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Commodity tax competition and industry location under the destination- and the origin-principle

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Abstract

We develop a model of commodity tax competition with monopolistically competitive internationally mobile firms, transport costs, and asymmetric country sizes. We investigate the impacts of non-cooperative tax setting, as well as of tax harmonization and changes in the tax principle, in both the short and the long run. The origin principle, when compared to the destination principle, is shown to exacerbate tax competition and to erode tax revenues, yet leads to a more equal spatial distribution of economic activity. This suggests that federations which care about spatial inequality, like the European Union, face a non-trivial choice for their tax principle that goes beyond the standard considerations of tax revenue redistribution.

Keywords: commodity tax competition, origin principle, destination principle, tax harmonization, industry location

JEL classification: F12, H22, H87, R12

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1 Introduction

Increases in factor mobility and economic integration more generally have given rise in the European Union (henceforth, EU) to concerns about the possibilities of tax competition eroding governments' ability to finance public expenditure and to maintain the welfare state. Devolution of responsibility for public services to regions within Europe has arguably further increased opportunities for harmful tax competition, both within and between countries. In the USA, where state and local taxes support several important categories of public expenditure, concern about tax competition has a much longer history but remains, nevertheless, a contentious issue. In recent years, one added source of concern in both the EU and the USA has been the development of e-commerce, which has exacerbated already existing pressures on cross-border tax systems (Goolsbee, 2001). Furthermore, in the case of the EU, increasing economic integration might be an important driver for regional inequalities, and these inequalities may be further amplified by tax competition. Since one of the social cohesion objectives of the EU, as explicitly spelled out by Article 130a of the Amsterdam Treaty of 1997, is to "aim at reducing disparities between the levels of development of the various regions and the backwardness of the least favoured regions or islands, including rural areas", tax competition may have additional indirect costs if it were to exacerbate spatial inequalities, thus leading to the increased use of structural funds to promote the development of backward areas.[1]

While much of the tax competition literature analyzes taxes on capital or corporate profits, there are important tax competition issues that arise for value-added taxes (henceforth, VAT) and retail sales taxes when consumers can shop in multiple jurisdictions. It is generally thought that there are two key questions in the design of indirect taxation systems with cross-border transactions (Keen *et al.*, 2002).[2] The first question asks *where taxes should be levied*. Two alternative regimes are traditionally considered. Under the 'destination or consumption-based principle' (henceforth, DP) tax is paid in the country where goods are consumed at the rate applied there, while under the 'origin or production-based principle' (henceforth, OP) tax is paid in the country where goods are produced at that country's rate. Accordingly, local consumption is taxed and exports are exempted under DP, while local production is taxed and imports are exempted under OP. Once a tax principle has been agreed on, the second question asks whether tax rates should be set independently

[1] The EU allocates roughly 35% of its budget to the European Regional Development Funds (195 million euros for the 2000–2006 period). Of these, almost 70% go to so-called 'Objective 1 regions', which are defined as those regions with an average income of less than 75% of the EU average.

[2] Our spatial setting differs markedly from the usual models of commodity tax competition focusing on cross-border shopping. Here, we consider a shipping model in which goods are traded between countries on segmented markets, and in which firms choose where to locate and to produce (instead of consumers choosing where to shop).

by national governments or rather *harmonized to some extent across countries.* While the former case allows for more flexibility in dealing with asymmetric shocks and entices governments to exert effort to collect taxes efficiently, it may make them engage in harmful tax competition.

Within the EU, the issues of choice of a tax principle and VAT harmonization are a recurrent source of debate (European Commission, 2000; Ebrill et al., 2001).[3] In particular, while "the concept of a definitive system of taxation in the Member State of origin [is] retained as a long-term Community objective" (European Commission, 2004b, p.1), with increasing direct cross-border sales to consumers, such a system for all types of transactions (partly motivated by the relative administrative ease for collecting and remitting tax revenue) has been met with skepticism by many countries which fear losing production and tax revenue. In the USA, a closely related important issue has been whether or not to close the use tax evasion loophole that puts increasing strain on local governments' budgets.[4] The Streamlined Sales Tax Project (SSTP) is an attempt at getting cooperation among states in taxation of cross-border purchases.[5] This proposal would result in DP treatment of mail-order and online purchases, and OP treatment of purchases by consumers who travel out-of-state. As in the EU, this reform proposal has not met with broad agreement, as shown by state governments' chronic delays in implementing the necessary regulatory requirements (Strayhorn, 2005).

The main objective of this paper is to provide a theoretical and numerical analysis of commodity tax competition, tax harmonization, and industry location in a framework featuring many firms, imperfect competition, and variable mark-ups. Our framework to study tax competition is the one developed by Behrens *et al.* (forthcoming), which uses a model of monopolistic competition that generates a linear demand system. This latter aspect allows us to capture the various impacts that tax incidence and trade costs may have on the equilibrium tax rates and the spatial distribution of industry. It also allows us to deal explicitly with spatial market segmentation, the importance of which has been put forward by empirical research (Engel and Rogers, 1996; Haskel and Wolf, 2001). These two aspects are usually neglected in the existing literature building on the CES model (e.g., Haufler and Pflüger, 2004) which, as we argue in this paper, may lead to misleading results. The downside of using such a rich modeling framework is that analytical results for the tax competition equilibria are largely out of reach. We, therefore, heavily rely on

[3]Recent experience with extending existing agreements on reduced VAT rates in construction and hospitality has shown that agreeing on tax matters is likely to get even more difficult in the enlarged EU.

[4]Every state that levies a retail sales tax also levies a use tax at the same rate, which applies to goods purchased out-of-state. Enforcement is difficult since the Supreme Court has ruled that out-of-state retailers cannot be compelled to collect these taxes unless the firms 'have nexus', i.e., do some business within the purchaser's state of residence.

[5]See `http://www.streamlinedsalestax.org/` for more information.

numerical analysis and 'simulate' the model for a large set of parameter values. This allows us to assess the robustness of the main findings and to derive comparative static results by running simple regressions on our artificial data set.

We consider a federation of two jurisdictions, each of which maximizes the sum of its residents' consumer surplus, returns to locally-owned capital, and the benefits of local public expenditure. We compare the equilibrium outcomes to two different cooperative outcomes. In the first, the federation chooses tax rates in both jurisdictions to maximize total welfare (optimal tax rates); in the second, the federation chooses a single harmonized tax rate with the same objective (full harmonization). We also deal with the question of how a switch from DP to OP for final consumption transactions, as initially envisaged by the European Commission (2004b), may *change the equilibrium tax rates and the spatial distribution of industry*. We thus explicitly take into account the fact that a switch from a 'consumption tax' (DP), which falls mostly on immobile consumers, to a 'production tax' (OP), which falls mostly on mobile firms, will have spatial effects in the long run. Our results confirm this intuition by showing that the 'race to the bottom' is particularly strong under OP, thus leading to quite low non-cooperative equilibrium tax rates. Yet, and contrary to the DP where the larger country charges the lower tax rate, the larger country charges the higher tax rate under OP. As a by-product of this result, the 'home market effect', which in general states that the larger country attracts a disproportionate share of firms (Helpman and Krugman, 1985), gets attenuated or reversed, which leads to a more equal equilibrium industry distribution. A direct policy implication of this finding is that, in the absence of tax harmonization, federations like the EU face a non-trivial trade-off: *more spatial inequality and more tax revenue under DP, or less spatial inequality and less tax revenue under OP*. Because a quite substantial part of the EU's structural funds, intended to alleviate spatial inequality and backwardness, are financed by national VAT revenues, the question of whether and how VAT rates and VAT regimes may exacerbate these inequalities in the first place deserves closer attention.[6]

The remainder of the paper is organized as follows. Section 2 presents the model and derives the market outcome. Section 3 then deals with the short run equilibrium and optimum of the tax game, both under DP and OP, taking the spatial distribution of industry as given. We also discuss the harmonized outcome. Section 4 turns to the long run equilibrium with internationally mobile firms. Using both a large grid simulation and a benchmark case, we investigate how a switch from DP to OP affects equilibrium tax rates and the spatial distribution of industry. We again discuss the harmonized outcome, taking into account firm mobility. Section 5 discusses the policy relevance of our main findings and concludes.

[6]During the 1990s, roughly 25-30% of the EU budget was financed by member states' VAT, a figure that has dropped to about 15% in recent years since direct 'gross national income'-based transfers have become more important.

2 The model

2.1 Preferences and technology

Consider an economy with two countries, labeled H and F, and a unit total mass of consumers. Each consumer is endowed with one unit of labor and one unit of capital. Let $\theta \in (0,1)$ denote the share (and mass) of consumers located in country H, which implies that θ also measures that country's shares (and masses) of labor and capital. Consumers are internationally immobile and supply labor only in the country where they reside.[7] By contrast, they are free to supply capital wherever they want. All consumers have identical quasi-linear utility functions over the consumption of two types of goods, a homogeneous good Z and a horizontally differentiated good that is provided as a continuum of varieties indexed by $v \in [0, N]$.[8] The former good is costlessly traded across countries, whereas any variety of the latter good incurs a trade cost of $\tau > 0$ units of good Z per unit of variety shipped across the two countries. Both types of goods can be costlessly traded within each country.

The subutility over the varieties of the differentiated good is quadratic as in Ottaviano *et al.* (2002). A resident of country $i = H, F$ solves the following consumption problem:

$$\max_{q_i(v),\ v\in[0,N];\ Z_i} \quad U_i \equiv \alpha \int_0^N q_i(v)\mathrm{d}v - \frac{\beta-\gamma}{2}\int_0^N [q_i(v)]^2\mathrm{d}v - \frac{\gamma}{2}\left[\int_0^N q_i(v)\mathrm{d}v\right]^2 + Z_i$$
$$\text{s.t.} \quad \int_0^N p_i(v)q_i(v)\mathrm{d}v + p_i^Z Z_i = R_i + w_i + p_i^Z \overline{Z}_0$$

where $q_i(v)$ and $p_i(v)$ are the consumption and the (consumer) price of variety v in country i; Z_i and p_i^Z are the consumption and the price of the homogeneous good; R_i is the return to the agent's unit of capital; w_i is the wage rate; $\overline{Z}_0$ is a sufficiently large initial endowment of the homogeneous good to ensure its consumption in equilibrium; and $\alpha > 0$, $\beta > \gamma > 0$ are parameters.

The homogeneous good Z is produced under constant returns to scale and perfect competition by using one unit of labor per unit of output. Due to perfect competition and free trade in that good, profit maximization then implies that $p_i^Z = w_i = 1$ in both countries, where the last equality is our choice of numéraire. By contrast, each variety of the differentiated good is produced under firm-level increasing returns to scale and monopolistic competition, with a fixed requirement ϕ of capital and a constant marginal requirement m

[7]In this respect, our model offers a better description of the EU, in which interregional labor mobility is much lower than in the USA (Faini, 1999).

[8]Quasi-linear preferences rank far behind homothetic preferences in general equilibrium models of trade. Yet, Dinopoulos *et al.* (2006, p.22) show that "quasi-linear preferences behave reasonably well in general-equilibrium settings".

of labor. Because there is a unit mass of capital, capital market clearing then implies that the total mass of firms is determined by $N = 1/\phi$.

In what follows, we present expressions for country H only. Symmetric expressions hold for country F. Because all goods produced in the same country enter consumers' utility functions symmetrically, we may drop the variety index v in what follows. Denote by $0 < \lambda < 1$ the share of firms (and varieties) located in country H. Letting q_{FH} stand for the consumption in country H of a variety produced in country F. Letting p_{HH} (resp., $p_{FH}+\tau$) be the mill (resp., the delivered) consumer price in country H for a variety produced in country H (resp., F), utility maximization yields the following demand functions

$$\begin{aligned} q_{HH} &= a - bp_{HH} + cN\left(\frac{P_H}{N} - p_{HH}\right) = a - (b + cN)p_{HH} + cP_H \\ q_{FH} &= a - (b + cN)(p_{FH} + \tau) + cP_H \end{aligned} \tag{1}$$

where $a \equiv \alpha/[\beta + (N-1)\gamma]$ expresses the desirability of the differentiated product with respect to the numéraire; where $b \equiv 1/[\beta + (N-1)\gamma]$ gives the link between individual and industry demands: consumers become more sensitive to price differences when b rises; where $c \equiv \gamma/(\beta - \gamma)[\beta + (N-1)\gamma]$ is an inverse measure of the degree of product differentiation between varieties: when $c \to \infty$, varieties are perfect substitutes, whereas they are independent for $c = 0$; and where

$$P_H/N \equiv \lambda p_{HH} + (1-\lambda)(p_{FH} + \tau) \tag{2}$$

stands for the average consumer price of the differentiated good in country H. Using (1) and (2), the consumer surplus in country H can then be expressed as follows:

$$\begin{aligned} C_H &= \frac{a^2 N}{2b} - aN\left[\lambda p_{HH} + (1-\lambda)(p_{FH} + \tau)\right] \\ &\quad + \frac{(b + cN)N}{2}\left[\lambda(p_{HH})^2 + (1-\lambda)(p_{FH} + \tau)^2\right] - \frac{cN^2}{2}\left[\lambda p_{HH} + (1-\lambda)(p_{FH} + \tau)\right]^2. \end{aligned}$$

In what follows, we superscript all relevant variables with d and o under DP and OP, respectively. A firm located in country H maximizes its profit given by

$$\Pi_H \equiv \theta[p_{HH}(1-t) - m]q_{HH} + (1-\theta)[p_{HF}(1-\bar{t}) - m]q_{HF} - r_H\phi$$

where $(t, \bar{t}) = (t_H^d, t_F^d)$ under DP, and where $(t, \bar{t}) = (t_H^o, t_H^o)$ under OP. Following Behrens *et al.* (forthcoming), we rewrite the profit functions using a device that allows us to treat an ad valorem tax as a specific tax and a pure profits tax:

$$\Pi_H = (1-t)\theta\left[p_{HH} - \frac{m}{(1-t)}\right]q_{HH} + (1-\bar{t})(1-\theta)\left[p_{HF} - \frac{m}{(1-\bar{t})}\right]q_{HF} - r_H\phi.$$

Letting $s \equiv t/(1-t)$ and $\overline{s} \equiv \overline{t}/(1-\overline{t})$, the profit function then becomes:

$$\Pi_H = \frac{1}{1+s}\theta\big[p_{HH} - m(1+s)\big]q_{HH} + \frac{1}{1+\bar{s}}(1-\theta)\big[p_{HF} - m(1+\bar{s})\big]q_{HF} - r_H\phi \qquad (3)$$

which is our working specification. Increasing t (resp., $\overline{t}$) amounts to increasing s (resp., $\overline{s}$). In what follows, we let $(s,\bar{s}) = (s^d_H, s^d_F)$ under DP and $(s,\bar{s}) = (s^o_H, s^o_H)$ under OP.

