CAPITAL TAX COMPETITION WITH HETEROGENEOUS FIRMS AND AGGLOMERATION EFFECTS

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Abstract

Our paper extends the capital tax competition literature by incorporating heterogeneous capital and agglomeration. Our model nests the standard tax competition model as well as the special case in which there is agglomeration but no firm/capital heterogeneity and the opposite case, firm heterogeneity with no agglomeration. We build on the existing tax competition literature as well as establish a link between this literature and the more recent work on agglomeration using the new economic geography model. Our main contribution lies in allowing for firm heterogeneity which we show plays a role similar to decreasing returns in regional production.

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Keywords: tax competition, heterogeneous firms, agglomeration.

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1 Introduction

The flurry of federation formation and dissolution around the world over the past fifty years has inspired sub-literatures in both international trade and public finance. The ability of any coalition formation model to explain the complex facts of economic history is limited by its underlying model of interregional competition (e.g., tariff wars or tax competition). One such model of interregional competition has served as the basis for the capital tax competition literature surveyed by Wilson (1999). Here each regional government possesses a single tax instrument — a proportional capital tax rate — to finance a publicly provided private good. Interregional tax competition leads to capital tax rates below socially optimal levels and consequently underprovision of the publicly provided private good. In this model larger regions are at a disadvantage because they perceive a more inelastic supply of capital than smaller regions, and as a consequence set a relatively high capital tax rate, export capital when efficiency would dictate no trade in capital, and suffer a lower utility level than smaller regions. Baldwin and Krugman (2004) and Baldwin, Forslid, Martin, Ottaviano, and Robert-Nicoud (2003) label this the basic tax competition model (BTCM) and note several ways in which this model is inconsistent with observations based on the history of federation formation in Europe. In this paper, we incorporate agglomeration and firm heterogeneity into an even simpler BTCM and show that our model can be consistent with the European Union facts highlighted by Baldwin and Krugman (2004).

The roots of the capital tax competition model in the present paper are like those of the BTCM except that each government can tax immobile labour as well as mobile capital. This eliminates the underprovision problem and leaves each government free to set its capital tax or subsidy rate to exploit its monopoly or monopsony power in the market for capital (see Hamada (1966) or Burbidge, DePater, Myers, and Sengupta (1997)). We build heterogeneous capital into the model by assuming each firm has productivity factors that determine how productive it will be in a given region and each firm locates where its profits are highest. Except for the marginal firm that is indifferent between locating in one region or the other, the firms in each region earn rents.[1]

Regions compete for firms.[2] Regional governments know the joint distribution of productivity factors but they cannot condition firm taxes or subsidies on the productivity or profitability of a given firm — a common proportional tax rate applies to all firms operating in its region.[3] To incorporate agglomeration into the

[1]Positive rent differentials across regions arise whenever there is heterogenity in the mobile factor. See Mansoorian and Myers (1993) for a model with mobile workers who differ in their preferences or their attachment to home.

[2]Other tax competition models with mobile firms can be found in Boadway, Cuff, and Marceau (2004) and Devereux, Lockwood, and Redoano (2002).

[3]Many regions tax some firms and subsidize others. We think the model in this paper

model, we assume a firm's output depends positively on the total output in the region. With constant returns to scale and homogeneous capital/firms capital-importing regions tax capital to drive down the after-tax price they must pay for their imports and capital-exporting regions subsidize capital to encourage capital to stay at home, which raises the return they receive on their capital exports. We demonstrate that the addition of increasing returns to scale and capital/firm heterogeneity does not alter fundamentally the character of this model — now if a region is a capital/firm importer its tax rate must exceed the other region's tax rate — but the tax rates could be of either sign and thus the model is consistent with a broader set of facts.

We present the model of the regional economy in the next section. In section 3, we characterize the regional equilibrium without tax competition and demonstrate that with Cobb-Douglas production functions the regional equilibrium is always efficient. We describe the tax competition game and characterize its Nash equilibria in section 4. We show that the Nash equilibrium will be efficient when regions are identical. We also demonstrate that agglomeration encourages a region to subsidize firms to correct for the positive externality, while firm heterogeneity induces a region to tax firms to capture location-specific rents. When regional endowments differ, the Nash equilibrium may be inefficient since each region has an incentive to manipulate the terms-of-trade. We illustrate this incentive by conducting a particular comparative static exercise — increasing one region's labour and firm/capital endowment proportionately, starting from symmetry. We show that the large region can either import or export and have either a higher or lower level of welfare depending on the relative strength of the two forces at work in the model – heterogeneity of firms and agglomeration. We prove that, in general, the region importing (exporting) firms will have a higher (lower) tax in any Nash equilibrium. We then show that some forms of tax harmonization can be Pareto improving. In section 5, we compare and contrast our results to those found in the economic geography literature. Section 6 summarizes and concludes.

2 Regional Economy

The economy consists of two regions, denoted A and B. There are H_i workers in region i (where i is either A or B). The workers are immobile, and each worker supplies one unit of labour at every wage rate. The total number of firms in the economy is fixed. Firms are assumed to be completely owned by workers in the economy. Workers in region i own a fraction γ_i of each firm in the economy where

$$\gamma_A + \gamma_B = 1.$$

could be extended to incorporate this feature of reality. See Taylor (2003) for an industrial organization model that explains why publishers offer lower prices for magazine subscriptions to attract new customers.

Each firm knows its productivity and the wage rates in each region. Given this information, a firm chooses its location and its employment of labour so as to maximize its profits. The productivity of any given firm in a given region is determined in part by its **productivity factors** (θ_A, θ_B). The distribution of productivity factors across firms is described by the density function $g(\theta_A, \theta_B)$, which has lower and upper bounds.

> ASSUMPTION: *Let S be the set of pairs (θ_A, θ_B) for which $g(\theta_A, \theta_B)$ is positive. Assume that there exists a positive number $\underline{\theta}$ such that $(\underline{\theta}, \underline{\theta})$ is a lower bound of S, and that there exists a positive finite number $\overline{\theta}$ such that $(\overline{\theta}, \overline{\theta})$ is an upper bound of S.*

A firm's productivity is also affected by agglomeration; each firm benefits from the presence of other firms in the region. It might be that a greater concentration of firms makes each firm more productive because transportation costs are lower or opportunities to trade more plentiful. Alternatively, it might be easier to learn about state-of-the-art production technologies when firms cluster together. The exact nature of the agglomeration effect is left unspecified. Instead, it is simply assumed that each firm's output is greater when economic activity in its region is greater.

Let y_i be a firm's output in region i, and let h be the quantity of labour employed by the firm. Let Y_i be regional output. Each firm's production function is

$$y_i = (1/\beta)(\theta_i)^{1-\beta}(Y_i)^{\alpha}h^{\beta}$$

where the parameters α and β are positive and smaller than one. This production function incorporates the basic assumptions: the firm's output rises with its own productivity factor, and both regional output and employment have positive but diminishing marginal products. The Cobb-Douglas function is used for tractability.

3 Regional Equilibrium

To begin, define the equilibrium in the regional economy as follows:

DEFINITION: *A* **regional equilibrium** *has these properties:*

> *(a) Each firm, knowing the regional outputs and wage rates, chooses a location (either region A or region B) and a level of employment to maximize its profits.*
>
> *(b) The wage rate w_i clears the labour market in region i.*
>
> *(c) Regional output is the aggregate of the outputs of the individual firms.*

3.1 Employment and Location Decisions

A firm that has decided to locate in region i can hire any quantity of labour at the market wage w_i. It will choose the quantity of labour h that maximizes its profits π_i, where

$$\pi_i = (1/\beta)(\theta_i)^{1-\beta}(Y_i)^{\alpha}h^{\beta} - w_i h.$$

This quantity of labour is:

$$\widehat{h}(\theta_i, Y_i, w_i) \equiv \theta_i (Y_i)^{\frac{\alpha}{1-\beta}} (w_i)^{-\frac{1}{1-\beta}}. \tag{1}$$

Evaluating the firm's output and profits at this employment level gives

$$y_i = (1/\beta)\theta_i (Y_i)^{\frac{\alpha}{1-\beta}} (w_i)^{-\frac{\beta}{1-\beta}} \tag{2}$$

$$\pi_i = (1-\beta)y_i. \tag{3}$$

A firm locates in the region in which its profits are greater. It will locate in region A if

$$\pi_A \geq \pi_B$$

or equivalently,

$$y_A \geq y_B$$

A firm's output in each region depends upon its productivity factor in that region *and* on the regional output and wage rate. Consequently, a firm will locate in region A if θ_A/θ_B is greater than or equal to the critical value k, where:

$$k = \left(\frac{Y_B}{Y_A}\right)^{\frac{\alpha}{1-\beta}} \left(\frac{w_A}{w_B}\right)^{\frac{\beta}{1-\beta}} \tag{4}$$

and it will locate in region B otherwise. This decision rule is the one required by part (a) of the definition of equilibrium. The employment rule required by the same part is (1).

