Diskussionsbeiträge

aus dem Volkswirtschaftlichen Seminar

der Universität Göttingen

Beitrag Nr. 108

International Commodity Taxation under Monopolistic Competition

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Juni 2001

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Abstract

We analyze non-cooperative commodity taxation in a symmetric two-country trade model characterized by monopolistic competition and international firm and capital mobility. In this setting, taxes in one country affect foreign welfare through the relocation of mobile firms and through changes in the rents accruing to capital owners. With consumption-based taxation, these fiscal externalities exactly offset each other and the non-cooperative tax equilibrium is Pareto efficient. With production-based taxation, however, there is an additional externality on the foreign price level which leads non-cooperative tax rates to exceed their Pareto efficient levels.

Keywords: tax competition, market imperfections, international trade

JEL-Classification: F12, H21, H87

*We thank Frank Stähler and Ian Wooton for helpful comments.

1 Introduction

During the last two decades, the fiscal importance of commodity taxes has increased considerably as many OECD countries have adjusted commodity tax rates upward in order to make up for revenue losses caused by income tax reforms. These reforms have emphasized the importance of maintaining national autonomy over the rates of general commodity taxation, in order to balance the government budget. This is true even in the European Union (EU), where a minimum value-added tax (VAT) rate of 15% has been introduced, but further VAT harmonization meets serious opposition from most EU member states.[1]

National autonomy over commodity tax rates raises, however, the possibility that these taxes are used strategically and tax competition results. For this reason the discussion has also stressed the importance of adopting an international tax regime that minimizes the incentives to pursue such beggar-thy-neighbour policies. The issue of choosing a tax principle that maximizes world welfare when countries behave non-cooperatively has been addressed in the literature mostly in a setting of perfect competition and commodity trade only. In the present paper we extend this framework by considering monopolistic competition and international firm mobility, thus linking our analysis to recent work in the international trade literature.

In principle, international commodity trade can be taxed either in the country of consumption (*destination principle*) or in the country of production (*origin principle*). Under the destination principle goods leave the exporting country free of tax, whereas under the origin principle commodities are traded at tax-inclusive prices.

Historically, world trade has been taxed under the destination principle and this is still true for the large majority of international transactions today. Two recent developments have, however, begun to undermine the general applicability of this tax scheme. First, regional integration of national markets creates increasing possibilities for consumers to shop in neighbouring jurisdictions, at the tax rates of the exporting country. This issue has been of central importance in the EU, where border controls between member states have been abolished. Cross-border shopping is also of concern at the U.S.-Canadian border and its role is likely to increase in

[1] At present, the EU's minimum VAT rate is binding only for Luxembourg.

other parts of the world as regional integration proceeds. Second – and perhaps even more important – is the growth of remote sales through mail-ordering and electronic commerce, which offers new possibilities for consumers to engage in tax arbitrage.[2] It is clearly recognized in both the European Union and the United States, however, that enforcing destination-based taxes on these purchases entails severe compliance costs for the businesses involved (Keen and Smith 1996, Mikesell 2000).

Given these practical shortcomings, the case for the destination principle has been reconsidered in recent years and it has been asked whether the theoretical arguments for this tax scheme vis-a-vis the competing origin principle are sufficiently strong and robust to warrant the additional administrative costs involved.

In a setting with perfectly competitive product markets there are two main arguments why commodity taxes should be levied in the country of consumption. First, tax differentials between countries distort international consumption patterns when taxes are levied under the destination principle, whereas international production patterns are distorted when taxes are levied under the origin principle. By the production efficiency theorem, this establishes a basic argument for consumption-based commodity taxation (e.g. Frenkel, Razin and Sadka 1991). Second, it has been shown that the destination principle prevents tax competition between governments, whereas non-cooperative tax policies lead to inefficiently low tax rates under the origin principle as a result of tax base externalities (Mintz and Tulkens 1986; Kanbur and Keen 1993).[3]

Matters may be different, however, when product markets are characterized by imperfect competition. Using a duopoly model with a homogeneous good and an integrated market, Keen and Lahiri (1998) have recently shown that consumption taxes will be inferior to production taxes in a variety of scenarios under both cooperative and non-cooperative tax setting. One particularly noteworthy result of their analysis

[2] Empirical evidence for the U.S. shows that residents of states with high sales taxes are significantly more likely to buy in the Internet (Goolsbee 2000). For the European Union, Nam, Parsche and Schaden (2001) calculate, on the basis of national accounts statistics, that VAT evasion has increased in eight out of ten selected member states during the time period 1994-1996.

[3] For large countries the comparison of non-cooperative tax policies under the two tax regimes is less conclusive, since terms of trade effects are also present. For more detailed surveys of this literature, see Lockwood (1998) and Wilson (1999).

is that when countries are identical, non-cooperative taxation under the destination principle causes efficiency losses whereas tax competition under the origin principle yields the first best. Haufler, Schjelderup and Stähler (2000) have introduced transport costs and market segmentation into this model and have shown that the welfare comparison between the two tax regimes becomes ambiguous in this case. For low levels of transport costs the origin principle continues to dominate, but this ranking is turned around in favour of the destination principle when transport costs become sufficiently high. Nevertheless, it remains true that a general welfare argument for consumption-based commodity taxation cannot be established in a setting of international duopoly.

It is well known in the modern international trade literature that policy results often depend on the specific model of imperfect competition used. An alternative – and popular – framework is the model of monopolistic competition and product differentiation.[4] This model and its 'economic geography' extensions have recently been applied to a number of different policy contexts including industrial policy (Flam and Helpman 1987, Venables 1987), the provision of public infrastructure and regional aid (Martin and Rogers 1995a, 1995b), capital and income tax competition (Andersson and Forslid 1999; Kind, Midelfart Knarvik and Schjelderup 2000; Baldwin and Krugman 2000), environmental tax competition (Pflüger 2001), and the fiscal effects of regional integration (Ludema and Wooton 2000). An important advantage of this model is that it can be extended to allow for the relocation decisions of internationally mobile firms, which have generally been neglected in the literature on international commodity tax competition.[5]

In this paper we study non-cooperative tax policy under destination- and origin-based commodity taxation in a framework of monopolistic competition and product differentiation and in the presence of international capital and firm mobility. Assuming that the two competing countries are identical, we are able to derive closed-form solutions for all endogenous variables of our model, making it easy to interpret the

[4]For a synthesis of different models of monopolistic competition, see Helpman and Krugman (1985, Section III; 1989, Ch. 7).

