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Tax Competition in the Presence of Environmental Spillovers

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Abstract

This paper examines the efficiency of destination- and origin-based consumption taxes, in the presence of consumption generated perfect cross-border pollution spillovers, when tax revenue either finances public pollution abatement or it is lump-sum distributed. When consumption tax revenue finances the provision of public pollution abatement and regions have identical preferences then, the non-cooperative equilibrium origin-based consumption taxes are efficient while the destination-based consumption taxes are inefficiently low. When, however, consumption tax revenue is lump-sum distributed, then, the destination-based tax principle leads to inefficiently low taxes while the origin-based tax principle leads either to inefficiently high or low taxes.

JEL classification: H21, H23, H41.

Keywords: Environmental spillovers, Efficiency, Tax competition, Tax principles.

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1 Introduction

The recent political developments unveil the difficulties regarding the implementation of the Paris climate agreement, the first-ever universal, legally binding global climate accord. Policymakers are rather skeptical when it comes to curb CO_2 emissions from production due to the fear for the loss of competitiveness of the local industries, e.g., Martin *et al.* (2014). In the public policy debate, however, less attention has been paid on emissions attributed to consumption. The radius of influence of consumption pollution may vary from a local level, such as various forms of Particulate Matters (e.g., $PM_{2.5}$ or PM_{10}), to an interregional or international level, such as carbon dioxide emissions (CO_2). Both types can affect human health and economic activity severely. Zhao *et al.* (2019) attest that of the 1.08 million premature deaths due to $PM_{2.5}$ emissions exposure in China in 2012, 20% are related to direct emissions from households activities (i.e., fuel combustion for home cooking, and/or independent heating) and 24% are related to household indirect emissions embodied in consumption of goods and services. Holladay (2008) summarizes that just under half of the CO_2 emissions in New York City are generated by consumption, while in North Carolina up to 54% of mercury emissions are by-products of consumption. As reported by Hu and McKitrick (2016) about half or more of various harmful pollutants in the US are generated from motor vehicles, whereas 71% of US CO_2 emissions are related to the consumption of energy.[1]

When pollution is generated from consumption, policies suited to regulate production generated pollution, e.g., emissions permits and quotas, are not appropriate to contain consumption emissions. Instead, consumption taxes and general goods and services taxes may serve as more suitable instruments, e.g., Fullerton and West (2002), Esteller-Moré *et al.* (2012), Michael and Hatzipanayotou (2013). Indeed, many governments have levied general consumption taxes or excise taxes on specific goods and services either to discourage "harmful" behaviors or to encourage "responsible" ones towards the environment. Such have been taxes on energy-consuming products, mineral oils and transport fuels, taxes on lightweight plastic bags, feed-in tariffs or premiums in the consumption of electricity, and taxes on products which produce environmentally harmful emissions.[2]

These tax policies present an advantage, this being the creation of revenue to governments over non-revenue generating environmental policies, e.g., environmental standards.[3] Such tax generated

[1] The US Environmental Protection Agency (EPA 2014) reports that in the US, about 40% of greenhouse gases are attributed to residential activity. In a highly influential study Jambeck *et al.* (2015) estimate the mass of land-based plastic waste entering the ocean and calculate that 275 million metric tons (MT) of plastic waste was generated in 192 coastal countries in 2010, with 4.8 to 12.7 million MT entering the ocean. Other examples of goods generating tailpipe pollution are fuels, tobacco products, pesticides, and solvents.

[2] For example, OECD (2014) pp. 135-160, reports: Per litre total taxation (VAT + excise) on premium unleaded gasoline: Australia 0.51, Canada 0.39, Germany 1.20, the U.K. 1.25, the U.S. 0.14. Per litre total taxation (VAT + excise) on light fuel oil for households: Austria 0.35, Denmark 0.95, Germany 0.25, the Netherlands 0.81. Taxes on sales and registration of motor vehicles: Austria VAT 20% + New Registration Tax (fuel efficiency, CO_2 emissions, polluting emissions), Belgium VAT 21% + Entry into Service Tax (age, engine power, CO_2 emissions, type of fuel gas), Germany VAT 19%, the Netherlands VAT 21% + Registration Tax (CO_2 emissions, motor fuel, value, electric propulsion), Norway VAT 25% + Registration Tax (engine performance, CO_2 emissions, NOx emissions, type of fuel, electric propulsion).

[3] Considering the specific case of pollution from motor vehicles Adamou *et al.* (2014) attest that welfare can increase when appropriate taxes yield positive revenues at the expense of consumer and producer surplus.

revenue can allow for the funding of various public sector activities, e.g., public pollution abatement to protect the environment.[4] Related to this issue, ample evidence shows that governments spend a considerable portion of their tax revenues for pollution and abatement control (PAC) activities. During 1990-2004 most countries public expenditures accounted for about $40-60\%$ of total PAC expenditures (see Linster and Zegel 2007). In a similar fashion, more than 60 countries world wide use feed-in tariffs, including the US, Canada, the European countries, Japan, and even China to finance renewable energy projects which contribute to climate mitigation (see Antoniou and Strausz 2017). Recent studies, e.g., Welsch (2006), Ng (2008), Vella *et al.* (2015), conclude that in developed countries higher marginal welfare gains occur for their residents with increased public expenditures on environmental improvements relative to other public sector expenditures.

Contribution of the paper: Motivated by the above developments we examine the efficiency of non-cooperative commodity taxation in the context of two regions Federal economy in the presence of perfect consumption generated cross-border pollution. Consumption taxes are levied on the basis of either the destination principle, i.e., commodity taxes which are levied in the jurisdiction of final consumption, or the origin principle, i.e., commodity taxes which are levied in the jurisdiction of production. Consumption tax revenue either finances the provision of public pollution abatement or is lump-sum distributed. This paper shows that, within our framework, both principles of commodity taxation are generally inefficient. When, however, revenue from taxation finances public pollution abatement, cross-border pollution is perfect, and preferences are identical, then the Nash equilibrium origin-based consumption taxes are efficient while destination-based taxes are inefficient. When consumption tax revenue is lump-sum rebated, the non-cooperative origin-based consumption taxes are either inefficiently low or high, and the Nash destination-based consumption taxes are inefficiently low.[5]

In the absence of consumption generated pollution, the literature has shown that consumption taxes under the destination principle are efficient while under the origin principle are inefficient. The reason for these opposing results relative to ours is the following: Under the destination principle consumption taxes of one region, in the absence of pollution, do not affect the welfare of the other region, while in the presence of consumption generated cross-border pollution they do. Under the origin principle, and in the absence of consumption pollution, a consumption tax by one region affects the welfare of the other region by decreasing its consumption and by changing the consumption tax revenue. In our model with public pollution abatement, when preferences are identical, a consumption tax by one region affects the other region's welfare negatively by reducing its consumption and positively by reducing its pollution. In this case, at the non-cooperative equilibrium, these two effects offset each other making consumption taxes efficient.

[4] Examples of public sector pollution abatement activities would include the treatment of waste in the sewage system, creation of environmentally friendlier landfills, tree-plantations for the absorption of CO_2 emissions, etc. Indirectly, the same effect is attained when public policies lead to a reduction of CO_2 emissions from consumption, such as the promotion of electric vehicles. Several EU countries provide incentives for this transition (see Balzhäuser 2020).

[5] Generally, the tax competition literature examines conditions under which non-cooperative policymaking may lead to socially efficient outcomes, e.g., Ogawa and Wildasin (2009), Silva and Yamaguchi (2010).