3.2 Regional Labour Markets

The total demand for labour in region A is

$$H_A^D = \int_{\underline{\theta}}^{\overline{\theta}} \int_{k\theta_B}^{\overline{\theta}} \widehat{h}(\theta_A, Y_A, w_A) g(\theta_A, \theta_B) d\theta_A d\theta_B$$

and the total demand for labour in region B is

$$H_B^D = \int_{\underline{\theta}}^{\overline{\theta}} \int_{\underline{\theta}}^{k\theta_B} \widehat{h}(\theta_B, Y_B, w_B) g(\theta_A, \theta_B) d\theta_A d\theta_B.$$

Alternatively,

$$H_i^D = (Y_i)^{\frac{\alpha}{1-\beta}} (w_i)^{-\frac{1}{1-\beta}} z_i(k)$$

where $z_i(k)$ aggregates the productivity factors of the firms that locate in region i under a particular value of k:

$$z_A(k) \equiv \int_{\underline{\theta}}^{\overline{\theta}} \int_{k\theta_B}^{\overline{\theta}} \theta_A g(\theta_A, \theta_B) d\theta_A d\theta_B$$

$$z_B(k) \equiv \int_{\underline{\theta}}^{\overline{\theta}} \int_{\underline{\theta}}^{k\theta_B} \theta_B g(\theta_A, \theta_B) d\theta_A d\theta_B.$$

Note that given any distribution of productivity factors

$$z'_A(k) = -kz'_B(k) \leq 0. \tag{5}$$

If an increase in the critical value k causes some firms that had previously located in A to shift to B, z_A falls and z_B rises. Each of the firms that switches from one region to the other is a marginal firm at the time of the switch, implying that θ_A is just equal to $k\theta_B$. The loss in region A's aggregate productivity is therefore k times as large as region B's gain.[4]

Part (b) of the definition of equilibrium requires labour demand to be equal to labour supply in each region. This requirement is satisfied when

$$(Y_i)^{\frac{\alpha}{1-\beta}} (w_i)^{-\frac{1}{1-\beta}} z_i(k) = H_i \qquad i = A, B \tag{6}$$

3.3 Regional Output

Part (c) of the definition of equilibrium states that the output of a region can be found by integrating over the outputs of the individual firms. There is, however, a simpler way of finding it. Since each firm's profits are fraction $1 - \beta$ of its output, each firm's wage bill is fraction β of its output. The regional outputs therefore satisfy the conditions

$$Y_i = (1/\beta) w_i H_i \qquad i = A, B \tag{7}$$

3.4 Equilibrium

An equilibrium consists of the following information:

- The location, output and employment of each firm.
- The market-clearing wage in each region.
- The output of each region.

[4] The inequality in (5) is weak because $z'_i(k)$ is equal to zero at any k for which there are no pairs (θ_A, θ_B) in S such that θ_A is equal to $\theta_B k$ (so that a small change in k does not induce any firm to switch regions).

Note, however, that if the values of k, Y_A, Y_B, w_A, and w_B are known, all of the remaining information can be deduced from them. The location of each firm is determined by k. Once the location of a firm is known, its employment of labour and its output are given by (1) and (2). The only arguments in these equations are Y_A, Y_B, w_A and w_B.

The five key variables are themselves determined by the five equation system consisting of (4), the two equations in (6), and the two equations in (7). This system can be considerably simplified. Use the last four equations (in pairs) to obtain each region's output and wage rate in terms of k:

$$Y_i = \left[(1/\beta)\,(H_i)^{\beta}\, z_i(k)^{1-\beta}\right]^{\frac{1}{1-\alpha}} \qquad i = A, B \tag{8}$$

$$w_i = \left[(1/\beta)^{\alpha}\,(H_i)^{\alpha+\beta-1}\, z_i(k)^{1-\beta}\right]^{\frac{1}{1-\alpha}} \qquad i = A, B \tag{9}$$

Output rises as the supply of labour rises and as the aggregate productivity of the firms in the region rises. The wage rises as the aggregate productivity of the firms rises, but might either rise or fall as the supply of labour rises. The latter result follows from the presence of agglomeration. Suppose that the supply of labour rises and that the wage adjusts to absorb all of the additional labour. The marginal product of labour at each firm falls because more labour is being used; but it rises because every firm is using more labour and producing more output, causing regional output to rise. The wage rate falls if the former effect dominates, and rises if the latter effect dominates.

Now consider the determination of k. Substituting (8) and (9) into (4) gives

$$k = \left(\frac{H_B}{H_A}\right)^{\frac{\beta}{1-\alpha}} \left(\frac{z_B(k)}{z_A(k)}\right)^{\frac{\alpha-\beta}{1-\alpha}}$$

or

$$k = L\mu(k) \tag{10}$$

where

$$L \equiv \left(\frac{H_B}{H_A}\right)^{\frac{\beta}{1-\alpha}}$$

$$\mu(k) \equiv \left(\frac{z_B(k)}{z_A(k)}\right)^{\frac{\alpha-\beta}{1-\alpha}}.$$

It follows from (10) that the equilibrium location of firms and consequently, the regional outputs and wage rates in equilibrium are all independent of the distribution of firm ownership in the economy. Firm ownership affects only the resources available to each region in equilibrium. To interpret (10), imagine that the firms initially allocate themselves between the two regions according to the rule:

Locate in A if θ_A is greater than or equal to $k\theta_B$; otherwise, locate in B.

For any given value of k, a firm maximizes its profits by locating in A if θ_A is greater than or equal to $L\mu(k)\theta_B$ and by locating in B if it is not. The equilibrium value of k is the one under which no firm regrets its location because the profit-maximizing critical value, $L\mu(k)$, is equal to the current critical value, k.[5]

If $L\mu(k)$ is greater than k, some of the firms that are initially located in A will move to B, causing k to rise; and if $L\mu(k)$ is smaller than k, some of the firms that are initially located in B will move to A, causing k to fall. This observation motivates the following definition:

> DEFINITION: *Let k^* be the value taken by k in an equilibrium. The equilibrium is* **stable** *if $L\mu(k)$ is greater than k when k is less than k^*, and less than k when k is greater than k^*. It is* **unstable** *if $L\mu(k)$ is less than k when k is less than k^*, and greater than k when k is greater than k^*.*

Equation (8) shows that in any equilibrium, each region's output is determined by k. Since the total output of the economy is the sum of the regional outputs, it is also determined by k. Differentiating $Y_A + Y_B$ with respect to k and simplifying the resulting expression shows that:

$$\text{sign}\left[\frac{d(Y_A + Y_B)}{dk}\right] = \text{sign}\left[\ L\mu(k) - k\right].$$

Let k^e be a stationary point of $Y_A + Y_B$. The stationary point is a local maximum if $L\mu(k)$ is greater than k when k is less than k^e, and less than k when k is greater than k^e. It is a local minimum if $L\mu(k)$ is less than k when k is less than k^e, and greater than k when k is greater than k^e.

Comparing these results with the above definition leads immediately to the following observation:

> LEMMA 1: *Let k^* be the value taken by k in a unique equilibrium. Then k^* maximizes total output if and only if the economy is stable, and it minimizes total output if and only if the economy is unstable.*

If the economy is stable, the regional equilibrium without tax competition will be output-maximizing. It is shown below that economies with strong agglomeration effects are not stable and total output will be maximized only when all firms locate in the same region.

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[5] Actually, (10) describes only an *interior* equilibrium. Suppose that all of the mobile firms locate in A when k is equal to k', and that all of the mobile firms locate in B when k is equal to k''. Then k' is an equilibrium if $L\mu(k')$ is less than k', and k'' is an equilibrium if $L\mu(k'')$ is greater than k''. This kind of equilibrium arises only when the interior equilibrium is unstable, and situations that give rise to unstable interior equilibria are largely ignored in the discussion that follows.

3.5 Symmetric Regions

Regions are symmetric if they have the same labour supplies and own an equal share of all firms in the economy, and if the frequency distribution of the productivity factors is symmetric, so

$$g(\theta', \theta'') = g(\theta'', \theta') \quad \forall \theta', \theta'' \in S.$$

With symmetric regions, the equilibrium value of k is characterized by:

$$k = \mu(k).$$

If β is greater than α, $\mu(k)$ is non-increasing in k (specifically, it is negatively sloped if the z_i' are non-zero and flat if they are equal to zero). This case is shown in Figure 1. The graphs of $\mu(k)$ and k are shown for all values of k between $\underline{k}$ and $\overline{k}$, where:

$$\underline{k} \equiv \underline{\theta}/\overline{\theta} < 1$$
$$\overline{k} \equiv \overline{\theta}/\underline{\theta} > 1.$$

We have

$$\lim_{k \to \underline{k}} \mu(k) = \infty$$

and

$$\lim_{k \to \overline{k}} \mu(k) = 0.$$

Since $\mu(k)$ is continuous and non-increasing, the graphs of $\mu(k)$ and k intersect exactly once between $\underline{k}$ and $\overline{k}$. With symmetry of the frequency distribution

$$z_A(1/k) = z_B(k)$$

and the equilibrium value of k is 1. This equilibrium is unique and stable, and by Lemma 1, maximizes the economy's total output. Every firm locates in the region in which it has the higher productivity factor θ_i.