[5]For an analysis that incorporates relocation decisions of firms into a model of international duopoly and strategic trade policy, see Janeba (1998).

results obtained. A striking result of the analysis is that non-cooperative tax policy under the destination principle achieves the first best, because the fiscal externalities associated with international capital and firm mobility exactly offset each other. A domestic tax rise drives firms to the foreign country and raises foreign welfare by reducing transport costs. At the same time, however, the tax also reduces the rents that accrue to foreign capital owners. Under the origin principle, these effects are also present but there is an additional negative externality on foreign consumers, which results from the tax-induced increase in the foreign price level. Hence, in direct contrast to the results of Keen and Lahiri (1998), the non-cooperative tax equilibrium under the destination regime strictly dominates the tax equilibrium under the origin principle in our differentiated product model.

The paper is set up as follows. In Section 2 we describe the symmetric monopolistic competition model that underlies our analysis. Section 3 derives the optimal commodity tax rates in the benchmark case where taxes are set cooperatively. Section 4 analyzes non-cooperative commodity taxation under the destination principle and Section 5 carries out the same analysis for the origin principle. Section 6 concludes.

2 The model

2.1 Consumption

We consider an open-economy version of the Dixit-Stiglitz-Krugman model of monopolistic competition (Dixit and Stiglitz 1977, Krugman 1979, 1980), where each variety of the differentiated good is produced using one unit of capital and a variable amount of labour (see Flam and Helpman 1987). There is a representative consumer in each of two identical countries, home and foreign, where the foreign country is denoted by an asterisk (*). The home consumer maximizes a quasi-linear utility function U, which is defined over a differentiated good D produced in the monopolistically competitive sector, and an outside numeraire good C produced under conditions of perfect competition

$$U = \alpha \ \ln D + C, \qquad \alpha > 0. \tag{1}$$

The differentiated good D consists of a large number of varieties. D_h is the home country's per-capita demand for each of N domestic varieties and D_f is the per-capita demand for N^* varieties produced abroad. Each variety is produced by one firm and varieties in each country are treated symmetrically, with $\sigma > 1$ denoting the elasticity of substitution between any pair of differentiated goods. Hence,

$$D = \left[N\ D_h^{\frac{\sigma-1}{\sigma}} + N^*\ D_f^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \qquad \sigma > 1. \tag{2}$$

The prices for home and foreign varieties are given by p_h and p_f, respectively. Trade in the differentiated good is subject to transportation costs, which are captured by multiplying the prices of imported varieties by a constant $\tau > 1$. In contrast to the usual specification of Samuelsonian 'iceberg' transport costs, we view transportation as a service that consumes real resources but enters the tax base of governments.[6] There are no transport costs for trade in the outside numeraire good.

An ad valorem commodity tax is levied on the differentiated good under either the destination principle (t_d) or the origin principle (t_o). Under the destination principle the home country's tax falls on the domestic consumption of all varieties of the commodity bundle D, whereas under the origin principle the tax falls on the domestic varieties produced for both the home and the foreign market. The commodity tax is selective in that the numeraire commodity C remains untaxed.[7] Denoting the consumer's income under the destination and origin principles by Y_k, $k \in \{d, o\}$, the budget constraints under the two tax regimes are given by

$$(1 + t_d) \left[N\ p_h\ D_h + N^*\ \tau\ p_f\ D_f \right] + C = Y_d, \tag{3a}$$

$$(1 + t_o)\ N\ p_h\ D_h + (1 + t_o^*) N^*\ \tau\ p_f\ D_f + C = Y_o. \tag{3b}$$

[6]We thus think of transport costs in the original Von Thünen sense, who took the cost of grain transport to consist largely of the grain consumed by the horses pulling the wagon (cf. Fujita, Krugman and Venables 1999, p. 59). If transport costs are of the strict iceberg form, no tax revenues can be collected on this service. This makes the analysis considerably more complex, as the overall level of transport costs (summed over both countries) will then be affected by tax policies. The analysis of this case is available from the authors upon request.

[7]This ensures that consumption- and production-based taxes have different real effects. If the numeraire good is also taxed at the same rate, then the two tax principles are equivalent under rather general conditions, including the case of imperfect competition (see Lockwood, de Meza and Myles 1994).

Introducing the dual price indices P_k, these budget constraints can be concisely written as

$$P_k \, D + C = Y_k \qquad \forall \, k \in \{d, o\}, \tag{4}$$

where

$$P_d = (1 + t_d) \left[N \, p_h^{1-\sigma} + N^* (\tau \, p_f)^{1-\sigma} \right]^{\frac{1}{1-\sigma}} , \tag{5a}$$

$$P_o = \left[N \left[(1 + t_o) \, p_h \right]^{1-\sigma} + N^* \left[(1 + t_o^*) \, \tau \, p_f \right]^{1-\sigma} \right]^{\frac{1}{1-\sigma}} . \tag{5b}$$

Maximizing (1) subject to (4) yields the demand functions for the aggregate commodity bundle D and the numeraire commodity C. From the properties of the quasi-linear utility function (1), total expenditures on differentiated goods are constant and all income changes affect only the demand for the competitively produced numeraire good

$$D = \alpha \, P_k^{-1} \qquad \forall \, k, \tag{6}$$

$$C = Y_k - \alpha \qquad \forall \, k. \tag{7}$$

At the second stage of budgeting consumers allocate their total expenditures for the differentiated good between the different varieties. Utility maximization with respect to D_h under the constraint of a fixed expenditure level for the bundle D yields the demand for a typical domestic variety

$$D_h = \left[\frac{(1 + t_k) \, p_h}{P_k} \right]^{-\sigma} D = \alpha \left[(1 + t_k) \, p_h \right]^{-\sigma} \; P_k^{\sigma-1} \qquad \forall \, k \in \{d, o\}. \tag{8}$$

Analogously, the demand for a typical variety produced abroad is

$$D_f = \left[\frac{(1 + t_k) \, \tau \, p_f}{P_k} \right]^{-\sigma} D = \alpha \left[(1 + t_k) \, \tau \, p_f \right]^{-\sigma} \; P_k^{\sigma-1} \qquad \forall \, k \in \{d, o\}, \tag{9}$$

where the *foreign* country's tax rate t_o^* is relevant under the origin principle.

