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On the Principles of Commodity Taxation under Interregional Externalities

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Abstract

We examine the efficiency of decentralized commodity taxation where consumption tax revenue finances public sector activities related to interregional externalities. We consider two cases; tax revenue finances (i) public pollution abatement in the presence of consumption generated transboundary pollution, and (ii) the provision of an interregional public consumption good, in the absence of pollution. The key result of our study is that in either case, non-cooperative equilibrium *origin-based* consumption taxes are efficient, while *destination-based* taxes are not. When consumption tax revenue is lump-sum distributed, neither type of consumption taxes is efficient.

JEL classification: H21, H23, H41.

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1 Introduction

In December 2015, 195 countries signed the Paris climate agreement (COP21), the first-ever universal, legally binding global climate accord. However, recent political developments unveil the difficulties regarding the implementation of this agreement. Since cooperative policies for resolving international issues are hard to achieve, it is of vital importance to explore possible ways to target the cooperative outcomes when the governments act independently, i.e., non-cooperatively, in pursuing their own national interest.

Motivated by the above developments, we examine the efficiency of decentralized commodity taxation in the context of a two-region Federal economy, where consumption tax revenue finances public sector activities related to interregional externalities. We consider two cases; tax revenue finances (i) public pollution abatement in the presence of consumption generated transboundary pollution, and (ii) the provision of an interregional public consumption good, in the absence of pollution. Consumption taxes are based on either the so-called *destination principle*, i.e., commodity taxes are levied in the jurisdiction of final consumption, or the so-called *origin principle*, i.e., commodity taxes are levied in the jurisdiction of production. The key result of our study is that in either case, non-cooperative equilibrium *origin-based* consumption taxes are efficient, while *destination-based* taxes are not. When consumption tax revenue is lump-sum distributed, neither type of consumption taxes is efficient.[1]

The novelty of these results rests on two pillars. First, it holds regardless of whether regions are symmetric or not, provided, however, that representative consumer across regions have the same income and preferences, or alternatively they have identical and homothetic preferences. Second, it does not require other mechanisms such as income transfers either between regions or different levels of government, e.g., federal and regional, in order to ensure the efficiency of the decentralized commodity tax setting. The rationale of our main result is the following. A higher origin-based consumption tax by one region, affects the other region's welfare negatively due to the reduction in consumption of the taxed commodity, and positively due to either the mitigation of the adverse pollution effect, or the favorable effect on consumption of the interregional public consumption good. Evaluated at the Nash equilibrium, these two externalities cancel each other out. Contrary to it, the non-cooperative equilibrium destination-based consumption taxes are inefficient in both cases, since there is only environmental or interregional public consumption good externality.

Despite the fact that our model can accommodate different versions of the same question

[1] Generally, the tax competition literature examines conditions under which decentralized policymaking may lead to socially efficient outcomes, e.g., Ogawa and Wildasin (2009), Silva and Yamaguchi (2010), Eichner and Runkel (2012).

regarding the optimality of decentralized commodity taxation we adapt it to the timely issue of transboudary pollution and the arising difficulties regarding the mitigation of climate change. In this regard, our study is founded on three important features which are strongly supported by real world practice. The *first* feature is consumption generated pollution. The *second* is the principle of commodity taxation, and the *third* is the existence of public pollution abatement. Regarding the consumption generated pollution, it is well known that a significant part of greenhouse emissions, e.g., CO_2 emissions, are attributed to consumption or residential activity. Hu and McKitrick (2016) report that "*....According to the US Environmental Protection Agency (EPA 2012), nearly one half of the emissions of smog-forming volatile organic compounds (VOCs), more than half of the nitrogen oxides (NOx) emissions, and about half of the toxic air pollutant emissions in US are generated from motor vehicles. .... For OECD countries, up to 90% of the total carbon monoxide (CO_2) is from the source "road" (OECD Statistics 2012).... The emissions related to consumption of energy in US are accountable for about 71% of US carbon dioxide emissions....*". Also, in 2014, EPA reports that in the US, about 40 percent of greenhouse gases are attributed to residential activity.[2]

In regards to our second feature, we argue that when pollution is generated from consumption, policies such as those implemented to regulate production generated pollution, e.g., emissions taxes and emissions permits, are not the most appropriate ones to contain consumption emissions. On these grounds, consumption taxes and general goods and services taxes ($GSTs$) may serve as more appropriate instruments to control consumption generated pollution, e.g., Fullerton and West (2002).[3] Indeed, recently many governments have used general consumption taxes or excise taxes on specific goods and services either to discourage "harmful" behaviors or to encourage "responsible" ones towards the environment in order to improve welfare. Such have been taxes on energy-consuming products, mineral oils and transport fuels, and taxes on products which produce environmentally harmful emissions, e.g., vehicles.[4] The introduction of feed-in tariffs or premiums in the consumption of elec-