2.2 Price equilibrium

In accord with empirical evidence, we assume that national product markets are segmented (Engel and Rogers, 1996; Haskel and Wolf, 2001) and that labor markets are local. Each firm, therefore, maximizes its domestic and foreign profits by maximizing each term in expression (3) independently. Since each firm is negligible to the market because of the continuum assumption, it takes the price index (2) as given. Yet, firms' pricing decisions remain interdependent 'in aggregate', because each firm must correctly anticipate what the average price of the market will be in equilibrium. Thus, our price equilibrium is formally equivalent to a Nash equilibrium with a continuum of players.

As shown by Behrens *et al.* (forthcoming), the Nash equilibrium (producer) prices in the absence of commodity taxes are given as follows:

$$\begin{aligned} p^*_{HH} &= \frac{2[a+(b+cN)m]+c(1-\lambda)N\tau}{2(2b+cN)} \\ p^*_{FH} &= \frac{2[a+(b+cN)m]+c(1-\lambda)N\tau}{2(2b+cN)} - \frac{\tau}{2} \end{aligned}$$

with symmetric expressions holding for country F. The equilibrium prices under DP can then be expressed with respect to the no-tax case:

$$\begin{aligned} p^d_{HH} &= p^*_{HH} + \frac{b+cN}{2b+cN}ms^d_H \\ p^d_{FH} &= p^*_{FH} + \frac{b+cN}{2b+cN}ms^d_H \end{aligned} \qquad (4)$$

whereas they are given by

$$\begin{aligned} p^o_{HH} &= p^*_{HH} + \frac{b+cN}{2b+cN}ms^o_H - \frac{c(1-\lambda)N}{2(2b+cN)}m(s^o_H - s^o_F) \\ p^o_{FH} &= p^*_{FH} + \frac{b+cN}{2b+cN}ms^o_F + \frac{c\lambda N}{2(2b+cN)}m(s^o_H - s^o_F) \end{aligned} \qquad (5)$$

under OP. Hence, (4) and (5) are consumer prices exclusive of trade costs. Finally, using these equilibrium prices, the equilibrium individual demands under the two tax principles can be rewritten as follows:

$$q^d_{HH} = (b+cN)\left[p^d_{HH} - m(1+s^d_H)\right] \qquad q^d_{FH} = (b+cN)\left[p^d_{FH} - m(1+s^d_H)\right]$$

and

$$q_{HH}^o = (b + cN)\left[p_{HH}^o - m(1 + s_H^o)\right] \qquad q_{FH}^o = (b + cN)\left[p_{FH}^o - m(1 + s_F^o)\right].$$

Symmetric expressions hold for country F.

Throughout this paper, we assume that marginal production cost m and trade costs τ are sufficiently low for international demands q_{HF} and q_{FH} to remain strictly positive for all firm distributions $\lambda \in [0, 1]$ under both tax principles. This is the case if trade costs are low enough. Specifically, it must be that:

$$\tau < \frac{2a}{2b + cN} - m\frac{2b}{2b + cN} \max\left\{s_H^d, s_F^d\right\} \tag{6}$$

under DP, and

$$\tau < \frac{2a}{2b + cN} - \max_{i=H,F i\neq j} m\left\{\frac{2b}{2b + cN}(1 + s_i^o) - (s_i^o - s_j^o)\right\} \tag{7}$$

under OP, which we assume to hold in the analytical developments. Note that conditions (6) and (7) depend on the tax rates, which are themselves generally endogeneous. This requires us to check ex post that these conditions are verified in each step of our numerical analysis at the equilibrium tax rates.

2.3 Spatial equilibrium

A spatial equilibrium is such that no agent has an incentive to change her international allocation of capital and such that no firm has an incentive to enter or exit the market. These two conditions will hold when no agent can get a higher rental rate by relocating her capital and when rental rates exactly absorb firms' operating profits. Formally, at an *interior spatial equilibrium* ($0 < \lambda^* < 1$), we have $r_H = r_F$ with r_H and r_F such that the profits (3) are equal to zero. In what follows, we restrict our analysis to the meaningful case of interior spatial equilibria only.[9]

Substituting the equilibrium quantities into the profits (3), the rental rates under DP in the two countries are as follows:

$$r_H^d = \frac{(b + cN)\theta}{\phi(1 + s_H^d)}\left[p_{HH}^d - m(1 + s_H^d)\right]^2 + \frac{(b + cN)(1 - \theta)}{\phi(1 + s_F^d)}\left[p_{HF}^d - m(1 + s_F^d)\right]^2 \tag{8}$$

$$r_F^d = \frac{(b + cN)(1 - \theta)}{\phi(1 + s_F^d)}\left[p_{FF}^d - m(1 + s_F^d)\right]^2 + \frac{(b + cN)\theta}{\phi(1 + s_H^d)}\left[p_{FH}^d - m(1 + s_H^d)\right]^2. \tag{9}$$

[9] The assumption of interior spatial equilibria across countries does not seem too stringent in practice, especially if one has in mind a more aggregate sectoral structure of the economy at the macro level.

The rental rates under OP are obtained in an analogous way and are given by:

$$r_H^o = \theta\frac{b+cN}{\phi(1+s_H^o)}\left[p_{HH}^o - m(1+s_H^o)\right]^2 + (1-\theta)\frac{b+cN}{\phi(1+s_H^o)}\left[p_{HF}^o - m(1+s_H^o)\right]^2 \quad (10)$$

$$r_F^o = (1-\theta)\frac{b+cN}{\phi(1+s_F^o)}\left[p_{FF}^o - m(1+s_F^o)\right]^2 + \theta\frac{b+cN}{\phi(1+s_F^o)}\left[p_{FH}^o - m(1+s_F^o)\right]^2. \quad (11)$$

Under DP, we can easily determine the spatial equilibrium by solving the equation $r_H^d = r_F^d$ (see Appendix A.1). Under OP, the spatial equilibrium is the solution to a quadratic equation that is too complex to allow for a detailed analytical investigation. Behrens *et al.* (forthcoming) provide an analysis of the special case where $\tau = 0$. We deal in this paper numerically with the case where $\tau > 0$.

2.4 Capital and tax revenues

Concerning the profit distribution, we assume that each agent holds a fully diversified portfolio and, therefore, has the same claim to her share in world profits. For a given spatial distribution λ of firms, the capital revenues R_H and R_F are equal and given by $R_H = R_F \equiv \lambda r_H + (1-\lambda) r_F$. Although this assumption is somewhat particular, it allows us to cut short a taxonomy of cases that arise under alternative assumptions on the distribution of capital incomes.[10]

Tax revenues associated with the tax rates s_H^d and s_F^d that accrue to the governments under DP are given by:

$$\begin{aligned} T_H^d &= \theta N \frac{s_H^d}{1+s_H^d}\left[\lambda p_{HH}^d q_{HH}^d + (1-\lambda) p_{FH}^d q_{FH}^d\right] \\ T_F^d &= (1-\theta) N \frac{s_F^d}{1+s_F^d}\left[\lambda p_{HF}^d q_{HF}^d + (1-\lambda) p_{FF}^d q_{FF}^d\right]. \end{aligned} \quad (12)$$

Under OP, tax revenues can be expressed as follows:

$$\begin{aligned} T_H^o &= \lambda N \frac{s_H^o}{1+s_H^o}\left[\theta p_{HH}^o q_{HH}^o + (1-\theta) p_{HF}^o q_{HF}^o\right] \\ T_F^o &= (1-\lambda) N \frac{s_F^o}{1+s_F^o}\left[\theta p_{FH}^o q_{FH}^o + (1-\theta) p_{FF}^o q_{FF}^o\right]. \end{aligned} \quad (13)$$

Expressions (12) and (13) clearly show that a commodity tax under DP corresponds to a consumption tax, which is thus proportional to market size θ; whereas a commodity tax under OP corresponds to a production tax, which is thus proportional to industry size λ.

[10] Capital market equilibrium requires that rates of return are equal in both jurisdictions in the long run, so that our assumption is less stringent. Yet, one should keep in mind that the precise ownership pattern will influence the tax competition game.

3 Short-run equilibrium and optimum

We start by analyzing the case where governments take the spatial distribution λ of the industry as given. This may be either due to the fact that capital is relatively immobile between countries, or because governments do not realize that changing their commodity tax rates may have an influence on the spatial structure of the economy. This short-run analysis provides a benchmark against which we can judge the outcome when the location choices of firms are taken into account. Doing so allows us to highlight the relative importance of factor mobility when deciding on a tax principle or on tax harmonization in the long-run, an aspect developed in Section 4 below.

3.1 The destination principle

Given our quasi-linear utility function, social welfare in each country may be expressed as the sum of consumers' surplus, firms' profits, and utility derived from the provision of local public goods financed by local tax revenues. Because of our assumption on the structure of capital ownership (namely full portfolio diversification), and recalling that wages are equal to one, welfare in both countries is given as follows:

$$
\begin{aligned}
W_H^d &= \theta \left[C_H^d + 1 + \lambda r_H^d + (1-\lambda) r_F^d \right] + g\left(T_H^d\right) \\
W_F^d &= (1-\theta) \left[C_F^d + 1 + \lambda r_H^d + (1-\lambda) r_F^d \right] + g\left(T_F^d\right)
\end{aligned}
$$

where g stands for the concave sub-utility derived from the consumption of the public good. In what follows, for numerical reasons, we set $g(\cdot) \equiv 2\sqrt{\cdot}$. Assuming that g is a linear function of T does not reduce the complexity of our model, yet generates additional difficulties because equilibrium tax rates could be zero (or even negative, i.e., consumption subsidies, as in Haufler and Pflüger, 2004) unless tax revenues enter with a sufficiently large weight (see, e.g., Laffont and Tirole, 1993).

Since λ is fixed in the short run, the non-cooperative tax equilibrium is a solution to the following first-order conditions:

$$
\begin{aligned}
\frac{\partial W_H^d}{\partial s_H^d} &= \theta \left[\frac{\partial C_H^d}{\partial s_H^d} + \lambda \frac{\partial r_H^d}{\partial s_H^d} + (1-\lambda) \frac{\partial r_F^d}{\partial s_H^d} \right] + \frac{\partial T_H^d}{\partial s_H^d} \left(T_H^d\right)^{-1/2} = 0 \\
\frac{\partial W_F^d}{\partial s_F^d} &= (1-\theta) \left[\frac{\partial C_F^d}{\partial s_F^d} + \lambda \frac{\partial r_H^d}{\partial s_F^d} + (1-\lambda) \frac{\partial r_F^d}{\partial s_F^d} \right] + \frac{\partial T_F^d}{\partial s_F^d} \left(T_F^d\right)^{-1/2} = 0.
\end{aligned}
$$

The expressions for the derivatives are given in Appendices A.2 and A.3. Although these analytical expressions are cumbersome, numerical simulations reveal that W_H^d is concave in s_H^d for any given value of s_F^d, which then yields a single-valued reaction function and (in our model) a unique equilibrium (see Figure 1 for an illustration of the short-run welfare surface W_H^d). In what follows, we denote by s_H^{d*} and s_F^{d*} the non-cooperative equilibrium tax rates under short-run DP.

Insert Figure 1 about here.[11]

The *cooperative equilibrium tax rates*, denoted by $\widetilde{s}_H^d$ and $\widetilde{s}_F^d$, are such that world welfare $W^d \equiv W_H^d + W_F^d$ is maximized with respect to s_H^d and s_F^d. Under DP with segmented markets, because foreign taxes have no direct impact on homes prices, we have:

$$\frac{\partial C_H^d}{\partial s_F^d} = \frac{\partial C_F^d}{\partial s_H^d} = \frac{\partial T_H^d}{\partial s_F^d} = \frac{\partial T_F^d}{\partial s_H^d} = 0$$

so that the cooperative equilibrium is a solution to the following first-order conditions:

$$\frac{\partial W^d}{\partial s_H^d} = \frac{\partial W_H^d}{\partial s_H^d} + (1-\theta)\left[\lambda \frac{\partial r_H^d}{\partial s_H^d} + (1-\lambda)\frac{\partial r_F^d}{\partial s_H^d}\right] = 0 \quad (14)$$

$$\frac{\partial W^d}{\partial s_F^d} = \frac{\partial W_F^d}{\partial s_F^d} + \theta\left[\lambda \frac{\partial r_H^d}{\partial s_F^d} + (1-\lambda)\frac{\partial r_F^d}{\partial s_F^d}\right] = 0. \quad (15)$$

Since the tax derivatives of the DP rental rates are all negative, i.e. $\partial r_H^d/\partial s_H^d < 0$, $\partial r_H^d/\partial s_F^d < 0$, $\partial r_F^d/\partial s_F^d < 0$ and $\partial r_F^d/\partial s_H^d < 0$, it is readily verified that

$$\frac{\partial W^d}{\partial s_H^d}(s_H^{d*}, s_F^{d*}) < \frac{\partial W_H^d}{\partial s_H^d}(s_H^{d*}, s_F^{d*}) = 0$$

$$\frac{\partial W^d}{\partial s_F^d}(s_H^{d*}, s_F^{d*}) < \frac{\partial W_F^d}{\partial s_F^d}(s_H^{d*}, s_F^{d*}) = 0$$

which establishes the following result.