Per-capita income Y derives from the value of factor endowments and tax revenue, which is redistributed to the individuals as a lump sum. There are L identical workers in the home country and each worker inelastically supplies one unit of labour. The production of one unit of the numeraire good C requires one unit of labour and no capital; this fixes the wage rate at unity. In addition, each country is endowed with K units of capital which are evenly distributed across the population. The rate of return on capital is endogenous and denoted by R. The income of a representative home individual is then given by

$$Y_d = 1 + R\ (K/L) + t_d \left[N\ p_h\ D_h + N^*\ \tau\ p_f\ D_f \right], \tag{10a}$$

$$Y_o = 1 + R\ (K/L) + t_o\ \left[N\ p_h\ D_h + N\ \tau\ p_h^*\ D_h^* \right], \tag{10b}$$

where p_h^* is the producer price for a domestic variety sold abroad and D_h^* is foreign demand for a domestic variety of good D. Note that in (10a)–(10b) we have assumed that tax revenue can be collected on the transport costs that are incurred by shipping goods abroad (see footnote 6).

Finally, we substitute (6) and (7) back into (1) to get the indirect utility function

$$V(t_k, t_k^*) = \alpha\ \ln \left(\alpha\ P_k^{-1} \right) + (Y_k - \alpha) \qquad \forall\ k \in \{d, o\}, \tag{11}$$

which depends on tax rates in both countries.

2.2 Production and market equilibrium

In the differentiated goods sector, the production of each variety, X_h, requires one unit of capital as a fixed cost. In addition, each unit of a variety is produced using one unit of labour so that variable costs are equal to unity. Market clearing for each domestic variety of the differentiated good requires that

$$X_h = L\ D_h + \tau\ L^*\ D_h^*,$$

where transport costs are included as an indirect demand.

The profits of a typical domestic firm are given by

$$\pi_h = (p_h - 1)\ L\ D_h + (p_h^* - 1)\ L^*\ D_h^* - R, \tag{12}$$

where $(p_h - 1)$ is the mark-up over wage costs (which equal one) and R is the interest rate to be paid for the capital input.

We make the Chamberlinian large group assumption, implying that each producer perceives an elasticity of demand that is approximately equal to the elasticity of substitution between any two varieties (σ). The profit-maximizing output price at home and abroad is identical and given by

$$p_h = p_h^* = \frac{\sigma}{\sigma - 1} \ . \tag{13}$$

Eq. (13) shows that producer prices are independent of the commodity tax rates in our model, under either the destination or the origin regime. Substituting (13) back into the profit expression (12), using (8)–(9) and $L = L^*$ from the assumption of identical endowments yields optimized profits $\hat{\pi}_h$. In the following, we use $\rho \equiv \tau^{1-\sigma}$ for brevity, where $0 < \rho < 1$.

Under the destination principle, the zero-profit conditions for a typical domestic and foreign firm imply

$$\hat{\pi}_d = \frac{\alpha L p_h^{1-\sigma}}{\sigma} \left[(1+t_d)^{-\sigma} P_d^{\sigma-1} + (1+t_d^*)^{-\sigma} \rho \, (P_d^*)^{\sigma-1} \right] - R = 0, \tag{14}$$

$$\hat{\pi}_d^* = \frac{\alpha L \, p_f^{1-\sigma}}{\sigma} \left[(1+t_d)^{-\sigma} \rho \, P_d^{\sigma-1} + (1+t_d^*)^{-\sigma} (P_d^*)^{\sigma-1} \right] - R^* = 0. \tag{15}$$

In a Chamberlinian long-run equilibrium, the interest rate equals the firms' operating surplus. Capital is freely mobile internationally so that $R = R^*$. Furthermore, under the assumptions made about production technologies the world capital stock determines the number of firms operating in equilibrium and hence the total number of varieties of the differentiated good. With identical endowments ($K = K^*$) the capital market clearing condition is

$$N + N^* = 2K. \tag{16}$$

The zero-profit conditions (14)–(15) and the capital market clearing condition (16) determine the three endogenous production variables N, N^*, R. In a first step we derive N (and the corresponding expression for N^*) from (14)–(15). Substituting in from (5a) and the analogous equation for the price level in the foreign country, and using $p_h = p_f$ from the symmetry of the model, we obtain

$$N_d = \frac{2K \, [(1+t_d^*) - \rho(1+t_d)]}{(1-\rho)[(1+t_d) + (1+t_d^*)]} \ . \tag{17}$$

In a second step, we use (16) to determine the international interest rate

$$R_d = \frac{\alpha \, L \, [(1+t_d) + (1+t_d^*)]}{2 \, \sigma \, K \, (1+t_d) \, (1+t_d^*)}. \tag{18}$$

In the symmetric equilibrium with $t_d = t_d^*$, it is easily verified from (17) that $N = N^* = K$. Similarly, with identical tax rates in both countries, eq. (18) reduces to

$$R = \frac{\alpha\, L}{(1 + t_d)\; K\; \sigma}. \tag{19}$$

Intuitively, the consumption tax raises the price level and reduces aggregate demand for the differentiated good. Since capital is employed only in this industry, its factor price must fall in the tax equilibrium.

In Appendix A we carry out the analogous computations for the origin principle. While the expressions for the equilibrium number of firms and the interest rate are more complex under this tax regime, the symmetric equilibrium (with $t_o = t_o^*$) has the same properties as the symmetric equilibrium with consumption-based taxes.

3 Cooperative tax policy

Before we turn to the analysis of non-cooperative taxation, it is useful to derive the optimal cooperative tax rate as a benchmark. The cooperative tax choice is based on the maximization of joint welfare in both regions, as given by the sum of indirect utilities expressed in (11) and its foreign counterpart. Hence, tax policy internalizes all spillovers that exist between the two countries.

In our symmetric model the distinction between the destination and the origin principles is immaterial for the analysis of cooperative taxation, and both regimes must yield the same tax rate. In the following, we derive the cooperative tax rate implemented via the destination regime and denote this tax rate by t_c. The first-order condition for t_c is given by[8]

$$\frac{\partial V}{\partial t_c} + \frac{\partial V^*}{\partial t_c} = 0 \quad \Longleftrightarrow -\frac{\alpha}{t_c}\,\varepsilon_{P_c,t_c} + \frac{Y}{t_c}\,\varepsilon_{Y_c,t_c} - \frac{\alpha}{t_c}\,\varepsilon_{P_c^*,t_c} + \frac{Y^*}{t_c}\,\varepsilon_{Y_c^*,t_c} = 0, \tag{20}$$

where $\varepsilon_{\theta,t_c} = d\ln\theta/d\ln t_c$ indicates the proportionate changes in the endogenous variables $\theta \in \{P_c, Y_c, P_c^*, Y_c^*\}$. Note first that an increase in the destination-based tax has an effect on the number of firms operating at home and abroad and therefore on price levels and income in both countries (see eqs. (5a), (10a) and their foreign

[8]From symmetry, the condition for the tax rate set by the foreign country is identical.

equivalents). This effect plays a prominent role in the analysis of non-cooperative taxation below. In the cooperative case, however, the effect of a *simultaneous* tax change in both countries on the number of firms is zero. For this reason we can evaluate the elasticities in (20) for $N = N^* = K$.