Figure 2 assumes that α is greater than β. The function $\mu(k)$ is now non-decreasing in k. Since

$$0 = \mu(\underline{k}) < \underline{k} < 1 < \overline{k} < \mu(\overline{k}) = \infty$$

there is at least one equilibrium, and multiple equilibria are possible. In this case, the symmetric equilibrium is unstable and by Lemma 1, minimizes total output. If the equilibrium is unique, total output is maximized when all of the firms locate in one region.[6] As an equilibrium with these properties is not very interesting, it is assumed henceforth that β is greater than α.

[6] If all of the firms locate in one region, some of them are choosing to locate in that region even though their productivity factor in that region is lower—possibly substantially lower—than their productivity factor in the other region. They do so because the agglomeration effect caused by concentrating all of the firms in one region more than compensates them for choosing the region in which their productivity factor is lower.

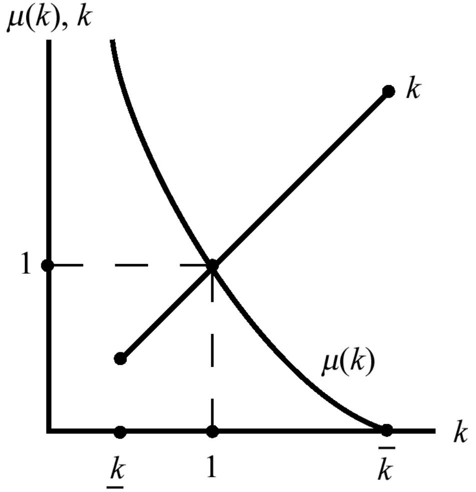


Figure 1: The equilibrium value of k when β is greater than α.

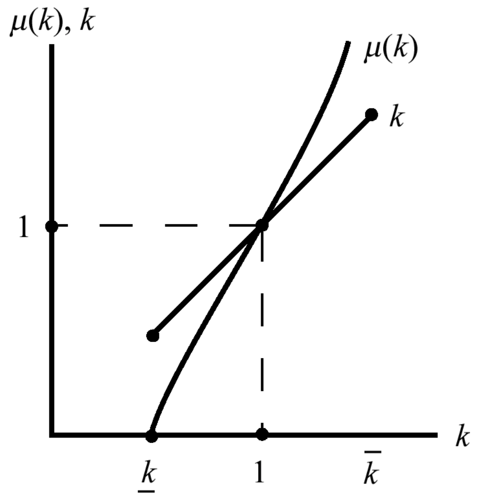


Figure 2: A unique equilibrium when α is greater than β.

3.6 Asymmetric Regions

Now, assume that both the distribution of labour supplies and of firm ownership, and the frequency distribution of the θs are all asymmetric. In this case, the equilibrium value of k in the economy is determined from:

$$k = L\mu(k).$$

With β greater than α, the equilibrium is unique and stable, and by Lemma 1 maximizes the economy's total output. The equilibrium value of k, however, will depend on the distribution of labour in the economy.[7] For example, if the frequency distribution of the productivity factors happened to be symmetric, then k will be greater, or less than, unity depending on whether region A has fewer, or more, workers than region B. In this case, it is output-maximizing for some firms to locate in a region for which they have a lower productivity factor.

4 Tax Competition

Now suppose each region has a government. The government of region i taxes both workers' incomes and firms' profits — not necessarily at the same rate — and uses the revenue to provide a private good to the workers in its region.[8] We assume it takes one unit of the private good to produce one unit of the publicly provided private good. Governments first select their tax and spending policies and then each firm knowing its own regional productivities as well as the regional wage and tax rates, chooses a location and a level of employment to maximize its after-tax profits.

The regional proportional tax on profits, denoted t_i, will not affect the firm's profit-maximizing level of employment, so before-tax profits are still a constant proportion of the firm's output as described by (3). Consequently for a given value of k, the equilibrium regional outputs and wages are still given by (8) and (9). The profit tax does, however, affect a firm's location decision. A firm will locate in region A if

$$(1 - t_A)y_A \geq (1 - t_B)y_B.$$

Using (2), (8), and (9), the critical value of k in equilibrium is now determined by

$$k = TL\mu(k) \tag{11}$$

where

$$T = \frac{1 - t_B}{1 - t_A}$$

[7] One can think about the downward sloping line in Figure 1 pivoting around the point $(0, \overline{k})$. It pivots to the left when $L < 1$ and to the right when $L > 1$.

[8] We implicitly rule out the possibility of transfer pricing by assuming the government can observe where a firm produces and the profit it earns.

Let k^n be the value of k in an equilibrium with tax competition. By definition, the equilibrium is stable if $TL\mu(k)$ is greater than k when k is less than k^n, and less than k when k is greater than k^n. From Lemma 1, the economy's total output is maximized only if the equilibrium is stable, and if tax rates are the same across regions, $T = 1$. Again, stability requires that $\beta > \alpha$. Therefore, assuming stability

$$\frac{\partial k}{\partial T} = \left(\frac{1}{T}\right)\left[\frac{1}{k} + \left(\frac{\beta - \alpha}{1 - \alpha}\right)(\phi_B(k) - \phi_A(k))\right]^{-1} > 0 \tag{12}$$

where

$$\phi_i(k) \equiv \frac{z_i'(k)}{z_i(k)}.$$

An increase in a region's tax rate reduces the measure of firms in that region. The regional equilibrium for a given pair of tax rates is described by (11). The next step is to determine what tax rates the regional governments will choose to maximize the welfare of their workers.

We assume preferences of a worker in region i can be represented by the following well-behaved utility function

$$U_i = u(c_i, g_i)$$

where c_i is the worker's consumption of some private good, and g_i is the quantity of a publicly provided private good. A worker has two sources of income: wage earnings and returns to firm ownership.[9] The government can impose a tax on the workers' incomes, and since labour is immobile and a worker's share of firm ownership is given, this tax is lump-sum. The income tax revenue can be combined with the revenue from the tax on profits to finance the publicly provided private good, or the income tax revenue could be split between the provision of the government good and the subsidization of the firms. (This subsidization would take the form of a negative proportional tax on profits.) In either case, the budget constraint for region i is

$$g_i = \frac{R_i}{H_i} - c_i$$

where R_i are the total resources available to residents of region i. Each worker in region i is allowed to retain a part of his income c_i as his private consumption, and the remainder of the region's resources are allocated to the government good.

[9] As workers are identical within a given region, we assume each worker in region i owns a share γ_i/H_i of *each* firm in the economy. So, each worker recieves a share of the after-tax profits from *every firm* in the economy. Therefore, all workers want every firm to locate in whichever region the firm can earn the highest after-tax profits. Allowing workers in each region to own different shares of the firms in the economy would complicate the model considerably.

The government in region i chooses a lump-sum tax, or equivalently private consumption, to maximize $u\left(c_i, R_i/H_i - c_i\right)$. The following condition holds

$$\frac{\partial u(c_i, g_i)/\partial g_i}{\partial u(c_i, g_i)/\partial c_i} = 1$$

and there is efficient provision of the publicly provided private good. Therefore, a worker's utility depends only on the available per capita resources in region i, that is

$$V\left(\frac{R_i}{H_i}\right) \equiv \max_{c_i} u\left(c_i, \frac{R_i}{H_i} - c_i\right).$$

Clearly, the government can maximize the worker's utility by choosing t_i to maximize its resources R_i since workers are immobile. The resources of the two regions can be written as

$$R_A = Y_A + (1-\beta)[\gamma_A(1-t_B)Y_B - \gamma_B(1-t_A)Y_A] \tag{13}$$

$$R_B = Y_B - (1-\beta)[\gamma_A(1-t_B)Y_B - \gamma_B(1-t_A)Y_A]. \tag{14}$$

The resources available to region A include all of its own output except for region B's share of region A's after-tax profits, plus region A's share of region B's after-tax profits. The resources of region B are calculated in a similar fashion.

Regional governments act non-cooperatively and choose their own profit tax rate taking as given the other region's tax rate. We can now define the tax competition game.

DEFINITION: *The* **tax competition game** *has these characteristics:*

(a) The players are the two governments, A and B.