Proposition 1 (short-run 'race to the top') *Assume that λ is fixed in the short-run. Then the non-cooperative tax rates s_H^{d*} and s_F^{d*} under the destination principle are higher than the cooperative tax rates $\widetilde{s}_H^d$ and $\widetilde{s}_F^d$.*

The intuition underlying the result in Proposition 1 is as follows. When country i changes its tax rate, it directly influences the profits of firms located in the other country. Part of this change feeds back into the income of country-i agents, an effect that is taken into account by the tax-setter in country i. Yet, the negative externality inflicted upon country-j agents is disregarded. Proposition 1 establishes that in the non-cooperative equilibrium this negative externality dominates the positive one, so that both countries would benefit from a coordinated reduction of tax rates.

The degree of excessiveness of equilibrium tax rates, when compared to optimum tax rates, depends on the countries' sizes. We can show the following result.

[11]The parameter values underlying Figure 1 are as follows (recall that λ is fixed in the short run): $\alpha = 3$, $\beta = 0.25$, $\gamma = 0.2$, $\tau = 0.07$, $\phi = 0.1$, $\lambda = 0.52$, $\theta = 0.6$ and $m = 0.6$.

Proposition 2 (size and excess rates) *Assume that λ is fixed in the short-run. The more similar the two countries are in terms of size, the larger the welfare gains from a coordinated reduction in tax rates under the destination principle.*

Proof. Using the expressions of the rental rate derivatives, as given in Appendix A.2, some standard computations show that conditions (14) and (15) can be rewritten as follows:

$$\begin{aligned}
\frac{\partial W^d}{\partial s_H^d} &= \frac{\partial W_H^d}{\partial s_H^d} + \theta(1-\theta)\left[\lambda K_1 + (1-\lambda)K_2\right] = 0 \\
\frac{\partial W^d}{\partial s_F^d} &= \frac{\partial W_F^d}{\partial s_F^d} + \theta(1-\theta)\left[\lambda K_3 + (1-\lambda)K_4\right] = 0
\end{aligned}$$

where K_i, for $i = 1,2,3,4$, are negative bundles of parameters that do not depend on θ. Since $\theta(1-\theta)$ is maximal when $\theta = 1/2$, we may conclude that the welfare gains are maximized when $\theta = 1/2$. ■

Proposition 2 shows that the fiscal externality is strongest when both countries are of roughly equal size. It is weakest when θ is close to 0 or 1, as most of the externality is internalized by the large country.

3.2 The origin principle

Analogously to DP, welfare in the two countries under OP is given by:

$$\begin{aligned}
W_H^o &= \theta\left[C_H^o + 1 + \lambda r_H^o + (1-\lambda)\, r_F^o\right] + 2\left(T_H^o\right)^{1/2} \\
W_F^o &= (1-\theta)\left[C_F^o + 1 + \lambda r_H^o + (1-\lambda) r_F^o\right] + 2\left(T_F^o\right)^{1/2}
\end{aligned}$$

The non-cooperative equilibrium s_H^{o*} and s_F^{o*} is a solution to the first-order conditions:

$$\begin{aligned}
\frac{\partial W_H^o}{\partial s_H^o} &= \theta\left[\frac{\partial C_H^o}{\partial s_H^o} + \lambda\frac{\partial r_H^o}{\partial s_H^o} + (1-\lambda)\frac{\partial r_F^o}{\partial s_H^o}\right] + \frac{\partial T_H^o}{\partial s_H^o}\left(T_H^o\right)^{-1/2} = 0 \\
\frac{\partial W_F^o}{\partial s_F^o} &= (1-\theta)\left[\frac{\partial C_F^o}{\partial s_F^o} + \lambda\frac{\partial r_H^o}{\partial s_F^o} + (1-\lambda)\frac{\partial r_F^o}{\partial s_F^o}\right] + \frac{\partial T_F^o}{\partial s_F^o}\left(T_F^o\right)^{-1/2} = 0.
\end{aligned}$$

The expressions for the derivatives are given in Appendices A.3 and A.4. The analytical expressions are again cumbersome, but numerical simulations over a large grid of admissible parameter values reveal that W_H^o is concave in s_H^o for any given value of s_F^o, which then yields a single-valued reaction function and (in our model) a unique equilibrium. In what follows, we denote by s_H^{o*} and s_F^{o*} the non-cooperative equilibrium tax rates under short-run OP.

The cooperative equilibrium tax rates, denoted by $\widetilde{s}_H^o$ and $\widetilde{s}_F^o$, are obtained by maximizing total welfare $W^o \equiv W_H^o + W_F^o$ and are a solution to:

$$
\begin{aligned}
\frac{\partial W^o}{\partial s_H^o} &= \frac{\partial W_H^o}{\partial s_H^o} + (1-\theta)\left[\frac{\partial C_F^o}{\partial s_H^o} + \lambda \frac{\partial r_H^o}{\partial s_H^o} + (1-\lambda)\frac{\partial r_F^o}{\partial s_H^o}\right] + \frac{\partial T_F^o}{\partial s_H^o}\left(T_F^o\right)^{-1/2} = 0 \\
\frac{\partial W^o}{\partial s_F^o} &= \frac{\partial W_F^o}{\partial s_F^o} + \theta\left[\frac{\partial C_H^o}{\partial s_F^o} + \lambda \frac{\partial r_H^o}{\partial s_F^o} + (1-\lambda)\frac{\partial r_F^o}{\partial s_F^o}\right] + \frac{\partial T_H^o}{\partial s_F^o}\left(T_H^o\right)^{-1/2} = 0
\end{aligned}
$$

Using the first-order conditions for the non-cooperative equilibrium, it follows that

$$
\begin{aligned}
\frac{\partial W^o}{\partial s_H^o}(s_H^{o*}, s_F^{o*}) &= (1-\theta)\left[\frac{\partial C_F^o}{\partial s_H^o} + \lambda \frac{\partial r_H^o}{\partial s_H^o} + (1-\lambda)\frac{\partial r_F^o}{\partial s_H^o}\right] + \frac{\partial T_F^o}{\partial s_H^o}\left(T_F^o\right)^{-1/2} \\
\frac{\partial W^o}{\partial s_F^o}(s_H^{o*}, s_F^{o*}) &= \theta\left[\frac{\partial C_H^o}{\partial s_F^o} + \lambda \frac{\partial r_H^o}{\partial s_F^o} + (1-\lambda)\frac{\partial r_F^o}{\partial s_F^o}\right] + \frac{\partial T_H^o}{\partial s_F^o}\left(T_H^o\right)^{-1/2}
\end{aligned}
$$

where the right-hand sides are evaluated at the non-cooperative equilibrium tax rates. Contrary to DP, as discussed in the foregoing, we can no longer clearly sign the residual terms. Using the expressions in Appendix A.4, one can indeed check that

$$
\underbrace{\frac{\partial C_F^o}{\partial s_H^o} < 0 \qquad \frac{\partial r_H^o}{\partial s_H^o} < 0}_{\text{negative effects}} \qquad \text{and} \qquad \underbrace{\frac{\partial r_F^o}{\partial s_H^o} > 0 \qquad \frac{\partial T_F^o}{\partial s_H^o} > 0}_{\text{positive effects}}
$$

so that the total effect can go either way. Stated differently, under the short-run OP the non-cooperative tax rates may a priori be either too low or too high with respect to the ones chosen in the cooperative outcome. The reason for the possible presence of a race to the bottom, even when firms are immobile, is that under OP an increase in the tax rate is formally equivalent to an increase in firms' production costs. Thus, governments have an incentive to cut rates to make domestic firms more competitive, thereby diverting tax revenues from the other country.[12]

Although the reversal in the rankings of equilibrium and optimum tax rates does not allow for clear-cut results, we can show that it is linked to basic parameters of the model. In particular, large values of a and low values of c lead to short-run non-cooperative tax rates that exceed the ones that would be chosen in the cooperative equilibrium. Stated differently, when varieties are sufficiently differentiated (small c) or when preferences for the differentiated good are strong (large a), the short-run equilibrium tax rates will be inefficiently large. The intuition underlying this result is as follows. When a is large or when c is small, firms price in the inelastic portion of their demand. Since the rate of tax pass-through increases with a and c under OP (see Behrens *et al.*, forthcoming), this raises consumer prices (when c becomes small enough, the pass-through becomes almost 100%).[13]

[12]Note that cutting taxes works like export subsidies under OP.

[13]Because we study ad valorem taxes, the pass-through rate varies even though demand is linear.

Hence, the negative effect of a tax increase on both home and foreign consumer surplus comes to dominate the positive effect of such an increase on tax revenues, which then leads the optimal rates to fall with respect to the equilibrium rates.

3.3 Comparing the two principles

Note first that consumer surplus is affected by tax rates only through consumer prices, regardless of the tax principle. As shown in Appendix A.3, the price derivatives satisfy the following relations:

$$\begin{array}{lll} \dfrac{\partial p^d_{HH}}{\partial s^d_H} > \dfrac{\partial p^o_{HH}}{\partial s^o_H} > 0 & \qquad & \dfrac{\partial p^d_{FH}}{\partial s^d_H} > \dfrac{\partial p^o_{FH}}{\partial s^o_H} > 0 \\ \dfrac{\partial p^o_{HH}}{\partial s^o_F} > \dfrac{\partial p^d_{HH}}{\partial s^d_F} = 0 & \qquad & \dfrac{\partial p^d_{FH}}{\partial s^d_H} > \dfrac{\partial p^o_{FH}}{\partial s^o_H} > 0. \end{array}$$

As one can see, consumer prices set by firms in country H are more sensitive to increases in local tax rates under DP than under OP, whereas the reverse holds with respect to consumer prices set by firms in country F. Thus, consumer surplus in country H is more sensitive to increases in its own tax rate under DP than under OP, whereas the externality imposed upon the other region is larger under OP than under DP:

$$\frac{\partial C^d_H}{\partial s^d_H} < \frac{\partial C^o_H}{\partial s^o_H} < 0 \quad \text{and} \quad \frac{\partial C^o_F}{\partial s^o_H} < \frac{\partial C^d_F}{\partial s^d_H} < 0.$$

The reason is that under DP the tax is a consumption tax, whereas under OP the tax is a production tax that can be partly exported to the foreign consumers. It can be further readily verified that

$$\frac{\partial^2 C^d_H}{\partial s^d_H \partial a} < \frac{\partial^2 C^o_H}{\partial s^o_H \partial a} < 0$$

which reveals that the differential sensitivity of consumer surplus with respect to taxes between the two regimes actually rises with the value of a. Consequently, under OP the marginal effect on consumer surplus of raising taxes is lower than the corresponding effect under DP for high values of a, which implies that tax rates will be higher in the former case than in the latter. This implies that the short-run OP rates may actually exceed the short-run DP rates for sufficiently high values of a.

3.4 Impacts of a regime change

It appears to be hopeless to pursue our formal analysis further. This is why we have chosen to appeal to numerical analysis by means of a simulation plan described below. Specifically, our numerical results aim to illustrate our previous findings and to discuss the possible impacts of a regime change and of tax harmonization (see Appendix B for a description of the methodology and its implementation). We begin with a baseline parameter set calibrated to yield tax rates in the approximate range of VAT rates in the EU. In addition, we have chosen parameters that yield plausible values for mark-ups and commodity flows.[14]

Table 1 lists results for the short-run DP and OP equilibria (t_H^{d*}, t_F^{d*}, t_H^{o*}, t_F^{o*}) as well as optimum tax rates ($\widetilde{t}_H^d$, $\widetilde{t}_F^d$, $\widetilde{t}_H^o$, $\widetilde{t}_F^o$) for our baseline parameter set: $\alpha = 3$, $\beta = 0.25$, $\gamma = 0.1$, $\phi = 0.1$, $\tau \in \{0.05, 0.07\}$, $m = 0.6$ and $\theta \in \{0.5, 0.51, 0.52, 0.53, 0.54, 0.55\}$. Hence, we keep all parameters fixed except θ and τ because we want to investigate how changes in trade costs and size asymmetries influence the tax outcomes.

In order to get an idea of how a switch from DP to OP may change the equilibrium tax rates when λ is held fixed in the short run, we find it relevant to fix λ at a 'reasonable' value. We hence choose to hold the spatial distribution of firms constant at the spatial equilibrium level in the non-cooperative Nash equilibrium under DP: $\overline{\lambda} = \lambda^d(s_H^{d*}, s_F^{d*})$.[15] Table 1 shows that the gap between OP equilibrium and optimal rates exceeds the DP gap when countries are of the same size. The magnitude of this effect varies with market size θ. Starting from the symmetric case ($\theta = 1/2$), as one country grows larger, its DP equilibrium tax rate falls; by contrast, the equilibrium OP rate rises (and can even exceed welfare-maximizing rates, as argued in the previous section). Note also that *equilibrium DP rates are less sensitive than OP rates to changes in market size*, and that this is more pronounced for the smaller country. These effects capture the difference between the two tax principles, namely 'consumption' versus 'production' tax. It is also worth pointing out that the gaps between equilibrium and optimal rates shrink as countries become asymmetric, which provides an illustration of Proposition 2. To see this more clearly, we may compute the welfare losses resulting from a switch from cooperative to non-cooperative tax setting: $\Delta W^d(\theta = 0.5) = -0.00354$ and $\Delta W^d(\theta = 0.55) = -0.0032$. Clearly, *cooperative tax setting in the short-run is more important when countries are of roughly equal sizes.* Yet, note that the loss due to tax competition is fairly weak in general. In percentage points, the loss when $\theta = 0.5$ is of 0.021%, and it is of 0.019% when $\theta = 0.55$, thus showing that the welfare gains from cooperative tax setting are almost negligible under the short-run DP.

