# *Agglomeration, Migration and Tax Competition**

**Kurt A. Hafner****

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Department of Economics; University of Bamberg, Germany

**Abstract**

The paper focuses on tax competition and international migration in R&D sectors as agglomeration forces and trade restrictions are present. Core countries in economically integrating regions adapt tax rates to keep their industrial status quo. Unlike the often discussed "race to the bottom" result, tax rates are increased and the provision of public goods is maintained. Additionally, tax rates that redistribute between mobile and immobile labor lead to a tax burden that favors mobile labor. As economic integration continues, the cutback of factor mobility restrictions for skilled labor supports economic development in core countries at the expense of periphery countries.

*JEL-Classifaction*: F12, F22, H73, R12

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**Otto-Friedrich-University Bamberg, Department of Social and Economic Science, Feldkirchenstr. 21, 96052 Bamberg, Germany. Email: kurt.hafner@sowi.uni-bamberg.de

## 1. Introduction

It is widely believed that further economic integration such as the enlargement of the EU to 25 countries through the integration of Central and Eastern European countries in May 2004 lead to painful adjustment processes within core and periphery countries. While some worry about the maintenance of large welfare states, others are concerned about remaining competitive. Considering tax competition for example, mobile factors are generally assumed to locate to regions, where taxes are low and/or the provision of public goods is high. Periphery countries therefore may decrease taxes to attract mobile factors pushing local economic development at the core countries' expense. As a result, countries adapt the same tax rates leading to "a race to the bottom" and to a sub-optimal provision of public goods as predicted by the standard tax competition literature, (e.g. Wilson, 1999). Accordingly, the overall provision of public goods would decline towards the lowest level within member states. Hence, should the EU consider tax harmonization to maintain social welfare? If not, should the cutback of factor mobility restriction be reversed as analyzed in Ottaviano and Thisse (2002) or, according to Lundborg and Segerstrom (2002), taxes be imposed to control such factor flows?

While capital is more likely to move to regions, where taxes are low and risk adjusted profits are high, the migration decision of labor takes into account taxes, wages and the provision of public goods. When factor owners move with their factors, countries compete with the provision of public goods such as the inclusion in social systems, education and/or security aspects amongst others. Hence, factor owners move to countries, even if income taxes are high, as long as the net incentive to migrate is positive. Furthermore, agglomeration rents in industrial clusters and/or industrialized countries can be taxed without provoking an outflow of input factors or a loss of industry shares. While there is no inherent incentive of clustering in the standard tax competition (perfect competition, constant return of scale), tax competition in the New Economic Geography (NEG) literature is different. Baldwin and Krugman (2004) show first "a race to the top" of tax rates among core countries and later, as integration continues, also among the periphery countries.[1] Baldwin et al. (2003) show amongst other things, that tax competition on mobile factors will result in the first best tax rate if factor owners move with their factors and governments are concerned about the mobile factor. Hence, tax competition would not harm social welfare at all with no "race to the bottom". In Anderson and Forslid (2003), a small redistribution between mobile and immobile factor shares due to a

[1] They underline their findings by empirical observation of the average total and corporate tax rates during the European integration process (1965-1994).

coordinated tax increase on mobile factors may lead to a catastrophic agglomeration with all industry and skilled labor concentrated. There is no need for an international tax difference and tax competition to cause industrial agglomerations.

In short, tax competition differs in models with labor as the taxable mobile factor and agglomeration rents. The paper studies tax competition and the provision of public goods, which is not present in the Baldwin and Krugman (2004) model and other contributions so far, and its impact on industrial agglomeration and migration. The structure of the paper is described as follows. Basic intuition about the model and its key features are presented in the section below. Section 3 present a standard NEG-model and introduces public goods. Steady state analysis of tax competition and the results of numerical simulation are given in section 4. Section 5 concludes. Finally, I list specific details about the numerical simulation and derivatives in appendix (A) and (B) respectively.

## 2. Agglomeration, Migration and Tax Competition

Following Hirschmann (1958) cost and demand linkages arise as firms are able to use intermediate goods more cheaply and face a greater consumer demand, where other firms and consumers are concentrated. This leads to circular causality and to self-reinforcing agglomeration effects of industrial activity (*centripetal forces*). At the same time competition in product and factor markets increases with the number of locally concentrated firms. These neoclassical forces as well as trade and transportation costs work against industrial agglomeration *(centrifugal forces)*. Hence, the trade off between these two forces determines the pattern of industrialization and the distribution of mobile factors between countries. As a key feature of NEG-models, spatial concentration of industry occurs when trade (transport) costs are at an intermediate level, whereas at high and at low trade (transport) costs industrial activity is more likely to be equally distributed. To cope with, I assume an agglomeration model with Marshallian externalities[2] and add international migration of skilled labor and the provision of public goods. The model allows analyzing tax competition and public goods as agglomeration forces as well as trade and migration restriction are present.

[2] For Marshall (1890) "mass production, the availability of specialized input services and the formation of highly skilled labor as well as the production of new ideas are crucial for the formation of industrial clusters"; see Fujita and Thisse (2002).

### *International Migration and R&D Activity*

I assume skilled labor as a single input factor employed in a public R&D sector. I further assume that firm' fix costs are reduced by the use of public financed research results, which itself depends on the presence of skilled labor. This idea is derived from Ottaviano (2001) and Forslid (1999), where a "footloose entrepreneur" is required as a fixed input to produce one single variety of industrial goods. Hence, the location of industry is driven by migration owing to real wage differences. In this paper, immigration of skilled labor leads to higher domestic R&D and therefore to lower break-even points for firms. Firm location is driven by short run profits and higher market entries of firms. If this leads to higher real wages, as factor market competition increases and price index decreases, further immigration occurs with a positive impact on industrial clusters. As in Forslid (1999), the presence of skilled labor determines the number of firms and industrial goods. If and to what extent factor mobility restriction and migration costs affect industrial agglomeration are therefore of major interest. Studies such as from Feldman and Florida (1994) emphasize the link of skilled labor, R&D activity and the clustering of firms. Accordingly, innovation is more likely to cluster in regions where R&D–oriented firms and universities are established and that their diffusion rate to structurally backward regions is relatively slow. As such regions become more attractive further concentration of firms and mobile factors occurs, pushing a region's capacity to innovate and grow.

