we obtain the matrix system (A.8). We examine the Nash equilibrium policies when the governments can impose (i) simultaneously both capital and consumption taxes, (ii) only a capital tax, and (iii)

[21] The tradable good whose consumption is not polluting could be certain types of services, e.g., financial, and customer services. The non-tradable good whose consumption is polluting, could be the use of electricity for leisure purposes.

only a consumption tax on the polluting non-tradable good 3.

4.1 Nash equilibrium consumption and capital taxes

Using equations (A.9) and (A.10) in the Appendix and following the methodology of the previous section, when simultaneously chosen, Home's Nash equilibrium consumption and capital taxes are given as follows:

$$\rho^N = -\alpha_3 \beta E_z E_{33}^* {Z_{33}^*}^{-1} R_{3K}^*, \tag{18}$$

$$\tau_3^N = \alpha_3 E_z. \tag{19}$$

Equations (18) and (19) indicate that the Nash equilibrium policy calls for (i) a capital subsidy, and (ii) as expected, a consumption tax on the non-tradable polluting good which equals the damage on welfare caused by a unit consumption of this good. Intuitively, a consumption tax on the non-tradable good reduces its demand, resulting to a lower producers' price and a lower marginal revenue product of capital. The latter effect induces a capital outflow from Home into Foreign. The increase in capital supply in Foreign, increases the production of the non-tradable good, leading to a lower price and increased consumption of that good in that country. Thus, pollution in Foreign increases, causing a pollution leakage effect affecting negatively Home's welfare. To reduce the inflow of pollution from Foreign, Home subsidizes capital in order to reduce capital outflow.

Comparing the present Nash equilibrium capital policy to the Nash equilibrium capital policy when the consumption of the tradable good is polluting, i.e., equations (18) and (10), we observe that the Nash equilibrium in the former case calls for a capital tax while in the latter calls for a capital subsidy. Thus the Nash equilibrium policy on capital depends crucially on which good's consumption is the polluting one.

To examine the efficiency of Nash equilibrium, as previously explained, we evaluate the signs of $\frac{du^*}{d\tau_3}$ and $\frac{du^*}{d\rho}$ at the Nash equilibrium values. Substituting into equations (A.11) and (A.12) in the Appendix the Nash equilibrium values from equations (18) and (19) we obtain:

$$\frac{du^*}{d\tau_3} \mid_{\rho^N, \tau_3^N} = -\alpha_3 \beta^* E_z^* E_{33} R_{33} Z_{33}^{-1} > 0 \quad \text{and} \quad \frac{du^*}{d\rho} \mid_{\rho^N, \tau_3^N} = -\frac{du^*}{d\rho^*} \mid_{\rho^{*N}, \tau_3^{*N}} = 0. \tag{20}$$

where the expression for $\frac{du^*}{d\rho^*}$ is given by equation (A.14) in the Appendix. From equation (20) we see that at the Nash equilibrium the slope of the joint welfare function in the case of consumption taxes is positive while in the case of capital taxes is zero. This implies that the Nash equilibrium consumption tax is inefficiently lower than the cooperative one, while the Nash equilibrium capital tax is efficient.

Similarly, we can examine the efficiency of Foreign's Nash equilibrium tax rates ρ^{*N} and τ_3^{*N} by using equations (A.13) and (A.16) from the Appendix.

4.2 Nash equilibrium capital taxes when consumption taxes are zero

Using equation (A.9) in the Appendix when consumption taxes are zero, for the case of Home, we get:

$$\rho^N = \alpha_3 E_z [E_{33} Z_{33}^{-1} R_{3K} - \beta E_{33}^* Z_{33}^{*^{-1}} R_{3K}^*]. \tag{21}$$

Equation (21) shows that the Nash equilibrium policy on capital is ambiguous. With both policy instruments being available, the Nash equilibrium is a capital subsidy. When only the policy on capital is available, the Nash equilibrium calls for a lower subsidy or even a tax. Since consumption taxes cannot be used, it is the policy on capital that is used to control for the locally generated consumption pollution. Intuitively, when consumption taxes are zero, consumption and pollution are high. The imposition of a lower capital subsidy or even a capital tax, causes a capital outflow, which reduces the domestic production of the non-tradable good, increasing its price, and reducing its consumption and thus the locally generated pollution. If pollution does not affect Foreign welfare, i.e., $\beta = 0$, then, the optimal policy calls for a capital tax.