Note, finally, that a switch from DP to OP will reduce equilibrium tax rates in both countries, but that the fall will be much larger in the small country. For given values of λ and θ this reduces tax revenues in the small country, thus providing a rationale for why

[14] Additional theoretical constraints stem from the fact that we focus on interior equilibria only ($0 < \lambda^* < 1$) in which there is bilateral trade, i.e., conditions (6) and (7) hold at the equilibrium tax rates. This places restrictions on the degree of asymmetry and the value of trade costs which explain why the intervals within which parameters are allowed to vary are relatively small.

[15] We may interpret this as a situation in which the economy is in its long-run DP equilibrium, and in which governments consider changing to OP without taking into account the subsequent adjustment in λ.

small countries may be opposed to regime changes in the short run.

4 Long-run equilibrium and optimum

We now relax the restrictive assumption of a fixed spatial distribution λ. Doing so is important for several reasons. First, it is well known that factor mobility has an important impact on non-cooperative equilibrium tax rates (the so-called 'race to the bottom' highlighted in most of the tax competition literature). Disregarding it may thus yield predictions that significantly differ from real world outcomes when firms are mobile. Second, tax competition and factor mobility may lead to an uneven spatial distribution of economic activities, which may pose problems on both efficiency and equity grounds in the EU. Since commodity taxation remains a national matter for now, non-cooperative tax setting is bound to have an impact on the spatial allocation of resources. It is, therefore, of interest to take into account these long-run effects when assessing the relative desirability of OP or DP.

Unfortunately, given increased complexity, analytical results on comparative statics are out of reach and we have to rely heavily on numerical simulations. However, for these simulations to be meaningful, we cannot restrict ourselves to the analysis of what is often called 'typical cases' as a necessarily limited gallery of alternative simulated scenarios would be of little use in terms of general insight. Hence, to convey a synthetic and systematic view of the implications of our theoretical model, we prefer to act as follows. First, we construct a grid of different parameter sets k with $k = 1, 2, \ldots, K$. Then, for a given tax principle, we compute the equilibrium tax rates for each parameter set k. We thus have K equilibrium tax rates associated with K parameter sets. Finally, by regressing the former on the latter, the regression coefficients can be interpreted as the 'average' impact of the parameters on the equilibrium tax rates, controlling for changes in the other parameters.[16]

In constructing the grid, we fix α, the demand intercept, at 3, and β at 0.25 – variations in these parameters have little effect on the outcomes. We allow θ to vary between 0.5 and 0.55, with steps of 0.01 (H is the larger region whenever population size differs). Trade cost, τ, varies between 0.03 and 0.15, with steps of 0.02, while unit variable cost, m, ranges from 0.4 to 1.4, in steps of 0.02. Thus, trade costs vary from 2% to over 10% of marginal cost. The intensity of preference for variety is measured by $\beta - \gamma$, and we vary γ from 0.1 to 0.2 in steps of 0.05, keeping β fixed. Since the demand intercept equals $\alpha/[\beta + (N-1)\gamma]$, we allow marginal cost to range from 15% to 95% of the demand intercept – implying that our simulations allow for considerable variation in the demand elasticity.

With 6 values for θ, 7 values of τ, 6 values for m, and 3 values for γ, we have a maximum

[16] This holds true provided one approximates linearly the non-linear relationships between the equilibrium tax rates and the parameters, as implied by the theoretical model.

of 756 possible simulation results. We conduct our simulations on this large grid only for the long-run equilibrium outcomes of the tax competition game. Our simulations yield interior solutions with positive trade flows across both regions for 629 of a possible 756 cases under DP, and for 464 cases under OP.[17] The intersection of interior solutions, with positive trade flows across regions and no full agglomeration of firms, under both OP and DP results in 444 cases.

Figures 2 and 3 display histograms for the simulations (using only the 444 cases valid under both principles). Equilibrium tax rates under DP vary from 5.96% to 22.7% for region H; rates in the smaller region are always higher, with a maximum difference of 2.7%. Equilibrium tax rates under OP range from 0.1% to 6.0% for region H; rates in the smaller region are always lower with a maximum difference of 1.0%. For the larger region, OP rates range from less than 2% to 28% of DP rates and are thus *substantially smaller* than DP rates. It should not be a surprise that these large differences in tax rates cause welfare to always be greater under DP, with the percentage difference varying from 3.2% to 12.9%.

Insert Figures 2 and 3 about here.

The equilibrium distribution, λ^*, of firms and capital across regions varies from 0.572 to 0.972 under DP when $\theta = 0.55$, and from 0.542 to 0.827 under OP. This shows that there is always more spatial inequality under DP than under OP when regions are not of the same size. Furthermore, a reverse home market effect (identified as a theoretical possibility in Behrens *et al.* (forthcoming) when tax rates are exogenously fixed) can occur in a tax competition equilibrium: the share of firms in the larger region is less than the share of consumers in that region.

Table 2 reports the regression results computed for our grid sample. The dependent variables are the tax rates under DP and OP, the capital distribution under DP and OP, as well as the corresponding gaps between regions and tax principles. The explanatory variables are the four parameters we vary in the simulations. We use all 444 cases for the tax rates and the difference across tax principles, while we focus only upon the cases in which $\theta \neq 0.5$ for tax differences across regions and for the share of capital in the large region (when $\theta = 0.5$, tax rates are equal and $\lambda^* = 0.5$). All but 2 of the 40 regression coefficients have t-statistics greater than 3 (and many are much higher), and adjusted R^2 values consistently exceed 0.8.

[17] All simulations converge for DP, whereas some of them did not converge for OP, but these appear to be cases where corner solutions or arbitrarily low tax rates would obtain. Using a finer simulation grid or larger parameter ranges yields a larger sample but leads also to more corner solutions. In any case, this does not modify the qualitative conclusions derived in the remainder of this paper.

As one can see from Table 2, increases in θ raise tax rates in the large region H under DP, and lowers rates in H under OP, while tax differentials rise with θ under DP and fall under OP. Increases in τ raise tax rates under both DP and OP, with a greater effect under OP. Increases in m lower tax rates under both principles, while increases in γ raise rates under both principles. This latter effect is due to the fact that when goods are very differentiated, substantial trade takes place so that governments have a stronger incentive to attract firms to save on trade costs. This exacerbates tax competition and drives down rates. Increases in θ, τ, and m reduce the difference between DP and OP rates, while increases in γ widen this gap. Note, finally, that increases in θ increase λ^* more than one-for-one (the home market effect holds on average), and that this effect is more pronounced under DP. Increases in τ, m and γ also reduce λ^* under both principles, and again the effect is greater under DP.

4.1 The destination principle

We now return to our baseline parameter values that yield rates close to EU levels. Table 3 presents both short-run and long-run equilibria under DP, where an L subscript denotes the long-run values. For our baseline parameter set (and for the others we tried), equilibrium rates change relatively little when capital mobility is taken into account. *Long-run equilibrium rates are always less than welfare-maximizing rates*, but the two stay within two percentage points of each other. Differences in market size have only small effects of rates. Capital mobility does not seem to lead to a vigorous race to the bottom under DP, which may explain why increases in capital mobility in the EU have had little effect on national VAT rates to date.

Note, finally, that the spatial distribution of industry becomes more even in the long-run equilibrium ($(\lambda^d)_L < \lambda^d$). This is due to the fact that the tax gap between the large and the small country shrinks when moving from the short- to the long-run. Yet, at the welfare maximizing long-run rates, the spatial allocation of industry would still be more equal than in the long-run equilibrium ($(\widetilde{\lambda}^d)_L < (\lambda^d)_L$). Stated differently, the non-cooperative outcome leads to excessive agglomeration in the large country.

4.2 The origin principle

We explore the consequences of a shift to using OP for VAT in two steps. First, at the spatial equilibrium under DP equilibrium taxes ($(\lambda^d)_L$), we solve for short-run equilibrium tax rates under OP. As shown by Table 4, while this change lowers rates, it is not dramatic (and it is a more damped response than the switch in short-run equilibrium rates from DP to OP). Second, we consider the effect of changing from DP to OP when countries take account of capital mobility in both games (see Figure 4 for an illustration of the long-run OP welfare surface W^o_H, and Figure 5 for an illustration of the global long-run welfare surface W^o). As shown by Table 3, *the race to the bottom is especially pronounced in this case* – rates fall to less than 2% for our baseline simulations. The strong opposition to recent proposals by the EU to switch to the origin principle appears to have a strong basis – competition for mobile capital would place a great strain on national budgets.

Insert Figures 4 and 5 about here.[18]

While the tremendous difference in the levels of tax rates between the two principles swamps most other considerations, asymmetries have different effects on tax rates. Under DP, as countries become asymmetric, the larger country reduces its tax rate and the smaller country raises its rate (as in the short run). In contrast, under OP, it is the smaller country that cuts its rate and the larger country that raises its rate, thus considerably dampening the home market effect – λ is much less responsive to increases in θ under the OP (as in Table 2). Hence, when spatial considerations matter (as they surely do in the EU), we cannot dismiss the OP out of hand on the sole basis that it may put pressure on national governments' tax revenues. We return to this point later in the policy discussion.

Tables 5 and 6 present welfare comparisons under the two tax principles. Not surprisingly, given the magnitude of the different effects of tax competition, competition barely affects welfare under DP and the welfare losses are thus small (ΔW^{d*}_H and ΔW^{d*}_F), whereas *welfare losses under OP (ΔW^{o*}_H and ΔW^{o*}_F) are between* 4 *and* 9% *relative to the cooperative outcome*, which are close to the welfare changes across the two principles at equilibrium rates.

4.3 Harmonizing tax rates

Concerns about tax competition as factors become increasingly mobile has led many federations to consider reducing the flexibility of member states in setting their tax rates. There have been EU proposals to place floors under tax rates or to require members to choose tax rates in a band around EU average rates. In the USA, states have considerable freedom under the Constitution to choose tax rates and systems, so this has not been a major issue. Within each state, however, local governments obtain all authority to levy taxes and to set tax rates from the state government. State governments have a large variety of policy instruments to prevent tax exporting by local jurisdictions, including setting minimum and maximum rates for particular taxes. An extreme form of preventing tax competition is to

[18] The parameter values underlying Figures 4 and 5 are as follows: $\alpha = 3$, $\beta = 0.25$, $\gamma = 0.2$, $\tau = 0.07$, $\phi = 0.1$, $\theta = 0.55$ and $m = 0.6$.

take a tax base from local governments and rebate revenue from the tax at a common rate to all local governments in proportion to their shares of that tax base.[19]

We have already solved for the optimum tax rates under DP and OP. The optimal rates when taking capital mobility into account differ from the short-run welfare maximizing rates, but not by very much (for $\theta = 1/2$, rates are the same in the short and long run and for either of the principles). In practice, it may be quite difficult for a federation to force jurisdictions to levy different tax rates (as opposed to letting countries choose tax rates within a band). It is therefore instructive to consider the issue of complete harmonization where the federation chooses a single tax rate for all countries.[20]

Tables 7 and 8 present harmonization outcomes under DP and OP in comparison with equilibrium and optimum rates. For DP, the harmonized rate (subscripted with har) lies between the optimal rates and above both countries' equilibrium rates. Increasing tax rates and eliminating the gap between them reduce spatial inequalities, although this effect is quantitatively small. The harmonized rate is also quite insensitive to asymmetries in country size. *The welfare losses from harmonization are relatively small under DP*, as can be seen from $\Delta W_H^{d\,\mathrm{har}}$ and $\Delta W_F^{d\,\mathrm{har}}$ in Table 6. It is worth noting that the large country loses and the small country gains relative to the cooperative outcome, which suggests that large countries are less likely to agree to give up their tax-setting powers under DP.

The effects of harmonization under OP are quite different. The harmonized rate is slightly less than the minimum of the optimal rates and considerably higher than the equilibrium rates. As countries become more asymmetric, the harmonized rate falls yet this change is quite small. Most surprisingly, *the harmonized rate leads to more firms locating in the larger country* – the spatial inequalities are almost as strong as under long-run equilibrium rates under DP. This effect stems from the fact that in equilibrium the larger country charges higher tax rates under OP than the small country, which reduces firms' incentive to agglomerate in the large country. Since tax harmonization eliminates this stabilizing mechanism, the spatial inequalities naturally increase in the presence of harmonization.

Along with the concentration of firms in the large country, Table 6 reveals that the small country loses in a move from the optimum to the harmonized rates, while the large country gains. Thus, under OP, a move to reduce the tax gap between countries leads

[19]In the EU, a minimum VAT rate of 15% has been introduced. In California, the state sales tax includes a 1.25% rate which goes to the local government where the sale occurred. Local government can levy an additional 1.25%, so the mandated portion is only a floor. While the mandated portion may have been an attempt to reduce tax competition, it has led to competition for retail centers through zoning (Lewis and Barbour, 1999).