### *Public Goods and Tax Competition*

I impose a lump-sum income tax to finance public research activity. Taxes are levied on mobile as well as on immobile factors, and income is spent in the host country, where factors are employed and being taxed ("origin principle" in tax lexicon). There are no factors repatriating earnings and GDP and GNI do not differ. Turning to government objectives and the provision of public goods, governments may concern about a representative consumer and adopt its objectives (Benthamite objectives), a specific group and choose objectives by a median voter (Non-Benthamite objectives) or their own objectives (Leviathan governments). Moreover, tax competition in standard NEG-models with labor as the mobile factor relies on the kind of initial equilibrium. Circular causality due to cost and demand linkages as well as migration flows causes industrial activity either being equally distributed between countries (*symmetric equilibrium*) or fully concentrated (*asymmetric equilibrium*). Hence, it is not possible to analyze partial agglomeration and tax competition as in Borck and Pflüger (2005). Tax competition is modeled for both equilibria as a non-cooperation game.

## 3. A Static Equilibrium Model

The model relies on the concept of monopolistic competition from Spence (1976) and Dixit and Stiglitz (1977), and its adaptation to regional economics by Krugman (1991a, 1991b) and Krugman and Venables (1995). Additionally, I assume vertical linkages among firms like in Venables (1996), Fujita, Krugman und Venables (1999) and Fujita and Thisse (2002). To deal with economic integration, iceberg trade costs as proposed by Samuelson (1954) are introduced. All corresponding key features as discussed by Baldwin et al. (2003) are present: agglomeration via the home-market effect, demand and cost linkages, endogenous asymmetry, catastrophic agglomeration, path-dependency, hump-shaped agglomeration rents, and multiple long run equilibria. In defining government utility function and tax competition, I follow Baldwin et al. (2003) and Baldwin and Krugman (2004).

### 3.1. Assumptions

There are two countries $(i = 1, 2)$, with identical endowments of mobile and immobile factors of production (unskilled workers ($L_i$), skilled labor ($H_i$), land ($B_i$), and industrial goods ($Z_{M,i}$)). Unskilled labor is mobile between sectors within a country, whereas skilled labor is mobile between countries. The share of land is fix between countries. Intermediate goods are subject to trade costs. Both countries have the same technology and there are three sectors: agriculture (A), manufacturing (M) and public R&D (R). I assume public financed research to reduce fix costs at the firm level.

***Agricultural Sector***

Agriculture is a Walrasian sector with perfect competition and constant returns. The homogenous agricultural good ($Q_{A,i}$) is traded without costs. Production follows a Cobb–Douglas functional term using $B_i$ and unskilled labor ($L_{A,i}$). Unskilled labor is employed by the agricultural sector as well as by the manufacturing sector. The nominal wage $(w_{A,i})$ rate with respect to unskilled labor is:

$$w_{A,i} = \theta(L_i - L_{M,i})^{\theta-1} B^{1-\theta}, \qquad \theta \in (0,1), \tag{1}$$

with $L_{M,i}$ as unskilled labor employed in the manufacturing sector, $\theta$ as the partial production elasticity of unskilled labor and $B_i = B$.

Following Puga (1999), I use a restricted profit condition to express agricultural gains $(\pi_{A,i})$ as a function of the price of the agricultural good ( $p_{A,i}$ ), nominal wages and land:

$$\pi_{A,i}(p_{A,i}, w_{A,i}, B) = \max\left\{p_{A,i}Q_{A,i} - w_{A,i}L_{A,i} \middle| Q_{A,i} \leq f(L_{A,i}, B)\right\}. \quad (2)$$

Due to the assumption of constant returns, $\pi_{A,i}$ in equation (2) is homogenous of degree one in *B* and can be rewritten by $p_{A,i} = 1$ to:

$$\pi_{A,i}(1, w_{A,i}, B) = B\, r_i(w_{A,i}), \quad (3)$$

with $r_i(w_{A,i})$ as maximized profit per unit land in country *i*.

***Manufacturing Sector***

I assume monopolistic competition and increasing returns for the industrial sector. In addition to unskilled labor, the manufacturing sector uses an aggregate $(Z_{M,i})$ of industrial goods *h* as an intermediate factor. Aggregate supply $(Q_{M,i})$ follows a Cobb–Douglas functional term with a CES aggregate of intermediate goods:

$$Q_{M,i} = L_{M,i}{}^{1-\mu} Z_{M,i}{}^{\mu},\ Z_{M,i} = \left(\sum_{j=1}^{2} \int_{h \in N_j} x_{j,i}^{\rho}(h)dh\right)^{1/\rho}, \qquad \mu \in (0,1);\ \rho \in (0,1), \quad (4)$$

with $\rho$ as the degree of product differentiation, $N_i$ as the number of firms (= number of goods) in country *i* and $\mu$ as the partial production elasticity of intermediate goods. The quantity of the produced good *j* in country *i* is denoted by $x_{j,i}$. The cost function $(C_{M,i}^{P})$ of a single manufacturing firm in country *i* is:

$$C_{M,i}^{P}(k) = (\alpha_i + \beta_i x_i(k)) w_{M,i}{}^{1-\mu} q_i^{\mu}, \quad (5)$$

where $q_i$ is the price index and $w_{M,i}$ is the nominal wage rate paid in the industrial sector. Perfect mobility of unskilled workers across sectors ensures that the wage is identical in the manufacturing and agricultural sector ($w_{M,i} = w_{A,i}$). As usual, production costs of a single variety of firm *k* in country *i* are divided into a fixed and variable part, $\alpha_i$ and $\beta$ respectively. Variable costs do not differ between countries. Due to the assumption of increasing returns, $x_i(k)$ also represents the produced amount of good *k* in country *i*.