The complexity of the various national tax systems, the recorded difficulties in many countries to monitor and collect tax revenue, and the rapid growth of cross-border electronic trade and sales of services, have put severe restraints on the enforceability of the *destination principle* (DP) commodity taxation. Because of such intricacies, quite often destination-based taxes are held accountable for various administrative difficulties such as double taxation, and uncertainty for businesses and fiscal authorities, e.g., see OECD (2014) pp. 25-28. Instead, an alternative principle of commodity taxation, the *origin principle* (OP) has been discussed in public policy debates.[6] The choice of the most appropriate principle of commodity taxation is part of an ongoing debate especially within the European Union which constitutes an economic union trading with the rest of the world and thus adopting a common principle of commodity taxation is of vital importance (COM 2011). Our study shows that under perfect cross-border pollution and when preferences are identical, the origin-based consumption taxes are efficient.

Structure of the paper: The rest of the paper is organized as follows. Section 2 presents the related literature, and Section 3 the model. In Section 4 we examine the welfare effects and the efficiency of the non-cooperative setting of origin and destination-based consumption taxes when consumption tax revenue finances the provision of public pollution abatement. In Section 5 we examine the efficiency of the non-cooperative setting of origin and destination-based consumption taxes when consumption tax revenue is lump-sum rebated to each region's representative household. Section 6 provides the concluding remarks.

2 Related Literature

The literature on interregional/international tax competition examines various aspects of the DP and OP taxation principles, e.g., welfare dominance of the one over the other, efficiency of decentralized tax setting under each regime, employment and revenue implications. In the context of models of perfect competition, a general result is that under the DP, and when regions/countries are small in world commodity markets, non-cooperatively chosen commodity taxes are set efficiently. Under the OP, the non-cooperatively chosen commodity taxes are set inefficiently low due to a fundamental tax base externality (one region's higher tax increases the tax base of the other), e.g., see Mintz and Tulkens (1986). Lockwood (2001) shows, among other things, that (i) destination-based Nash equilibrium taxes are second-best efficient, and (ii) under the origin principle the tax base (fiscal) externality can be of any sign depending on the relationship between the private goods in consumption (i.e., complements or substitutes). Other studies examining the welfare ranking of the two taxation principles, include Keen and Wildasin (2004), who conclude that OP consumption taxes may be superior to DP taxes, source-based taxation of capital income may be superior to residence-based taxation, and tariff on trade flows may dominate free-trade. Moriconi and Sato (2009) in a model of two symmetric small open economies examine the impact

[6] As noted in OECD (2014), p. 24, "*...The key economic difference between the two principles is that the destination principle places all firms competing in a jurisdiction on an even footing whereas the origin principle places consumers in different jurisdictions on even footing...*".

of commodity tax competition on welfare and employment under DP and OP, in the presence of unemployment due to a rigid nominal wage. They show, among other things, that under DP the non-cooperative equilibrium taxes are higher than the optimal level, while under OP the results are ambiguous. Antoniou *et al.* (2019) show that the Nash equilibrium destination-based consumption taxes are lower than the corresponding cooperative equilibrium rates, if the exported goods are non-labor intensive. In the framework of imperfectly competitive open economy models, the issue of efficiency of the destination vs. origin-based commodity taxation has been examined, among others, by Keen and Lahiri (1998), Lockwood (2001), Keen *et al.* (2002), Haufler and Pflüger (2007), Kotsogiannis and Lopez-Garcia (2007). In the context of a small open economy, Davies and Paz (2011), and Chao and Yu (2015) examine the welfare implications of tariff and consumption tax reforms under destination and origin-based tax principles. Recently, Moriconi *et al.* (2019) shed light on the interaction between commodity taxation and product market regulations in open-to-trade economies.

The literature examining the welfare ranking of the DP and OP taxation principles in the presence of pollution externalities is very thin. Cremer and Gahvari (2006), in a perfectly competitive model of two identical small open economies set conditions under which either the DP or the OP taxation regime can Pareto-dominate the other in the presence of production generated pollution. However, to the best of our knowledge, the welfare ranking of the the DP and OP taxation principles in the presence of transboundary consumption generated pollution has not been examined.[7]

3 The Model

We consider a world of three open economies, Home, Foreign, and the Rest of the World (ROW) whose role is implicit in the analysis. Hence, variables related to ROW are not explicitly defined. Variables of Foreign are denoted by an asterisk ($*$). Home and Foreign are two regions which constitute a Federal economy vis-a-vis the ROW.[8] A representative household resides in the two regions and in the ROW, consuming three internationally traded commodities. A *numeraire* commodity 0 is produced by the two regions and the ROW, and it is exported by ROW to Home and Foreign. By assumption, the *numeraire* commodity is not traded between Home and Foreign.

Commodity 1, is produced by Home and ROW, and Home exports this good to Foreign and the ROW. Commodity 2 is produced by Foreign and ROW, and Foreign exports this good to Home and the ROW.[9] Consumption of the *numeraire* commodity 0 is a clean activity, but one unit

[7] A number of studies consider the environmental and welfare implications of consumption or emission taxes in the presence of local or cross-border consumption generated pollution, e.g., Chao *et al.* (2012), Michael and Hatzipanayotou (2013), Tsakiris *et al.* (2019). Other studies, using different analytical frameworks, examine the issue of efficiency of different policies in the presence of local or transboundary production generated pollution e.g., Silva and Caplan (1997), Chen and Woodland (2013), Angelopoulos *et al.* (2017), Montagna *et al.* (2020).

[8] Following examples such as the EU, the US, and Canada, Home and Foreign can be viewed either as two countries constituting an economic union vis-a-vis the ROW, or as two regions of a federal economy vis-a-vis the ROW.

[9] This pattern of production specialization implies that the economic union is a net exporter of goods "1" and "2" to ROW and a net importer of the numeraire, and is commonly used in the relevant literature of international

of consumption of commodities 1 and 2 generates one unit of pollution. Consumption generated pollution is perfectly transboundary affecting negatively the utility of households in Home and Foreign. Incoming pollution from the *ROW* to the two regions is simply a fixed additive term into their overall pollution functions, to be defined later on, and thus we opt to neglect it. The representative household in a region derives utility from the consumption of goods and from clean environment.

The production of all goods is untaxed.[10] Home and Foreign are small open economies relative to the *ROW*, i.e., their tax policies do not affect the world prices of the three consumption goods, and world commodity and factor markets are perfectly competitive. Moreover, trade of Home and Foreign with *ROW* is free. That is, neither region levies any tax on its exports to the *ROW*, or a tariff on its imports. As a result, producer prices in Home and Foreign are constant and for simplicity are set equal to one.[11] The production side is conveniently represented by the Gross Domestic Product (*GDP*) function. The *GDP* functions denote the maximum value of domestic production given producer prices and factor supplies. For example, consider Home which produces commodities "0" and "1". In this case, revenue from production is $R(P,\Omega) = \max\{p_0 x_0(p_0, p_1; \Omega_0) + p_1 x_1(p_0, p_1; \Omega_1)\}$ where $p_0 = p_1 = 1$. The profit maximizing output of each good is denoted by x_j, $j = 0, 1$. Ω_j is the amount of factors used in the production of the j^{th} commodity, $P \equiv [p_0, p_1]$, and Ω is the region's vector of fixed factor endowments. Because, by assumption, producer prices and factor endowments are constant, the *GDP* function reduces to a fixed value, i.e., $R(P,\Omega) \equiv R$. Similarly, we define Foreign's *GDP* functions as $R^*(P^*, \Omega^*) \equiv R^*$, where $P^* \equiv [p_0, p_2]$, $p_2 = 1$, and Ω^* is its vector of fixed factor endowments.[12]

Demand conditions and preferences are represented by the minimum expenditure function. Let, $e(1, q_1, q_2, r, u) = min\left\{\sum_{i=0}^{2} q_i c_i \mid \ U(c_0, c_1, c_2, r) \geq u\right\}$, be the minimum expenditure function for Home's representative household, where c_i, $i = 0, 1, 2$, are the quantities consumed of the three commodities. It captures the household's minimum expenditure required to attain a level of utility u at given consumer prices $q_0(= 1)$, q_1 and q_2, and level of overall pollution r. With e_{q_i} $(= \partial e/\partial q_i)$ we denote the i^{th} commodity's compensated demand function, $e_u(= \partial e/\partial u)$ is positive and is the

commodity taxation. For example, in Haufler (1994), this pattern of production and trade ensures that (i) no region can simultaneously export and import the same commodity, and (ii) a region's multilateral trade must be balanced. Other studies in this literature, e.g., Haufler and Pflüger (2007), and Moriconi and Sato (2009) also consider a three tradable good, two country model, each country producing two goods, i.e., the numeraire and one of the other two.