[20]We do not consider the possibility of revenue transfers between regions by the federation. If the tax base originally belonged to the regional governments, agreements on rates to reduce the impact of tax competition may be much simpler than regional transfers.

to greater inequality, both in welfare and spatial terms. While harmonized outcomes are clearly better for both countries than tax competition, the distributional implications may make agreement difficult. Contrary to the DP case, it is now the small countries which are less likely to agree to give up their tax-setting powers.

4.4 Tax competition and the spatial distribution of firms

Changes in the tax principle and changes in the type of tax competition not only affect tax rates and welfare, but they also influence the degree of spatial inequality in the economy. In a model comparable to ours, Ottaviano and van Ypersele (2005) have shown that there is usually too much agglomeration in equilibrium, so tax differentials provide an instrument to reduce spatial inequality and increase welfare. The spatial allocation of capital under non-cooperative short run DP (λ^d in Table 1) exhibits a strong home market effect. Behrens *et al.* (forthcoming) have shown that symmetric increases in tax rates reduce the magnitude of the home market effect because higher taxes reduce overall demand for all varieties.

A switch from short-run to long-run equilibrium taxes under DP reduces spatial inequality slightly (for $\theta = 0.55$ and $\tau = 0.05$ from 0.786 to 0.765, or for $\tau = 0.07$ from 0.704 to 0.689; see Table 3). This seems puzzling at first since tax competition leads to lower equilibrium rates in the long run, which should strengthen the home market effect. Yet, higher tax rates in the smaller region reduce demand in that region more than in the larger region, hence making exports from the larger region a smaller part of each firm's production (in contrast, firms in the smaller region export proportionally more). Since equilibrium long run DP tax rates are below optimal rates, the spatial distribution of firms at optimal tax rates is more equal, although the effect seems small in magnitude. Because the long run optimal tax rates under DP result in higher tax rates in the smaller region, harmonization reduces spatial inequalities.

Table 4 compares the long-run spatial allocation under DP to that under OP. Tax rates fall dramatically with the shift to OP (which strengthens the home market effect), but under OP, it is the larger region which charges the higher tax rates. The tax differential favors firms producing in the smaller region for sales both at home and abroad. Roughly, the switch from DP to OP cuts the magnitude of the home market effect in half. Switching from equilibrium to optimal tax rates under OP in the long-run actually reverses the home market effect considerably (the share of firms in the larger region is less than the share of consumers in that region). This effect has two sources: much higher tax rates reduce the home market effect and the tax differential favors the smaller region, which is strong enough for the reversal. Because the equilibrium and optimal tax differentials favor the smaller region under OP, harmonization results in more spatial inequality, approximately the same degree as we find with harmonization under DP.

5 Policy relevance and conclusions

As argued previously, the questions of which tax principle should be used and whether commodity tax rates should be harmonized are important but contentious issues in several federations like the EU and the USA. Switching from one principle to the other or harmonizing rates is unlikely to leave the economies of member states unaffected, both in the short and in the long run. The most visible short-run impact is that of tax revenue redistribution among the various national and local tax authorities of the federation. It is, for example, estimated that a switch from OP to DP for Texas in-state shipments under the Streamlined Sales Tax Project (SSTP) could "cause a redistribution of local sales tax revenues from larger urban areas, where goods are purchased to smaller, suburban and rural areas where they are delivered. As much as \$160 million in local sales tax revenue could be redistributed in such a manner" (Strayhorn, 2005, p.1). Given the magnitude of the figures, the redistribution of tax revenue attracts the most attention from economists and policy makers. Yet, we have argued that one may miss an important part of the story by focusing exclusively on the direct short-run effects and by neglecting the indirect long-run effects. The latter mainly stem from the redistribution of industry, which may adjust location in order to better exploit tax-differentials across regions. Firms' locational incentives are themselves largely conditioned by the tax principle applied to commodity transactions. A switch from a 'consumption based' tax principle (DP), which falls mainly on immobile consumers, to a 'production based' tax principle (OP), which falls mainly on mobile producers, may have important long-run consequences by providing firms with stronger incentives to relocate to low-tax regions. This effect is further amplified by the fact that, in the case of DP, firms established in different locations only differ by the tax rates they face for selling to local consumers; whereas under OP *they differ by the tax rate for selling to all consumers in the federation.* In our model of tax competition, these two effects of a switch from DP to OP translate into a fierce 'race to the bottom', leading to excessively low tax rates and a strong erosion in tax revenues. This result suggests that some form of fiscal harmonization may be desirable to prevent harmful tax competition under OP. On the contrary, welfare losses due to non-cooperative tax-setting under DP are quite low in general, so that harmonization does not appear to be necessary in that case.

Note that the foregoing results are in line with the ones one may expect in most models of tax competition when considering switching the tax burden from the immobile to the mobile agents. Our analysis goes further by highlighting the spatial impacts of such a change in tax principle. This aspect may be quite important for federations with commitment to some regional cohesion objective. We have shown that under DP tax competition, by lowering equilibrium tax rates slightly below the optimal tax rates, leads to more spatial inequality, which may interfere with regional cohesion objectives and, therefore, generate additional costs in the form of transfer payments aimed at reducing spatial inequalities.

Concerning the potential impacts of a switch from DP to OP, we have shown that tax revenues decrease significantly whereas *the spatial distribution of firms becomes more even because the larger region sets the higher equilibrium tax rate*. Stated differently, although tax revenues decrease, so does spatial inequality. Since there is a tendency for excess agglomeration in equilibrium (Ottaviano and van Ypersele, 2005), less agglomeration may actually be welfare improving as less structural funds are required to alleviate regional inequalities. How tax revenue and spatial inequality are traded off is, ultimately, a political and societal question of the 'efficiency vs equity' type to which our model can provide no answer. The gains from switching to OP are lower costs of collecting and remitting tax revenues, as well as less spatial inequality, whereas the costs are lower tax revenues. Although this trade off can only be resolved by knowing society's 'aversion for spatial inequality', which we have not specified in our model, it is important to point out that given the magnitudes of welfare differences under OP and DP (see Table 9 for a summary of the figures) in our model, it is unlikely that forcing a more equal spatial distribution under OP offsets the high costs in terms of foregone tax revenue. A switch to an origin-based commodity taxation may therefore put strain on the integration process and undermine the financing of the welfare state, triggering strong resistance especially from the large contributing regions.[21]

To conclude, we find that there is no general presumption in favor of OP based commodity taxation. Neither is there in favor to DP based commodity taxation. This finding may explain why proposals to reform commodity taxation, as advocated by some members in the EU and in the USA, have not met broad agreement and quick implementation of changes by the other members.

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Appendix A: Analytical expressions

A.1. DP spatial equilibrium: The unique solution to the equilibrium condition $r_H^d = r_F^d$ is given by:

$$\lambda^d = \frac{1}{2} + \frac{2\left[2a - b\tau - 2bm(1+s_H^d)(1+s_F^d)\right]}{cN\tau\left[1+\theta s_F^d + (1-\theta)s_H^d\right]}\left(\theta - \frac{1}{2}\right) + \frac{2a-b\tau}{cN\tau\left[1+\theta s_F^d + (1-\theta)s_H^d\right]}[\theta s_F^d - (1-\theta)s_H^d]. \tag{16}$$

A.2. Short-run DP derivatives: We can calculate the derivatives component by component. Considering consumer surplus, this yields:

$$\frac{\partial C_H^d}{\partial s_H^d} = \left\{-a + (b+cN)\,p_{HH}^d - cN\left[\lambda p_{HH}^d + (1-\lambda)(p_{FH}^d+\tau)\right]\right\}\lambda N\frac{\partial p_{HH}^d}{\partial s_H^d} + \left\{-a + (b+cN)\left(p_{FH}^d+\tau\right) - cN\left[\lambda p_{HH}^d + (1-\lambda)\left(p_{FH}^d+\tau\right)\right]\right\}(1-\lambda)N\frac{\partial p_{FH}^d}{\partial s_H^d}$$

$$\frac{\partial C_F^d}{\partial s_F^d} = \left\{-a + (b+cN)\left(p_{HF}^d+\tau\right) - c\left[\lambda\left(p_{HF}^d+\tau\right) + (1-\lambda)Np_{FF}^d\right]\right\}\lambda N\frac{\partial p_{HF}^d}{\partial s_F^d} + \left\{-a + (b+cN)\,p_{FF}^d - cN\left[\lambda\left(p_{HF}^d+\tau\right) + (1-\lambda)p_{FF}^d\right]\right\}(1-\lambda)N\frac{\partial p_{FF}^d}{\partial s_F^d}$$

The derivatives of tax revenues are as follows:

$$\frac{\partial T_H^d}{\partial s_H^d} = \theta N\frac{s_H^d}{1+s_H^d}\left\{\frac{\lambda p_{HH}^d q_{HH}^d + (1-\lambda)p_{FH}^d q_{FH}^d}{s_H^d(1+s_H^d)} + \lambda q_{HH}^d\frac{\partial p_{HH}^d}{\partial s_H^d} + \lambda p_{HH}^d\left[-\left(b+(1-\lambda)cN\right)\frac{\partial p_{HH}^d}{\partial s_H^d} + (1-\lambda)cN\frac{\partial p_{FH}^d}{\partial s_H^d}\right] + (1-\lambda)q_{FH}^d\frac{\partial p_{FH}^d}{\partial s_H^d} + (1-\lambda)p_{FH}^d\left[-\left(b+\lambda cN\right)\frac{\partial p_{FH}^d}{\partial s_H^d} + \lambda cN\frac{\partial p_{HH}^d}{\partial s_H^d}\right]\right\}$$

$$
\begin{aligned}
\frac{\partial T_F^d}{\partial s_F^d} &= (1-\theta)N\frac{s_F^d}{1+s_F^d}\left\{\frac{\lambda p_{HF}^d q_{HF}^d+(1-\lambda)p_{FF}^d q_{FF}^d}{s_F^d(1+s_F^d)}\right.\\
&+\lambda q_{HF}^d\frac{\partial p_{HF}^d}{\partial s_F^d}+\lambda p_{HF}^d\left[-\left(b+(1-\lambda)cN\right)\frac{\partial p_{HF}^d}{\partial s_F^d}+(1-\lambda)cN\frac{\partial p_{FF}^d}{\partial s_F^d}\right]\\
&\left.+(1-\lambda)q_{FF}^d\frac{\partial p_{FF}^d}{\partial s_F^d}+(1-\lambda)p_{FF}^d\left[-\left(b+\lambda cN\right)\frac{\partial p_{FF}^d}{\partial s_F^d}+\lambda cN\frac{\partial p_{HF}^d}{\partial s_F^d}\right]\right\}
\end{aligned}
$$

Using expression (8), we further have:

$$
\begin{aligned}
\frac{\partial r_H^d}{\partial s_H^d} &= \theta\frac{b+cN}{\phi(1+s_H^d)}\left[2\left(p_{HH}^d-m(1+s_H^d)\right)\left(\frac{\partial p_{HH}^d}{\partial s_H^d}-m\right)-\frac{\left(p_{HH}^d-m(1+s_H^d)\right)^2}{1+s_H^d}\right]\\
&= -\left[p_{HH}^d-m(1+s_H^d)\right]\theta\frac{b+cN}{\phi(1+s_H^d)}\left[\frac{2bm}{2b+cN}+\frac{p_{HH}^d-m(1+s_H^d)}{1+s_H^d}\right]
\end{aligned}
$$

and

$$
\frac{\partial r_H^d}{\partial s_F^d}=(1-\theta)\frac{b+cN}{\phi(1+s_F^d)}\left[2\left(p_{HF}^d-m(1+s_F^d)\right)\left(\frac{\partial p_{HF}^d}{\partial s_F^d}-m\right)-\frac{\left(p_{HF}^d-m(1+s_F^d)\right)^2}{1+s_F^d}\right]
$$

whereas expression (9) yields:

$$
\frac{\partial r_F^d}{\partial s_H^d}=\theta\frac{b+cN}{\phi(1+s_H^d)}\left[2\left(p_{FH}^d-m(1+s_H^d)\right)\left(\frac{\partial p_{FH}^d}{\partial s_H^d}-m\right)-\frac{\left(p_{FH}^d-m(1+s_H^d)\right)^2}{1+s_H^d}\right]
$$

and

$$
\frac{\partial r_F^d}{\partial s_F^d}=(1-\theta)\frac{b+cN}{\phi(1+s_F^d)}\left[2\left(p_{FF}^d-m(1+s_F^d)\right)\left(\frac{\partial p_{FF}^d}{\partial s_F^d}-m\right)-\frac{\left(p_{FF}^d-m(1+s_F^d)\right)^2}{1+s_F^d}\right].
$$

The derivatives of the rental rates are all strictly negative under the trade feasibility conditions (6) and (7).