When the number of firms in each country is fixed a destination-based tax raises the price level in the home country by the full amount of the tax, whereas the foreign country's price level is unaffected. These results are derived in Appendix B and are summarized in

$$\varepsilon_{P_c,t_c} = \frac{t_c}{(1+t_c)}, \qquad \varepsilon_{P_c^*,t_c} = 0. \tag{21}$$

The changes in domestic and foreign income are given by

$$\varepsilon_{Y,t_c} = \frac{\alpha}{Y}\left[\frac{1}{(1+t_c)\,\sigma}\,\varepsilon_{R,t_c} + \frac{t_c}{(1+t_c)}\left(1 - \frac{t_d}{(1+t_d)}\right)\right], \tag{22}$$

$$\varepsilon_{Y^*,t_c} = \frac{\alpha}{Y^*(1+t_c)\,\sigma}\,\varepsilon_{R,t_c}\,. \tag{23}$$

The first term in the square bracket of (22) gives the change in the return to capital in the home country, whereas the second term is the net change in tax revenues. In the foreign country [eq. (23)] the return to capital will fall by the same amount due to perfect capital mobility, but tax revenues in this country are unaffected.

It remains to compute the change in the return to capital in both countries from (18). In elasticity form, this is given by

$$\varepsilon_{R,t_c} = \frac{-t_c}{2(1+t_c)} < 0. \tag{24}$$

An increase in the domestic consumption tax reduces the rate of return to capital in both countries, since it makes the domestic market less profitable for both domestic and foreign producers.

We substitute (24) into (22)–(23) and use the resulting expressions along with (21) in (20). Solving for the optimal coordinated tax rate $\hat{t}_c$ gives

$$\hat{t}_c = \frac{-1}{\sigma}\,. \tag{25}$$

The cooperatively chosen subsidy in (25) corresponds to a first-best allocation in the present model.[9] The consumer price for a domestic variety of the differentiated

[9] It is straightforward to show that the same optimal tax formula is obtained under autarky.

good is $(1 + t_c)\, p_h$. Substituting in from (13) and (25) shows that the consumer price equals unity and hence marginal cost. The price of imported varieties is $\tau(1 + t_c)\, p_f$, which also equals total marginal costs of production and transportation. It is shown in Appendix C that identical results are obtained under the origin principle. Summarizing these results gives

Proposition 1: *The optimal cooperative policy under both the destination and the origin principle is a subsidy at rate* $1/\sigma$*. This policy achieves a first-best allocation.*

Intuitively, the cooperative subsidy counteracts the price distortion arising from monopolistic competition and restores an efficient allocation of consumption between the differentiated good and the numeraire good. From (13) we know that an increase in σ reduces the mark-up charged by the monopolistically competitive firms; hence, it also reduces the need for a subsidy. In the extreme, as $\sigma \to \infty$ producers of all varieties of bundle D behave in a perfectly competitive way and the optimal subsidy is zero.

Proposition 1 can be related to a result in Keen and Lahiri (1998, Proposition 2, last part) for their duopoly model with homogeneous products. According to their analysis, a first-best allocation can be achieved under both the origin and the destination basis when production efficiency requires only one firm to produce. But when preferences are of the Dixit-Stiglitz type and technologies are characterized by increasing returns to scale, then profit maximization by firms will ensure that no variety is produced by more than one firm (Helpman and Krugman 1985, Ch. 7). Therefore, in our model of monopolistic competition cooperative tax policy under either the origin or the destination principle will always lead to a Pareto efficient outcome.

The first-best optimum obtained in the cooperative case serves as a convenient benchmark to identify potential inefficiencies that arise from non-cooperative taxation under either the destination or the origin principle. In the following, we will analyze the two different tax regimes in turn.

4 Tax competition with destination-based taxes

We first study non-cooperative tax policy under the destination principle. The core question asked is whether national policy-makers have an incentive to pursue beggar-thy-neighbour policies under this tax principle, leading to inefficient commodity tax choices in the resulting (symmetric) Nash equilibrium.

We have already determined the response of the international interest rate to a change in the destination-based tax rate of the home country [eq. (24)]. This effect is unchanged here because the elasticity of the international interest rate with respect to tax changes is not influenced by the relocation of firms. Next, we turn to the change in the number of firms operating at home and abroad as a result of a domestic tax increase. Differentiating (17) with respect to t_d and using the symmetry of the model to simplify the resulting expression yields

$$\varepsilon_{N,t_d} = \frac{-(1+\rho)}{2(1-\rho)} \frac{t_d}{1+t_d} < 0 \ . \tag{26}$$

Furthermore, since the total number of firms is fixed, we have $\varepsilon_{N^*,t_d} = -\varepsilon_{N,t_d}$. These effects show that in the presence of transport costs a tax increase in the home country leads some domestic firms to leave the country and set up production abroad.[10] The reason is that the domestic tax increase raises the price index of differentiated goods in the home country (see below) and makes the domestic market less profitable, relative to the foreign market. Since aggregate transport costs borne by consumers are raised when the number of foreign-based firms increases, this effect causes policy-makers to perceive an extra cost of destination-based commodity taxation in an open economy with internationally mobile firms and costly trade.

The tax-induced changes in the interest rate and the location decisions of firms affect both the price level and the per-capita income of consumers. The effect on the home country's price level is given by (see Appendix B)

$$\varepsilon_{P_d,t_d} = \frac{t_d}{(1+t_d)} \left[1 + \frac{1}{2(\sigma-1)}\right] > 0 \ . \tag{27}$$

[10] It is seen from (26) that ε_{N,t_d} is negatively related to transport costs and tends to infinity when trade costs become arbitrarily small. (Note that $\rho \equiv \tau^{1-\sigma}$ tends to zero when transport costs tend to infinity, but $\rho \rightarrow 1$ when transport costs are negligible.)