(b) Government i (where i is either A or B) chooses the tax rate t_i; the tax rate must be smaller than unity, but it can be either positive or negative.

(c) The governments recognize that, for any pair of tax rates they choose, the economy will reach an equilibrium as described by (8), (9), and (11). Hence, each government recognizes that the output of its own region depends upon both profit tax rates.

(d) Each government i wishes to maximize R_i.

A **Nash equilibrium** in the tax competition game is a pair (t_A, t_B) such that neither government can increase its own resources by unilaterally deviating from the equilibrium.

Region A's best tax rate is the solution to the problem:

$$\max_{t_A} R_A = \widetilde{Y}_A(T) + (1-\beta)[\gamma_A(1-t_B)\widetilde{Y}_B(T) - \gamma_B(1-t_A)\widetilde{Y}_A(T)]$$

where $\widetilde{Y}_i(T)$ is region i's output under an equilibrium with k given by (11). The first-order condition for a maximum is

$$\gamma_B(1-\beta)\widetilde{Y}_A + \left\{[1-\gamma_B(1-\beta)(1-t_A)]\frac{\partial \widetilde{Y}_A}{\partial T} + \gamma_A(1-\beta)(1-t_B)\frac{\partial \widetilde{Y}_B}{\partial T}\right\}\frac{\partial T}{\partial t_A} = 0. \tag{15}$$

Likewise, the first-order condition for region B's best tax rate is

$$\gamma_A(1-\beta)\widetilde{Y}_B + \left\{[1-\gamma_A(1-\beta)(1-t_B)]\frac{\partial \widetilde{Y}_B}{\partial T} + \gamma_B(1-\beta)(1-t_A)\frac{\partial \widetilde{Y}_A}{\partial T}\right\}\frac{\partial T}{\partial t_B} = 0. \tag{16}$$

Since T affects Y_i only through its effect on k,

$$\frac{\partial \widetilde{Y}_i}{\partial T} = \frac{\partial Y_i}{\partial k}\frac{\partial k}{\partial T}$$

where using (8),

$$\frac{\partial Y_i}{\partial k} = Y_i\left(\frac{1-\beta}{1-\alpha}\right)\phi_i(k).$$

The pair (t_A, t_B) is a Nash equilibrium if the triplet (t_A, t_B, k^n) is a solution to (11), (15) and (16).

4.1 Nash Equilibrium with Symmetric Regions

Assume that the density function of the productivity factors is symmetric and that the regions have equal labour supplies and equal firm ownership shares:

$$L = 1$$

$$\gamma_A = \gamma_B = 1/2$$

The regions are identical and will choose the same tax rate. Every firm will locate in the region in which its productivity factor is higher. The equilibrium distribution of firms maximizes total output in the economy:

$$T = 1$$

$$k^n = 1.$$

The last restriction implies that (11) can be removed from the three equation system determining t_A, t_B and k^n. Imposing all of the above restrictions, and recalling (5), shows that the common value of t_A and t_B is

$$t = 1 - \left[(1-\alpha)\left(1+\frac{1}{2\phi_B(1)}\right)\right]^{-1}. \tag{17}$$

A critical issue in tax competition is whether regions will tax profits at all. The fear of losing firms to other regions might drive the tax rates ever downward, until each region is subsidizing profits because the other region is subsidizing profits. Equation (17) offers some insight into the conditions under which regions subsidize and the conditions under which they tax. The tax is positive if the expression in square brackets is greater than one, and it is negative — that is, it is a subsidy — if the expression is less than unity. Equivalently,

$$\text{sign}\,[t] = \text{sign}\,[(1-\alpha) - 2\alpha\phi_B(1)]$$

Figure 3 shows the pairs (α, β) for which the equilibrium outcome involves taxes and the pairs for which it involves subsidies. (The pairs below the diagonal line have an unstable symmetric equilibrium, and hence have been excluded from consideration.) Note that:

- The more important is agglomeration (that is, the greater is α), the less likely the regions are to tax firms. Agglomeration increases the value of having a firm locate in a region (through its external effects on other firms), and hence increases the cost of driving firms out of the region through high taxes. Agglomeration can be removed from the model by simply setting α equal to zero.

- The less the firms' productivity factors vary across regions, the greater is $z'_B(1)$ and the less likely the regions are to tax. With minimal heterogeneity, all firms will want to locate in B if k exceeds one by an arbitrarily small amount, and all firms will want to locate in A when k falls short of one by an arbitrarily small amount. For this to be the case with z_B continuous, z'_B must approach infinity in the neighbourhood of unity. In the limit as $z'_B(1)$ approaches infinity, all of the firms will be virtually identical. It is then almost certain that the regions will subsidize firms.

These results extend previous results in the literature. Burbidge, DePater, Myers and Sengupta (1997) show, in a model with no agglomeration and no heterogeneity, that regions that import capital will reduce the price of these imports by taxing capital, while regions that export capital will raise the price of the exported capital by subsidizing capital at home. In a symmetric equilibrium, of course, no region is a net exporter or a net importer of capital, so that the tax rate on capital is equal to zero. Burbidge and Cuff (2003) generalize these findings by introducing agglomeration into this model. They show that, when homogeneous capital has a positive external effect on the region's output, each region subsidizes capital in an attempt to gain the benefit of the externality. When capital is homogeneous $z'_B(1)$ is infinite, or equivalently, $\phi_B(1)$ is infinite.

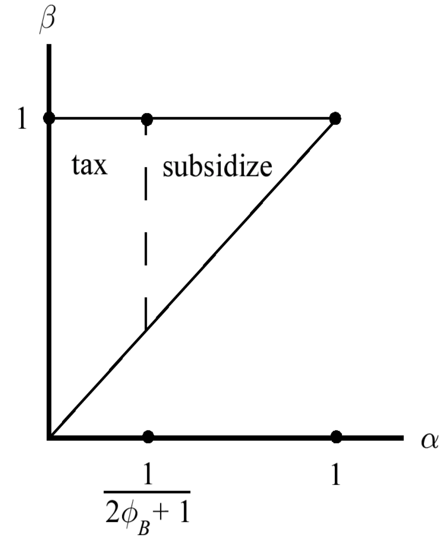


Figure 3: The enclosed region consists of the pairs (α, β) for which the symmetric equilibrium under fixed taxes is stable. This region is divided into two sections, one in which the symmetric equilibrium involves taxes and one in which it involves subsidies. A decrease in $z'_B(1)$ shifts the dividing line to the right.

The dashed line in Figure 3 then shifts leftward until it passes through the origin, eliminating the region in which capital is taxed. If α is equal to zero, capital is neither taxed nor subsidized (as in Burbidge et al. (1997)); and if α is greater than zero, capital is subsidized.

A novel feature of the current model is firm heterogeneity. In any equilibrium, almost all of the firms are inframarginal; they earn rents in their preferred locations. The regions naturally have an incentive to tax these rents. The greater is the degree of heterogeneity — the farther to the right is the dashed line in Figure 3 — the more likely the incentive to tax inframarginal firms dominates the incentive to subsidize capital. Also, given the degree of heterogeneity of the firms, the positive externality associated with capital becomes larger as α becomes larger, and hence regions tax when α is small and subsidize when it is large.

In this model, the symmetric Nash equilibrium is efficient because regions tax profits at the same rate.[10] The allocation of firms in the economy maximizes total output. There is no trade in the symmetric Nash equilibrium and all workers in the economy are equally well-off. It is natural then to ask what happens when regions are asymmetric.

4.2 Nash Equilibrium with Asymmetric Regions

If regions differ in their labour endowment and shares of firm ownership, and the frequency distribution of factor productivities is asymmetric, then the allocation of firms in the Nash equilibrium may be inefficient. The Nash equilibrium is efficient only if regions happen to choose the same profit tax rate. Any inefficiency arises solely because each regional government has an incentive to manipulate the terms of trade and set different tax rates. As a result, total output in the economy, or equivalently, total resources available to the two regions, will not be maximized. It is possible then that some form of tax harmonization may achieve a Pareto improvement. We first illustrate the terms-of-trade effect and then characterize the Pareto-improving tax harmonization schemes.

4.2.1 Terms-of-Trade Effect

Define the net payment in output to foreign owners of firms operating in region i as the difference between the output of region i, and the total resources of region i,[11]

$$I_i \equiv Y_i - R_i \tag{18}$$

If $I_i > 0$, then region i is a net firm importer; if $I_i < 0$, then region i is a net firm exporter. Given that the total number of firms in the economy is fixed, the two regions are closed – if one is a capital exporter the other must be a

[10] The allocation of the mobile factor with symmetric regions will still be efficient if workers are not taxed. The provision of the government good, however, will be inefficiently low.