A.3. Price derivatives: The price derivatives are all quite simple under the destination principle:

$$
\frac{\partial p_{HH}^d}{\partial s_H^d}=\frac{\partial p_{FH}^d}{\partial s_H^d}=\frac{\partial p_{HF}^d}{\partial s_F^d}=\frac{\partial p_{FF}^d}{\partial s_F^d}=\frac{b+cN}{2b+cN}m>0
$$

whereas

$$
\frac{\partial p_{HH}^d}{\partial s_F^d}=\frac{\partial p_{FH}^d}{\partial s_F^d}=\frac{\partial p_{HF}^d}{\partial s_H^d}=\frac{\partial p_{FF}^d}{\partial s_H^d}=0.
$$

The price derivatives under the origin principle for firms established in country H are as follows:

$$\begin{aligned}
\frac{\partial p_{HH}^o}{\partial s_H^o} &= \frac{(b+cN)\,m}{(2b+cN)} - \frac{c(1-\lambda)Nm}{2\,(2b+cN)} > 0 \\
\frac{\partial p_{HH}^o}{\partial s_F^o} &= \frac{c(1-\lambda)Nm}{2\,(2b+cN)} > 0 \\
\frac{\partial p_{HF}^o}{\partial s_H^o} &= \frac{(b+cN)\,m}{(2b+cN)} - \frac{c(1-\lambda)Nm}{2\,(2b+cN)} > 0 \\
\frac{\partial p_{HF}^o}{\partial s_F^o} &= \frac{c(1-\lambda)Nm}{2\,(2b+cN)} > 0
\end{aligned}$$

whereas those for firms established in country F are as follows:

$$\begin{aligned}
\frac{\partial p_{FH}^o}{\partial s_F^o} &= \frac{(b+cN)\,m}{(2b+cN)} - \frac{c\lambda Nm}{2\,(2b+cN)} > 0 \\
\frac{\partial p_{FH}^o}{\partial s_H^o} &= \frac{c\lambda Nm}{2\,(2b+cN)} > 0 \\
\frac{\partial p_{FF}^o}{\partial s_F^o} &= \frac{(b+cN)\,m}{(2b+cN)} - \frac{c\lambda Nm}{2\,(2b+cN)} > 0 \\
\frac{\partial p_{FF}^o}{\partial s_H^o} &= \frac{c\lambda Nm}{2\,(2b+cN)} > 0.
\end{aligned}$$

A.4. Short-run OP derivatives: We can calculate the derivatives component by component. Considering consumer surplus, this yields:

$$\begin{aligned}
\frac{\partial C_H^o}{\partial s_H^o} &= \left\{-a+(b+cN)\,p_{HH}^o - cN\left[\lambda p_{HH}^o + (1-\lambda)(p_{FH}^o+\tau)\right]\right\}\lambda N \frac{\partial p_{HH}^o}{\partial s_H^o} \\
&\quad + \left\{-a+(b+cN)\left(p_{FH}^o+\tau\right) - cN\left[\lambda p_{HH}^o + (1-\lambda)\left(p_{FH}^o+\tau\right)\right]\right\}(1-\lambda)N\frac{\partial p_{FH}^o}{\partial s_H^o}
\end{aligned}$$

$$\begin{aligned}
\frac{\partial C_F^o}{\partial s_F^o} &= \left\{-a+(b+cN)\left(p_{HF}^o+\tau\right) - cN\left[\lambda\left(p_{HF}^o+\tau\right) + (1-\lambda)p_{FF}^o\right]\right\}\lambda N \frac{\partial p_{HF}^o}{\partial s_F^o} \\
&\quad + \left\{-a+(b+cN)\,p_{FF}^o - cN\left[\lambda\left(p_{HF}^o+\tau\right) + (1-\lambda)p_{FF}^o\right]\right\}(1-\lambda)N\frac{\partial p_{FF}^o}{\partial s_F^o}
\end{aligned}$$

and

$$\begin{aligned}
\frac{\partial C_H^o}{\partial s_F^o} &= \left\{-a+(b+cN)\,p_{HH}^o - cN\left[\lambda p_{HH}^o + (1-\lambda)(p_{FH}^o+\tau)\right]\right\}\lambda N \frac{\partial p_{HH}^o}{\partial s_F^o} \\
&\quad + \left\{-a+(b+cN)\left(p_{FH}^o+\tau\right) - cN\left[\lambda p_{HH}^o + (1-\lambda)\left(p_{FH}^o+\tau\right)\right]\right\}(1-\lambda)N\frac{\partial p_{FH}^o}{\partial s_F^o}
\end{aligned}$$

$$\begin{aligned}
\frac{\partial C_F^o}{\partial s_H^o} &= \left\{-a+(b+cN)\left(p_{HF}^o+\tau\right) - c\left[\lambda\left(p_{HF}^o+\tau\right) + (1-\lambda)p_{FF}^o\right]\right\}\lambda N \frac{\partial p_{HF}^o}{\partial s_H^o} \\
&\quad + \left\{-a+(b+cN)\,p_{FF}^o - cN\left[\lambda\left(p_{HF}^o+\tau\right) + (1-\lambda)p_{FF}^o\right]\right\}(1-\lambda)N\frac{\partial p_{FF}^o}{\partial s_H^o}.
\end{aligned}$$

Derivatives of the tax revenues get a bit more complicated: Using the expressions of the equilibrium quantities as given in Subsection 3.2, we get:

$$
\begin{aligned}
\frac{\partial T_H^o}{\partial s_H^o} &= \lambda N \frac{s_H^o}{1+s_H^o}\left\{\frac{\theta p_{HH}^o q_{HH}^o + (1-\theta) p_{HF}^o q_{HF}^o}{s_H^o(1+s_H^o)}\right. \\
&\quad +(b+cN)\theta\left[\frac{\partial p_{HH}^o}{\partial s_H^o}(2p_{HH}^o - m(1+s_H^o)) - m p_{HH}^o\right] \\
&\quad \left. +(b+cN)(1-\theta)\left[\frac{\partial p_{HF}^o}{\partial s_H^o}(2p_{HF}^o - m(1+s_H^o)) - m p_{HF}^o\right]\right\} \\
\frac{\partial T_F^o}{\partial s_F^o} &= (1-\lambda) N \frac{s_F^o}{1+s_F^o}\left\{\frac{(1-\theta) p_{FF}^o q_{FF}^o + \theta p_{FH}^o q_{FH}^o}{s_F^o(1+s_F^o)}\right. \\
&\quad +(b+cN)(1-\theta)\left[\frac{\partial p_{FF}^o}{\partial s_F^o}(2p_{FF}^o - m(1+s_F^o)) - m p_{FF}^o\right] \\
&\quad \left. +(b+cN)\theta\left[\frac{\partial p_{FH}^o}{\partial s_F^o}(2p_{FH}^o - m(1+s_F^o)) - m p_{FH}^o\right]\right\} \\
\frac{\partial T_H^o}{\partial s_F^o} &= \lambda N (b+cN) \frac{s_H^o}{1+s_H^o}\left[\theta(2p_{HH}^o - m(1+s_H^o))\frac{\partial p_{HH}^o}{\partial s_F^o}\right. \\
&\quad \left. +(1-\theta)(2p_{HF}^o - m(1+s_H^o))\frac{\partial p_{HF}^o}{\partial s_F^o}\right] \\
\frac{\partial T_F}{\partial s_H} &= (1-\lambda) N (b+cN) \frac{s_F^o}{1+s_F^o}\left[\theta(2p_{FH}^o - m(1+s_F^o))\frac{\partial p_{FH}^o}{\partial s_H^o}\right. \\
&\quad \left. +(1-\theta)(2p_{FF}^o - m(1+s_F^o))\frac{\partial p_{FF}^o}{\partial s_H^o}\right].
\end{aligned}
$$

As to the derivatives of the rental rates of capital, using (10) and (11) we have

$$
\begin{aligned}
\frac{\partial r_H^o}{\partial s_H^o} &= \frac{(b+cN)\,\theta}{\phi(1+s_H^o)}\left[-\frac{(p_{HH}^o - m(1+s_H^o))^2}{1+s_H^o} + 2\,(p_{HH}^o - m(1+s_H^o))\left(\frac{\partial p_{HH}^o}{\partial s_H^o} - m\right)\right] \\
&\quad + \frac{(b+cN)\,(1-\theta)}{\phi(1+s_H^o)}\left[-\frac{(p_{HF}^o - m(1+s_H^o))^2}{1+s_H^o} + 2\,(p_{HF}^o - m(1+s_H^o))\left(\frac{\partial p_{HF}^o}{\partial s_H^o} - m\right)\right] \\
\frac{\partial r_F^o}{\partial s_F^o} &= \frac{(b+cN)\,\theta}{\phi(1+s_F^o)}\left[-\frac{(p_{FH}^o - m(1+s_F^o))^2}{1+s_F^o} + 2\,(p_{FH}^o - m(1+s_F^o))\left(\frac{\partial p_{FH}^o}{\partial s_F^o} - m\right)\right] \\
&\quad + \frac{(b+cN)\,(1-\theta)}{\phi(1+s_F^o)}\left[-\frac{(p_{FF}^o - m(1+s_F^o))^2}{1+s_F^o} + 2\,(p_{FF}^o - m(1+s_F^o))\left(\frac{\partial p_{FF}^o}{\partial s_F^o} - m\right)\right]
\end{aligned}
$$

and

$$
\begin{aligned}
\frac{\partial r_H^o}{\partial s_F^o} &= \frac{2\,(b+cN)}{1+s_H^o}\left[\theta\,(p_{HH}^o - m(1+s_H^o))\,\frac{\partial p_{HH}^o}{\partial s_F^o} + (1-\theta)\,(p_{HF}^o - m(1+s_H^o))\,\frac{\partial p_{HF}^o}{\partial s_F^o}\right] \\
\frac{\partial r_F^o}{\partial s_H^o} &= \frac{2\,(b+cN)}{1+s_F^o}\left[\theta\,(p_{FH}^o - m(1+s_F^o))\,\frac{\partial p_{FH}^o}{\partial s_H^o} + (1-\theta)\,(p_{FF}^o - m(1+s_F^o))\,\frac{\partial p_{FF}^o}{\partial s_H^o}\right].
\end{aligned}
$$

Appendix B: Numerical implementation

The implementation of the short run analysis is quite straightforward, since all analytical expressions can be established in closed form (see Appendix A). Note also that we can readily compute that equilibrium allocation under DP (as given in Appendix A.1) and derive all the short run results with a fixed distribution λ.

The long run analysis under OP is more involved since it requires solving a quadratic equation that usually is too complicated to handle analytically when $\tau > 0$ (see Behrens *et al.*, 2006). Yet we can handle this problem numerically as follows. Under OP, the rental rate of capital in the two countries is given by

$$r_H^o = \theta \frac{b + cN}{\phi(1 + s_H^o)} \left[p_{HH}^o - m(1 + s_H^o)\right]^2 + (1 - \theta) \frac{b + cN}{\phi(1 + s_H^o)} \left[p_{HF}^o - m(1 + s_H^o)\right]^2$$

and

$$r_F^o = (1 - \theta) \frac{b + cN}{\phi(1 + s_F^o)} \left[p_{FF}^o - m(1 + s_F^o)\right]^2 + \theta \frac{b + cN}{\phi(1 + s_F^o)} \left[p_{FH}^o - m(1 + s_F^o)\right]^2.$$

The spatial equilibrium is a solution to the quadratic equation $r_H^o = r_F^o$. All λ terms are buried in the prices and enter those terms linearly. Rewrite the equation as

$$\Delta\left(\lambda; s_H^o, s_F^o\right) = r_H^o\left(\lambda; s_H^o\right) - r_F^o\left(\lambda; s_F^o\right).$$

A spatial equilibrium allocation of capital corresponds to $\Delta(\lambda^*) = 0$. For a stable equilibrium, if $\lambda > \lambda^*$, then $\Delta\left(\lambda; s_H^o, s_F^o\right) < 0$. Thus, a stable equilibrium has $d\Delta/d\lambda < 0$. Given that Δ is a quadratic equation in λ, we can write it as:

$$\Delta\left(\lambda; s_H^o, s_F^o\right) = A\lambda^2 + B\lambda + C = 0.$$

Since $d\Delta/d\lambda = 2A\lambda + B$, the sign of A determines which root is the stable one (negative derivative with respect to λ in the neighborhood of the root). If $A > 0$, the smaller root (the one subtracting the discriminant) is stable, while if $A < 0$, the larger root is the stable one. Writing $\lambda^* = -B/2A \pm \sqrt{B^2 - 4AC}/2A$, the stable root always subtracts the discriminant. Note, finally, that when $s_F^o = s_H^o$, the equation is linear in λ. Since $B < 0$, the linear equation solution is always stable.

An easier approach that we can use if there is only one solution with $0 < \lambda < 1$ (which is the case for our benchmark set of parameter values) is to take

$$\Delta\left(\lambda; s_H^o, s_F^o\right) = r_H^o\left(\lambda; s_H^o\right) - r_F^o\left(\lambda; s_F^o\right) = 0$$

and view it as a (well-behaved) level curve and totally differentiate to find the expressions

$$\frac{\partial \lambda}{\partial s_H^o}\Big|_{\Delta=0} \qquad \textit{and} \ \frac{\partial \lambda}{\partial s_F^o}\Big|_{\Delta=0}.$$

We simply have

$$\frac{\partial \lambda}{\partial s_H^o}\Big|_{\Delta=0} = -\left(\frac{\partial r_H}{\partial s_H^o} - \frac{\partial r_F}{\partial s_H^o}\right)\left(\frac{\partial r_H}{\partial \lambda} - \frac{\partial r_F}{\partial \lambda}\right)^{-1}$$

where $\partial r_H^o/\partial s_H^o$ is given in Appendix A.4 and where

$$\frac{\partial r_H}{\partial \lambda} = 2\theta \frac{b+cN}{\phi(1+s_H^o)}\left[p_{HH}^o - m(1+s_H^o)\right]\frac{\partial p_{HH}^o}{\partial \lambda} + 2(1-\theta)\frac{b+cN}{\phi(1+s_H^o)}\left[p_{HF}^o - m(1+s_H^o)\right]\frac{\partial p_{HF}^o}{\partial \lambda}$$

$$\frac{\partial r_F}{\partial s_H^o} = 2(1-\theta)\frac{b+cN}{\phi(1+s_F^o)}\left[p_{FF}^o - m(1+s_F^o)\right]\frac{\partial p_{FF}^o}{\partial s_H^o} + 2\theta\frac{b+cN}{\phi(1+s_F^o)}\left[p_{FH}^o - m(1+s_F^o)\right]\frac{\partial p_{FH}^o}{\partial s_H^o}$$

and

$$\frac{\partial r_F}{\partial \lambda} = 2(1-\theta)\frac{b+cN}{\phi(1+s_F^o)}\left[p_{FF}^o - m(1+s_F^o)\right]\frac{\partial p_{FF}^o}{\partial \lambda} + 2\theta\frac{b+cN}{\phi(1+s_F^o)}\left[p_{FH}^o - m(1+s_F^o)\right]\frac{\partial p_{FH}^o}{\partial \lambda}.$$

Using a strictly increasing logistic transformation of λ, i.e.,

$$\widetilde{\lambda} \equiv \ln\left(\frac{\lambda}{1-\lambda}\right)$$

as the variable the non-linear equation solver is searching over, we can evaluate the derivative of λ with respect to s_H^o and s_F^o numerically in a straightforward way. We implemented this procedure using `Matlab` and the associated optimization toolbox.