In the special case where countries are symmetric, we have that $E_{33} = E_{33}^*$, $R_{3K}^* = R_{3K}$, and $Z_{33} = Z_{33}^*$. The Nash equilibrium capital tax in equation (21) reduces to $\rho^N = \alpha_2 E_z (1 - \beta) E_{33} Z_{33}^{-1} R_{3K}$. If cross border pollution is perfect, i.e., $\beta = 1$, then the Nash equilibrium policy on capital is again a zero tax. If, however, $\beta < 1$, then the optimal policy is a capital tax. It is worth emphasizing that when countries are symmetric and $\beta < 1$, the optimal policy on capital is opposite to the one when both policy instruments are available. Thus, the Nash equilibrium policy on capital is subsidy when both policy instruments are available and it is a tax when only the policy on capital is available.

4.3 Nash equilibrium consumption taxes when capital taxes are zero

Using equations (A.10) and (A.15) in the Appendix and setting $\frac{du}{d\tau_3} = 0$, $\frac{du^*}{d\tau_3^*} = 0$, we get the Nash equilibrium consumption tax on the non-tradable good for Home when capital taxes are zero as follows:

$$\tau_3^N = \alpha E_z - (B_3/\Phi_3), \tag{22}$$

where $B_3 = \alpha_3 \beta E_z E_{33}^* R_{3K}^* R_{K3} < 0$ and as shown in the Appendix, $\Phi_3 = \Delta - E_{33} Z_{33}(R_{KK} + \widetilde{R}_{K^*K^*}^*) < 0$. Equation (22) shows that the Nash equilibrium consumption tax on non-tradable good is lower than the pollution damage on welfare caused by the consumption of a unit of the non-tradable good. The reason for this lower consumption tax is to reduce the cross border pollution leakage, i.e., reduced spillback.

Observing equations (22) and (15) we conclude that in the absence of capital taxes/subsidies, the small open economies do have an incentive to act strategically in policy making, regardless of whether consumption pollution is due to the tradable or the non-tradable good. In either case, they engage in a race to the bottom in setting consumption taxes, in order to mitigate the pollution leakage effect.

The following Proposition summarizes the main findings of this section.

Proposition 3 *Consider the case where only the consumption of the non-tradable good is polluting. Then,*

- *When both instruments are available, the Nash equilibrium calls for (i) a consumption tax on the non-tradable polluting good, and (ii) a capital subsidy. The Nash equilibrium consumption tax is inefficiently low while the capital subsidy is efficient.*
- *When a consumption tax is the only available instrument, the Nash equilibrium consumption tax on non-tradable good is lower than αE_z.*
- *When a capital tax is the only available instrument, the Nash equilibrium calls (i) for a capital tax or a subsidy when countries are asymmetric, and (ii) a positive (zero) capital tax when countries are symmetric and $\beta < 1 (\beta = 1)$.*

5 Concluding Remarks

We develop a model of two asymmetric and small economies in world commodity and capital markets. The key features of the model are the existence of non-tradable goods, international capital mobility, and cross-border pollution due to the consumption of tradable or of non-tradable goods. These features of the model lead to strategic policy interaction between them.

The key results of the paper are the following. The Nash equilibrium policy calls for a consumption tax and a capital tax or subsidy. The strategic policy interaction between the two small open economies comes about because when one of them imposes a consumption tax to control for the locally generated consumption pollution, consumption leakage effect emerges from the other due to the presence of international capital mobility and of the non-tradable goods. Then, to mitigate this leakage effect, countries must adopt either a capital tax or a capital subsidy, depending on whether it is the consumption of the tradable or of the non-tradable good that pollutes. That is, the capital tax/subsidy is non-zero, despite the use of consumption taxes to control for pollution generated from consumption. Moreover, irrespectively of which good's consumption is polluting, the Nash equilibrium policy on capital is efficient while the consumption tax is inefficiently low. In the absence of non-tradable goods, the Nash equilibrium policy on capital is zero taxes.

If governments cannot use simultaneously both policy instruments, but only one, then, the Nash equilibrium level of this instrument is chosen to deal with both, the locally generated consumption pollution and the pollution leakage effect from the other country. Thus, when only consumption taxes are available, the Nash equilibrium policy calls for a lower consumption tax compared to the case where both policy instruments are available. When only capital taxes are at the governments' disposal, compared to the case where both policy instruments are available, the Nash equilibrium policy on capital calls (i) for a lower tax or even a subsidy when the consumption of the tradable good pollutes, and (ii) for a lower subsidy or even a tax when the consumption of the non-tradable good pollutes.