[2] CO_2 emissions related to residential activity are attributed to, e.g., fossil fuels burned for heat, electricity, the use of products containing greenhouse gases, the handling of waste, and to recreational transportation such as use of passenger cars, sport utility vehicles, pickup trucks, and minivans. A smaller fraction of CO_2 emissions comes from other modes of transportation, e.g., freight trucks, commercial aircraft, ships, boats, and trains, pipelines and lubricants.

[3] When pollution is a function of consumption then a consumption and an emission (Pigouvian) tax may be equivalent in terms of policy effectiveness.

[4] For example, OECD (2014) pp. 135-160, reports: Per litre total taxation (VAT + excise) on premium unleaded gasoline: Australia 0.51, Austria 0.95, Canada 0.39, Germany 1.20, Greece 1.29, Japan 0.65, Norway 1.47, Sweden 1.26, Switzerland 0.93, 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, Hungary 0.88, Israel 1.1, Korea 0.21, the Netherlands 0.81, Norway 0.63, Sweden 1.01, the U.K. 0.37. 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

tricity is also a widely used policy instrument of this type.

These revenue yielding tax policies gain an advantage relative to other environmental policies that do not generate revenues such as environmental standards, since they can also allow for the funding of public sector activities to protect the environment, which brings us to the third analytical feature of our framework, i.e., public pollution abatement. Related to this issue of public pollution abatement, 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).[5] 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.

The complexity of the various national tax systems, the recorded difficulties in many countries to monitor and collect tax revenue, 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 the above, quite often destination-based taxes are held accountable for various administrative complexities 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). In light of the real world considerations and of the two systems of interregional/international commodity taxation discussed above, the following policy dilemmas, puzzling policymakers and theorists alike, arise naturally, "*should commodity taxes be levied in the source location, i.e., origin-based taxes,*

gas), Germany VAT 19%, Iceland VAT 25.5% + Vehicle registration Fee (CO_2 emissions, electric propulsion), 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), Spain VAT 21% + Vehicle Registration Tax (CO_2 emissions), the US gas guzzler tax (fuel efficiency).

[5] They also report that public PAC expenditures as a percentage of total PAC expenditures averaged 55% in Canada, Finland, France and Korea, 77% in Germany, 35% in Japan, and 40% in the US.

[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...*".

or in the location of final consumption, destination-based taxes?", "*can governments achieve the cooperative outcomes when they act independently, i.e., non-cooperatively, in the pursuit of their national interest?*". Our study advocates that origin-based consumption taxes are those leading to the cooperative solution. This policy recommendation may have important implications for policymakers as it does not require any form of interregional cooperation on behalf of the participants.

1.1 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).[7] 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 Pareto efficient international taxation may require production inefficiencies in the allocation of world resources. As a result, 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 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. Gauthier (2018) in a model of spatial differentiation with heterogeneous consumers in terms of their preferences in purchasing home vs foreign (imported) goods, shows that decentralized origin-based commodity taxation can lead to a

[7]Kanbur and Keen (1993) in a single commodity partial equilibrium model of (DP) tax-competition between two countries, conclude that differences in their size (population) exacerbate the inefficiencies of non-cooperative behavior, harming them both. 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 Lockwood (2001), Keen *et al.* (2002), Haufler and Pflüger (2004, 2007), Behrens *et al.* (2009), and Fujiwara (2016).

socially efficient outcome. Antoniou *et al.* (2018) 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.

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 (2004, 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. Chao and Yu (2015), in the context of a small open economy with production generated pollution, examine the environmental implications of tariff and consumption tax reforms under destination and origin-based tax principles. 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.[8]

2 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.[9] 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.[10] Consumption of the

[8] 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., Krutilla (1991), Chao *et al.* (2012). Other studies, using different analytical frameworks, examine the issue of efficiency of different policies in the presence of transboundary production generated pollution e.g., Silva and Caplan (1997), Finus and Pintassilgo (2012), Angelopoulos *et al.* (2017), Tsakiris *et al.* (2018).

[9] 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.