[11] Given the assumptions on workers' preferences, all of the regional resources will be consumed by the workers.

capital importer. Firm importers have to make payments to foreign investors and therefore have an incentive to tax firms to drive down the after-tax return received by foreign owners. Firm exporters have an incentive to subsidize firms to increase the payments they receive from the firms they own that are located outside of the region. Each region has an incentive to manipulate the terms-of-trade.

To illustrate this incentive, imagine that, beginning from the symmetric equilibrium, a small quantity of labour and a small share of the ownership of firms is transferred from region B to region A, so that region A becomes proportionately larger than region B. The regional endowment ratio of labour to share of firm ownership will be the same in each region. It is assumed for this exercise that the frequency distribution of the θs remains symmetric. Normalizing the population is to one, we assume

$$H_A = x, \quad \gamma_A = x, \quad H_B = 1 - x, \quad \gamma_B = 1 - x$$

The comparative statics exercise then is to increase x marginally from an initial value of 1/2 and to determine how net payments and per capita resources, which measures workers' welfare change, in each region. To highlight the different forces at work in the model, we consider three benchmark cases. They are:

- The *standard model* with no agglomeration effects and minimal heterogeneity of firms.
- The *agglomeration only* model which retains agglomeration effects but assumes that the differences among firms are arbitrarily small.
- The *heterogeneity only* model which has no agglomeration effects but permits heterogeneity among firms.

Agglomeration can be removed from the model by simply setting α equal to zero, but heterogeneity among firms cannot be completely eliminated. There will be minimal heterogeneity if z'_B approaches infinity in the neighbourhood of unity.[12]

Table 1 shows the impact of a marginal increase in x, starting from the symmetric equilibrium, on the variables of interest in each of the three benchmark models.[13] The table focuses on region A, but the symmetry of the two regions implies that the change in region B is the same size as the change in region A but of opposite sign. The comparative statics exercise is such that the proportional increases in both region A's labour supply and its share of firm ownership are equal to 2.

[12]Equivalently, z'_A must approach negative infinity at $k = 1$.

[13]The results presented in Table 1 are derived in the Appendix.

Table 1: **The comparative statics of a regional economy with tax competition.**			
	Standard Model	**Agglomeration Only**	**Heterogeneity Only**
Initial t	0	$-$	$+$
$\frac{dt_A}{dx}$	0	$+$	$-$
$\frac{dY_A}{dx}\frac{1}{Y_A}$	0	$\frac{\beta(2-\alpha)-\alpha}{(\beta-\alpha)(1-\alpha)} > 2$	$2\frac{\beta-\phi_A\left((1+\beta)^2-4\phi_A\beta\right)}{(1-2\phi_A\beta)(1-2\phi_A)} \in (0,2)$
$\frac{dR_A}{dx}\frac{1}{R_A}$	2	$\frac{2}{1-\alpha} > 2$	$2\frac{\beta-2\phi_A}{1-2\phi_A} \in (0,2)$
$\frac{dI_A^n}{dx}$	0	$+$	$-$
$\frac{dk^n}{dx} \div \frac{dk^e}{dx}$	1	$1-\frac{\alpha}{2\beta} < 1$	$\frac{1+\beta(1-4\phi_A)}{2\beta(1-2\phi_A)} > 1$
$\frac{d[(R_A^e/H_A)-(R_A^n/H_A)]}{dx}$	0	$+$	$+$

Consider first the standard model. In this model:

- If the firms were allocated efficiently, then the increase in A's share of the firms would be the same as the increase in A's share of ownership. Neither region would be a capital exporter or capital importer, and hence neither would have an incentive to move its tax rate away from zero.

- If each region were to leave its tax rate unchanged, the taxes would not distort the firms' location decisions, and the equilibrium allocation of firms would be the same as the efficient allocation.

It follows that the equilibrium is characterized by unchanged tax rates, no net capital exports or imports, and the efficient allocation of firms. In the absence of agglomeration, the regional production function displays constant returns to scale, so A's output rises by the same proportion as its population. Its resources, R_A, rise by the same rate, leaving per capita resources unchanged. Each person's welfare is a monotonic function of per capita resources, so welfare is unchanged by the posited transfer of resources. The Nash equilibrium is always efficient when there are no agglomeration effects and minimal firm heterogeneity.

Now consider the model in which there is agglomeration but minimal heterogeneity. At symmetry, both regions are subsidizing firms to correct properly for the positive externality generated by capital. Capital imports are, of course, zero. Once labour has been shifted from B to A, the efficient allocation of firms results in a higher firm-to-labour ratio in A than in B. If there were no adjustment in tax rates, the equilibrium adjustment would match the efficient adjustment. Moving towards the efficient allocation of firms, however, makes A a net firm importer and the government of region A, as a firm importer, has an incentive to restrict imports to lower the price it has to pay for its imports. Thus, region A reduces the rate at which it subsidizes firms. At the same time, the opposite is happening in region B where the government is trying to stem the outflow of firms to region

A by subsidizing firms at a higher rate. These tax adjustments moderate the movement of firms, so that the number of firms actually transferred between the regions is smaller than the efficient number. In other words, k^n falls but by less than it should for economic efficiency. Per capita resources (utility) go(es) up in region A since the proportional increase in A's resources is greater than 2.

Finally, consider the model in which firms are heterogeneous but there is no agglomeration. Firm heterogeneity is like the opposite of agglomeration. At symmetry, each regional government taxes the rents of the firms located in its region. Once labour has been shifted from B to A, it is efficient to increase the number of firms in A by a proportion smaller than 2. If there were no adjustment of tax rates (so that the taxes would not distort the firms' location decisions), the equilibrium increase in the number of firms in A would be the same as the efficient increase. But moving this number of firms makes A a net firm exporter and B a net firm importer, causing A to reduce its tax rate and B to increase its tax rate. These adjustments encourage firms to move into A, so the actual increase in the number of firms is greater than the efficient increase. Thus, k^n falls but by more than it should for economic efficiency. Per capita resources in region A go down since the proportional increase in region A's resources is less than 2.

Table 1 (last row) also illustrates that as we move away from symmetry when there is no agglomeration and minimal heterogeneity regions are just as well off in the Nash equilibrium as they are when they do not use profits taxes, i.e., the efficient outcome.[14] With either agglomeration or heterogeneity, the large region will be worse off in the Nash equilibrium than in the efficient outcome. The large region 'loses' at tax competition. Both agglomeration and the heterogeneity of firms create externalities from the location of firms. With agglomeration, firms generate a positive externality (moving one more firm into a region increases the output of each firm in the region) and with heterogeneity, firms generate a negative externality (moving one more firm into a region reduces the rents earned by those firms located in the region). At the same time, the regions' incentive to manipulate the terms-of-trade results in too many firms locating in the smaller region when there is agglomeration only and too few firms locating in the smaller region when there is heterogeneity only. Consequently, the smaller region benefits in each case from the inefficient allocation of firms. The small region 'wins' at tax competition. Clearly, this result also holds if there is both agglomeration and heterogeneity. This exercise, however, stepped only slightly away from symmetry

[14] This is in contrast to the result of the basic tax competition model (BTCM) that small regions (in terms of worker population) can be better off in the Nash equilibrium than in the efficient allocation. See Wilson (1991) and Bucovetsky (1991). Small regions would also win at tax competition if there were more than 2 regions with equal endowment ratios competing for firms in our model with no agglomeration and minimal heterogenity. See Peralta and van Ypersele (2002).

and kept the endowment ratios constant across the two regions. It's easy to imagine that even with equal endowment ratios region A could 'win' at the tax competition game if it had sufficient monopsony power, i.e., owned most of both factors. Likewise, region A could win if it owned more firms than region B but had the same number of workers. Of course, with unequal endowment ratios one has to decide how to determine a region's 'size' before making any statements about whether the large or small region wins at tax competition.[15]

The above comparative static exercise showed that when there is agglomeration, heterogeneous firms, and a symmetric distribution of firm productivities, a marginal shift in regional endowments from region B to region A starting from the symmetric equilibrium can result in either region becoming a firm importer or firm exporter. The exercise also demonstrated that with equal endowment ratios the importing region will have both a higher tax rate (or lower subsidy rate) and a higher level of welfare than the exporting region. These results hold more generally under any assumed distribution of the θs.

The terms-of-trade effect can be summarized as follows:

Result 1: *If the economy is stable, then in any Nash equilibrium*

$$\text{sign}\left[I_A\right] = \text{sign}\left[t_A - t_B\right].$$

The net importer of firms in *any* Nash equilibrium will have a higher tax rate regardless of the sign of the tax rate, i.e., if both regions are subsidizing firms in the Nash equilibrium then the net importer of firms subsidizes firms at a lower rate. This result holds for any distribution of regional endowments and it follows from the region's first-order conditions and the (assumed) stability of the economy.[16] If endowment ratios happen to be the same in both regions then the following two results will also hold in the general model.