Appendix

The consumption of the tradable good is polluting $(\alpha_2 > 0, \;\; \alpha_3 = 0)$

Totally differentiating the system of equations (1)-(7), and substituting the expressions for dz and dz^* into the differentiated income-expenditure identities, we obtain the following matrix system when the traded good 2 is polluting:

$$\begin{bmatrix} 1 & 0 & -\rho & E_{23}\left(\alpha_2 E_z - \tau_2\right) & \alpha_2 E_z \beta E_{23}^* \\ 0 & 1 & \rho^* & \alpha_2 E_{z^*}^* \beta^* E_{23} & E_{23}^*\left(\alpha_2 E_z^* - \tau_2^*\right) \\ 0 & 0 & H & R_{K3} & -R_{K^*3}^* \\ 0 & 0 & -R_{K3} & Z_{33} & 0 \\ 0 & 0 & R_{K^*3}^* & 0 & Z_{33}^* \end{bmatrix} \begin{bmatrix} du \\ du^* \\ dK \\ dp_3 \\ dp_3^* \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} d\rho + \begin{bmatrix} 0 \\ 0 \\ -1 \\ 0 \\ 0 \end{bmatrix} d\rho^*$$

$$+ \begin{bmatrix} -E_{22}\left(\alpha_2 E_z - \tau_2\right) \\ -\alpha_2 E_{z^*}^* \beta^* E_{22} \\ 0 \\ -E_{23} \\ 0 \end{bmatrix} d\tau_2 + \begin{bmatrix} -\alpha_2 E_z \beta E_{22}^* \\ -E_{22}^*\left(\alpha_2 E_z^* - \tau_2^*\right) \\ 0 \\ 0 \\ -E_{23}^* \end{bmatrix} d\tau_2^*, \tag{A.1}$$

where $H = R_{KK} + R_{K^*K^*}^* (< 0)$, $Z_{33} = E_{33} - R_{33} (< 0)$, and $Z_{33}^* = E_{33}^* - R_{33}^* (< 0)$. The determinant of the left-hand-side coefficients matrix is $\Delta = Z_{33} Z_{33}^* \left(\widetilde{R}_{KK} + \widetilde{R}_{K^*K^*}^*\right)$ is negative, $\widetilde{R}_{KK} = R_{KK} + R_{K3} Z_{33}^{-1} R_{K3} (< 0)$ and $\widetilde{R}_{K^*K^*}^* = R_{K^*K^*}^* + R_{K^*3}^* Z_{33}^{*-1} R_{K^*3}^* (< 0)$.

$$\Delta \frac{du^*}{d\rho} = -Z_{33} Z_{33}^* \left[\rho^* - R_{K^*3}^* Z_{33}^{*-1} E_{23}^* \left(\alpha_2 E_z^* - \tau_2^*\right) + R_{K3} Z_{33}^{-1} \alpha_2 E_{z^*}^* \beta^* E_{23}\right], \tag{A.2}$$

$$\Delta \frac{du^*}{d\tau_2} = \left\{ \begin{array}{c} -\alpha_2 E_{z^*}^* \beta^* Z_{33} Z_{33}^* \left[E_{22}\left(\widetilde{R}_{KK} + \widetilde{R}_{K^*K^*}^*\right) - E_{23} Z_{33}^{-1} E_{23}\left(R_{KK} + \widetilde{R}_{K^*K^*}^*\right)\right] \\ +E_{23} R_{K3} Z_{33}^* \left[-\rho^* + R_{K^*3}^* Z_{33}^{*-1} E_{23}^* \left(\alpha_2 E_z^* - \tau_2^*\right)\right] \end{array} \right\}, \tag{A.3}$$

$$\Delta \frac{du^*}{d\tau_2^*} = \left\{ \begin{array}{c} (\alpha_2 E_{z^*}^* - \tau_2^*)[-E_{22}^* \Delta + E_{23}^* E_{32}^* (H Z_{33} + R_{K3} R_{3K})] \\ +E_{23}^* R_{3K^*}^* Z_{33} (\rho^* + \alpha_2 \beta^* E_{z^*}^* E_{23} R_{3K} Z_{33}^{-1}) \end{array} \right\}, \tag{A.4}$$