Firms are price setters and are therefore able to raise prices ($p_{M,i}$) above marginal costs:

$$p_{M,i}(k) = (1/\rho)\beta w_{M,i}^{\ 1-\mu} q_i^{\mu}, \tag{6}$$

with $(1/\rho)$ as a constant mark-up factor. The short-term profits $(\pi_{M,i})$ of a firm, determined by free entry into markets, are calculated as:

$$\pi_{M,i}(k) = \frac{p_{M,i}}{\sigma}\left(x_i - x_i^{\ b}\right), \qquad \sigma \in (1,\infty), \tag{7}$$

with $\sigma = 1/(1-\rho) > 1$ as the elasticity of substitution between goods and $x_i^b = \alpha_i(\sigma-1)/\beta$ as break-even output. In the long run, firm profits in equation (7) are zero.

***Public R&D Sector***

The public R&D sector uses skilled labor as the only input factor. Under the assumption of decreasing returns, perfect competition and a Cobb Douglas functional term, research output $(R_i)$ in country *i* is:

$$R_i = H_i^{\ \iota}, \qquad \iota \in \left]0,1\right[, \tag{8}$$

with $\iota$ as the partial production elasticity of skilled labor. The overall research level $(F_i)$ in country i is determined by the compounded output of both R&D sectors. Depending on international technology diffusion, each country has a relative share of research:

$$F_i = \left(R_i + \Gamma R_j\right) / \sum_{i=1}^{2} R_i, \qquad j = 1,2; \ j \neq i; \qquad \Gamma \in (0,1), \tag{9}$$

with $\Gamma$ as the degree of technology spillover effect. A global spillover effect ($\Gamma = 1$) means that both countries transfer research results to each other without losing application or, to put it differently, without redundancy. By $\Gamma = 0$, a country's research level is determined by its own research activity.

As discussed, fundamental research reduces fixed costs at the firm level:

$$\alpha_i = A / F_i , \qquad \beta_i = \beta = (\sigma - 1)/\sigma , \tag{10}$$

where $A$ is a constant technology parameter and variable costs are normalized. Hence, a higher $F_i$ leads to lower fixed costs and by $x_i^b$ in equation (7) to higher short run profits and to a higher market entry.

***Government: Taxation and Utility***

A lump-sum tax ($t_i$) on taxable income ($Y_i$) is levied to finance the public R&D sector and therefore skilled labor:

$$t_i Y_i = w_{H,i} H_i , \tag{11}$$

with $w_{H,i}$ as the nominal wage rate for skilled labor in country i. $Y_i$ is traced back to factor income of unskilled and skilled labor as well as to gains resulting from agriculture and manufacturing:

$$Y_i = w_{A,i} L_i + w_{H,i} H_i + B r_i (w_{A,i}) + \int_{k \in N_i} \pi_{M,i}(k) dk . \tag{12}$$

Substituting equation (11) in equation (12) and rearrangement yields to:

$$(1 - t_i) Y_i = w_{A,i} L_i + B r_i (w_{A,i}) + \int_{k \in N_i} \pi_i (k) dk \equiv Y_i^{GDP} , \tag{13}$$

with $Y_i^{GDP}$ as GDP. Note that $Y_i^{GDP}$ consists only of factor income of unqualified labor, agricultural gains and short run profits: within a country, an income tax and its redistribution as factor payments do not change total factor income.

Following Baldwin et al. (2003), the utility function $(W_i)$ for a government with Benthamite objectives can be stated as:

$$W_i \ (G_i, C_i^R) = G_i^{\psi_i} C_i^{R^{1-\psi_i}} ; \ G_i = t_i Y_i / q_i ; \ C_i^R = (1 - t_i) Y_i / q_i , \ \psi \in (0,1) \tag{14}$$

with $\psi_i$ as the public good preference in country *i*. $G_i$ is the provision of public goods and $C_i^R$ is the consumption of a representative consumer after taxation. Hence, government decision in choosing the right tax rate is ambivalent. On the one hand, governments have to consider that taxes obviously reduce individual consumption. On the other hand, higher tax revenue and its use for the provision of public goods (i.e. higher research activity) favor the country as a whole as higher domestic R&D attract more firms. Rearranging equation (14) leads to:

$$W_i = (Y_i / q_i)\left(t_i^{\psi_i}(1-t_i)^{1-\psi_i}\right). \tag{15}$$

***Consumption***

A representative consumer has time-invariant, identical preferences towards goods produced in either country. Love of variety preferences is a Cobb–Douglas CES nest using the agricultural good, an aggregate of industrial goods and public goods. Using for consumption the same CES aggregate as for production, the utility function $(U_i^R)$ is:

$$U_i^R = Q_{A,i}{}^{1-\gamma-\psi_i} Z_{M,i}{}^{\gamma} G_i^{\psi_i}, \; Z_{M,i} = \left( \sum_{j=1}^{2} \int_{h \in N_j} x_{j,i}^{\rho}(h)dh \right)^{1/\rho}, \gamma \in (0,1), \tag{16}$$

with $\gamma$ as the consumption share of the industrial products. Optimization leads to the following indirect utility function:

$$U_i^R = [Y_i^R t_i^{\psi_i}(1-t_i)^{(1-\psi_i)}]1^{-(1-\gamma-\psi_i)} q_i^{-\gamma}. \tag{17}$$

The first part of the indirect utility function describes exactly equation (15) in nominal terms. In optimizing state utility, the indirect utility function of a representative consumer is maximized as well. For analytical reasons, the price index for the industrial products is the same for consumers and producers.