Result 2: *If regions have the same labour to share of firm ownership endowment ratio, then the region importing (exporting) firms will have a higher (lower) level of welfare in any Nash equilibrium.*

Result 3: *If regions have the same labour to share of firm ownership endowment ratio, then the residents of the region with the higher tax rate have a higher level of welfare in any Nash equilibrium.*

By definition, to be an importer the region must be paying more to foreign owners than it is receiving from its ownership share of firms located in the other

[15] In the tariff literature, regional size is determined by a region's endowment of the traded good. 'Large' countries have more monopoly power and will win tariff wars in the sense that they will be better off in the Nash equilibrium than under free trade (Kennan and Riezman, 1990). Burbidge et al. (1997) derive a similiar result in the BTCM with head taxes – the region with the greater endowment ratio of capital to labour will win at tax competition..

[16] See Appendix for all proofs.

region.[17] From Result 1, the importing region will have the higher tax rate. Since profits are a fixed share of total output, it follows that the importing region will also have higher per capita output if endowment ratios are the same. The importing region will also have higher per capita resources. If endowment ratios are not the same across regions, however, then residents of the importing region may have lower welfare.

The Nash equilibrium is output-maximizing only if regions happen to choose the same profit tax rate. This will be the case if regions are symmetric but it may also occur if regions are asymmetric.[18] Inefficiencies arise in the Nash equilibrium when regions differ in their endowments and/or when the distribution of firm productivities is asymmetric solely because each regional government has an incentive to manipulate the terms of trade.

4.2.2 Role for Tax Harmonization

With any non-zero equilibrium tax differential, the allocation of firms in the economy will be inefficient. Total output in the economy can be increased by reallocating firms across the two regions. This suggests that adopting a common tax rate may be Pareto improving. We first prove the following result.

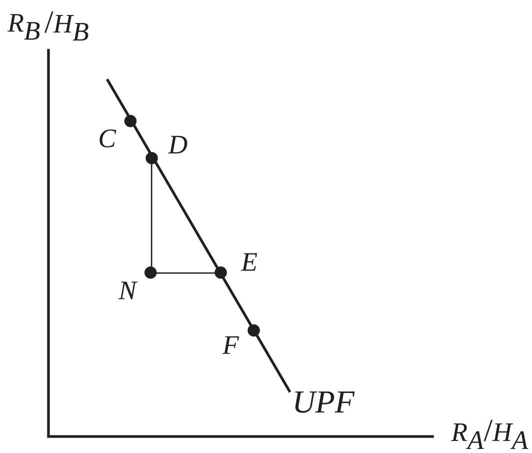
RESULT 4: *If the economy is stable, then starting from any Nash equilibrium a marginal reduction in the tax rate differential makes both regions better off.*

In any Nash equilibrium, each region is already doing the best it can given the other region's choice of tax rate. Therefore, a region's resources are affected only by the marginal change in the other region's tax rate. A small reduction in the tax differential will increase total output in the economy (assuming stability) and each region will be made better off. Thus, starting from any Nash equilibrium a small change that moves the tax rates closer together is Pareto improving. What happens when there are large changes in the regional tax rates towards a common rate?

With a common tax rate, total output in the economy is maximized. The allocation of firms which achieves this outcome is unique. Therefore, the resources available to a given region will be linear in the common tax rate, i.e., output in each region is uniquely determined. How the maximized total output is divided between the two regions will depend on the common rate adopted (and on the given distribution of endowments in the economy). The economy has a linear utility possibility frontier (UPF) as shown in Figure 4. Any Nash equilibrium with unequal tax rates will achieve a point below the UPF.

[17]To see this, substitute in the expressions for regional resources (13) and (14) into the definition of net payments (18).

[18]With a symmetric distribution of the θs and constant endowment ratios as in the comparative static exercise, the Nash equilibrium will always be inefficient.



N: Nash equilibrium.
C: Taxes are harmonized at *B*'s Nash equilibrium tax rate.
D: Taxes are harmonized at the Pareto-improving rate most favourable to *B*.
E: Taxes are harmonized at the Pareto-improving rate most favourable to *A*.
F: Taxes are harmonized at *A*'s Nash equilibrium tax rate.

Now, suppose one of the region's equilibrium tax rate was chosen to be the common rate. That region will no longer be making a best response to the tax rate of the other region and therefore, the region will be made worse off. Since total output in the economy increases with the adoption of a common rate, the other region must be strictly better off. Such a tax harmonization scheme is not Pareto improving and we have the following result.[19]

RESULT 5: *If tax rates are unequal in the Nash equilibrium, then there are some tax harmonization schemes that are not Pareto improving.*

It follows that there exists some common tax rate $\widehat{t}$ such that with the adoption of this rate one region is just as well off as it is in the Nash equilibrium, i.e., its total resources are the same. Since total output is higher with the common rate, the other region must be strictly better off. This region will have more resources under the common rate than in the Nash equilibrium. Therefore, we have a Pareto improvement. This argument can be made for either region and again since resources are linear in the common tax rate we have Result 6.

RESULT 6: *In any Nash equilibrium with a non-zero tax rate differential, there exists some tax rates $\widehat{t}_A$ and $\widehat{t}_B$, lying between the equilibrium tax rates t_A and t_B, such that any harmonized tax rate between $\widehat{t}_A$ and $\widehat{t}_B$ is Pareto improving.*

The set of Pareto-improving harmonized tax rates can be seen in Figure 4.

5 Relationship to Economic Geography Model

Tax competition has recently become a focus of research in the economic geography literature.[20] Baldwin and Krugman (2004) argue that the predictions of the BTCM are inconsistent with their interpretation of recent European history. In their model two regions, the core and the periphery, use capital tax rates to compete for mobile capital. They focus on equilibria in which capital is fully agglomerated in the core.[21] They model the history of the European Union (EU) as a gradual reduction over time in trade costs (tariff barriers) between the core and the periphery. In their model, agglomeration creates rents which can be taxed. These agglomeration rents are maximized at intermediate levels of trade

[19] Unlike the BTCM surveyed in Wilson (1999), raising both tax rates can never be Pareto improving. Increasing either tax rate above the maximum equilibrium rate will always make one region worse off.

[20] For example, see Kind et al. (2000) and Ludema and Wooton (2000). Baldwin et al. (2003) summarize the tax competition findings of these and other papers in the economic geography literature.

[21] Borck and Pflüger (2004) focus on tax competition equilibria with partial agglomeration of the mobile factor, i.e., most, but not all, of the mobile factor is located in the core region. They show that a tax differential between the core and the periphery can also arise in such equilibria.

costs. When trade costs are high, trade is limited and agglomeration rents are low. When trade costs are low, rents are also low since location becomes less important. Thus, their model predicts that the difference between the capital tax rates of the core and of the periphery will be a bell-shaped function of trade costs. They argue that their model is consistent with the capital tax rate data reported in Devereux, Griffith, and Klemm (2002) who show that over time capital tax rates amongst the original members of the EU (the core) have been quite stable but the tax rates in some countries that joined later (the periphery) have been U-shaped over time. Closer inspection of Baldwin and Krugman's model reveals though that, in their model, the capital tax rate of the periphery is independent of trade costs and it is the capital tax rate of the core that is a bell-shaped function of trade costs. These tax patterns are inconsistent with the data in Devereux et al (2002). In this respect, we believe our model could be used to provide an alternative, and possibly more accurate, explanation of what happened during the development of the European Union.[22] Of course, to do this we would have to construct the history of capital imports/exports between the core and periphery during the formation of the European Union to generate a prediction about the shape of the tax differential. As well, we would also have to determine whether agglomeration forces or the distribution of firm productivities has changed over time.

Baldwin and Krugman (2004) are also critical of the BTCM because the model cannot explain why high tax countries are more capital (or firm) intensive than low tax countries. In our model, there can be a positive correlation between the tax rates and the utilization ratios of the mobile to the immobile factor. Our model is also consistent with countries having the same population but different tax rates a possibility that is ruled out in the BTCM.[23] Baldwin and Krugman go beyond this latter point and say:

> "... increasing the degree of openness, we would see the emergence of the core-periphery outcome with the mobile factor flowing from south to north. Although a full analysis of this possibility would require detailed dynamic reasoning, we conjecture that we would see the high tax nation being an importer of capital. This contradicts the BTCM prediction" (Baldwin and Krugman (2004), p.19).

This is exactly what our model (or its forerunner) predicts.

[22] They may be other explanations for the persistence of such tax differentials. For example, in Wooders and Zissimos (2003) firms are also heterogeneous in that they have different technological requirements for levels of amenity provision. Competition for mobile firms brings about excessive differentials in taxation and amenity provision.