[10]The production of goods can be either a polluting or a clean activity. Note that we assume that Home and Foreign are small open economies where producer prices are not affected by consumption taxes. Therefore, changes in consumption taxes do not affect production and production generated emissions.

[11]The assumption of fixed producer prices is commonly used in the literature of international commodity taxation. For example, in Lockwood (2001, p.285), producers prices are constant and set equal to one, due to perfect international labor mobility (assumption A1, p.284), and due to same wages in the two countries, which are set equal to one. In Moriconi and Sato (2009) due to the fixed factor prices, producers prices are also fixed. Finally, Haufler and Pflüger (2007) by choice of units, fix to one the wage rate and producer prices in the two countries. Here we consider fixed, and equal to unity, producer prices due to the assumption that regions are small open economies and the structure of interregional and international trade.

[12]For the properties of the GDP or revenue function, see e.g., Michael and Hatzipanayotou (2013), Tsakiris *et al.* (2019). In the present framework with perfectly competitive product markets, consumption taxes do not affect producer prices.

reciprocal of the marginal utility of income, and e_r denotes the *marginal willingness to pay* for pollution reduction, alternatively the marginal damage from pollution, and is positive since pollution affects negatively the utility. The $e(.)$ function is strictly concave in consumer prices, i.e., $e_{q_1q_1}$ and $e_{q_2q_2}$ are negative, and commodities 1 and 2 can be substitutes (complements) in consumption, i.e., $e_{q_1q_2} = e_{q_2q_1} > 0\,(< 0)$.[13] It is assumed that all income effects fall on the *numeraire* commodity, thus, $e_{q_1u} = e_{q_2u} = 0$ and that the level of pollution does not affect consumption, i.e., $e_{q_ir} = 0$.[14] Equivalently, the minimum expenditure function for Foreign's household is given by $e^*(1, q_1^*, q_2^*, r^*, u^*)$, with similar properties applying.[15]

An active government in Home and Foreign taxes the consumption of polluting commodities at a uniform specific rate t in Home and t^* in Foreign according to the origin, i.e., t_o and t_o^*, or destination, i.e., t_d and t_d^*, principle of commodity taxation. We further assume that *ROW* follows only the destination principle of taxation regarding commodities 1 and 2, while the numeraire commodity 0 is untaxed in the two regions and in the *ROW*.[16] In Section 4, we assume that in addition to the three consumption goods, there is another imported good by Home and Foreign from *ROW*, which is used for the provision of public pollution abatement in the two regions. Revenue from commodity taxation in the two regions finances public pollution abatement.[17]

4 Tax competition with consumption pollution and public pollution abatement

Consider the case where Home and Foreign abate consumption generated pollution using a good imported from *ROW*, at quantities g and g^*, respectively. The world price of this good is p_g, and it is constant for the two regions. The purchases of g and g^* are financed by levying origin or destination-based consumption taxes. Assuming that both governments maintain balanced budgets, their budget constraints are:

$$p_g g = t_o \left[e_{q_1}(.) + e^*_{q_1^*}(.)\right] \quad \text{and} \qquad p_g g^* = t_o^* \left[e_{q_2}(.) + e^*_{q_2^*}(.)\right] \tag{1}$$

[13] All subscripts of the expentiture function denote partial derivatives, e.g., $e_{q_1q_1} = \partial e_{q_1}/\partial q_1$. The use of the duality approach via the GDP and minimum expenditure functions presents a great deal of algebraic simplicity and clarity of the results.

[14] A utility function compatible with these assumptions is an additively separable function, e.g., $U(c_0, c_1, c_2, r) = V(c_0, c_1, c_2) - f(r)$. We assume that the sub-utility $V(c_0, c_1, c_2) = c_0 + \nu(c_1, c_2)$ is quasi-linear and increasing in consumptions, with income effects falling on the *numeraire* commodity 0. $f(r)$ is increasing and convex in r. Because of the above specification, the expenditure function $e(.)$ entails complete separability between consumption and pollution, i.e., $e_{q_ir} = 0$, see Bandyopadhyay *et al.* (2013, ft. 15). That is, the relative demands are independent of the environmental damage. For the properties of the expenditure function see, e.g., Kreickemeier (2005), Palivos and Tsakiris (2011), and Antoniou *et al.* (2019).

[15] Qualitatively similar results can be obtained using general utility functions where income effects on all commodities are not zero assuming that regions are symmetric. The analysis of this case is omitted since it is mathematically complex without providing significant insights to the results.

[16] The assumption of an untaxed numeraire commodity is common in the international commodity taxation literature, since all tax systems exempt from taxation a share of national product, e.g., see Moriconi and Sato (2009).

[17] At a theoretical level, public pollution abatement has been considered by several studies within the trade and environment literature. See, among others, Hadjiyiannis *et al.* (2013), Vlassis (2013), Nimubona and Rus (2015), Pantelaiou *et al.* (2020).

under origin-based consumption taxes, and

$$p_g g = t_d \left[e_{q_1}(.) + e_{q_2}(.)\right] \qquad \text{and} \qquad p_g g^* = t_d^* \left[e^*_{q_1^*}(.) + e^*_{q_2^*}(.)\right] \tag{2}$$

under destination-based consumption taxes.[18] It is important to note that in our context, public pollution abatement entails the role of an interregional public good, e.g., environmental clean-up activities by a public sector, in the sense that a higher (lower) level of g or g^* by one region results to lower (higher) cross-border pollution.

With public pollution abatement, overall pollution in the two regions is defined as follows:

$$r = r^* = \left[e_{q_1}(.) + e_{q_2}(.) - g\right] + \left[e^*_{q_1^*}(.) + e^*_{q_2^*}(.) - g^*\right]. \tag{3}$$

We consider the case of perfect cross-border pollution.[19] Note that since tax policies by Home and Foreign do not affect world commodity prices, consumption in *ROW* is unaffected by changes in t_j and t_j^*, $j = d, o$. Consumption tax policies in Home and Foreign affect only the levels of consumption of commodities 1 and 2 in these two regions.

Since consumption tax revenue is earmarked for financing public sector pollution abatement, the representative household's budget constraint in each region requires that total private spending on commodities must equal income from production. That is:

$$e\left(q_1, q_2, r, u\right) = R \qquad \text{and} \qquad e^*\left(q_1^*, q_2^*, r^*, u^*\right) = R^*. \tag{4}$$

We examine the welfare effects and the efficiency of decentralized setting of origin and destination-based consumption taxes in the presence of consumption generated cross-border pollution and public pollution abatement.