[10] 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 the relevant literature of international 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.

numeraire commodity 0 is a clean activity, but one unit of consumption of commodities 1 and 2 generates one unit of pollution (see footnote 3). Consumption generated pollution is 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 a non-polluting and untaxed activity. 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, producers 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. Since the latter are assumed fixed, they are omitted from Home and Foreign's GDP functions, which can be written as $R(.)$ and $R^*(.)$, respectively.[12] [13]

Let $e\left(1, q_1, q_2, r, u\right)$ be the minimum expenditure function for Home's representative household capturing the minimum expenditure required to attain a level of utility u at given consumer prices q_1 and q_2, and level of overall pollution r. With $e_{q_i}\left(= \partial e/\partial q_i\right)$ we denote the i^{th} commodity's compensated demand function, where $i = 1, 2$, e_u is the reciprocal of the marginal utility of income, and e_r denotes the *marginal willingness to pay* for pollution reduction (or alternatively the marginal damage from pollution) and is positive since pollution affects negatively the utility. The $e\left(.\right)$ function is strictly concave in consumer prices,

[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 example, consider Home which produces commodities "0" and "1". In this case, revenue from production is $R\left(P, \Omega\right) = \max\left\{p_0 x_0\left(p_0, p_1; \Omega_0\right) + p_1 x_1\left(p_0, p_1; \Omega_1\right)\right\}$ where $p_0 = p_1 = 1$. The 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, $P \equiv \left[p_0, p_1\right]$, and $\Omega \equiv \left[\Omega_0, \Omega_1\right]$ is the region's vector fixed factor endowments. Because, by assumption, producer prices and factor endowments are constant, the GDP function is denoted as $R\left(.\right)$. For the properties of the revenue function, see e.g., Keen and Kotsogiannis (2014), Lapan and Sikdar (2017).

[13] In the present framework with perfectly competitive product markets, consumption taxes do not affect producer prices. If, however, product markets are imperfectly competitive, then consumption taxes affect producer prices and levels of production.

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., $e_{q_1q_2} = e_{q_2q_1} > 0\,(< 0)$.[14] 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., $e_{q_ir} = 0$.[15] Equivalently, the minimum expenditure function for Foreign's household is given by $e^*\left(1, q_1^*, q_2^*, r^*, u^*\right)$, with similar properties applying.[16]

An active government in Home and Foreign taxes the consumption of polluting commodities at a 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.[17] For simplicity we also assume uniform destination or origin-based consumption taxes in Home and Foreign on all commodities instead of commodity-specific taxes on each commodity in each region. In Section 3, 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 adatement in the two regions. Revenue from commodity taxation in the two regions finances public pollution abatement.[18] In order to ascertain the validity of the results under other assumptions, in Section 4 we assume that consumption tax revenue is lump-sum distributed. In Section 5, in the absence of consumption pollution, we assume that tax revenue finances the provision of an interregional public consumption good imported from ROW.

3 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

[14] All subscripts denote partial derivatives, e.g., $e_{q_1q_1} = \partial e_{q_1}/\partial q_1$.

[15] Assuming $e_{q_ir} = 0$ implies that the polluting good and pollution (clean environment) are independent in consumption, e.g., see Keen and Kotsogiannis (2014).

[16] The above assumptions regarding the minimum expenditure function are supported by a quasi-linear utility function $U(c_0, c_1, c_2, r) = V(c_0, c_1, c_2) - f(r)$, where c_i, $i = 0, 1, 2$, are the quantities consumed of the three commoditities. For the properties of the expenditure see, e.g., Kreickemeier (2005), Keen and Kotsogiannis (2014), and Antoniou *et al.* (2018).

[17] 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).

[18] In a theoretical level, public pollution abatement has been considered by several studies within the trade and environment literature. See, among others, Silva and Caplan (1997), Hadjiyiannis *et al.* (2013), Vlassis (2013).

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.[19] Assuming that both governments maintain balanced budgets, their budget constraints are:

$$p_g g = t_o \left(e_{q_1} + e^*_{q^*_1} \right) \quad \text{and} \qquad p_g g^* = t^*_o \left(e_{q_2} + e^*_{q^*_2} \right) \tag{1}$$

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.[20] 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.[21] 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.

The two regions' income-expenditure identities require that total private spending on commodities must equal income from production. That is:

$$e \left(1, q_1, q_2, r, u \right) = R(.) \qquad \text{and} \qquad e^* \left(1, q^*_1, q^*_2, r^*, u^* \right) = R^*(.). \tag{4}$$

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.

[19] In our context, public pollution abatement entails the role of an interregional public good, e.g., environmental clean-up activities, in the sense that a higher (lower) level of g or g^* by one region results to lower (higher) cross-border pollution.

[20] 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 distributed 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.

[21] The assumption of perfectly transboundary pollution emissions is relevant for the case of emissions such as GHG, e.g, CO_2 pollutants.