[23] A similar prediction arises in Baldwin and Krugman (2004), see their Result 3. Of course, these results come about simply because regions differ along additional dimensions than in the BTCM – heterogenity of firm productivities in our model, and sequential tax-setting behaviour in Baldwin and Krugman's model.

There are, however, technical differences between our models. Baldwin and Krugman's results are derived from a 'limit-taxing' game in which the core sets its tax rate followed by the periphery; our results follow from a simultaneous-move Nash game.[24] This difference in structure induces different predictions regarding the effects of tax harmonization. We quote Result 4 in Baldwin and Krugman (2004):

> "Result 4: In contrast to the BTCM result, upward harmonization of tax rates in the presence of capital mobility is not a Pareto improvement. In fact harmonizing tax rates at any single level makes one or both nations worse off."

In our model, upward harmonization of tax rates is also never Pareto improving.[25] Some common tax rate between the two different Nash equilibrium tax rates can, however, result in a Pareto improvement.

Obviously our model and Baldwin and Krugman's model omit important features of reality. To mention just two omissions in a long list, neither model pays any attention to the mobility of labour (an important aspect in the development of the European Union) and neither model explains why there can be differential tax treatment of firms within a given region. Both models emphasize the importance of agglomeration rents but our model also highlights the possibility of rents arising from firm heterogeneity. In particular, our model suggests that tax policy may be influenced by rents arising from the interactions between agglomeration and firm heterogeneity.

6 Concluding Remarks

The incorporation of both agglomeration and heterogeneity of capital/firms into the BTCM with (head) taxes on immobile labour expands the set of facts that can be explained by capital tax competition models. In particular, the limitations of the BTCM without head taxes, so emphasized by Baldwin and Krugman (2004), are eliminated. Among other things, we show that regions may subsidize or tax the mobile factor, there may be a positive or negative correlation between regional tax rates and the ratio of mobile to immobile factor utilized in the regions, and the larger region (in terms of size of supply of immobile factor) may export or import the mobile factor as well as have a higher or lower per capita income than the smaller region. Nevertheless, it is important to realize that our generalization

[24] The possibility of lumpy investment, i.e., a region can attract *all or none* of the mobile factor from the other region, gives rise to the possibility of non-existence of pure-strategy equilibria. A pure strategy Nash equilibrium of the simultaneous-move tax game does not exist when there is full agglomeration (Baldwin et al., 2003) and generally does not exist when there is only partial agglomeration (Borck and Pflüger, 2004).

[25] Setting a tax floor below the lowest equilbrium tax rate (Result 5, Baldwin and Krugman (2004)) would have no effect in our model as regions act simultaneously.

of the BTCM with head taxes does not fundamentally alter the character of this model — now if a region is a capital/firm importer its tax rate must exceed the other region's tax rate — but the "tax" rates could be of either sign whereas in the BTCM with head taxes, capital importers tax capital and capital exporters subsidize capital.

Those familiar with the BTCM without head taxes may wish to know how our results would change if each region's only tax were a tax on capital or firms. Our model shows that agglomeration gives regions an incentive to subsidize capital and that heterogeneity of capital gives regions an incentive to tax capital. These incentives would still exist in a BTCM without head taxes but the equilibrium capital tax rates could never be negative. Thus, the under-provision result of the BTCM without head taxes could be worsened or improved with the existence of agglomeration and heterogeneity of capital depending on their relative strengths. The terms-of-trade effect described above would also be present even if regions were unable to tax immobile labour. Thus, our paper suggests that in the BTCM, without head taxes but with agglomeration and heterogeneous capital, it is possible that the larger region would import capital from the smaller region, and have a higher tax rate, and/or a lower level of utility.

Appendix

Notation. Equation (11) implies that the equilibrium value of k with given profit taxes can be written as

$$k^n = \widehat{k}(TL) \tag{A1}$$

while section 3.4 demonstrates that the value of k that maximizes total output is

$$k^e = \widehat{k}(L)$$

Thus, k^n and k^e coincide if and only if the regions set the same tax rate. Using the symmetry of the density function g, it can be shown that

$$\widehat{k}'(1) = \left[1 + 2\left(\frac{\alpha - \beta}{1 - \alpha}\right)\phi_A(1)\right]^{-1}$$

$$\widehat{k}'' = -2\left(\frac{\alpha - \beta}{1 - \alpha}\right)\phi_A(1)\left[1 + 2\left(\frac{\alpha - \beta}{1 - \alpha}\right)\phi_A(1)\right]^{-2}$$

Note write (8) as

$$Y_i = \psi_i(k, H_i) \qquad i = A, B$$

Let the composites of these functions with (A1) be

$$Y_A = m(TL, H_A) \qquad m_1 < 0$$

$$Y_B = n(TL, H_B) \qquad n_1 > 0$$

The symmetry of the density function g implies that, for each H,

$$m(T, H) = n(1/T, H)$$

Twice differentiating this equation and evaluating the derivatives under symmetry shows that

$$n_1(1, H) = -m_1(1, H)$$

$$n_{11}(1, H) = m_{11}(1, H) + 2m_1(1, H)$$

Again under symmetry,

$$m_1 \equiv \frac{\partial \psi_A}{\partial k}\widehat{k}' = m\left(\frac{1 - \beta}{1 - \alpha}\right)\phi_A\widehat{k}'$$

$$m_{11} \equiv \frac{\partial^2 \psi_A}{\partial k^2}\left(\widehat{k}'\right)^2 + \frac{\partial \psi_A}{\partial k}\widehat{k}'' = -m_1/2$$

implying

$$m_1 + m_{11} = m_1/2$$

Also,

$$m_2 \equiv \frac{\partial \psi_A}{\partial H_A} = \frac{\beta}{1-\alpha}\frac{m}{H_A}$$

$$m_{12} = \frac{\beta}{1-\alpha}\frac{m_1}{H_A}$$

Tax Rate Changes. For simplicity, define the functions

$$\rho_i(t_A, t_B, \gamma_A, \gamma_B, H_A, H_B) \equiv \frac{\partial R_i}{\partial t_i} \qquad i = A, B$$

Assume that

$$\gamma_A = 1 - \gamma_B = x$$

$$H_A = 1 - H_B = x$$

Then a Nash equilibrium is a pair (t_A, t_B) such that

$$\rho_i(t_A, t_B, x, 1-x, x, 1-x) = 0 \qquad i = A, B$$

Evaluated at the symmetric equilibrium ($x = 1/2$),

$$\frac{\partial \rho_A}{\partial t_A} = \frac{\partial \rho_B}{\partial t_B} = \frac{m_{11} + 2m_1}{(1-t)^2} < 0$$

$$\frac{\partial \rho_B}{\partial t_A} = \frac{\partial \rho_A}{\partial t_B} = -\frac{m_{11} + m_1}{(1-t)^2} > 0$$

where t is the tax rate under the symmetric equilibrium.

Given that the economy is initially in a symmetric equilibrium, the effects of marginally increasing x (so that region A's share of the available labour and the ownership of firms both rise) are found by applying Cramer's rule and exploiting the symmetries in the reaction functions. (For example, the observation that

$$\frac{\partial \rho_A}{\partial \gamma_A} = \frac{\partial \rho_B}{\partial \gamma_B}$$

and

$$\frac{\partial \rho_B}{\partial \gamma_A} = \frac{\partial \rho_A}{\partial \gamma_B}$$

is used.) It is found that

$$\begin{aligned}\frac{\partial t_A}{\partial x} = -\frac{\partial t_B}{\partial x} &= \left[\frac{\partial(\rho_A - \rho_B)}{\partial H_A} + \frac{\partial(\rho_A - \rho_B)}{\partial \gamma_A}\right]\left[\frac{\partial \rho_A}{\partial t_A} - \frac{\partial \rho_A}{\partial t_B}\right]^{-1} \\ &= (1-t)^2\left[\alpha - \frac{1-\beta-\alpha}{2\phi_A}\right]\end{aligned}$$

The tax changes in the three cases follow immediately from this equation.