4.1 Origin-based consumption taxes

Home and Foreign tax only the production which is used for consumption in Home and Foreign. That is, Home taxes the production of good 1, while Foreign taxes the production of good 2 which are used for consumption in Home and Foreign. Their exports to *ROW* are completely untaxed. Following the relevant literature, e.g., Haufler (1994), we refer to this principle of commodity taxation as "*restricted origin principle*".[20] With origin-based consumption taxes, prices are $q_1 =$

[18] Alternative specifications of the government budget constraints can be easily introduced with the present analytical apparatus, e.g., the tax revenue partly finances the purchases of g and g^* and partly is either lump-sum returned to the representative household or it finances the purchases of other, interregional or local, public consumption goods. These specifications only raise additional algebraic complexities without contributing to the importance and clarity of the results.

[19] A more general formulation for the levels of pollution r and r^* could be that, $r = \left[e_{q_1}(.) + e_{q_2}(.) - g\right] + \theta\left[e^*_{q_1^*}(.) + e^*_{q_2^*}(.) - g^*\right]$ and $r^* = \left[e^*_{q_1^*}(.) + e^*_{q_2^*}(.) - g^*\right] + \theta^*\left[e_{q_1}(.) + e_{q_2}(.) - g\right]$. $0 \leq \theta \leq 1$ and $0 \leq \theta^* \leq 1$ denote the rates of cross-border pollution from Foreign to Home and vice-versa, with $\theta = \theta^* = 0$ denoting local pollution and $\theta = \theta^* = 1$ denoting perfect cross-border pollution.

[20] In Haufler (1994), the two union countries apply the origin principle of commodity taxation for their mutual trade, and the destination principle for the trade between each of them and the *ROW*.

$1 + t_o$ and $q_2 = 1 + t_o^*$ in Home, and $q_1^* = 1 + t_o$ and $q_2^* = 1 + t_o^*$ in Foreign. That is, $q_1 = q_1^*$ and $q_2 = q_2^*$. Consumption tax revenue in Home and Foreign, respectively, are given by the right-hand side terms in equations (1). Equations (4) along with equations (1) and (3) constitute a system of five equations in u, u^*, g, g^* and r, in terms of the policy parameters t_o and t_o^*.

Totally differentiating equations (1) and (3) we obtain the effects of changes in t_o and t_o^* on aggregate pollution as follows:

$$dr = dr^* = \left[-E_{q_1} + (p_g - t_o)\, E_{q_1q_1} + (p_g - t_o^*)E_{q_2q_1}\right] p_g^{-1} dt_o \\ + \left[-E_{q_2} + (p_g - t_o)\, E_{q_1q_2} + (p_g - t_o^*)E_{q_2q_2}\right] p_g^{-1} dt_o^*, \tag{5}$$

where $E_{q_1} = e_{q_1} + e^*_{q_1^*}$ and $E_{q_2} = e_{q_2} + e^*_{q_2^*}$ are, respectively, the aggregate consumption for commodity 1 and 2 by the two regions, and $E_{q_1q_1} = e_{q_1q_1} + e^*_{q_1^*q_1^*} < 0$, and $E_{q_1q_2} = e_{q_1q_2} + e^*_{q_1^*q_2^*} \gtrless 0$.

Totally differentiating equations (4), changes in Home and Foreign's welfare are given as:

$$e_u du = -e_r dr - e_{q_1} dt_o - e_{q_2} dt_o^* \quad \text{and} \quad e^*_{u^*} du^* = -e^*_{r^*} dr^* - e^*_{q_1^*} dt_o - e^*_{q_2^*} dt_o^*, \tag{6}$$

where $e_u du$ ($e^*_{u^*} du^*$) denotes the change in the representative household's welfare or real income. Equations (6) show that an increase in Home's origin-based consumption tax affects Foreign's welfare directly by reducing its consumption and indirectly by affecting its pollution. Using equation (5) in equations (6) we obtain analytically the welfare effects of changes in origin-based consumption taxes as follows:

$$e_r^{-1} p_g e_u du = \left[e_r^{-1}(e_r - p_g)\, e_{q_1} + e^*_{q_1^*} - (p_g - t_o)\, E_{q_1q_1} - (p_g - t_o^*)\, E_{q_2q_1}\right] dt_o \\ + \left[e_r^{-1}(e_r - p_g)\, e_{q_2} + e^*_{q_2^*} - (p_g - t_o)\, E_{q_1q_2} - (p_g - t_o^*)\, E_{q_2q_2}\right] dt_o^*, \text{ and} \tag{7}$$

$$e^{*-1}_{r^*} p_g e^*_{u^*} du^* = \left[e^{*-1}_{r^*}(e_r^* - p_g)\, e^*_{q_1^*} + e_{q_1} - (p_g - t_o)\, E_{q_1q_1} - (p_g - t_o^*)\, E_{q_2q_1}\right] dt_o \\ + \left[e^{*-1}_{r^*}(e_r^* - p_g)\, e^*_{q_2^*} + e_{q_2} - (p_g - t_o)\, E_{q_1q_2} - (p_g - t_o^*)\, E_{q_2q_2}\right] dt_o^*. \tag{8}$$

Equations (7) and (8) indicate that a higher origin-based consumption tax improves a region's welfare if (i) the price of the public abatement commodity is lower than the marginal willingness to pay for pollution abatement, i.e., $e_r - p_g > 0$ and $e_r^* - p_g > 0$, and is higher than the tax level, i.e., $p_g - t_o > 0$ and $p_g - t_o^* > 0$, and (ii) commodities 1 and 2 are complements in consumption, i.e., $E_{q_2q_1} = E_{q_1q_2} < 0$.

4.1.1 Efficiency of the Nash equilibrium

Setting $e_u\,(du/dt_o) = 0$ and $e^*_{u^*}\,(du^*/dt_o^*) = 0$, in equations (7) and (8) and solving them simultaneously, the Nash equilibrium origin-based consumption taxes, with cross-border pollution and public pollution abatement, are given as follows:

$$t_o^N = p_g + \bar{E}_{q_1q_1}^{-1}\left[e_r^{-1}e_{q_1}\left(p_g - e_r\right) - e^*_{q_1^*} - E_{q_2q_2}^{-1}E_{q_2q_1}\left(e_{r^*}^{*^{-1}}e^*_{q_2^*}\left(p_g - e^*_{r^*}\right) - e_{q_2}\right)\right], \text{ and}$$

$$t_o^{*^N} = p_g + \bar{E}_{q_2q_2}^{-1}\left[e_{r^*}^{*^{-1}}e^*_{q_2^*}\left(p_g - e^*_{r^*}\right) - e_{q_2} - E_{q_1q_1}^{-1}E_{q_1q_2}\left(e_r^{-1}e_{q_1}\left(p_g - e_r\right) - e^*_{q_1^*}\right)\right]. \tag{9}$$

where $\bar{E}_{q_1q_1} = E_{q_1q_1} - E_{q_1q_2}E_{q_2q_2}^{-1}E_{q_2q_1} < 0$ and similarly $\bar{E}_{q_2q_2} < 0$.