Interpreting this expression is straightforward: the first term in the square bracket is the direct effect of a tax increase on the domestic consumer price. The second term in the bracket gives the additional increase in consumer prices due to the fact that transport costs are now incurred for a larger number of varieties.[11]

Finally, the income change for a typical domestic worker is

$$\varepsilon_{Y,t_d} = \frac{\alpha\ t_d}{Y\ (1+t_d)} \left[\frac{-1}{2\ (1+t_d)\ \sigma} + \frac{1}{(1+t_d)} \right]. \tag{28}$$

A tax increase has two counteracting effects. The negative first effect derives from the reduction in the world interest rate, which reduces the value of the domestic capital endowment. The positive second effect gives the net increase in tax revenues collected, taking account of the changes in demand patterns at home and abroad.

We are now ready to determine the optimal destination-based tax rate of the home government, treating the foreign tax rate as fixed. Differentiating the indirect utility function (11) with respect to t_d yields the first-order condition

$$\frac{\partial V}{\partial t_d} = \frac{-\alpha}{t_d}\ \varepsilon_{P_d,t_d} + \frac{Y}{t_d}\ \varepsilon_{Y,t_d} = 0. \tag{29}$$

As in the cooperative equilibrium, all welfare effects are incorporated in the changes of the price level and per-capita income. Substituting in from (27) and (28) and solving for the optimal non-cooperative tax rate $\hat{t}_d$ gives

$$\hat{t}_d = \frac{-1}{\sigma} = \hat{t}_c. \tag{30}$$

Hence, the non-cooperative tax rate chosen under the destination principle is first-best, and it reproduces the optimal tax rate in the cooperative tax equilibrium. At first sight, this is a surprising result in the present model because a tax rise in the home country will induce some firms to relocate abroad, lowering aggregate transport costs for foreign consumers [cf. eq. (26)]. This is a *positive* externality from the perspective of the foreign country, which tends to cause a downward competition of commodity tax rates. At the same time, however, a tax increase in the home country also has a *negative* externality for the foreign country since it lowers the

[11] Correspondingly, the (indirect) effect through the relocation of firms lowers the price level in the foreign country. Since there is no direct effect of a domestic consumption tax increase on the foreign country, the overall effect of a rise in t_d on P_d^* is negative.

world interest rate and thus shifts some of the tax burden on foreign capital owners. It turns out that the positive and the negative effect on foreign welfare exactly offset each other, leaving no net strategic effect for the home country. Due to symmetry, the same is true for the foreign country. This is summarized in

Proposition 2: *The non-cooperative tax equilibrium under the destination principle is Pareto efficient and tax rates are the same as in the cooperative equilibrium.*

We emphasize that the offsetting fiscal externalities caused by firm mobility on the one hand and capital mobility on the other are no coincidence in the present model. Both are caused by the same underlying change, the reduced profitability of the home market as a result of the consumption tax increase. If this effect is strong it will lead to a large drop in the international interest rate, but at the same time it causes a larger number of firms to relocate to the other country, other things being equal. Furthermore, the gain to foreign consumers from the relocation of firms is independent of the level of transport costs. If transport costs are raised, then foreigners experience a larger real income gain for *each* firm that moves to their country. At the same time, however, it is seen from eq. (26) that a higher level of τ reduces the elasticity with which firms respond to a tax increase (see footnote 10).

5 Tax competition with origin-based taxes

Under the origin principle, the commodity tax falls on all domestically produced varieties of the differentiated good. Hence, the tax directly affects the profitability of firms operating in the home country. We start by computing the change in the return to capital under this tax regime. From eq. (A.4) in the appendix, this is given by

$$\varepsilon_{R,t_o} = \frac{-t_o}{2(1+t_o)} < 0\ . \tag{31}$$

Eq. (31) shows that the effect of a tax rise on the international interest rate is the same under the origin and destination regimes [see eq. (24)]. This should not be surprising in a symmetric model, since the change in the interest rate is determined by the overall increase in the world price level for differentiated goods. As we will see below, the *sum* of the price level increases in the two countries is the same for a given increase in either the consumption or the production tax.

The change in the number of firms is obtained by differentiating (A.3) in the appendix with respect to t_o. This yields

$$\varepsilon_{N,t_o} = -\left[\frac{1+2\rho(2\sigma-1)+\rho^2}{(1-\rho^2)}\right]\frac{(1+\rho)}{2(1-\rho)}\frac{t_o}{(1+t_o)} < 0\ . \tag{32}$$

Comparing this with (26) and noting that the square bracket in (32) is larger than one in absolute value implies that an equiproportionate tax change leads to a larger relocation of firms under the origin regime as compared to the destination regime.

Turning to the effect on the price level in the home country, we totally differentiate (5b) and use (32) to get (see Appendix C)

$$\varepsilon_{P_o,t_o} = \frac{t_o}{(1+t_o)}\left[\frac{1}{1+\rho} + \frac{[1+2\rho(2\sigma-1)+\rho^2]}{2(\sigma-1)\,(1-\rho^2)}\right] > 0\ . \tag{33}$$

The first term in the square bracket gives the expenditure share for domestically produced varieties of the differentiated commodity. Comparing this to the corresponding term under the destination principle [eq. (27)], we see that the direct effect on the home country's price level is weaker for the production tax, since imported varieties are not affected. The second term in (33) again gives the indirect effect through the relocation of firms. As discussed above, this isolated term exerts a stronger upward pressure on the domestic price level as compared to a tax rise under the destination principle, because a larger number of firms move abroad for a given tax change.

In an analogous way, we can determine the response of the *foreign* price level to the domestic production tax. This yields

$$\varepsilon_{P_o^*,t_o} = \frac{t_o}{(1+t_o)}\left[\frac{\rho}{1+\rho} - \frac{[1+2\rho(2\sigma-1)+\rho^2]}{2(\sigma-1)\,(1-\rho^2)}\right] > 0\ . \tag{34}$$

The first term in the square bracket is the expenditure share for foreign varieties of the differentiated good. This term shows that a tax rise under the origin principle exerts a direct positive effect on the foreign price level, an effect that is absent under the destination regime (cf. footnote 11). It is also seen from (33) and (34) that the sum of the direct effects on the home and the foreign country's price level is unity, and is thus the same as under the destination principle. Since indirect effects sum to zero under both tax principles, world demand for the differentiated good falls by the same amount. This explains why the response of the international interest rate is identical in the two tax regimes.