***Migration-Decision of Skilled Labor***

I assume that skilled labor takes into account local tax rates, the price level, nominal wage rates as well as migration costs ($m_i$). In considering nominal wages, skilled labor also accounts for the provision of public goods as nominal wages are financed by lump-sum taxes, which are levied in order to provide such goods. Hence, the migration condition of skilled labor is derived from equation (17) as:

$$\frac{q_i^{-\gamma}(1-t_i)(1-m_i)(w_{H,i})}{q_j^{-\gamma}(1-t_j)(1-m_j)(w_{H,j})}=1, \qquad j=1,2;\ j\neq i. \tag{18}$$

**3.2. General Equilibrium Conditions**

Owing to the assumption of increasing returns, each good is produced by a single firm *k* located in a single region. Hence, total demand for one good produced in country *i* is composed of consumer and producer demand from both countries:

$$x_i(k)=p_{M,i}(k)^{-\sigma}\left(e_i q_i^{(\sigma-1)}+e_j q_j^{(\sigma-1)}\tau_{j,i}^{(1-\sigma)}\right), \qquad j=1,2;\ j\neq i. \tag{19}$$

Intermediate goods are subject to iceberg trade costs $(\tau_i)$ : units ($\tau_{j,i}\geq 1$) in country *i* shrink to one unit in country *j*.[3] $p_{M,i}(k)$ is the producer price and is listed as the *free-on-board* price (*FOB*).

The price index for the bundle of industrial goods in country *i* can be written as:

$$q_i=\left[\int_{h=N_i}\left(p_{M,i}(h)\right)^{(1-\sigma)}dh+\int_{h\in N_j}\left(p_{M,j,i}(h)\tau_{j,i}\right)^{(1-\sigma)}dh\right]^{1/(1-\sigma)}, \ j=1,2;\ j\neq i. \tag{20}$$

In each country, the price index depends on local prices, which in turn depend on *FOB* prices and local trade costs.

Total expenditure ($e_i$) is composed of consumer and producer expenditure on industrial products:

$$e_i=\gamma\left(w_{A,i}L_i+Br_i(w_{A,i})+\int_{k\in N_i}\pi_{M,i}(k)dk-C_i^M\right)+\mu\int_{k\in N_i}C_{M,i}^P(k)dk, \tag{21}$$

with $C_i^M=m_i w_{H,i}(H_i-H_i^0)\geq 0$ as total migration costs of skilled labor for net immigration to country *i*. $H_i^0$ represents the original endowment of skilled labor. Note, that if there is a net emigration of skilled labor ($H_i-H_i^0<0$), migration costs for country *i* will be zero. Due to

[3] To keep analysis simple, tariff does not generate domestic income and parts of the traded quantity melt away.

the assumption of lump-sum taxation and equation (11), skilled labor income does not enter equation (21). The first part of equation (21) stands for the net expenditure of consumers, while the second part represents the share of firms' cost spending. The remaining part of cost spending $(1-\mu)$ is directed towards unskilled labor demand.

According to Shephard's Lemma, differentiating the cost function with respect to the unskilled wage rate leads to:

$$L_{M,i} = (1-\mu) \int_{k \in N_i} C^P_{M,i}(k)dk \,/\, w_{A,i} \,. \tag{22}$$

Given the optimized tax rate by equation (15) and the nominal wage by equation (18), demand of skilled labor is calculated by equation (11) and $Y_i^{GDP} = (1-t_i)Y_i$ to:

$$H_i = \left( \frac{t_i}{(1-t_i)} Y^{GDP} \right) / \, w_{H,i} \,. \tag{23}$$

### 3.3. Steady State Equilibrium

Both economies are characterized by an initial equilibrium. Exogenous shocks such as trade liberalization, the cutback of factor mobility restrictions or strategic tax-setting lead to a transition phase, where countries and sectors are marked by fluctuations in firms and labor. Following Puga (1999), the adjustment process can be stated as:

$$\dot{N}_i = \lambda_1 \pi_{M,i}(N_1, N_2) \text{ and } \dot{H}_i = \lambda_2 \varpi_{H,i}(H_1, H_2) \,, \tag{24}$$

with $\dot{N}_i$ and $\dot{H}_i$ as the derivatives for the quantity of firms and skilled labor with respect to the adjustment time, whilst reaching a new steady-state equilibrium. $\lambda_1$ and $\lambda_2$ are positive constants whereas $N_i$ as well as $H_i$ are static variables. $\varpi_{H,i}$ is the real wage rate of skilled labor after taxation and migration costs as expressed in equation (18). The share of unskilled labor in the manufacturing and agricultural sectors is determined by industrial demand and is not included in an explicit adjustment process.

In stable steady-state equilibrium, there are no incentives for firms to relocate and therefore no short run profits. Both countries have a static share of firms if

$$\frac{\partial \pi_{M,i}}{\partial N_i} \le 0\,. \tag{25}$$

It follows from equation (7) that $x_i = x_i^b = \alpha_i(\sigma - 1)/\beta$. Hence, the number of firms in country *i* is endogenously determined by equation (22):

$$N_i = \frac{L_{M,i} w_{A,i}}{(1-\mu) w_{A,i}^{(1-\mu)} q_i^{\mu} \alpha_i \sigma}\,. \tag{26}$$

The model and the equilibrium conditions are described by equations (1)–(26).

## 4. Tax Competition and Strategic Tax-Setting

The model is analytically not solvable owing to the discussed circular causalities. The problem arises with the assumption of Dixit-Stiglitz monopolistic competition, CES utility, and iceberg trade costs. Ignoring tax competition for a moment, and assuming that neither migration costs nor factor mobility restrictions exist, trade cost reduction would lead to the well known 'tomahawk-bifurcation' pattern of industrial distribution and to multiple equilibria.[4] Given multiple solutions, the complexity of the model increases as tax competition and strategic tax-setting is added to the model. Steady state analyses therefore rely on numerical simulations.