We evaluate whether in the presence of cross-border pollution and public pollution abatement, the Nash origin-based consumption taxes are equally efficient as the corresponding cooperative taxes. The cooperative equilibrium origin-based consumption taxes are determined by simultaneously setting $e_u\left(du/dt_o\right) + e^*_{u^*}\left(du^*/dt_o\right) = 0$ and $e_u\left(du/dt_o^*\right) + e^*_{u^*}\left(du^*/t_o^*\right) = 0$. Evaluating the sign of the slope of the joint welfare functions at the Nash equilibrium, it suffices to determine the signs of $e_u^*\left(du^*/dt_o\right)$ and $e_u\left(du/dt_o^*\right)$ respectively, since at the Nash equilibrium $e_u\left(du/dt_o\right) = e_u^*\left(du^*/dt_o^*\right) = 0$. The impact on u^* of changes in t_o, after some algebraic manipulation is given by:[21]

$$e^*_{u^*}\frac{du^*}{dt_o}\mid_N = \underbrace{-e^*_{q_1^*}}_{private\ consumption\ spillover}\quad\underbrace{-e^*_{r^*}(dr^*/dt_o)}_{environmental\ spillover} = e_{q_1}\left(\frac{e^*_{r^*}}{e_r} - \frac{e^*_{q_1^*}}{e_{q_1}}\right). \tag{10}$$

The intuition for the result in equation (10) is as follows. When Home increases its origin-based consumption tax, first it affects Foreign's welfare negatively due to the reduction of the consumption of good 1. This is what we call, *private consumption spillover*, is captured by the term $-e^*_{q_1^*}$ and is negative. Second, it exerts an ambiguous impact on Foreign's welfare through its impact on the region's level of pollution. This we call *environmental spillover*, captured by the term $-e^*_r(dr^*/dt_o)$. At the Nash equilibrium this spillover is positive since $(dr^*/dt_o) = -e_{q_1}/e_r < 0$.[22] Therefore, at Nash equilibrium the two externalities are of opposite sign, and thus the total effect on welfare is ambiguous. Elaborating further, equation (10), shows that the overall impact of Home's higher consumption tax on Foreign's welfare can be written as $e_{q_1}\left(\frac{e^*_{r^*}}{e_r} - \frac{e^*_{q_1^*}}{e_{q_1}}\right)$. This expression allows us to identify clear conditions under which the decentralized setting of the origin-based consumption taxes is efficient. Specifically, if $\frac{e^*_{r^*}}{e_r} = \frac{e^*_{q_1^*}}{e_{q_1}}$, then the negative *private consumption spillover* is exactly equal to the positive *environmental spillover*, and thus, the Nash equilibrium origin-based consumption taxes are efficient. Under our assumption of quasi-linear utility functions, the above condition is satisfied when also preferences are identical across the two regions. Based on the above we state the following Proposition.

Proposition 1 *The Nash equilibrium origin-based consumption taxes are efficient when (i) prefer-*

[21] From equation (7), $e_r^{-1}p_g e_u \frac{du}{dt_o}\mid_N = 0 \Longrightarrow -\left(p_g - t_o\right)E_{q_1q_1} - \left(p_g - t_o^*\right)E_{q_2q_1} = -e_r^{-1}\left(e_r - p_g\right)e_{q_1} - e^*_{q_1^*}$. Substituting this expression into the expression for $e_{r^*}^{*^{-1}}p_g e_u^*\frac{du^*}{dt_o}$, after some algebra, we arrive at the result in equation (10).

[22] Since at Nash equilibrium $e_r^{-1}p_g e_u\frac{du}{dt_o}\mid_N = 0$ and $e_{r^*}^{*^{-1}}p_g e_u^*\frac{du^*}{dt_o^*}\mid_N = 0$, then from equation (5) we get that at Nash $(dr^*/dt_o) = (-e_{q_1}/e_r) < 0$.

ences are identical and quasi-linear across the two regions, (ii) consumption generated cross-border pollution is perfect, and (iii) the consumption tax revenue finances public pollution abatement.

The novelty of the result of the above Proposition rests on two pillars. First, it holds regardless of whether regions are symmetric or not, provided, however, that individuals in each region have the same preferences. Second, contrary to related studies, e.g., Silva and Yamaguchi (2010), Silva and Caplan (1997), it does not require other mechanisms such as income transfers either between regions or different levels of government in order to ensure the efficiency of the non-cooperative setting of commodity taxes.[23]

4.2 Destination-based consumption taxes

Next, we consider the case of the destination-based consumption taxes. Consumer prices now are $q_1 = 1 + t_d$, $q_2 = 1 + t_d$, $q_1^* = 1 + t_d^*$ and $q_2^* = 1 + t_d^*$. Equations (4) along with equations (2) and (3) constitute a system of five equations in u, u^*, g, g^* and r, in terms of the policy parameters t_d and t_d^*. Totally differentiating equations(3) and (2) we obtain the effects of changes in consumption taxes on aggregate pollution as follows:

$$\begin{aligned} dr = dr^* &= \left[(p_g - t_d)(Z_{q_1} + Z_{q_2}) - (e_{q_1} + e_{q_2})\right] p_g^{-1} dt_d \\ &+ \left[(p_g - t_d^*)(Z^*_{q_1^*} + Z^*_{q_2^*}) - \left(e^*_{q_1^*} + e^*_{q_2^*}\right)\right] p_g^{-1} dt_d^*, \end{aligned} \tag{11}$$

where $Z = e_{q_1} + e_{q_2}$, $Z_{q_1} = e_{q_1 q_1} + e_{q_2 q_1}$ and $Z_{q_2} = e_{q_1 q_2} + e_{q_2 q_2}$. For example, Z_{q_1} captures the changes in Home's consumption of commodities 1 and 2 due to changes in the consumer price of good 1 as a result of changes in t_d. By the properties of the expenditure function $(Z_{q_1} + Z_{q_2})$ is negative.[24] Similarly, we define $Z^* = e^*_{q_1^*} + e^*_{q_2^*}$, $Z^*_{q_1^*} = e^*_{q_1^* q_1^*} + e^*_{q_2^* q_1^*}$, $Z^*_{q_2^*} = e^*_{q_1^* q_2^*} + e^*_{q_2^* q_1^*}$, and $(Z^*_{q_1^*} + Z^*_{q_2^*})$ is also negative.

Totally differentiating equations (4), changes in Home and Foreign's regional welfare are given as:

$$e_u du = -e_r dr - (e_{q_1} + e_{q_2}) dt_d, \quad \text{and} \qquad e^*_{u^*} du^* = -e^*_{r^*} dr^* - (e^*_{q_1^*} + e^*_{q_2^*}) dt_d^* \,. \tag{12}$$

Equation (12) shows, for example, that an increase in the destination tax of one region affects its own welfare directly by reducing its consumption and indirectly by affecting its pollution. The effect on the other region's welfare is only indirect through changes in its level of pollution. Using equation (11) in equations (12) we obtain the welfare effects of changes in taxes t_d and t_d^*, on the

[23] The literature on the efficiency of the origin and destination principle usually employs models where regions/countries are symmetric or identical, e.g., see Moriconi and Sato (2009), Haufler and Pflüger (2007).