The effect of the production tax on the income of the home individual is given by

$$\varepsilon_{Y,t_o} = \frac{\alpha\ t_o}{Y\ (1+t_o)} \left[\frac{-1}{2\ (1+t_o)\ \sigma} + \frac{1}{(1+t_o)} - \frac{4\sigma t_o \rho}{2(1+t_o)(1-\rho)^2} \right]. \tag{35}$$

The first two terms in this equation correspond to the analysis under the destination principle [eq. (28)]. The negative first term results from the reduction in interest income, whereas the sum of the last two terms gives the net increase in tax revenues. The negative last term, which is absent under the destination principle, reflects the fact that tax revenues are directly reduced through the relocation of firms when taxes are levied on domestic production.

Finally, we determine the optimal tax rate under the origin principle. The first-order condition under the destination principle [eq. (29)] is unchanged, except that t_d is replaced by t_o. Substituting in from (33) and (35) and solving for t_o gives

$$\hat{t}_o = \frac{-(1-\rho)[(2\sigma-1)(1-\rho)+2\sigma^2\rho]}{\sigma\{[2\sigma-(1-\rho)](1-\rho)+4\sigma(\sigma-1)\rho\}} < 0. \tag{36}$$

This result shows that, in contrast to the destination principle, the non-cooperative tax rate chosen under the origin principle will not generally be Pareto efficient. Instead, the tax rate under the origin principle will generally be higher (i.e., the subsidy is smaller) than in the cooperative benchmark. To see this, start from a prohibitively high level of transport costs ($\tau \to \infty$ and hence $\rho \to 0$). In this case, the origin-based tax rate replicates the cooperative tax rate $\hat{t}_c = -1/\sigma$, which also equals the tax rate under autarky. In the opposite polar case of zero transport costs ($\tau = 1$), the optimal production tax is $\hat{t}_o = 0$. More generally, differentiating (36) with respect to τ shows that the production tax rises monotonically (i.e., the subsidy becomes smaller) when transport costs are reduced. This implies that for any non-prohibitive level of transport costs the optimal production tax will exceed its Pareto efficient level. Our results are summarized in

Proposition 3: *For all finite levels of transport costs, the non-cooperative tax equilibrium under the origin principle is not Pareto efficient. Tax rates are higher than in the cooperative equilibrium.*

To explain this difference to the optimal non-coordinated tax policy under the destination principle, we focus on the fiscal externalities associated with production taxes in the present model. Firstly, the negative externality, which operates through the reduction in foreign interest incomes, is the same in both tax regimes. Secondly, there is again a positive externality on foreign consumers, as they face lower aggregate transport costs due to the relocation of firms in their country of residence. In fact, we have seen in our discussion of eq. (32) that this effect is stronger now than under the destination principle. There is a third externality under the origin principle, however, which arises from the direct positive effect that a domestic production tax has on the foreign price level for differentiated goods [eq. (34)]. This is an additional negative externality which dominates the more elastic response of mobile firms to a domestic tax increase. Therefore, the net effect of all fiscal externalities is negative under the origin principle, and this explains why the non-coordinated tax rate exceeds the cooperative one.

Taken together, Propositions 2 and 3 lead to the unambiguous conclusion that the non-cooperative equilibrium under the destination principle Pareto dominates the non-cooperative equilibrium under the origin principle. This is precisely the opposite result to that of Keen and Lahiri (1998, Proposition 6) in a setting of international duopoly. In their analysis, non-cooperative taxes levied under the origin principle yield the first-best, whereas the tax rates chosen under the destination principle depart from their Pareto optimal levels.

An intuitive explanation for this striking contrast can be given by pointing to the fundamental dissimilarities in the market structure and in the type of trade considered by Keen and Lahiri and in the present paper. When consumers desire variety and firms produce with increasing returns, each firm specializes in one variety and faces no direct (import) competitor. Hence, there is one-way trade in heterogeneous products. In the setting of Keen and Lahiri, domestic and foreign firms produce homogeneous products and trade, if it occurs at all, is two-way trade in identical products. This results in fundamentally different strategic incentives for governments in the two trade settings and under the two alternative tax regimes.

In the homogeneous duopoly model, strategic motives are directed primarily at the distribution of firms' profits. Under the origin principle, each country has an incentive to *subsidize* domestic production, in order to shift profits to the domestic firm.[12] This strategic motive is compatible with the goal to correct the domestic production inefficiency via a subsidy and is responsible for the Pareto optimality of origin-based commodity taxation. Under the destination principle, in contrast, a subsidy to domestic consumption will increase the profits earned by the foreign firm in the home market. Hence, strategic considerations conflict with domestic production efficiency, leading to inefficient tax rates in the non-cooperative equilibrium. For this reason, the ability to act directly on firms' output decisions is a distinct potential advantage of the origin principle in the duopoly model (Keen and Lahiri 1998, p. 343).

In our model of monopolistic competition, this same feature turns out to be the source of the inefficiency caused by origin-based commodity taxation. Producer prices are unaffected by taxes in equilibrium [eq. (13)] so that the entire burden of either destination- or origin-based taxes is exclusively on consumers. If the tax is levied under the destination principle it is borne solely by domestic residents, whereas an origin-based tax falls on both domestic and foreign consumers. Foreign consumers cannot avoid the tax-induced increase in import prices because imported varieties are not produced domestically. Hence, there is a strategic incentive for each country to impose a *positive tax* on domestic production, which conflicts with the goal to counteract the domestic distortion by means of a subsidy. Under the destination principle, in contrast, only the externalities associated with international firm and capital mobility are present. Since these are exactly offsetting, tax policy is targeted exclusively at the domestic inefficiency resulting from imperfect competition, even if tax rates are set non-cooperatively.

6 Conclusions

It is widely acknowledged that taxing international trade in the country of consumption is welfare superior to production-based taxation when commodity markets are perfectly competitive. However, as Keen and Lahiri (1998) have recently argued from a model with homogeneous products, no transport costs, and duopoly competition

[12] This motive is familiar from the literature on strategic trade policy (Brander and Spencer 1985).

between firms, this ranking may be turned around in favour of the origin principle if there is imperfect competition in product markets. This caveat is important from a policy perspective because economic integration and the emergence of new technologies – the Internet, in particular – make it more costly to enforce the taxation of goods and services in the country of consumption.