3.1 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*".[22] With origin-based consumption taxes, prices are $q_1 = 1 + t_o$ 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:

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

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:

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

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:

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

[22] 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*.

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

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 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., $E_{q_2 q_1} = E_{q_1 q_2} < 0$.

3.1.1 Efficiency of the Nash equilibrium

Setting $e_u \left(du/dt_o\right) = 0$ and $e_{u^*}^* \left(du^*/dt_o^*\right) = 0$, 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:

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

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

where $\bar{E}_{q_1 q_1} = E_{q_1 q_1} - E_{q_1 q_2} E_{q_2 q_2}^{-1} E_{q_2 q_1} < 0$ and similarly $\bar{E}_{q_2 q_2} < 0$.

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:[23]

[23] From equation (7), $e_r^{-1} p_g e_u \frac{du}{dt_o} \mid_N = 0 \Longrightarrow - \left(p_g - t_o\right) E_{q_1 q_1} - \left(p_g - t_o^*\right) E_{q_2 q_1} = -e_r^{-1} \left(e_r - p_g\right) e_{q_1} - e_{q_1^*}^*$. Substituting this expression into the expression for $e_{r^*}^{*^{-1}} p_g e_u^* \frac{du^*}{dt_o}$, after some algebra, we arrive to the result in equation (10).

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

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 externality*, 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 externality*, captured by the term $-e^*_r(dr^*/dt_o)$. At the Nash equilibrium this externality is positive since $(dr^*/dt_o) = -e_{q_1}/e_r < 0$.[24] 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 coincides with their cooperative setting. Specifically, if $\frac{e^*_{r^*}}{e_r} = \frac{e^*_{q_1^*}}{e_{q_1}}$, then the negative *private consumption externality* is exactly equal to the positive *environmental externality*, and thus, the Nash and cooperative equilibrium origin-based consumption taxes are equally efficient. Based on the above we state the following Proposition.

Proposition 1 *Consider two small open regional economies where there is consumption generated cross-border pollution, origin-based consumption taxes are levied on the polluting goods, and the consumption tax revenue finances public pollution abatement. The decentralized (Nash) equilibrium and the cooperative equilibrium origin-based consumption taxes coincide if,* $\frac{e^*_{r^*}}{e_r} = \frac{e^*_{q_1^*}}{e_{q_1}}$.

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 income and preferences, or alternatively they have identical and homothetic preferences.[25] 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 decentralized commodity tax setting.[26]

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

[25] Homothetic preferences means that consumers with different incomes facing the same consumer prices, consume the same goods in the same proportions, i.e., the Engel curves are straight lines.

[26] 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).

Corollary 1 *Consider two small open regional economies where there is consumption generated cross-border pollution, origin-based consumption taxes are levied on the polluting goods, and the consumption tax revenue is used to finance public pollution abatement. The Nash equilibrium and the cooperative equilibrium origin-based consumption taxes coincide if the representative individuals in the two regions have identical incomes and preferences, or have identical and homothetic preferences.*

3.2 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:

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

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.[27] 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 two regions welfare as follows:

[27]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 $q(Z_{q_1} + Z_{q_2}) = \frac{q_0}{q}(q_0 e_{q_0 q_0}) < 0$.

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

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

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 $p_g > t_d^*$.

3.2.1 Efficiency of the Nash equilibrium

Setting $e_u \left(du/dt_d \right) = 0$ and $e^*_{u^*} \left(du^*/dt_d^* \right) = 0$, 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:

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

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 $e_u \left(du/dt_d \right) + e^*_{u^*} \left(du^*/dt_d \right) = 0$ and $e_u \left(du/dt_d^* \right) + e^*_{u^*} \left(du^*/t_d^* \right) = 0$. Evaluating the sign of the slopes of these joint welfare functions at Nash equilibrium, it suffices to determine the signs of $e^*_{u^*} \left(du^*/dt_d \right)$ and $e_u \left(du/dt_d^* \right)$ respectively, since at Nash equilibrium $e_u \left(du/dt_d \right) = e^*_{u^*} \left(du^*/t_d^* \right) = 0$. Consider, for example, the joint welfare function when Home changes its destination-based consumption tax. Evaluating its slope at Nash equilibrium gives:[28]

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

The expression in equation (16) is positive, indicating that the Nash equilibrium tax rate t_d^{*N} is lower than the corresponding cooperative equilibrium destination-based consumption tax, i.e., $t_d^N < t_d^C$. It is only in the absence of such an externality that Nash and cooperatively set destination-based consumption taxes are equally 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 externality.* 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 externality* of the higher t_d on Foreign's welfare is not accounted for by Home, when the latter region acts Nash (non-cooperatively). Thus, its Nash equilibrium destination-based consumption tax is smaller than the corresponding cooperative tax. On the basis of these results we state the following proposition.