To start with, it is worthwhile to inspect government function with Benthamite objectives and its use to model tax competition. Turning to the impact of tax competition on steady state equilibria, I distinguish between two steady state equilibria. In the case of *a symmetric equilibrium* with equally distributed industry and factor shares, states are primarily not interested in changing their status quo. Governments maximize their utility function by choosing an optimal tax rate either in a cooperative or a non-cooperative way. In the case of *a core-periphery equilibrium* with industry shares fully concentrated in the core country, the structurally backward country may have an incentive to snatch industry shares and mobile factors from the core country by strategic tax-setting. However, the core country may anticipate such strategic behavior and choose tax rates accordingly. To cope with, I adopt the limited tax

[4] A 'tomahawk-bifurcation' pattern describes a symmetric equilibrium with an equal industry share in both countries at high and low trade costs and an asymmetric equilibrium with a concentration of industry share in one country at an intermediate level of trade costs. Additionally, there is a range of trade costs with multiple equilibria, which may lead either to full agglomeration or to symmetric distribution of industrial activity. Path dependency is responsible for the observed outcome.

game proposed by Baldwin and Krugman (2004). The procedure in both cases is the same: I consider cooperation with no tax deviation first, and then introduce tax competition as a non-cooperation game.

### 4.1. Government Taxation and Tax Policies

Following Baldwin et al. (2003), one way to find the optimal tax rate for a symmetric equilibrium is to assume initially that all factors are internationally immobile (i.e. migration condition equation (18) does not apply) and to calculate the first best tax rate. Afterwards, factor mobility is allowed for to show whether the result changes or not.

Accordingly, the term $(Y_i / q_i)$ in equation (15) is a parameter and does not vary with tax rates. It is easy to derive from equation (15) that the first best tax rate equals the public good preference: $t^* = \psi$. The next step is to allow for factor mobility by equation (18). If country 1 does not want to deviate from the first best solution nor does country 2, $t^* = \psi$ would also be a Nash equilibrium with an equal share of mobile factors in both countries: $S_H = H_1 /(H_1 + H_2) = 1/2$. However, if one country has an incentive to deviate, the first best solution is not a Nash equilibrium.

To ascertain whether the first best solution is a Nash equilibrium or not, I differentiate government utility at the proposed symmetric equilibrium. Equation (15) is facilitated by dropping country indexes and using two sub-functions to: $W = g[H] f[t]$, with $g[H] = (Y/q)$ and $f[t] = \left(t^{\psi}(1-t)^{1-\psi}\right)$. Total differentiation and evaluation leads to same equation as in Baldwin et al. (2003):

$$\frac{dW}{dt} = \left.\frac{d(t^{\psi}(1-t)^{1-\psi})}{dt}\right|_{t=\psi} \frac{Y}{q} + \left.\left((\psi^{\psi}(1-\psi)^{1-\psi})\frac{d(Y/q)}{dt}\right)\right|_{S_H=1/2}, \qquad (27)$$

where $t = \psi$ and $S_H = H_1 /(H_1 + H_2) = 1/2$. Due to the optimal first best tax rate, the first term in equation (27) is zero. Hence, the sign of $dW/dt$ depends only on the second term and therefore on $d(Y/q)/dt$. Using the definition of $Y$ by equation (12), I derive the following expression:

$$\left.\frac{d(Y/q)}{dt}\right|_{S_H=1/2} = \left(\frac{L}{q}\frac{dw_A}{dN} + \frac{B}{q}\frac{dr(w_A)}{dL_A}\frac{dL_A}{dN} - \frac{Y}{q^2}\frac{dq}{dN}\right)V + \frac{w_H}{q}\left(1 + \frac{H}{w_H}\frac{dw_H}{dH}\right)\frac{dH}{dt},$$

(28)

where $\frac{d(\int \pi(h)dh)}{dt} = 0$ and $V = \frac{dN}{dF}\frac{dF}{dH}\frac{dH}{dt}$. Derivatives are evaluated at the proposed symmetric equilibrium.

A further look at equation (28) and the corresponding equations leads by comparative statistics to the following conclusion:

$$\frac{dH}{dt} > 0\,;\; V > 0;\; \left.\frac{d(w_A)}{dN}\right|_{V>0} > 0\,;\; \left.\frac{dr(w_A)}{dL_A}\frac{dL_A}{dN}\right|_{V>0} < 0\,;\; \left.\frac{dq}{dN}\right|_{V>0} < 0\,;$$

$$\varepsilon_{w_H,H} = \frac{H}{w_H}\frac{dw_H}{dH} = -1. \tag{29}$$

All other things constant, a higher tax rate leads to an increase in skilled labor by equation (18). Hence, an increase in skilled labor increases the number of firms ($V > 0$) and therefore increases unskilled nominal wages, which decreases the agricultural profit share per unit of land, and decreases the price index. Finally, the elasticity of skilled wages with respect to skilled labor is negative.[5] The negative effect of the agricultural profit rate does not outmatch the other effects. As a result, $d(Y/q)/dt$ is positive and therefore $dW/dt$ as well: countries have an incentive to deviate from the first-best solution by higher tax rates. The symmetric first-best solution is not a Nash equilibrium and optimal tax rates are derived numerically.

Indeed, numerical simulations show that the optimal tax rate approaches one, which means a nearly 100% income transfer from immobile to mobile factors. By equation (14), governments are concerned about the provision of public goods as well as the consumption of a representative consumer. An income transfer from one group to another group does not affect consumption as a whole as GDP remains unchanged. Hence, governments with Benthamite objectives can raise utility by higher taxes and more public goods, while consumption expressed by a representative consumer is unaffected.

[5] More details about the derivatives in equation (29) are listed in appendix (B).