In the present paper we have incorporated the policy question raised by Keen and Lahiri (1998) into an established new trade model with differentiated products, transport costs, and international mobility of capital and firms (Flam and Helpman, 1987). The complexity of this framework has made it necessary to retain other simplifying assumptions – standard ones in the trade literature –, such as the symmetry of countries and firms, or the absence of a government revenue constraint. Furthermore, given that the control over commodity tax rates is still in the hands of national governments worldwide, the analysis has focused on the case of non-cooperative tax policies.

In this setting some new arguments for consumption-based commodity taxation have emerged. First, even though there are fiscal externalities under the destination principle, the incentive to attract internationally mobile firms on the one hand and to tax the rents earned by foreign investors on the other tend to be offsetting – not only qualitatively, but also quantitatively. Second, under the origin principle, but not under the destination principle, there is a fundamental incentive to raise production taxes strategically, as foreign consumers' love of variety prevents them from switching to imperfect domestic substitutes.

To conclude, our analysis has identified a setting of imperfect competition where non-cooperative taxation under the destination principle unambiguously dominates the outcome under the origin principle. More generally, different models of imperfect competition will yield different results, depending on which type of fiscal externalities dominates in the framework used. However, the important point to emphasize is that imperfect competition as such does not lead to a general argument in favour of origin-based commodity taxes. Given the rather clear-cut preference for the destination principle in perfectly competitive markets, it may then indeed be worth to accept some administrative and compliance costs in order to maintain this principle as a general scheme for taxing international trade.

Appendix

A. Market equilibrium under the origin principle

Under the origin principle, the zero-profit conditions for a typical domestic and foreign firm are

$$\hat{\pi}_o = \frac{\alpha L p_h^{1-\sigma}}{\sigma} \left[(1+t_o)^{-\sigma} P_o^{\sigma-1} + (1+t_o)^{-\sigma} \rho \, (P_o^*)^{\sigma-1} \right] - R = 0. \tag{A.1}$$

$$\hat{\pi}_o^* = \frac{\alpha L p_f^{1-\sigma}}{\sigma} \left[(1+t_o^*)^{-\sigma} \rho \, P_o^{\sigma-1} + (1+t_o^*)^{-\sigma} (P_o^*)^{\sigma-1} \right] - R^* = 0. \tag{A.2}$$

The zero-profit conditions (A.1)–(A.2) and the capital market clearing condition (16) are substituted in (5b) and its equivalent for the foreign country. Introducing $\gamma \equiv (1+t_o)^{\sigma}(1+t_o^*)^{\sigma}$, this yields for the number of firms in the home country

$$N_o = \frac{2K \, \gamma \, (1+t_o^*)^{1-\sigma} \left[(1+\rho^2)\,(1+t_o)^{-\sigma} - 2\rho(1+t_o^*)^{-\sigma} \right]}{(1+\rho^2)[(1+t_o)+(1+t_o^*)] - 2\rho[(1+t_o)^{1-2\sigma} + (1+t_o^*)^{1-2\sigma}]}. \tag{A.3}$$

For the interest rate under the origin principle, we get

$$R_o = \frac{\alpha L \left\{ \gamma \, (1+\rho^2) \, [(1+t_o)^{-1} + (1+t_o^*)^{-1}] - 2\rho[(1+t_o)^{2\sigma-1} + (1+t_o^*)^{2\sigma-1}] \right\}}{2 \, \sigma \, K \, [(1+t_o)^{\sigma} - \rho(1+t_o^*)^{\sigma}] \, [(1+t_o^*)^{\sigma} - \rho(1+t_o)^{\sigma}]}. \tag{A.4}$$

Setting $t_o = t_o^*$ in (A.3) gives $N = K$, whereas (A.4) reduces to eq. (19) in the text.

B. Cooperative and non-cooperative tax policy under the destination principle

<u>Changes in price levels:</u> Totally differentiating (5a) and dividing by P_d gives

$$\frac{dP_d}{P_d} = \frac{1}{(1+t_d)} \, dt_d + \frac{1}{1-\sigma} \left(\frac{P_d}{1+t_d} \right)^{\sigma-1} \left[p_h^{1-\sigma} dN + (\tau p_f)^{1-\sigma} dN^* \right]$$

and analogously for the foreign country. Introducing elasticities, using $\varepsilon_{N,t_d} = -\varepsilon_{N^*,t_d}$ and $p_h = p_f$, $N = N^* = K$ from symmetry gives

$$\varepsilon_{P_d,t_d} = \frac{t_d}{(1+t_d)} + \frac{1}{(1-\sigma)} \frac{(1-\rho)}{(1+\rho)} \, \varepsilon_{N,t_d}, \tag{A.5}$$

$$\varepsilon_{P_d^*,t_d} = -\frac{1}{(1-\sigma)} \frac{(1-\rho)}{(1+\rho)} \, \varepsilon_{N,t_d}. \tag{A.6}$$

Changes in income: For the home country, totally differentiating (10a) yields

$$\varepsilon_{Y,t_d} \equiv \frac{dY/Y}{dt_d/t_d} = \frac{\beta_1}{Y}\,\varepsilon_{R,t_d} + \frac{\beta_2}{Y}\,(1+\varepsilon_{D_h,t_d}+\varepsilon_{N,t_d}) + \frac{\beta_3}{Y}\left(1+\varepsilon_{D_f,t_d}+\varepsilon_{N^*,t_d}\right), \quad \text{(A.7)}$$

$$\beta_1 = R\,\frac{K}{L}, \quad \beta_2 = t_k p_h D_h N, \quad \beta_3 = t_k \tau p_f D_f N^* \qquad \forall\, k \in \{d,o\}.$$

We use (19) to reduce β_1. To simplify β_2 and β_3 we use eqs. (8) and (9), respectively, and substitute (5a). This gives

$$\beta_1 = \frac{\alpha}{(1+t_k)\,\sigma}, \quad \beta_2 = \frac{\alpha\, t_k}{(1+t_k)\,(1+\rho)}, \quad \beta_3 = \frac{\alpha\,\rho\, t_k}{(1+t_k)\,(1+\rho)}\ \forall\, k. \qquad \text{(A.8)}$$

The changes in the demand for domestic and foreign varieties are obtained from (8) and (9), respectively. This gives

$$\varepsilon_{D_h,t_d} = \varepsilon_{D_f,t_d} = -\sigma\,\frac{t_d}{(1+t_d)} + (\sigma-1)\,\varepsilon_{P_d,t_d}. \qquad \text{(A.9)}$$