Proposition 2 *Consider two small open regional economies where there is consumption generated cross-border pollution, destination-based consumption taxes are levied on the polluting goods, and the consumption tax revenue finances public pollution abatement. The Nash equilibrium destination-based consumption taxes are lower than the corresponding cooperative taxes.*

4 Tax competition with consumption pollution, without public pollution abatement

Now, we examine the welfare effects and the efficiency of decentralized 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 redistributed 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:

[28] 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).

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

4.1 Origin-based consumption taxes

Combining equations (1) and (4), the regions income-expenditure identities in this case are:

$$\begin{aligned} e(1, q_1, q_2, r, u) &= R(.) + t_o E_{q_1}(q_1, q_2, r, r^*, u, u^*), \\ e^*(1, q_1^*, q_2^*, r^*, u^*) &= R^*(.) + t_o^* E_{q_2}(q_1, q_2, r, r^*, u, u^*), \end{aligned} \tag{18}$$

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.

4.1.1 Efficiency of the Nash equilibrium

To ascertain the efficiency of the decentralized setting of origin-based consumption taxes, we evaluate the signs of the slopes of the joint welfare functions at Nash equilibrium.[29] 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 where Home rises 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:

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

[29] 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.

where $\bar{E}_{q_1q_1} = E_{q_1q_1} - E_{q_1q_2}E^{-1}_{q_2q_2}E_{q_2q_1} < 0$.[30] 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 externality* (i.e., $-e^*_{q_1^*} < 0$), second through a *public revenue externality, i.e.,*$-t^*_o E_{q_2q_1}$, whose sign is ambiguous, depending on whether commodities 1 and 2 are complements or substitutes in consumption.[31] Haufler and Pflüger (2007), without consumption pollution, demonstrate that the sum $-e^*_{q_1^*} - E^{-1}_{q_2q_2}E_{q_2q_1}e_{q_2}$, is negative. Third, through the positive *environmental externality, i.e.,* $-e^*_{r^*}(dr/dt_o) = -e^*_{r^*}\bar{E}_{q_1q_1} > 0$. Thus, the sum of the three terms is ambiguous, without, however, excluding the possibility that it can also be equal to zero.

At this point, it is important to compare the results in equations (10) and (19). That is, the efficiency of the decentralized setting of origin-based consumption taxes, when tax revenue finances public pollution abatement vis-a-vis to when it is lump-sum distributed. 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 externality*, 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 externality*, 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 distributed, an additional effect arises. This effect we call *public revenue externality*, which captures the change in Foreign's consumption tax revenue, at the given t^{*N}_o, 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 externality*, in the case of public pollution abatement is "*embedded*" into the positive *environmental externality.* The discussion of equation (10) established sufficient conditions under which the negative private consumption externality and the positive environmental externality cancel each other out, resulting in $e^*_{u^*}\frac{du^*}{dt_o} \mid_N = 0$, thus, rendering efficient the decentralized setting of origin-based consumption taxes when consumption tax revenue finances public pollution abatement. These clear-cut conditions, however, cease to hold when consumption tax revenue is lump-sum distributed, i.e., equation (19), and in this case, the efficient setting of decentralized origin-based consumption taxes could occur, more likely than not, out of sheer coincidence.

[30] The analytical result for $e^*_{u^*}\frac{du^*}{dt_o} \mid_N$ emerges after some algebra, by substituting the Nash equilibirum value of t^{*N}_o given in equation (A.3), and the expression $(dr/dt_o) = E_{q_1q_1} + E_{q_2q_1}$ into the first right-hand-side expression of equation (19).

[31] For example, if commodities 1 and 2 are complements, i.e., $E_{q_2q_1} < 0$, a higher t_o by Home also reduces aggregate consumption of commodity 2, thus Foreign's consumption tax revenue and welfare.

4.2 Destination-based consumption taxes

Combining equations (2) and (4), with destination-based consumption taxes and consumption tax revenues being lump-sum distributed to the local households, the regions income-expenditure identities are:

$$\begin{aligned} e\left(1, q_1, q_2, r, u\right) &= R(.) + t_d\left(e_{q_1} + e_{q_2}\right), \\ e^*\left(1, q_1^*, q_2^*, r^*, u^*\right) &= R^*(.) + t_d^*\left(e^*_{q_1^*} + e^*_{q_2^*}\right). \end{aligned} \tag{20}$$

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.