$$\Delta \frac{du}{d\tau_2^*} = \left\{ \begin{array}{c} -\alpha_2 \beta E_z \left[\Delta E_{22}^* - E_{23}^* E_{32}^* \left(H Z_{33} + R_{K3} R_{3K}\right)\right] \\ +E_{23}^* R_{K3}^* Z_{33} \left[-\rho + R_{K3} Z_{33}^{-1} E_{23} \left(\alpha_2 E_z - \tau_2\right)\right] \end{array} \right\}, \tag{A.5}$$

$$\Delta \frac{du^*}{d\rho^*} = Z_{33} Z_{33}^* \left[\rho^* - R^*_{K^*3} Z^{*^{-1}}_{33} E^*_{23} \left(\alpha_2 E^*_z - \tau^*_2 \right) + R_{K3} Z^{-1}_{33} \alpha_2 E^*_{z^*} \beta^* E_{23} \right], \tag{A.6}$$

$$\Delta \frac{du}{d\rho^*} = Z_{33} Z_{33}^* \left[-\rho + (\alpha_2 E_z - \tau_2) E_{23} Z^{-1}_{33} R_{3K} - \alpha_2 \beta E_z E^*_{23} Z^{*-1}_{33} R^*_{3K} \right]. \tag{A.7}$$

Proof of the sign of Φ_2

$$\begin{aligned} \Phi_2 &= \Delta E_{22} - E_{23} Z^{-1}_{33} E_{32} (R_{KK} + \widetilde{R}^*_{K^*K^*}) Z_{33} Z^*_{33} \Longrightarrow \\ \Phi_2 &= \Delta \left[E_{22} - E_{23} Z^{-1}_{33} E_{32} \frac{(R_{KK} + \widetilde{R}^*_{K^*K^*}) Z_{33} Z^*_{33}}{(\widetilde{R}_{KK} + \widetilde{R}^*_{K^*K^*}) Z_{33} Z^*_{33}} \right] \Longrightarrow \Phi_2 = \Delta \left[E_{22} - E_{23} Z^{-1}_{33} E_{32} \Gamma \right], \end{aligned}$$

where by the properties of the revenue function, $0 < \Gamma = [R_{KK} + \widetilde{R}^*_{K^*K^*}]/[\widetilde{R}_{KK} + \widetilde{R}^*_{K^*K^*}] < 1$. Recall also that from the properties of the minimum expenditure function, $\widetilde{E}_{22} = E_{22} - E_{23} Z^{-1}_{33} E_{32} < 0$. Therefore, $E_{22} - E_{23} Z^{-1}_{33} E_{32} \Gamma < 0$. Thus, $\Phi_2 > 0$.

The consumption of the non-tradable good is polluting ($\alpha_2 = 0, \quad \alpha_3 > 0$)

Using similar procedure, we get following matrix system when the consumption of tradable goods is a clean activity while the consumption of non-tradable good is polluting:

$$\begin{bmatrix} 1 & 0 & -\rho & E_{33}(\alpha_3 E_z - \tau_3) & \alpha_3 E_z \beta E^*_{23} \\ 0 & 1 & \rho^* & \alpha_3 E^*_{z^*} \beta^* E_{33} & E^*_{33}(\alpha_3 E^*_z - \tau^*_3) \\ 0 & 0 & H & R_{K3} & -R^*_{K^*3} \\ 0 & 0 & -R_{K3} & Z_{33} & 0 \\ 0 & 0 & R^*_{K^*3} & 0 & Z^*_{33} \end{bmatrix} \begin{bmatrix} du \\ du^* \\ dK \\ dp_3 \\ dp^*_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} d\rho + \begin{bmatrix} 0 \\ 0 \\ -1 \\ 0 \\ 0 \end{bmatrix} d\rho^*$$

$$\begin{bmatrix} -E_{33}(\alpha_3 E_z - \tau_3) \\ -\alpha_3 E^*_{z^*} \beta^* E_{33} \\ 0 \\ -E_{33} \\ 0 \end{bmatrix} d\tau_3 + \begin{bmatrix} -\alpha_3 E_z \beta E^*_{33} \\ -E^*_{33}(\alpha_3 E^*_z - \tau^*_3) \\ 0 \\ 0 \\ -E^*_{33} \end{bmatrix} d\tau^*_3, \tag{A.8}$$

$$\Delta \frac{du}{d\rho} = -Z_{33} Z^*_{33} \left[-\rho + (\alpha_3 E_z - \tau_3) E_{33} Z^{-1}_{33} R_{3K} - \alpha_3 \beta E_z E^*_{23} Z^{*^{-}}_{33} R^*_{3K} \right], \tag{A.9}$$