*Optimal Tax-Setting (Non-Benthamite Objectives)*

I rearrange state utility to account for those who have to carry the tax burden. Remember that although all factor income groups are taxed, a redistribution of tax revenue to factors employed in the R&D-sectors causes a real tax burden for the immobile factors. Hence, equation (14) changes to:

$$W_i \ (G_i, C_i^L) = G_i^{\psi_i} C_i^{L^{1-\psi_i}}, \ G_i = t_i Y_i / q_i, \ C_i^L = (1-t_i) Y_i^{GDP} / q_i, \qquad (30)$$

with $C_i^L$ as the consumption of immobile consumer. The Non-Benthamite objective function for the government is now described by a median voter model and by its adoption of the specific consumer tastes of immobile factors.

## 4.2. Tax Competition and Symmetric Equilibrium

I assume a symmetric equilibrium with equal industry shares and identical factor endowments in both countries. Trade costs are high ($\tau = 3.0$) and spillover effects are symmetric ($\Gamma_i = \Gamma = 0.5$). Furthermore, there are no migration costs and no factor mobility restrictions for equally industrialized countries ($m = 0$).To set an optimal tax rate governments maximize their utility functions taking the tax rate of the counterpart as a constant. In general, governments can choose either a cooperative or a non-cooperative way. If one of these two strategies leads to a stable equilibrium, the corresponding tax rate as a market result should be observed. However, the equilibrium might not be pareto-efficient: although there is no incentive to deviate, there could be a solution resulting in higher utilities for both countries. This situation is best described with the prisoner's dilemma.

In the cooperation case, governments cooperate and set identical tax rates. In doing so, there is no additional migration and firm fluctuation preserving the industrial status. Figure 1 shows simulation results for government utilities with respect to tax rates ($t \in (0,1)$) assuming different but identical public good preferences for both countries. According to Figure 1, the higher the preference for public goods in a country is, the more the utility function shifts to the right. Hence, governments increase their utility by higher tax rates. The peaks of the utility functions in Figure 1 characterize the optimal tax rates. As a general result, the optimal tax rate increases, the stronger the preference for public goods is. However, public good preference should not be too high: the optimal tax rate for $\psi = 0.5$ approaches one leaving no room for further analysis.

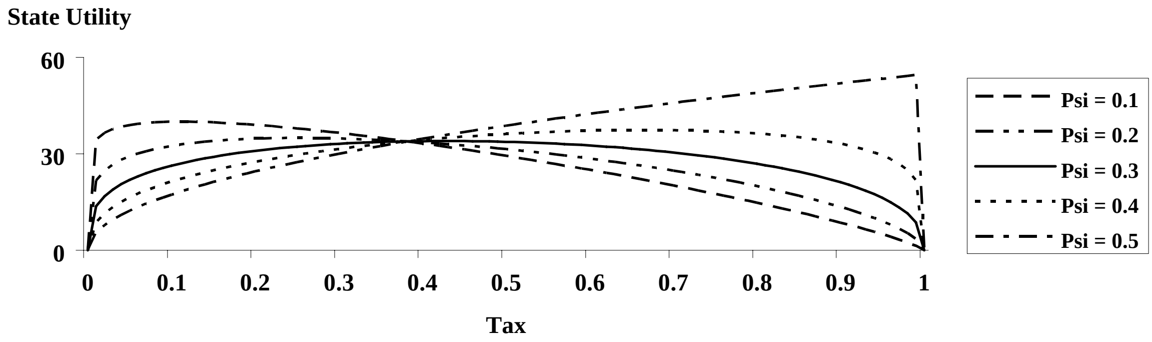


**Figure 1: Symmetric Equilibrium: Coordinated Tax-Setting**

Analyzing a non-cooperation case, I concentrate on a preference value of $\psi = 0.3$ and assume that both countries know their optimal tax rate and their corresponding utility values if both were to cooperate. Fixing the tax rate of country 1 at the optimal value for cooperation $(\overline{t_1^*} = t^{*c}\big|_{\psi=0.3})$, as presented in Figure 1, and varying country's 2 tax rate ($t_2 \in (0,1)$), Figure 2 shows a range of tax rates which lead to higher utilities for country 2 than for country 1.

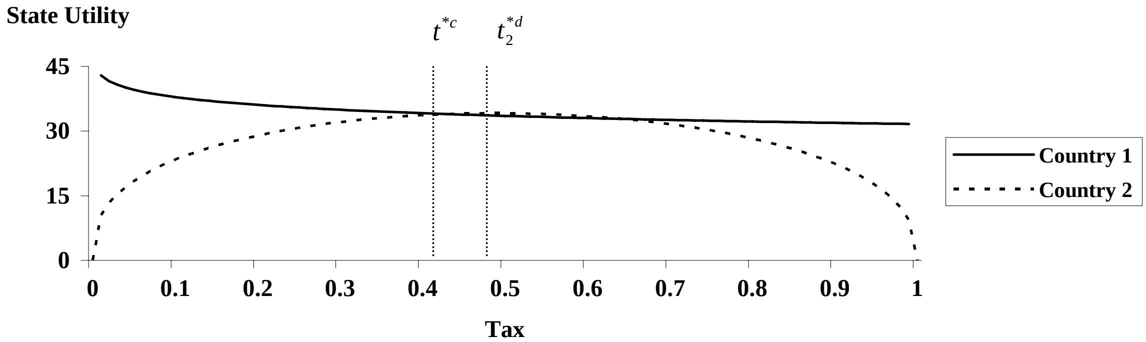


**Figure 2: Symmetric Equilibrium: Strategic Tax-Setting**

More precisely, country 2 obtains a higher utility level by choosing a deviation rate $t_2^{*d}\big|_{\psi=0.3}$ instead of $t^{*c}\big|_{\psi=0.3}$. Hence, country 2 gains by deviation ($W_2^{*d}\big|_{\psi=0.3} > W_2^{*c}\big|_{\psi=0.3}$). In attracting more skilled labor, the share of domestic R&D and industrial activity in country 2 would increase at country 1's expense. Of course the same strategic behavior can be conceded to country 1. Hence, both countries would have an incentive to deviate from the cooperative solution by a higher tax rate. The result is a non-cooperative symmetric equilibrium, where both countries set identical but higher tax rates than in the cooperation case. However, these symmetric tax rates are suboptimal. Such a prisoner's dilemma leaves both countries worse off, while their industrial status quo remains unchanged. The resulting redistribution of higher income tax revenue favors skilled labor at the expense of unskilled labor. Hence, coordinated tax-setting such as tax harmonization would lead to lower income taxes and therefore to a lower tax burden for unskilled labor.[6]