4.2.1 Efficiency of the Nash equilibrium

To ascertain whether the decentralized 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:

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

where $e^*_{u^*}\frac{du^*}{dt_d}\mid_N > 0$, since $\left(Z_{q_1} + Z_{q_2}\right) < 0$. Equivalently,[32] $e_u\frac{du}{dt_d^*}\mid_N = -e_r\left(Z^*_{q_1^*} + Z^*_{q_2^*}\right) > 0$. 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 distributed to the regions' households. Then,*

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

(i) The Nash equilibrium destination-based consumption taxes are inefficient, leading to lower Nash tax rates relative to the cooperative tax levels.

(ii) The Nash equilibrium origin-based consumption taxes, in general, are inefficient, and only incidentally can be equally efficient as the corresponding cooperative equilibrium taxes.

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 distributed or it finances the provision of public pollution abatement. Consider now the case where commodity taxes are levied on grounds of the origin principle. In the absence of consumption pollution, an increase in the origin consumption tax by Home, increases the consumer price of good 1 in both regions and thus it affects the consumption of good 1 and consumption tax revenue in Foreign. The sum of these two effects is negative, rendering the origin principle inefficient, e.g., Haufler and Pflunger (2007). In the presence of cross-border consumption pollution, however, and when tax revenue finances the provision of public pollution abatement, an increase in the origin consumption tax causes two effects. On the one hand it reduces the consumption of good 1 (negative effect), but on the other hand, at Nash equilibrium, it reduces pollution (positive effect). Under the conditions of Proposition 1, these two opposite effects are of equal magnitude and cancel each other out, rendering the origin principle efficient.

5 Tax competition and interregional public consumption goods

In this section we consider the case where there is no consumption pollution and no public pollution abatement. Instead, consumption tax revenue finances the provision of an interregional public consumption good, e.g., measures for the prevention of infectious diseases, or adapting measures against climatic changes such as building flood defences or choosing tree species and forestry practices less vulnerable to storms and fires.

The relevant literature has examined the efficiency of decentralized commodity taxation on grounds of destination or origin-based tax competition only in the presence of local public consumption goods, e.g., Haufler and Pflüger (2007), and Moriconi and Sato (2009). However, the efficiency of decentralized commodity taxation in the presence of interregional public goods is yet to be examined.[33]

On the basis of the above, our interpretation of consumption tax revenue financing g and g^* is along the lines of a more pragmatic view that consumption tax revenue finances the provision of an interregional public consumption good, rather than being fully earmarked for the provision of public pollution abatement. Letting g and g^* be the quantities of the interregional public consumption good purchased by Home and Foreign, its overall consumption in the two regions is:[34]

$$G = g + g^*, \tag{22}$$

and the two regions income-expenditure identities are given by:

$$e\left(1, q_1, q_2, G, u\right) = R(.) \qquad \text{and} \qquad e^*\left(1, q_1^*, q_2^*, G, u^*\right) = R^*(.). \tag{23}$$

5.1 The efficiency of decentralized origin-based consumption taxes

Totally differentiating equations (1), (22) and (23), after some algebra we obtain the welfare effects of changes in t_o and t_o^* as follows:

$$\begin{aligned} e_G^{-1} p_g e_u du = &\left[-\left(e_G + p_g\right) e_{q_1} e_G^{-1} - e^*_{q_1^*} - t_o E_{q_1 q_1} - t_o^* E_{q_2 q_1}\right] dt_o \\ &+ \left[-\left(e_G + p_g\right) e_{q_2} e_G^{-1} - e^*_{q_2^*} - t_o E_{q_1 q_2} - t_o^* E_{q_2 q_2}\right] dt_o^*. \end{aligned} \tag{24}$$

$$\begin{aligned} e_G^{*-1} p_g e^*_{u^*} du^* = &\left[-\left(e^*_G + p_g\right) e^*_{q_1^*} e_G^{*-1} - e_{q_1} - t_o E_{q_1 q_1} - t_o^* E_{q_2 q_1}\right] dt_o \\ &+ \left[-\left(e^*_G + p_g\right) e^*_{q_2^*} e_G^{*-1} - e_{q_2} - t_o E_{q_1 q_2} - t_o^* E_{q_2 q_2}\right] dt_o^*. \end{aligned} \tag{25}$$

[33] Relating the provision of international or interregional public goods and destination and origin-based commodity taxes has been examined in models of international or interregional tax harmonization, e.g., see Karakosta *et al.* (2014). This, however, is a distinct literature not related to the present study.