The Allocation of Firms. Assume again that x rises from 1/2, shifting both labour and firm ownership from region B to region A. The change in k^n is

$$\frac{dk^n}{dx} = \widehat{k}'(1)\left(\frac{2}{1-t}\frac{dt_A}{dx} - \frac{4\beta}{1-\alpha}\right) < 0$$

while the change in k^e is

$$\frac{dk^e}{dx} = -\widehat{k}'(1)\frac{4\beta}{1-\alpha} < 0.$$

Taking the ratio,

$$\frac{dk^n/dx}{dk^e/dx} = \frac{1+\beta(1-4\phi_A)}{2\beta(1-2\phi_A)} - \frac{\alpha}{2\beta}.$$

Now consider the three cases. Heterogeneity is minimized by letting ϕ_A approach $-\infty$:

$$\lim_{\phi_A \to -\infty} \frac{dk^n/dx}{dk^e/dx} = 1 - \frac{\alpha}{2\beta} < 1.$$

Setting α equal to zero in the above equation yields the results for the standard model:

$$\lim_{\phi_A \to -\infty} \frac{dk^n/dx}{dk^e/dx} = 1.$$

Finally, if there is heterogeneity but no agglomeration ($\alpha = 0$) and

$$\frac{dk^n/dx}{dk^e/dx} = \frac{1+\beta(1-4\phi_A)}{2\beta(1-2\phi_A)} > 1.$$

Output and Resources. In the neighbourhood of a symmetric equilibrium, the proportional changes in region A's output and resources are

$$\frac{dY_A}{dx}\frac{1}{Y_A} = \frac{1}{1-\alpha}\left[2\beta + (1-\beta)\phi_A(1)\widehat{k}'(1)\frac{dTL}{dx}\right]$$

$$\frac{dR_A}{dx}\frac{1}{R_A} = \frac{2}{1-\alpha}\left[\frac{2\phi_A(1)-\beta}{2\phi_A(1)-1}\right].$$

The results for the three cases are obtained by imposed additional restrictions on these equations. The model with agglomeration only is obtained by letting ϕ_A approach $-\infty$, and the model with heterogeneity only is obtained by setting α equal to 0. The standard model employs both assumptions.

Table 2 shows the values taken by these, and other necessary derivatives, in each of the three special cases.

Table 2: The comparative statics of a regional economy with and without tax competition.			
	Standard Model	**Agglomeration Only**	**Heterogeneity Only**
Initial t	0	$-\frac{\alpha}{1-\alpha}<0$	$\frac{1}{1-2\phi_A}>0$
$\frac{dH_A}{dx}\frac{1}{H_A}, \frac{d\gamma_A}{dx}\frac{1}{\gamma_A}$	2	2	2
$\frac{dt_A}{dx}$	0	$\frac{\alpha}{(1-\alpha)^2}>0$	$2\frac{(1-\beta)\phi_A}{(1-2\phi_A)^2}<0$
$\frac{dY_A^n}{dx}\frac{1}{Y_A}$	2	$\frac{\beta(2-\alpha)-\alpha}{(\beta-\alpha)(1-\alpha)}>2$	$2\frac{\beta-\phi_A\left((1+\beta)^2-4\phi_A\beta\right)}{(1-2\phi_A\beta)(1-2\phi_A)}\in(0,2)$
$\frac{dR_A^n}{dx}\frac{1}{R_A}$	2	$\frac{2}{1-\alpha}>2$	$2\frac{\beta-2\phi_A}{1-2\phi_A}\in(0,2)$
$\frac{dR_A^n}{dx}\frac{1}{R_A}-\frac{dH_A}{dx}\frac{1}{H_A}$	0	$2\frac{\alpha}{1-\alpha}>0$	$-2\frac{1-\beta}{1-2\phi_A}<0$
$\frac{dR_A^e}{dx}\frac{1}{R_A}$	0	$2\frac{\beta-\alpha+\alpha\beta}{\beta-\alpha}>2$	$2-2\frac{\beta(1-2\beta)}{1-2\phi_A\beta}\in(0,2)$
$\frac{1}{R_A}\frac{d(R_A^e-R_A^n)}{dx}$	0	$2\frac{\alpha^2(1-\beta)}{(\beta-\alpha)(1-\alpha)}>0$	$2\frac{(1-\beta)^2}{(1-2\phi_A\beta)(1-2\phi_A)}>0$

Proof of Result 1. From the expression for T,

$$\frac{\partial T}{\partial t_A}=\frac{T}{1-t_A}>0,\quad \frac{\partial T}{\partial t_A}=-\frac{1}{1-t_A}<0 \tag{A2}$$

Using the expression for $\partial T/\partial t_A$ and multiplying (15) by $(1-t_A)$ yields

$$\gamma_B(1-\beta)\left(1-t_A\right)Y_A+\left\{[1-\gamma_B(1-\beta)(1-t_A)]\frac{\partial Y_A}{\partial T}+\gamma_A(1-\beta)(1-t_B)\frac{\partial Y_B}{\partial T}\right\}T=0. \tag{A3}$$

Likewise, using the expression for $\partial T/\partial t_B$ and multiplying (16) by $(1-t_B)$, we have

$$\gamma_A(1-\beta)\left(1-t_B\right)Y_B-\left\{[1-\gamma_A(1-\beta)(1-t_B)]\frac{\partial Y_B}{\partial T}+\gamma_B(1-\beta)(1-t_A)\frac{\partial Y_A}{\partial T}\right\}T=0. \tag{A4}$$

Region A's net payment can be written as

$$I_A\equiv Y_A-R_A=\gamma_B(1-\beta)\left(1-t_A\right)Y_A-\gamma_A(1-\beta)\left(1-t_B\right)Y_B \tag{A5}$$

Subtracting (A3) from (A4), and grouping terms yields

$$I_A=-T\left(\frac{\partial Y_A}{\partial k}+\frac{\partial Y_B}{\partial k}\right)\frac{\partial k}{\partial T} \tag{A6}$$

Stability implies that $\partial k/\partial T$ is positive, so

$$\operatorname{sign}\left[I_A\right]=\operatorname{sign}-\left[\frac{\partial Y_A}{\partial k}+\frac{\partial Y_B}{\partial k}\right] \tag{A7}$$

Let k^e be a unique maximum of $Y_A + Y_B$. Then, by definition

$$\text{sign}\left[\frac{\partial Y_A}{\partial k} + \frac{\partial Y_B}{\partial k}\right] = \text{sign}\left[k^e - k\right] \tag{A8}$$

Given stability, it follows from (A2) that k is increasing in t_A and decreasing in t_B. Total output is maximized when tax rates are equal. Taken together,

$$\text{sign}\left[k^e - k\right] = \text{sign}\left[t_B - t_A\right] \tag{A9}$$

Together, (A7) to (A9) yield Result 1.

Proof of Result 2. Suppose $I_A > 0$. Then, dividing (A5) by $H_A H_B$ and assuming equal endowment ratios γ_i / H_i yields

$$(1 - t_A)\,\frac{Y_A}{H_A} > (1 - t_B)\,\frac{Y_B}{H_B}.$$

>From Result 1, $t_A > t_B$ and so

$$\frac{Y_A}{H_A} > \frac{Y_B}{H_B}. \tag{A10}$$

The net importing region will have higher per capita output. Using (13) and (14),

$$\frac{R_A}{H_A} - \frac{R_B}{H_B} = \frac{Y_A}{H_A}\left[1 - (H_A + H_B)(1 - \beta)\frac{\gamma_B}{H_B}\,(1 - t_A)\right]$$
$$-\frac{Y_B}{H_B}\left[1 - (H_A + H_B)(1 - \beta)\frac{\gamma_A}{H_A}\,(1 - t_B)\right] > 0, \tag{A11}$$

where the inequality follows from (A10), equal endowment ratios, and Result 1. If instead $I_A < 0$ the inequality sign of (A11) would be reversed.

Proof of Result 3. Focus on Region A and note that starting from the Nash equilibrium a change in t_B will affect only region A's resources since region A has already optimized with respect to t_A for a given level of t_B. Therefore, using (13) the change in region A's resources from a marginal change in the tax rate of the other region is given by

$$\begin{aligned}\frac{dR_A}{dt_B} &= -(1 - \beta)\gamma_A Y_B + \left\{\left[1 - \gamma_B(1 - \beta)(1 - t_A)\right]\frac{\partial \widetilde{Y}_A}{\partial T} + \gamma_A(1 - \beta)(1 - t_B)\frac{\partial \widetilde{Y}_B}{\partial T}\right\}\frac{\partial T}{\partial t_B} \\ &= \left(\frac{\partial Y_A}{\partial k} + \frac{\partial Y_B}{\partial k}\right)\frac{\partial k}{\partial T}\frac{\partial T}{\partial t_B}\end{aligned} \tag{A12}$$

where the second equality follows from (15). Assuming a stable equilibrium, $\partial k/\partial T > 0$. Performing a similar exercise for region B yields

$$\frac{dR_B}{dt_A} = \left(\frac{\partial Y_A}{\partial k} + \frac{\partial Y_B}{\partial k}\right)\frac{\partial k}{\partial T}\frac{\partial T}{\partial t_A} \tag{A13}$$

Consider a change in the tax rates such that $dt_A = -dt_B$. Suppose region A is a net importer so by Result 1, $t_A > t_B$ and $k^n > k^e$. From Lemma 1, an increase in k reduces total output. Since T is decreasing in t_B and increasing in t_A, a decrease in t_A will increase resources in each region. Suppose instead region A is a net exporter, so $t_A < t_B$ and $k^n < k^e$. Now, an increase in k increases total output and thus, an increase in t_A will increase resources in each region.

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