[24] From the properties of the expenditure function we know that $q_0 e_{q_1 q_0} + q_1 e_{q_1 q_1} + q_2 e_{q_1 q_2} = 0$, and $e_{q_i q_j} = e_{q_j q_i}$. Since producer prices of both goods equal 1 and consumption taxes are the same, we have $q_1 = q_2 = q$. Thus $q_0 e_{q_1 q_0} + q(e_{q_1 q_1} + e_{q_1 q_2}) = q_0 e_{q_1 q_0} + q Z_{q_1} = 0$. Similarly, $q_0 e_{q_2 q_0} + q Z_{q_2} = 0$. Thus, $q(Z_{q_1} + Z_{q_2}) = -q_0(e_{q_0 q_1} + e_{q_0 q_2})$, which can be written as $q(Z_{q_1} + Z_{q_2}) = \frac{q_0}{q}(q_0 e_{q_0 q_0}) < 0$.

two regions' welfare as follows:

$$\begin{aligned} e_r^{-1} p_g e_u du = & -\left[(p_g - t_d)(Z_{q_1} + Z_{q_2}) - e_r^{-1}(e_{q_1} + e_{q_2})(-p_g + e_r)\right] dt_d \\ & -\left[(p_g - t_d^*)\left(Z^*_{q_1^*} + Z^*_{q_2^*}\right) - \left(e^*_{q_1^*} + e^*_{q_2^*}\right)\right] dt_d^* \ , \end{aligned} \tag{13}$$

$$\begin{aligned} e_{r^*}^{*^{-1}} p_g e^*_{u^*} du^* = & -\left[(p_g - t_d^*)\left(Z^*_{q_1^*} + Z^*_{q_2^*}\right) - e_{r^*}^{*^{-1}}\left(e^*_{q_1^*} + e^*_{q_2^*}\right)(-p_g + e^*_{r^*})\right] dt_d^* \\ & -\left[(p_g - t_d)(Z_{q_1} + Z_{q_2}) - (e_{q_1} + e_{q_2})\right] dt_d, \end{aligned} \tag{14}$$

Equations (13) and (14) indicate that a higher own destination-based consumption tax improves a region's welfare if the price of the public abatement commodity is (i) higher than the tax level, i.e., $p_g > t_d$ and $p_g > t_d^*$, and (ii) lower than the marginal willingness to pay for pollution abatement, i.e., $-p_g + e_r$ and $-p_g + e^*_{r^*} > 0$. A higher destination-based consumption tax by one region improves the other's welfare if $p_g > t_d$ and $p_g > t_d^*$.

4.2.1 Efficiency of the Nash equilibrium

Setting $e_u\,(du/dt_d) = 0$ and $e^*_{u^*}\,(du^*/dt_d^*) = 0$, in equations (13) and (14), the Nash equilibrium destination-based consumption taxes with consumption generated cross-border pollution and public pollution abatement are given as follows:

$$\begin{aligned} t_d^N &= p_g - e_r^{-1}(Z_{q_1} + Z_{q_2})^{-1}(e_{q_1} + e_{q_2})(-p_g + e_r)\,, \\ t_d^{*N} &= p_g - e_{r^*}^{*^{-1}}\left(Z^*_{q_1^*} + Z^*_{q_2^*}\right)^{-1}\left(e^*_{q_1^*} + e^*_{q_2^*}\right)(-p_g^* + e_r^*)\,. \end{aligned} \tag{15}$$

Equations (15) indicate that the Nash equilibrium destination-based consumption taxes are positive, provided that $(-p_g + e_r) \geqslant 0$ and $(-p_g + e^*_{r^*}) \geqslant 0$. Furthermore, if $(-p_g + e_r) = (<)0$ and $(-p_g + e^*_{r^*}) = (<)0$, then, the Nash equilibrium destination-based consumption taxes equal (exceed) the fixed price of the public abatement commodity.

To assess whether Nash destination-based consumption taxes are equally efficient as the corresponding cooperative taxes, we follow the same procedure as in the case of origin-based consumption taxes. The cooperative equilibrium destination-based consumption taxes t_d^C and t_d^{*C} are determined by simultaneously setting $e_u\,(du/dt_d) + e^*_{u^*}\,(du^*/dt_d) = 0$ and $e_u\,(du/dt_d^*) + e^*_{u^*}\,(du^*/t_d^*) = 0$. Evaluating the sign of the slopes of these joint welfare functions at Nash equilibrium, it suffices to determine the signs of $e^*_{u^*}\,(du^*/dt_d)$ and $e_u\,(du/dt_d^*)$ respectively, since at Nash equilibrium $e_u\,(du/dt_d) = e^*_{u^*}\,(du^*/t_d^*) = 0$. Consider, for example, the joint welfare function when Home changes its destination-based consumption tax. Evaluating its slope at Nash equilibrium gives:[25]

$$e^*_{u^*}\frac{du^*}{dt_d}\mid_N = \underbrace{e^*_{r^*}e_r^{-1}\left(e_{q_1}+e_{q_2}\right)}_{environmental\ spillover}. \tag{16}$$

The expression in equation (16) is positive, indicating that the Nash equilibrium tax rate t_d^{*N} is inefficiently low. It is only in the absence of such a spillover that Nash set destination-based consumption taxes are efficient, e.g., Lockwood (2001), Haufler and Pflüger (2007). Intuitively, an increase e.g., in t_d affects Foreign's welfare only through the changes in pollution. This effect is the *environmental spillover*. That is, when Home acts non-cooperatively, an increase in t_d decreases consumption of both commodities 1 and 2. Then, overall consumption generated pollution in Home and Foreign falls. This positive *environmental spillover* of the higher t_d on Foreign's welfare is not accounted by Home, when the latter region acts Nash (non-cooperatively). Thus, its Nash equilibrium destination-based consumption tax are inefficiently low. On the basis of these results we state the following proposition.

Proposition 2 *The Nash equilibrium destination-based consumption taxes are inefficiently low when consumption generated cross-border pollution is perfect, and the consumption tax revenue finances public pollution abatement.*

In concluding this section, we note that when cross-border pollution is imperfect, i.e., $0 < \theta, \theta^* < 1$, neither the origin nor the destination principle of commodity taxation is efficient.

5 Tax competition with consumption pollution, without public pollution abatement

Now, we examine the welfare effects and the efficiency of non-cooperative setting of consumption taxes under the two tax principles in the presence of consumption cross-border pollution, but without public pollution abatement. Consumption tax revenues are lump-sum rebated to the regions' representative households. Overall pollution in Home and Foreign equals total consumption of the two polluting goods in both regions plus the fixed amount of pollution transmitted from ROW, which is omitted as it is constant. Then, equation (3) reduces to:

$$r = r^* = e_{q_1}(.) + e_{q_2}(.) + e^*_{q_1^*}(.) + e^*_{q_2^*}(.). \tag{17}$$

5.1 Origin-based consumption taxes

Combining equations (1) and (4), the representative household's budget constraint in each region requires that total private spending on commodities must equal income from production plus lump-

[25] From equation (12) we have $e_u\frac{du}{dt_d}\mid_N = 0 \Rightarrow \frac{dr}{dt_d} = -e_r^{-1}\left(e_{q_1}+e_{q_2}\right)$, and $e^*_{u^*}\frac{du^*}{dt_d} = -e^*_{r^*}\frac{dr^*}{dt_d}$. Since by equation (11) $\frac{dr}{dt_d} = \frac{dr^*}{dt_d}$, then at Nash equilibrium we obtain equation (16).

sum rebated consumption tax revenue. That is:

$$e(q_1, q_2, r, u) = R + t_o E_{q_1}(q_1, q_2, r, r^*, u, u^*),$$
$$e^*(q_1^*, q_2^*, r^*, u^*) = R^* + t_o^* E_{q_2}(q_1, q_2, r, r^*, u, u^*), \tag{18}$$

recall that $E_{q_1} = e_{q_1} + e^*_{q_1^*}$ and $E_{q_2} = e_{q_2} + e^*_{q_2^*}$. Equations (17) and (18) constitute a system of three equations in u, u^*, and r, in terms of the policy parameters t_o and t_o^*. Totally differentiating equations (17) and (18), after some algebra, yields the overall changes in the levels of welfare in Home and Foreign due to changes in t_o and t_o^*. The results are presented by equations (A.1) and (A.2) in the Appendix.