**4.3. Limited Tax Game and Agglomeration**

Turning to a core-periphery equilibrium, the structurally backward country may have an incentive to compete with tax rates. If this results in a higher tax yield relatively to the core country, offering higher wages leads skilled labor to inward migration. Reducing or reversing the industrialized country's comparative cost advantage of having a high research level, firms begin to shift their production towards the structurally backward country. In doing so, they benefit not only from the increasing share of R&D activity, but also from low unskilled labor costs. Hence reinforcing circular processes, which were once responsible for the formation of the core-periphery pattern, would lead to a catch up of the structurally backward country. However, the core country could be aware of the strategic tax-setting of its counterpart and chooses its optimal tax rate in such a way as to offset the effects on migration and production outsourcing. Baldwin and Krugman (2004) propose a limited tax game: the core country sets its optimal tax rate $(t_1)$ in the first stage, whereas the periphery country chooses its tax rate $(t_2)$ in the second stage. In the third stage, migration and production occur until both economies reach steady state equilibria.

Industrialized countries are in general characterized by a higher tax burden than developing countries. This might be the result of higher need and/or higher preferences towards public goods: rich voters tend to desire more public spending and are willing to carry a higher tax burden than poor voters in developing countries. As discussed by Figure 1, tax rates will increase the higher the preference for public goods is. Accordingly, I assume that the core country has a higher preference towards public good spending than the structurally backward country $(\psi_1 > \psi_2)$.[7]

To start with, I assume an asymmetric equilibrium with industrial agglomeration in country 1 and agricultural hinterland in country 2. Trade costs are low $(\tau = 1.1)$). Initially, there no

[6] The derived results remain valid for values of trade costs and public good preferences as long as there is an initial symmetric equilibrium.

[7] As a general result, nominal and real wages for unqualified labor are higher in the core than in the periphery. Considering unqualified labor as a median voter and bearing in mind that a lump-sum income tax and its redistribution does not change GDP, core countries are indeed richer than the periphery.

migration costs ($m_1 = m_2 = 0$). This simplification is relaxed later on. In solving the tax game, the second step is solved first followed by the first step:

(1) The tax decision of country 2 by equation (30) is solved first assuming the optimal tax rate of country 1 as given ($t_2^{*d}\big|_{t_1^*}$).

(2) Taking into account the solution derived in step (1), country 1 tries to offset the effect of country 2's strategic tax rate on migration flows and on firm location keeping the migration condition by equation (18) unchanged.

The cooperation solution, where countries do not have an interest in changing their status quo, is given as a benchmark. As discussed in Figure 1, each country sets its optimal tax rate according to the public good preference. The optimum for both countries under the condition of cooperation and maintaining the status quo is obtained with $t_1^{*c} = 0.43$ and $t_2^{*c} = 0.25$ for assumed values of $\psi_1 = 0.3$ and $\psi_2 = 0.2$ respectively.

Solving tax game step (1) numerically, country 2 takes the optimal tax rate of country 2 as a constant ($\overline{t_1^{*c}} = 0.43$) and varies its tax rate in order to attract skilled labor and trigger dislocation of core country's firms. Figure 3a) shows government utilities, whereas the absolute number of firms is shown in Figure 3b).[8]

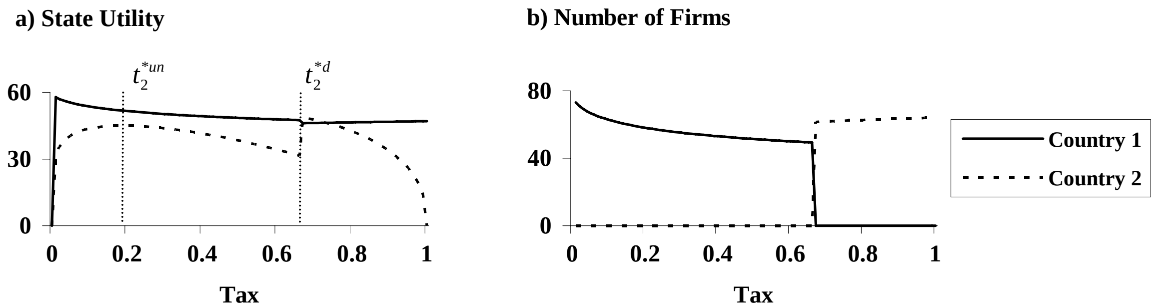


**Figure 3: Core-Periphery: Deviation of Country 2**

Note that the utility function as well as the corresponding number of firms is discontinuous. By a value of $t_2^{*d}\big|_{t_1^{*c}=0.43} = 0.67$ massive inward migration of skilled labor[9] leads to a disloca-

[8] The whole range of tax rate values is shown to give a full description of the impact of tax deviation. However, only tax rates higher than $t_2^{*c} = 0.25$ lead to inward migration and therefore to a structural change.