To double-check the results, we also used `Mathematica` to solve formally for the implicit function expressions of the derivatives $d\lambda/ds_H^o$ and $d\lambda/ds_F^o$, which are then subsequently used in the computations of the equilibrium and optimum tax rates. Both the `Matlab` and `Mathematica` programs are available upon request and yield the same numerical results for our benchmark parameter sets.

Table 1 — Short-run destination- and origin-principle tax equilibria.

θ	τ	t_H^{d*}	t_F^{d*}	$\overline{\lambda} = \lambda^d$	$\widetilde{t}_H^d$	$\widetilde{t}_F^d$	t_H^{o*}	t_F^{o*}	$\widetilde{t}_H^o$	$\widetilde{t}_F^o$
0.5	0.05	0.2109	0.2109	0.5	0.1971	0.1971	0.1507	0.1507	0.1971	0.1971
0.51	0.05	0.2075	0.2144	0.5573	0.1940	0.2003	0.1551	0.1472	0.2014	0.1922
0.52	0.05	0.2042	0.2180	0.6146	0.1910	0.2036	0.1616	0.1450	0.2046	0.1871
0.53	0.05	0.2009	0.2217	0.6719	0.1881	0.2070	0.1694	0.1443	0.2060	0.1817
0.54	0.05	0.1978	0.2254	0.7290	0.1853	0.2105	0.1788	0.1449	0.2043	0.1762
0.55	0.05	0.1947	0.2293	0.7861	0.1825	0.2142	0.1901	0.1473	0.1987	0.1704
0.5	0.07	0.2114	0.2114	0.5	0.1972	0.1972	0.1479	0.1479	0.1972	0.1972
0.51	0.07	0.2080	0.2149	0.5408	0.1941	0.2004	0.1508	0.1455	0.2003	0.1939
0.52	0.07	0.2047	0.2185	0.5816	0.1911	0.2037	0.1543	0.1437	0.2029	0.1903
0.53	0.07	0.2014	0.2222	0.6223	0.1882	0.2072	0.1584	0.1424	0.2047	0.1866
0.54	0.07	0.1983	0.2260	0.6630	0.1854	0.2107	0.1631	0.1418	0.2055	0.1827
0.55	0.07	0.1952	0.2299	0.7036	0.1827	0.2144	0.1686	0.1417	0.2050	0.1787

Notes: $m = 0.6$, $\beta = 0.25$, $\gamma = 0.2$, $\alpha = 3$, $K = 1.0, \phi = 0.1$ $(N = 10)$

Table 2 — Regression results for the large grid.

Dependent var.	t_H^*	t_H^*	$t_F^* - t_H^*$	$t_F^* - t_H^*$	$t_H^* - t_H^*$	λ^*	λ^*	$\lambda^* - \lambda^*$
Tax principle	DP	OP	DP	OP	DP − OP	DP	OP	DP − OP
# Obs.	444	444	363	363	444	363	363	363
Coefficient:	θ	−0.13	0.02	0.34	−0.10	−0.15	4.64	2.54
θ	−0.13	0.02	0.34	−0.10	−0.15	4.64	2.54	2.11
	(−3.30)	(1.83)	(43.76)	(−36.07)	(−4.33)	(30.93)	(24.24)	(32.65)
τ	0.07	0.26	0.01	−0.02	−0.19	−1.17	−0.47	−0.69
	(3.07)	(35.53)	(1.67)	(−13.97)	(−9.36)	(−16.25)	(−9.48)	(−22.42)
m	−0.06	−0.01	−0.001	0.003	−0.05	−0.07	−0.05	−0.02
	(−31.14)	(−14.14)	(−4.42)	(22.81)	(−29.56)	(−11.01)	(−10.46)	(−8.65)
γ	1.00	0.29	0.09	−0.01	0.70	−2.14	−1.36	−0.78
	(50.53)	(45.95)	(26.53)	(−5.67)	(39.70)	(−33.76)	(−30.74)	(−28.70)
Adj. R^2	0.90	0.85	0.89	0.85	0.88	0.84	0.81	0.84

Notes: t-statistics in parenthesis

Table 3 — Short- and long-run destination principle.

θ	τ	t_H^{d*}	t_F^{d*}	λ^d	$(t_H^{d*})_L$	$(t_F^{d*})_L$	$(\lambda^d)_L$	$(\widetilde{t}_H^d)_L$	$(\widetilde{t}_F^d)_L$	$(\widetilde{\lambda}^d)_L$
0.5	0.05	0.2109	0.2109	0.5000	0.1824	0.1824	0.5	0.1971	0.1971	0.5
0.51	0.05	0.2075	0.2144	0.5573	0.1801	0.1848	0.5535	0.1948	0.1994	0.5531
0.52	0.05	0.2042	0.2180	0.6146	0.1778	0.1874	0.6070	0.1926	0.2018	0.6061
0.53	0.05	0.2009	0.2217	0.6719	0.1757	0.1900	0.6604	0.1905	0.2043	0.6592
0.54	0.05	0.1978	0.2254	0.7209	0.1736	0.1928	0.7139	0.1884	0.2068	0.7122
0.55	0.05	0.1947	0.2293	0.7801	0.1716	0.1957	0.7674	0.1863	0.2094	0.7652
0.5	0.07	0.2114	0.2114	0.5	0.1830	0.1830	0.5	0.1972	0.1972	0.5
0.51	0.07	0.2080	0.2149	0.5408	0.1807	0.1855	0.5381	0.1950	0.1996	0.5378
0.52	0.07	0.2047	0.2185	0.5816	0.1784	0.1880	0.5761	0.1928	0.2020	0.5755
0.53	0.07	0.2014	0.2222	0.6223	0.1763	0.1907	0.6142	0.1906	0.2045	0.6132
0.54	0.07	0.1983	0.2260	0.6630	0.1742	0.1935	0.6523	0.1885	0.2070	0.6510
0.55	0.07	0.1952	0.2299	0.7036	0.1722	0.1964	0.6903	0.1865	0.2096	0.6887

Notes: $m = 0.6$, $\beta = 0.25$, $\gamma = 0.2$, $\alpha = 3$, $K = 1.0, \phi = 0.1$ $(N = 10)$

Table 4 — Switch from long-run DP to short- and long-run OP.

θ	τ	$(t_H^{d*})_L$	$(t_F^{d*})_L$	$(\lambda^d)_L$	t_H^{o*}	t_F^{o*}	$(t_H^{o*})_L$	$(t_F^{o*})_L$	$(\lambda^o)_L$
0.5	0.05	0.1824	0.1824	0.5000	0.1507	0.1507	0.0078	0.0078	0.5000
0.51	0.05	0.1801	0.1848	0.5535	0.1550	0.1475	0.0081	0.0074	0.5248
0.52	0.05	0.1778	0.1874	0.6070	0.1605	0.1454	0.0084	0.0071	0.5497
0.53	0.05	0.1757	0.1900	0.6604	0.1673	0.1444	0.0088	0.0067	0.5745
0.54	0.05	0.1736	0.1928	0.7139	0.1756	0.1446	0.0092	0.0063	0.5994
0.55	0.05	0.1716	0.1957	0.7674	0.1854	0.1462	0.0096	0.0060	0.6244
0.5	0.07	0.1830	0.1830	0.5000	0.1479	0.1479	0.0140	0.0140	0.5000
0.51	0.07	0.1807	0.1855	0.5381	0.1505	0.1457	0.0145	0.0136	0.5186
0.52	0.07	0.1784	0.1880	0.5761	0.1536	0.1440	0.0150	0.0131	0.5372
0.53	0.07	0.1763	0.1907	0.6142	0.1573	0.1427	0.0154	0.0126	0.5558
0.54	0.07	0.1742	0.1935	0.6523	0.1614	0.1420	0.0159	0.0122	0.5744
0.55	0.07	0.1722	0.1964	0.6903	0.1661	0.1417	0.0164	0.0117	0.5931

Notes: $m = 0.6$, $\beta = 0.25$, $\gamma = 0.2$, $\alpha = 3$, $K = 1.0, \phi = 0.1$ $(N = 10)$

Table 5 — Welfare impacts of non-cooperative tax setting under long-run DP.

		maximal welfare		changes with respect to maximal welfare			
θ	τ	$\widetilde{W}_H^d$	$\widetilde{W}_F^d$	ΔW_H^{d*} in %	ΔW_F^{d*} in %	$\Delta W_H^{d\,\mathrm{har}}$ in %	$\Delta W_F^{d\,\mathrm{har}}$ in %
0.5	0.07	8.3110	8.3110	-0.0220	-0.0220	0	0
0.51	0.07	8.4726	8.1495	-0.0191	-0.0249	-0.0151	0.0144
0.52	0.07	8.6342	7.9881	-0.0162	-0.0279	-0.0308	0.0279
0.53	0.07	8.7958	7.8268	-0.0133	-0.0308	-0.0466	0.0403
0.54	0.07	8.9573	7.6656	-0.0105	-0.0337	-0.0626	0.0511
0.55	0.07	9.1189	7.5046	-0.0079	-0.0365	-0.0786	0.0602

Notes: $m = 0.6$, $\beta = 0.25$, $\gamma = 0.2$, $\alpha = 3$, $K = 1.0, \phi = 0.1$ $(N = 10)$

Table 6 — Welfare impacts of non-cooperative tax setting under long-run OP.

		maximal welfare		changes with respect to maximal welfare			
θ	τ	$\widetilde{W}_H^o$	$\widetilde{W}_F^o$	ΔW_H^{o*} in %	ΔW_F^{o*} in %	$\Delta W_H^{o\,\mathrm{har}}$ in %	$\Delta W_F^{o\,\mathrm{har}}$ in %
0.5	0.07	8.3110	8.3110	-6.5286	-6.5286	0	0
0.51	0.07	8.4487	8.1733	-6.0393	-7.0336	0.7808	-0.8319
0.52	0.07	8.5864	8.0355	-5.5650	-7.5552	1.5134	-1.7182
0.53	0.07	8.7240	7.8978	-5.1049	-8.0941	2.2002	-2.6626
0.54	0.07	8.8616	7.7599	-4.6616	-8.6514	2.8434	-3.6694
0.55	0.07	8.9991	7.6221	-4.2252	-9.2281	3.4450	-4.7440

Notes: $m = 0.6$, $\beta = 0.25$, $\gamma = 0.2$, $\alpha = 3$, $K = 1.0, \phi = 0.1$ $(N = 10)$

Table 7 — Tax harmonization under the destination principle.

θ	$(t_H^{d*})_L$	$(t_F^{d*})_L$	$(\lambda^d)_L$	$(\widetilde{t}_H^d)_L$	$(\widetilde{t}_F^d)_L$	$(\widetilde{\lambda}^d)_L$	$(t_{\mathrm{har}}^d)_L$	$(\lambda_{\mathrm{har}}^d)_L$
0.5	0.1830	0.1830	0.5	0.1972	0.1972	0.5	0.1972	0.5
0.51	0.1807	0.1855	0.5381	0.1950	0.1996	0.5378	0.1972	0.5317
0.52	0.1784	0.1880	0.5761	0.1928	0.2020	0.5755	0.1972	0.5634
0.53	0.1763	0.1907	0.6142	0.1906	0.2045	0.6132	0.1971	0.5950
0.54	0.1742	0.1935	0.6523	0.1885	0.2070	0.6510	0.1970	0.6267
0.55	0.1722	0.1964	0.6903	0.1865	0.2096	0.6887	0.1969	0.6584

Notes: $m = 0.6$, $\beta = 0.25$, $\gamma = 0.2$, $\alpha = 3$, $K = 1.0, \phi = 0.1$ $(N = 10)$, $\tau = 0.07$

Table 8 — Tax harmonization under the origin principle.

θ	$(t^{*o}_H)_L$	$(t^{*o}_F)_L$	$(\lambda^o)_L$	$(\widetilde{t}^o_H)_L$	$(\widetilde{t}^o_F)_L$	$(\widetilde{\lambda}^o)_L$	$(t^o_{\text{har}})_L$	$(\lambda^o_{\text{har}})_L$
0.5	0.0140	0.0140	0.5	0.1972	0.1972	0.5	0.1972	0.5
0.51	0.0145	0.0136	0.5186	0.1979	0.1966	0.5019	0.1971	0.5316
0.52	0.0150	0.0131	0.5372	0.1986	0.1959	0.5038	0.1967	0.5634
0.53	0.0154	0.0126	0.5558	0.1992	0.1953	0.5057	0.1960	0.5951
0.54	0.0159	0.0122	0.5744	0.1999	0.1946	0.5076	0.1950	0.6268
0.55	0.0164	0.0117	0.5931	0.2005	0.1940	0.5094	0.1938	0.6586

Notes: $m = 0.6$, $\beta = 0.25$, $\gamma = 0.2$, $\alpha = 3$, $K = 1.0, \phi = 0.1$ $(N = 10)$, $\tau = 0.07$

Table 9 — Welfare changes and spatial changes between OP and DP.