5.1.1 Efficiency of the Nash equilibrium

To ascertain the efficiency of the non-cooperative setting of origin-based consumption taxes, we evaluate the signs of the slopes of the joint welfare functions at Nash equilibrium.[26] Doing so, it suffices to determine the sign of the terms $e^*_{u^*}(du^*/dt_o)$ and $e_u(du/dt_o^*)$, since at Nash equilibrium $e_u(du/dt_o) = e^*_{u^*}(du^*/t_o^*) = 0$. Consider the case of an increase in Home's tax rate, t_o. Substituting t_o^{*N} from equations (A.3) into the expression for $e^*_{u^*}(du^*/dt_o)$ in equation (A.2), we obtain:

$$e^*_{u^*}\frac{du^*}{dt_o} \quad |_N = \underbrace{-e^*_{q_1^*}}_{\text{private consumption spillover}} \quad \underbrace{+t_o^{*N} E_{q_2 q_1}}_{\text{public revenue spillover}} \quad \underbrace{-e^*_{r^*}(dr^*/dt_o)}_{\text{environmental spillover}} =$$
$$= -e^*_{q_1^*} - E^{-1}_{q_2 q_2} E_{q_2 q_1} e_{q_2} - e^*_{r^*}\bar{E}_{q_1 q_1}, \tag{19}$$

where $\bar{E}_{q_1 q_1} = E_{q_1 q_1} - E_{q_1 q_2} E^{-1}_{q_2 q_2} E_{q_2 q_1} < 0$.[27] Equation (19) indicates that the impact of a higher t_o on Foreign's welfare (u^*) is through three effects. First, through the negative *private consumption spillover* (i.e., $-e^*_{q_1^*} < 0$), second through a *public revenue spillover, i.e.,* $t_o^{*N} E_{q_2 q_1}$, whose sign is ambiguous, depending on whether commodities 1 and 2 are complements or substitutes in consumption.[28] Third, through the positive *environmental spillover, i.e.,* $-e^*_{r^*}(dr/dt_o) = -e^*_{r^*}\bar{E}_{q_1 q_1} > 0$. The sum of the three terms is ambiguous irrespectively of whether the two goods are complements or substitutes in consumption. Let, for example, commodities 1 and 2 be complements in consumption i.e., $E_{q_2 q_1} < 0$. If in absolute terms the negative sum of the first two effects is larger (smaller) than the *environmental spillover*, then $e^*_{u^*}\frac{du^*}{dt_o} \ |_N < 0 \ (> 0)$. In this case, the Nash equilibrium origin taxes are inefficiently high (low).[29]

[26] Using equations (A.1) and (A.2) in the presence of consumption generated cross-border pollution the cooperative consumption taxes under the origin principle of taxation are given by equation (A.8). The cooperative taxes under the origin-based taxation principle are the same as those under the destination-based principle, since the two regimes are equivalent under cooperative taxation.

[27] The analytical result for $e^*_{u^*}\frac{du^*}{dt_o} \ |_N$ emerges by substituting the expressions for the Nash equilibrium value t_o^{*N}, given in equation (A.3), and for $(dr^*/dt_o) = E_{q_1 q_1} + E_{q_2 q_1}$ into the right-hand-side of equation (19).

[28] For example, if commodities 1 and 2 are complements, i.e., $E_{q_2 q_1} < 0$, a higher t_o by Home also reduces aggregate consumption of commodity 2, thus Foreign's consumption tax revenue and welfare.

[29] Haufler and Pflüger (2007), without consumption pollution, demonstrate that the sum $-e^*_{q_1^*} - E^{-1}_{q_2 q_2} E_{q_2 q_1} e_{q_2}$, is negative.

At this point, it is important to compare the results in equations (10) and (19). That is, the efficiency of the non-cooperative setting of origin-based consumption taxes, when tax revenue finances public pollution abatement vis-a-vis to when it is lump-sum rebated to the representative household. The impact of a higher t_o on Foreign's welfare is decomposed as follows. First, in both cases there is (i) a negative *private consumption spillover*, i.e., $-e^*_{q^*_1}$, due to lower consumption of good 1 in Foreign as Home raises its origin-based consumption tax on this commodity, and (ii) an *environmental spillover*, i.e., $-e^*_{r^*}(dr^*/dt_o)$, which as shown by our analysis, exerts a positive impact on Foreign's welfare at Nash equilibrium. When consumption tax revenue is lump-sum rebated to the representative household, an additional effect arises. This effect we call *public revenue spillover*, which captures the change in Foreign's consumption tax revenue, at the given t_o^{*N}, as a result of changes in consumption of good 2 in both regions, resulting from the higher consumption tax t_o on good 1. The sign of this effect is ambiguous. Thus, the sign of the sum of these three effects is also ambiguous. The *public revenue spillover*, in the case of public pollution abatement is "*embedded*" into the *environmental spillover.* The discussion of equation (10) established sufficient conditions under which the negative private consumption spillover and the positive environmental spillover cancel each other out, resulting in $e^*_{u^*} \frac{du^*}{dt_o} \mid_N = 0$, thus, rendering efficient the Nash setting of origin-based consumption taxes when consumption tax revenue finances public pollution abatement. Such clear-cut conditions, however, do not exist when consumption tax revenue is lump-sum rebated to the representative household, i.e., equation (19).

5.2 Destination-based consumption taxes

Combining equations (2) and (4), with destination-based consumption taxes and consumption tax revenues being lump-sum rebated to the local households, their budget constraints, respectively, are:

$$\begin{aligned} e\left(q_1, q_2, r, u\right) &= R + t_d\left(e_{q_1} + e_{q_2}\right), \\ e^*\left(q_1^*, q_2^*, r^*, u^*\right) &= R^* + t_d^*\left(e^*_{q_1^*} + e^*_{q_2^*}\right). \end{aligned} \tag{20}$$

Equations (17) and (20) constitute a system of three equations in u, u^*, and r, in terms of the policy parameters (t_d, t_d^*). We examine the effects of changes in t_d and t_d^* on Home's welfare. Totally differentiating equations (17) and (20), after some algebra, yields the overall changes in the levels of welfare in Home and Foreign due to changes in t_d and t_d^*. The results are presented by equations (A.4)-(A.6) in the Appendix.

5.2.1 Efficiency of the Nash equilibrium

To ascertain whether the non-cooperative setting of destination-based consumption taxes is efficient, again we evaluate the signs of $e^*_{u^*}\left(du^*/dt_d\right)$ and $e_u\left(du/dt_d^*\right)$ at Nash equilibrium, since $e_u\left(du/dt_d\right) =$

$e^*_{u^*}\left(du^*/t^*_d\right) = 0$. Doing so, we obtain:

$$e^*_{u^*}\frac{du^*}{dt_d}\mid_N = \underbrace{-e^*_{r^*}\left(Z_{q_1}+Z_{q_2}\right)}_{environmental\ spillover}, \tag{21}$$

where $e^*_{u^*}\frac{du^*}{dt_d}\mid_N > 0$, since $\left(Z_{q_1}+Z_{q_2}\right) < 0$. Equivalently,[30] $e_u \frac{du}{dt^*_d}\mid_N = -e_r\left(Z^*_{q^*_1}+Z^*_{q^*_2}\right) > 0$. This is to say that the slopes of the joint welfare functions at Nash equilibrium are positive. Thus, the Nash equilibrium destination-based consumption taxes are lower than the corresponding cooperative equilibrium taxes. The intuition of this result follows along the lines of the case of destination-based consumption taxes when consumption tax revenue finances public pollution abatement, i.e., see equation (16).

Proposition 3 *Consider two small open regional economies where there is consumption generated cross-border pollution, destination or origin-based consumption taxes are levied on the polluting goods, and the consumption tax revenue is lump-sum rebated to the regions' households. Then,*

(i) The Nash equilibrium destination-based consumption taxes are always inefficiently low.