[34] This is an assumption for analytical simplicity, quite prevalent in the relevant literature, e.g., Bjorvatn and Schjelderup (2002). Alternatively, it is easy to model the case where each region finances the provision of a different interregional public good, enjoyed, however, by consumers in both regions.

where $e_G < 0$ and $e^*_G < 0$ respectively denote the marginal willingness to pay for the provision of the public consumption good in Home and Foreign.[35] Equations (A.9) and (A.10) in the Appendix provide algebraic details of these results.

Ascertaining the efficiency of the decentralized setting of origin-based consumption taxes, it suffices to evaluate the signs of $e^*_{u^*}(du^*/dt_o)$ and $e_u(du/dt^*_o)$ respectively at Nash equilibrium. Following some algebra we obtain:

$$e^*_{u^*}\frac{du^*}{dt_o}\mid_N = \underbrace{-e^*_{q^*_1}}_{private\ consumption\ externality} \quad \underbrace{-e^*_G(dG/dt_o)}_{int'l\ public\ good\ externality} = e_{q_1}\left(\frac{e^*_G}{e_G} - \frac{e^*_{q^*_1}}{e_{q_1}}\right). \tag{26}$$

Equation (26) is similar to equation (10). A discussion comparing the results in equations (26) and (19), follows along the lines of that comparing the results in equations (10) and (19).

5.2 The efficiency of decentralized destination-based commodity taxes

Totally differentiating equation (22) and (2), and (23), after some algebra, we obtain the welfare effects of changes in t_d and t^*_d as follows:

$$\begin{aligned} p_g e_u du = &-e_G\left[t_d\left(Z_{q_1}+Z_{q_2}\right)+e_G^{-1}\left(e_{q_1}+e_{q_2}\right)\left(p_g+e_G\right)\right]dt_d \\ &-e_G\left[t^*_d\left(Z^*_{q^*_1}+Z^*_{q^*_2}\right)+\left(e^*_{q^*_1}+e^*_{q^*_2}\right)\right]dt^*_d\ , \end{aligned} \tag{27}$$

$$\begin{aligned} p_g e^*_{u^*} du^* = &-e^*_G\left[t^*_d\left(Z^*_{q^*_1}+Z^*_{q^*_2}\right)+e^{*^{-1}}_G\left(e^*_{q^*_1}+e^*_{q^*_2}\right)\left(p_g+e^*_G\right)\right]dt^*_d \\ &-e^*_G\left[t_d\left(Z_{q_1}+Z_{q_2}\right)+\left(e_{q_1}+e_{q_2}\right)\right]dt_d, \end{aligned} \tag{28}$$

Equations (A.11) and (A.12) in the Appendix provide some algebraic details of these results.

As shown thus far, to examine the efficiency of the decentralized setting of destination-

[35] Contrary to e_r and $e^*_{r^*}$ which are positive, e_G and e^*_G are negative. This is because, on the one hand, higher levels of r and r^* reduce welfare, thus requiring higher level of expenditure on private consumption goods to maitain a constant level of utility. On the other hand, higher levels of G increase welfare, thus requiring lower level of expenditure on private consumption goods to maintain a constant level of utility.

based consumption taxes, it suffices to evaluate the signs of $e^*_{u^*}\left(du^*/dt_d\right)$ and $e_u\left(du/dt^*_d\right)$ respectively at Nash equilibrium. Following some algebra we obtain:

$$e^*_{u^*}\frac{du^*}{dt_d}\mid_N = \underbrace{e^*_G e_G^{-1}\left(e_{q_1}+e_{q_2}\right)}_{int'l\ public\ good\ externality} > 0. \tag{29}$$

Since by equation (29) $\frac{du^*}{dt_d}$ is non-zero, we can conclude that under any form of interregional public consumption goods, the decentralized setting of destination-based consumption taxes is inefficient. Using the equations (26),(29) and the discussion after equations (10) and (19), we state the following Proposition:

Proposition 4 *Consider two small open regional economies without consumption generated pollution and where origin or destination-based consumption taxes are used to finance an interregional public consumption good. Then, i) the Nash and the cooperative equilibrium origin-based consumption taxes are equally efficient if the individuals in the two regions have identical incomes and preferences, or have identical and homothetic preferences and ii) the Nash destination-based consumption taxes are inefficient and lower than their corresponding cooperative rates.*

The literature on interregional commodity taxation, has shown that in the presence of local public consumption goods, the Nash destination-based consumption taxes are set at the efficient (cooperative) level, e.g., see Haufler and Pflüger (2007). The Nash origin-based consumption taxes may be higher or lower than their corresponding cooperative rates. Here it is shown that in the context of interregional public consumption goods and under certain conditions, the decentralized setting of origin-based consumption taxes is efficient, while the decentralized setting of destination-based consumption taxes is inefficient. The intuition of this result is the same as the one for the cases where consumption tax revenue finances the provision of public pollution abatement.