$$\Delta \frac{du}{d\tau_3} = \left\{ \begin{array}{c} (\alpha_3 E_z - \tau_3)[-E_{33}\Delta + E_{33} E_{33} (H Z^*_{33} + R^*_{K3} R^*_{3K})] \\ + Z^*_{33} E_{33} R_{3K} (\rho + \alpha_3 \beta E_z E^*_{33} Z^{*^{-1}}_{33} R^*_{3K}) \end{array} \right\}, \tag{A.10}$$

$$\Delta \frac{du^*}{d\rho} = -Z_{33}Z^*_{33}\left[\rho^* - R^*_{K^*3}Z^{*^{-1}}_{33}E^*_{33}\left(\alpha_3 E^*_z - \tau^*_3\right) + R_{K3}Z^{-1}_{33}\alpha_3 E^*_{z^*}\beta^* E_{33}\right], \tag{A.11}$$

$$\Delta \frac{du^*}{d\tau_3} = \left\{ \begin{array}{c} -\alpha_3 E^*_{z^*}\beta^* E_{33}Z_{33}Z^*_{33}\left[\left(\widetilde{R}_{KK} + \widetilde{R}^*_{K^*K^*}\right) - E_{33}Z^{-1}_{33}\left(R_{KK} + \widetilde{R}^*_{K^*K^*}\right)\right] \\ +E_{33}R_{K3}Z^*_{33}\left[-\rho^* + R^*_{K^*3}Z^{*^{-1}}_{33}E^*_{33}\left(\alpha_3 E^*_z - \tau^*_3\right)\right] \end{array} \right\}, \tag{A.12}$$

$$\Delta \frac{du}{d\rho^*} = Z_{33}Z^*_{33}\left[-\rho + (\alpha_3 E_z - \tau_3)E_{33}Z^{-1}_{33}R_{3K} - \alpha_3\beta E_z E^*_{33}Z^{*-1^-}_{33}R^*_{3K}\right], \tag{A.13}$$

$$\Delta \frac{du^*}{d\rho^*} = -Z_{33}Z^*_{33}\left[\rho^* - R^*_{K^*3}Z^{*^{-1}}_{33}E^*_{33}\left(\alpha_3 E^*_z - \tau^*_3\right) + R_{K3}Z^{-1}_{33}\alpha_3 E^*_{z^*}\beta^* E_{33}\right], \tag{A.14}$$

$$\Delta \frac{du^*}{d\tau^*_3} = \left\{ \begin{array}{c} \left(\alpha_3 E^*_z - \tau^*_3\right)\left[-E^*_{33}\Delta + E^*_{33}E^*_{33}(HZ_{33} + R_{K3}R_{3K})\right] \\ +Z_{33}E^*_{33}R^*_{3K}(\rho^* + \alpha_3\beta^* E^*_z E_{33}Z^{-1}_{33}R_{3K}) \end{array} \right\}, \tag{A.15}$$

$$\Delta \frac{du}{d\tau^*_3} = \left\{ \begin{array}{c} -\alpha_3 E_z\beta\left[E^*_{33}\Delta - E^*_{33}E^*_{33}\left(HZ_{33} + R_{K3}R_{3K}\right)\right] \\ +E^*_{33}R^*_{K3}Z_{33}\left[-\rho + R_{3K}Z^{-1}_{33}E_{33}\left(\alpha_3 E_z - \tau_3\right)\right] \end{array} \right\}. \tag{A.16}$$

Proof of the sign of Φ_3

$$\begin{aligned} \Phi_3 &= \Delta - E_{33}(R_{KK} + \widetilde{R}^*_{K^*K^*})Z^*_{33} \Longrightarrow \\ \frac{\Phi_3}{\Delta} &= 1 - [E_{33}(R_{KK} + \widetilde{R}^*_{K^*K^*})Z^*_{33}]/\Delta \Longrightarrow \frac{\Phi_3}{\Delta} = [Z_{33} - E_{33}\Gamma]/Z_{33}, \end{aligned}$$

where $\Gamma = [R_{KK} + \widetilde{R}^*_{K^*K^*}]/[\widetilde{R}_{KK} + \widetilde{R}^*_{K^*K^*}] < 1$. Using the properties of the expenditure and GDP functions, $\frac{\Phi_3}{\Delta} > 0$. Thus $\Phi_3 < 0$.

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