(ii) The Nash equilibrium origin-based consumption taxes are inefficiently low when the environmental spillover is sufficiently large.

In the context of competitive markets, the literature has shown that the destination principle is usually efficient, while the origin principle is not. An intuitive explanation of why the present results are in contrast to existing results of the literature is as follows. In the absence of cross-border consumption pollution, an increase in the destination consumption tax by one region, e.g., Home, does not affect consumer prices in the other, i.e., Foreign. Thus, the latter region's consumption and consumption tax revenue remain unaffected, rendering this policy efficient. In the presence of cross-border consumption pollution, however, changes in Home's destination consumption tax affect its consumption and pollution which in turn affects Foreign's welfare. In this case, commodity taxation on the basis of the destination principle is inefficient. Furthermore, note that in our framework, this pollution externality exists regardless of whether consumption tax revenue is lump-sum returned to the representative household or it finances the provision of public pollution abatement.

In concluding this section, it is important to note that when the consumption tax revenue is partially distributed between the financing of public sector pollution abatement activity and lump-sum rebated to the representative household, then, neither the destination nor the origin-based consumption taxes are efficient.

6 Concluding remarks

A key issue in international commodity taxation is whether taxes should be levied in the jurisdictions of destination or origin. Based on the fundamental characteristics and differences of the

[30] Combining equations (A.4) and (A.6) we get that $e^*_{u^*}(du^*/dt_d) = -e^*_r(dr/dt_d)$, where $(dr/dt_d) = (Z_{q_1} + Z_{q_2})$.

two tax principles, OECD (2014), p. 24, reports ".... the destination principle is the international norm and is sanctioned by the OECD International VAT/GST Guidelines and by the World Trade Organization rules ...".

Without disputing the proclaimed advantages or disadvantages that international organizations and policy makers attribute to one tax system over the other, this paper shows that, within our framework, both principles of commodity taxation are generally inefficient. When, however, revenue from taxation finances public pollution abatement, cross-border pollution is perfect, and preferences are identical, then the Nash equilibrium origin-based consumption taxes are efficient while destination-based taxes are inefficient. When consumption tax revenue is lump-sum rebated, the non-cooperative origin-based consumption taxes are either inefficiently low or high, and the Nash destination-based consumption taxes are inefficiently low.

Similar conclusions apply to cases where other types of interregional externalities are considered. For example, if instead of considering perfect cross-border pollution, there is an interregional public consumption good. In this case, when consumption tax revenue finances the provision of the interregional public consumption good and preferences in the two regions are identical, it can be shown that the non-cooperative origin-based consumption taxes are efficient while the Nash destination-based consumption taxes are inefficiently low.

Our results contribute to the theoretical literature on the efficiency of the non-cooperative setting of commodity taxation under the destination and origin-based principles. That is, the efficiency of alternative principles of commodity taxation depends on the presence or not of interregional externalities, and on the use of consumption tax revenue, i.e., finance public pollution abatement, or the provision of an interregional pubic good, or its lump-sum distribution to households.

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Appendix

Consumption pollution without public pollution abatement: Origin-based consumption taxes

Totally differentiating equations (18) and (17), yields:[31]

$$e_u du = [(-e_r + t_o) E_{q_1q_1} - e_r E_{q_2q_1} + e^*_{q^*_1}]dt_o + [(-e_r + t_o) E_{q_1q_2} - e_r E_{q_2q_2} - e_{q_2}]\, dt^*_o. \tag{A.1}$$

$$e^*_{u^*} du^* = \left[(-e^*_{r^*} + t^*_o) E_{q_2q_1} - e^*_{r^*} E_{q_1q_1} - e^*_{q^*_1}\right] dt_o + [(-e^*_{r^*} + t^*_o) E_{q_2q_2} - e^*_{r^*} E_{q_1q_2} + e_{q_2}]\, dt^*_o. \tag{A.2}$$

Sufficient, but not necessary conditions, for a higher origin-based consumption tax to improve a region's own welfare are that: (i) the consumption tax is smaller than the marginal environmental damage of pollution in the region, i.e., $(-e_r + t_o) < 0$ and $(-e^*_{r^*} + t^*_o) < 0$, and (ii) commodities 1 and 2 are complements in consumption, i.e., $E_{q_1q_2} = E_{q_2q_1} < 0$. However, a higher tax by one region still exerts an ambiguous impact on the other's welfare.

Setting $e_u\,(du/dt_0) = 0$ and $e^*_{u^*}\,(du^*/dt^*_o) = 0$, in equations (A.1) and (A.2), the Nash equilibrium origin-based consumption taxes are given as follows:

$$t^N_o = E^{-1}_{q_1q_1}\left[e_r\,(E_{q_1q_1} + E_{q_2q_1}) - e^*_{q^*_1}\right], \quad t^{*N}_o = E^{-1}_{q_2q_2}\,[e^*_r\,(E_{q_2q_2} + E_{q_1q_2}) - e_{q_2}]\,. \tag{A.3}$$

Consumption pollution without public pollution abatement: Destination-based consumption taxes

Totally differentiating equation (17) we obtain:

$$dr = (Z_{q_1} + Z_{q_2})\, dt_d + \left(Z^*_{q^*_1} + Z^*_{q^*_2}\right) dt^*_d\ . \tag{A.4}$$

Totally differentiating equations (20) and (17), after some algebra, yields:

$$e_u du = (Z_{q_1} + Z_{q_2})\,(-e_r + t_d) dt_d - \left(Z^*_{q^*_1} + Z^*_{q^*_2}\right) e_r dt^*_d \quad \text{, and} \tag{A.5}$$

$$e^*_{u^*} du^* = \left(Z^*_{q^*_1} + Z^*_{q^*_2}\right)(-e^*_{r^*} + t^*_d) dt^*_d - (Z_{q_1} + Z_{q_2})\, e^*_{r^*} dt_d \quad , \tag{A.6}$$

An increase in the own destination-based consumption tax improves (worsens) Home's welfare if it is lower (higher) than the household's marginal willingness to pay for pollution abatement, e.g.,

[31] The total differentiation of these two equations yields $e_u du = -e_r dr + \left(e^*_{q^*_1} + t_o E_{q_1q_1}\right) dt_o + (-e_{q_2} + t_o E_{q_1q_2})\, dt^*_o$, and $dr = (E_{q_1q_1} + E_{q_2q_1})\, dt_o + (E_{q_2q_2} + E_{q_1q_2})\, dt^*_o$. Substituting the expression for dr into that for du yields equation (A.1). Similar calculations apply for the derivations of $e^*_{u^*} du^*$ and dr^*.

$(-e_r + t_d) < 0(> 0)$. A higher destination-based tax by Foreign, improves Home's welfare. Similar results are derived for changes in t_d and t_d^* on Foreign's welfare.

Setting $e_u \left(du/dt_d \right) = 0$ and $e^*_{u^*} \left(du^*/dt^*_d \right) = 0$, in equations (A.5) and (A.6), the Nash equilibrium destination-based consumption taxes are given as follows:

$$t_d^N = e_r \qquad \text{and} \qquad t_d^{*N} = e^*_{r^*}. \tag{A.7}$$

Using equations (A.5), (A.6) and setting $e_u \left(du/dt_d \right) + e^*_{u^*} \left(du^*/dt_d \right) = 0$ and $e_u \left(du/dt^*_d \right) + e^*_{u^*} \left(du^*/t^*_d \right) = 0$, gives the cooperative destination-based consumption taxes:

$$t_d^C = t_d^{*C} = e_r + e^*_{r^*}. \tag{A.8}$$

Clearly, $t_d^C > t_d^N$, $t_d^{*C} > t_d^{*N}$.

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