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 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 Organisation 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, under certain conditions, in the presence of interregional externalities the Nash equilibrium origin-based consumption taxes are efficient, while destination-based taxes in all these cases are inefficient. In particular, we show that the origin-based consumption taxes are efficient (i) in the presence of consumption generated cross-border pollution and where revenue from taxation finances public pollution abatement, and (ii) in the absence of pollution, the revenue from taxation finances the provision of an interregional public consumption good. These results hold not only in the context of symmetric regions, but also in the case where households have identical incomes and preferences or have identical and homothetic preferences. However, the Nash equilibrium destination-based commodity taxes are inefficient. In the presence of interregional externalities, when consumption tax revenue is lump-sum distributed, the efficient setting of decentralized origin-based consumption taxes could occur, more likely than not, out of sheer coincidence. Our results contribute to the theoretical literature of interregional tax competition, but more importantly, they enrich the arguments favouring the implementation of origin-based taxation in the corresponding policy debates.

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Appendix

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

Totally differentiating equations (18) and (17), yields:[36]

$$\begin{aligned} e_u du = {} & [(-e_r + t_o) E_{q_1 q_1} - e_r E_{q_2 q_1} + e^*_{q_1^*}] dt_o \\ & + [(-e_r + t_o) E_{q_1 q_2} - e_r E_{q_2 q_2} - e_{q_2}] dt_o^*. \end{aligned} \tag{A.1}$$

[36] The total differentiation of these two equations yields $e_u du = -e_r dr + \left(e^*_{q_1^*} + t_o E_{q_1 q_1}\right) dt_o + (-e_{q_2} + t_o E_{q_1 q_2}) dt_o^*$, and $dr = (E_{q_1 q_1} + E_{q_2 q_1}) dt_o + (E_{q_2 q_2} + E_{q_1 q_2}) dt_o^*$. Substituting the expression for dr into that for du yields equation (A.1).

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

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

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

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

Totally differentiating equation (17) we obtain:

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

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

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

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

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., $(-e_r + t_d) < 0 (> 0)$. 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:

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

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

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

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

Interregional public consumption goods and the efficiency of decentralized origin-based consumption taxes

Totally differentiating equations (1) and (22) we obtain the effects of changes in t_o and t^*_o on G as follows:

$$\begin{aligned} dG &= \left[E_{q_1} + t_o E_{q_1 q_1} + t^*_o E_{q_2 q_1}\right] p_g^{-1} dt_o \\ &\quad + \left[E_{q_2} + t_o E_{q_1 q_2} + t^*_o E_{q_2 q_2}\right] p_g^{-1} dt^*_o. \end{aligned} \tag{A.9}$$

Totally differentiating equations (23), changes in Home and Foreign's welfare are given as:

$$e_u du = -e_G dG - e_{q_1} dt_o - e_{q_2} dt^*_o \quad \text{and} \quad e^*_{u^*} du^* = -e^*_G dG - e^*_{q_1^*} dt_o - e^*_{q_2^*} dt^*_o \tag{A.10}$$

Using equation (A.9) in equations (A.10) we obtain equations (24) and (25) in the text.

Interregional public consumption goods and the efficiency of decentralized destination-based consumption taxes

Totally differentiating equation (22) and (2), we obtain the effects of changes in t_d and t^*_d on aggregate G as follows:

$$\begin{aligned} dG &= \left[t_d(Z_{q_1} + Z_{q_2}) + (e_{q_1} + e_{q_2})\right] p_g^{-1} dt_d \\ &\quad + \left[t^*_d(Z^*_{q_1^*} + Z^*_{q_2^*}) + \left(e^*_{q_1^*} + e^*_{q_2^*}\right)\right] p_g^{-1} dt^*_d. \end{aligned} \tag{A.11}$$

Totally differentiating equations (23), changes in Home and Foreign's welfare are given as:

$$e_u du = -e_G dG - (e_{q_1} + e_{q_2}) dt_d, \quad \text{and} \qquad e^*_{u^*} du^* = -e^*_G dG^* - (e^*_{q^*_1} + e^*_{q^*_2}) dt^*_d \ , \qquad \text{(A.12)}$$

where using equation (A.11) in equations (A.12) we obtain equations (27) and (28) in the text.

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