Substituting (A.8) and (A.9) in (A.7) and using $\varepsilon_{N^*,t_d} = -\varepsilon_{N,t_d}$ yields

$$\varepsilon_{Y,t_d} = \frac{\alpha}{Y}\left[\frac{1}{(1+t_d)\,\sigma}\,\varepsilon_{R,t_d} + \frac{1-t_d\,(\sigma-1)}{(1+t_d)} + \frac{t_d\,(\sigma-1)}{(1+t_d)}\,\varepsilon_{P_d,t_d} + \frac{(1-\rho)\,t_d}{(1+t_d)(1+\rho)}\,\varepsilon_{N,t_d}\right]. \qquad \text{(A.10)}$$

In the foreign country, $\varepsilon_{D_h^*,t_d} = \varepsilon_{D_f^*,t_d} = 0$. Hence

$$\varepsilon_{Y^*,t_d} = \frac{\alpha}{Y^*}\left[\frac{1}{(1+t_d)\,\sigma}\,\varepsilon_{R,t_d} - \frac{(1-\rho)\,t_d}{(1+t_d)(1+\rho)}\,\varepsilon_{N,t_d}\right]. \qquad \text{(A.11)}$$

Cooperative tax policy: The two countries treat N and N^* as fixed so that $\varepsilon_{N,t_d} = 0$. Using this in (A.5), (A.6), (A.10) and (A.11) gives equations (21)–(23) in the text.

Non-cooperative tax policy: Substituting (26) into (A.5) yields (27) in the text. Substituting (24)–(27) into (A.10) and cancelling terms yields eq. (28).

C. Cooperative and non-cooperative tax policy under the origin principle

Changes in price levels: Totally differentiating (5b) and dividing by P_o gives

$$\frac{dP_o}{P_o} = P_o^{\sigma-1}\; N\; p_h^{1-\sigma}(1+t_o)^{-\sigma}\; dt_o$$

$$+\frac{1}{1-\sigma}\; P_o^{\sigma-1}\left\{[(1+t_o)\,p_h]^{1-\sigma}dN + [(1+t_o^*)\tau p_f]^{1-\sigma}dN^*\right\}$$

and analogously for the foreign country. Introducing elasticities, using $\varepsilon_{N,t_o} = -\varepsilon_{N^*,t_o}$ and $p_h = p_f$, $N = N^* = K$ from symmetry gives

$$\varepsilon_{P_o,t_o} = \frac{t_o}{(1+\rho)(1+t_o)} + \frac{1}{(1-\sigma)}\frac{(1-\rho)}{(1+\rho)}\,\varepsilon_{N,t_o}, \tag{A.12}$$

$$\varepsilon_{P_o^*,t_o} = \frac{\rho\, t_o}{(1+\rho)\,(1+t_o)} - \frac{1}{(1-\sigma)}\frac{(1-\rho)}{(1+\rho)}\,\varepsilon_{N,t_o}. \tag{A.13}$$

Changes in income: For the home country, totally differentiating (10b) yields

$$\varepsilon_{Y,t_o} \equiv \frac{dY/Y}{dt_o/t_o} = \frac{\beta_1}{Y}\,\varepsilon_{R,t_o} + \frac{\beta_2}{Y}\,(1+\varepsilon_{D_h,t_o}+\varepsilon_{N,t_o}) + \frac{\beta_3}{Y}\left(1+\varepsilon_{D_h^*,t_o}+\varepsilon_{N,t_o}\right), \tag{A.14}$$

where β_1, β_2 and β_3 are given in (A.8). The change in the domestic and the foreign demand for a domestic variety are obtained from (8) and its foreign equivalent. This gives

$$\varepsilon_{D_h,t_o} = -\sigma\,\frac{t_o}{(1+t_o)} + (\sigma-1)\,\varepsilon_{P_o,t_o}, \quad \varepsilon_{D_h^*,t_o} = -\sigma\frac{t_o}{(1+t_o)} + (\sigma-1)\,\varepsilon_{P_o^*,t_o}\,. \tag{A.15}$$

Substituting (A.8) and (A.15) in (A.14) and using $\varepsilon_{N^*,t_o} = -\varepsilon_{N,t_o}$ yields

$$\varepsilon_{Y,t_o} = \frac{\alpha}{Y}\left[\frac{1}{(1+t_o)\,\sigma}\,\varepsilon_{R,t_o} + \frac{t_o\,(\sigma-1)}{(1+\rho)(1+t_o)}\left(\varepsilon_{P_o,t_o} + \rho\,\varepsilon_{P_o^*,t_o}\right)\right.$$
$$\left. + \frac{t_o}{(1+t_o)}\left(\frac{1-t_o\,(\sigma-1)}{(1+t_o)} + \varepsilon_{N,t_o}\right)\right]\,. \tag{A.16}$$

In the foreign country, a change in t_d has no direct effect on tax revenue, but demand for foreign varieties is affected in both countries due to changes in the price index for differentiated goods. Using (9) and its foreign equivalent, these effects are

$$\varepsilon_{D_f,t_o} = (\sigma-1)\,\varepsilon_{P_o,t_o}, \quad \varepsilon_{D_f^*,t_o} = (\sigma-1)\,\varepsilon_{P_o^*,t_o}\,.$$

This gives

$$\varepsilon_{Y^*,t_o} = \frac{\alpha}{Y^*}\left[\frac{1}{(1+t_o)\,\sigma}\,\varepsilon_{R,t_o} + \frac{t_o\,(\sigma-1)}{(1+\rho)(1+t_o)}\left(\rho\,\varepsilon_{P_o,t_o} + \varepsilon_{P_o^*,t_o}\right) - \frac{t_o}{(1+t_o)}\,\varepsilon_{N,t_o}\right]\,. \tag{A.17}$$

Cooperative tax policy: We set $\varepsilon_{N,t_d} = 0$ in (A.12)–(A.13) and (A.16)–(A.17). Substituting the simplified equations (A.12)–(A.13) and (A.16)–(A.17) along with (31) into (20) shows that the cooperative tax rate under the origin principle is $(-1/\sigma)$, which is the same result as under the destination principle [eq. (25)].

Non-cooperative tax policy: Substituting (32) into (A.12) and (A.13) yields eqs. (33) and (34) in the text. Substituting (32)–(34) into (A.16) and cancelling terms yields eq. (35).

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