	Equilibrium welfare differentials					spatial inequality			
θ	W^{d*}_H	W^{d*}_F	W^{o*}_H	W^{o*}_F	$(\Delta W_H)\%$	$(\Delta W_F)\%$	$(\lambda^{d*})_L$	$(\lambda^{o*})_L$	$(\Delta\lambda)\%$
0.5	8.3444	8.3444	7.7098	7.7098	8.23%	8.23%	0.5000	0.5000	0.0%
0.51	8.5070	8.1818	7.8807	7.5390	7.86%	8.53%	0.5531	0.5248	5.4%
0.52	8.6696	8.0193	8.0515	7.3682	7.68%	8.84%	0.6061	0.5497	10.26%
0.53	8.8323	7.8570	8.2224	7.1975	7.42%	9.16%	0.6592	0.5745	14.47%
0.54	8.9950	7.6948	8.3932	7.0267	7.17%	9.51%	0.7122	0.5994	18.82%
0.55	9.1576	7.5327	8.5641	6.8560	6.93%	9.87%	0.7652	0.6244	22.55%

Notes: $m = 0.6$, $\beta = 0.25$, $\gamma = 0.2$, $\alpha = 3$, $K = 1.0, \phi = 0.1$ $(N = 10)$, $\tau = 0.05$

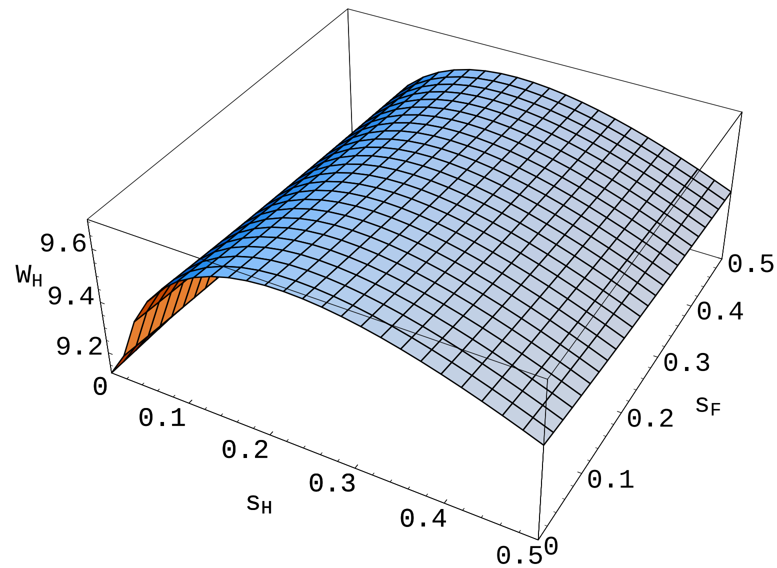

Figure 1. Welfare surface $W_H^d(s_H^d, s_F^d)$ under short-run DP

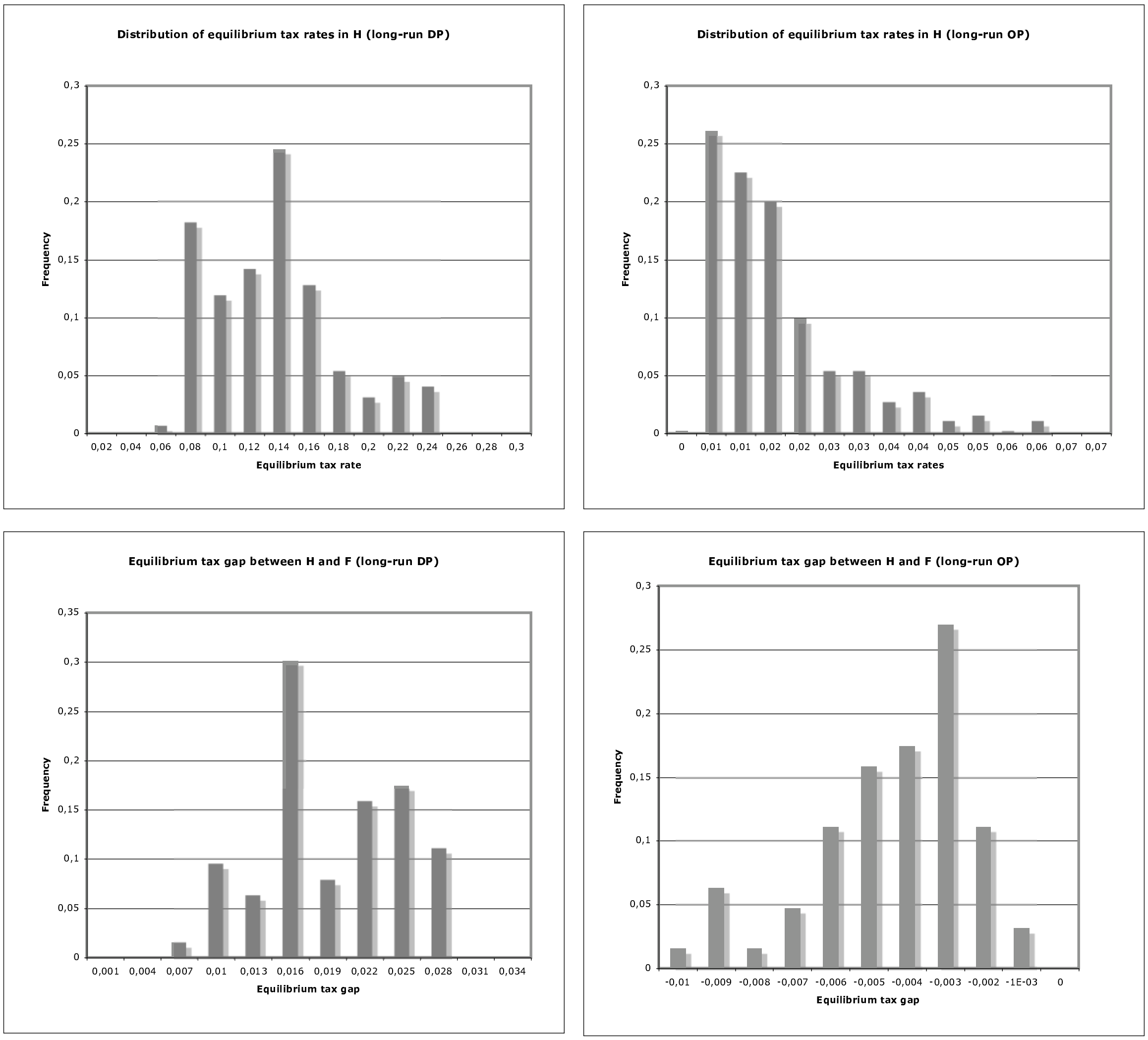

Figure 2: Histograms for the large grid.

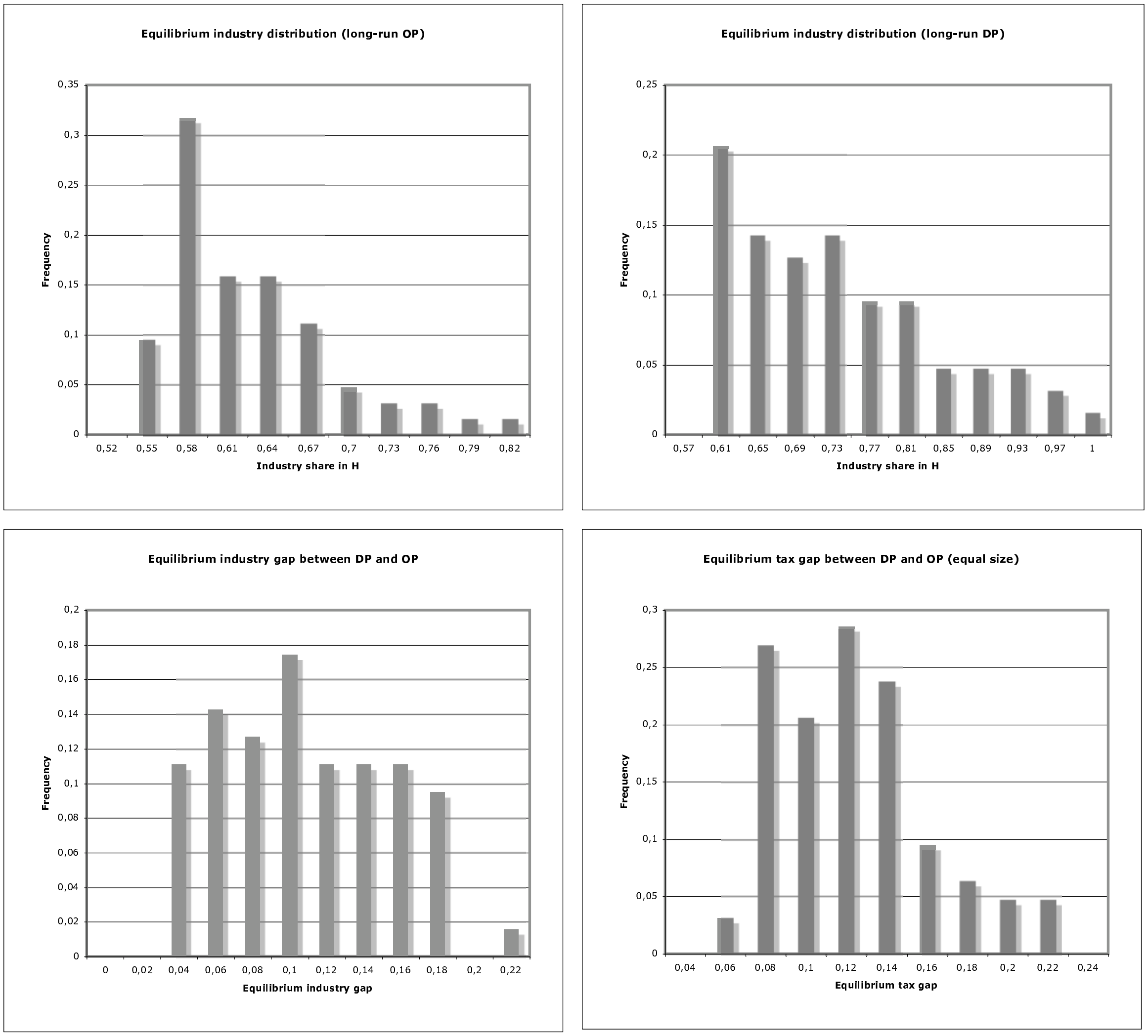

Figure 3: Histograms for the large grid (continued).

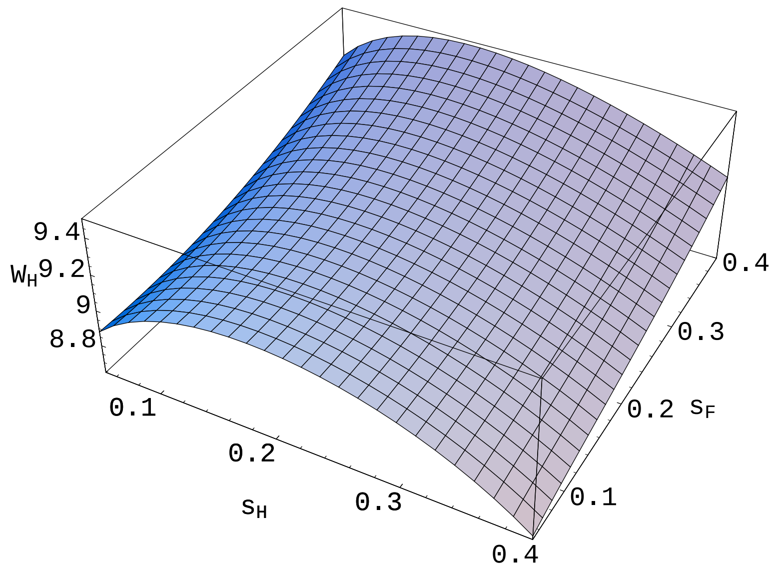

Figure 4. Welfare surface $W_H^o(s_H^o, s_F^o)$ under long-run OP

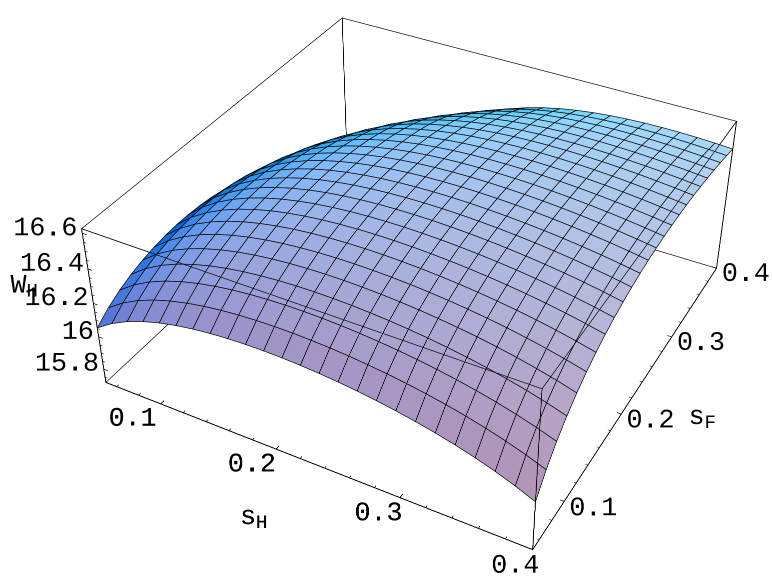

Figure 5. Global welfare surface $W^o(s_H^o, s_F^o)$ under long-run OP