[9] While there is a continuous flow of skilled labor from country 1 to country 2, reaching $t_2^{*d}$ results in a jump in inward migration.

tion of firms as shown in Figure 3b). As a result, the industrialization course is reversed with industrial agglomeration in country 2 and agricultural production in country 1. Figure 3a) shows two relevant tax rates for country 2: the first tax rate $t_2^{*un} = 0.19$ represents the unconstrained optimum for remaining agricultural hinterland; the second tax rate $t_2^{*d} = 0.67$ characterizes deviation and being industrialized.[10] However, country 2 would prefer to raise its tax rate in order to get the core ($W_2^{*d} > W_2^{*un}$).

Taking this into account, tax game step (2) is solved by country 1 in such a way that the effect of higher wage proposals offered by country 2 on migration decisions by equation (18) is neutralized. In doing so, country 1 has to increase its tax rate to offer higher wages. Equation (18) is rearranged to:

$$t_1^{eq} = 1 - (1 - t_2^{*nd}) / \Omega^{CP} , \qquad (31)$$

with $\Omega^{CP} = \dfrac{w_{H,1} / q_1^{-\gamma}}{w_{H,2} / q_2^{-\gamma}}$ as the real wage gap of skilled labor, $t_1^{eq}$ as the equilibrium tax rate for country 1 to sustain the core-periphery pattern and $t_2^{*nd}$ as country's 2 non-deviation tax rate. As long as country 1 is willing to keep equation (31) unchanged by choosing a strategic tax rate itself, the core-periphery equilibrium remains stable. Considering $t_1^{*d}$ as an optimal response to $t_2^{*d}\big|_{t_1^*}$ solved in the first step, country 1 has to be sure, that there is no incentive left for country 2 to an even higher tax rate. If not, country 1 has to solve tax game step (2) again, considering country 2's new strategic deviation tax rate. Step (1) and (2) of the tax game will be repeated as long as country 2 gain the core and raise utility by deviation ($W_2^{*d} > W_2^{*un}$) or country 1 surrender the core and rest on agricultural production. Figure 4 shows the stylized decision problem for country 1.[11]

The diagram in Figure 4 reproduces the choices for country 2 in either remaining underdeveloped (lower utility curve) or gaining the core and being industrialized (upper utility curve). Country 1's decision problem is such that it has to raise its tax rate to a level where country 2 is indifferent between $t_2^{*d} = t_2^{*nd}$ as a strategic tax rate to get the core and $t_2^{*d} = t_2^{*un}$ as an optimal tax rate to refrain from tax competition. In this case, country 2 would not deviate and

[10] At the same time that industry shares switch from country 1 to country 2, preferences for public goods are adjusted such that country 2–being core country–now accounts for the higher preference.
[11] Note the difference to the model analyzed by Baldwin and Krugman (2004), where the periphery has to lower tax rates in order to attract mobile factors.

would prefer to set the unconstrained optimal tax rate $t_2^{*un}$. Having identified country's 2 non-deviation tax rate $t_2^{*nd}$, equation (31) determines the equilibrium tax rate $t_1^{eq}$ of country 1.

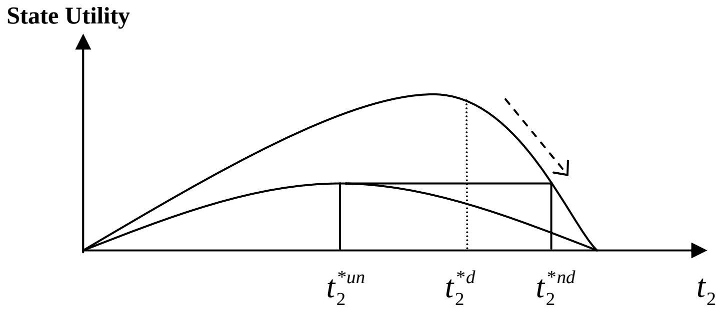


**Figure 4: Tax Game: Decision Problem of Country 1**

Finally, country 1 has to ascertain whether it is worthwhile keeping the core or not:

$$W_1^{eq} \geq W_1^{*un}, \tag{32}$$

where $W_1^{*un}$ corresponds to an optimal utility value being agricultural hinterland. As long as both countries have the same share of immobile factors, the potential to be core or periphery country is the same for both. Hence, the utility curves plotted in Figure 4 also apply for country 1. In any case, the periphery can only attract skilled labor to such an extent that the industrialization process might be reversed by setting a higher tax rate than the core. Therefore, the core country's tax rate $t_1^{eq}$ is always lower than $t_2^{*nd}$. As Figure 4 shows, keeping the core and engaging in tax competition is always the better choice for country 1 than losing the core ($W_1^{eq} > W_2^{*nd} = W_2^{*un}$). Numerical simulations prove that country 1 has to raise tax rates up to $t_1^{eq}$ in order to keep the core and to prevent country 2 being industrialized. Country 2 keep $t_2^{*un}$ as the best response to $t_1^{eq}$. To sum up, tax competition leads industrialized countries to increase their tax rates. In pushing their comparative cost advantage of higher research activity, industrialized countries prevent migration and production outsourcing from occurring.

***Economic Integration: Trade Liberalization***

Additionally, numerical simulations also show that as economies become closer (i.e. in terms of trade liberalization), the core country has to increase its tax rate to an even higher extent favoring therefore skilled labor at the expense of unskilled labor. Figure 5 plots equilibrium tax rates $t_1^{eq}$ and $t_2^{*un}$ on the right scale as well as the real wage ratio of skilled to unskilled labor on the left scale. As integration continues (i.e. trade cost reduction from $\tau = 1.1$ to $\tau = 1.08$), tax competition pushes country 1 to increase its tax rates leaving unskilled labor worse off relative to skilled labor. Moreover, by migration of skilled labor to the core country, the wages of skilled labor in the periphery also increase, although tax rates remain unchanged. The real wage ratio of skilled to unskilled labor rises in country 2 but to a lower extent than in country 1. Hence, skilled labor is always favored as economic integration continues.

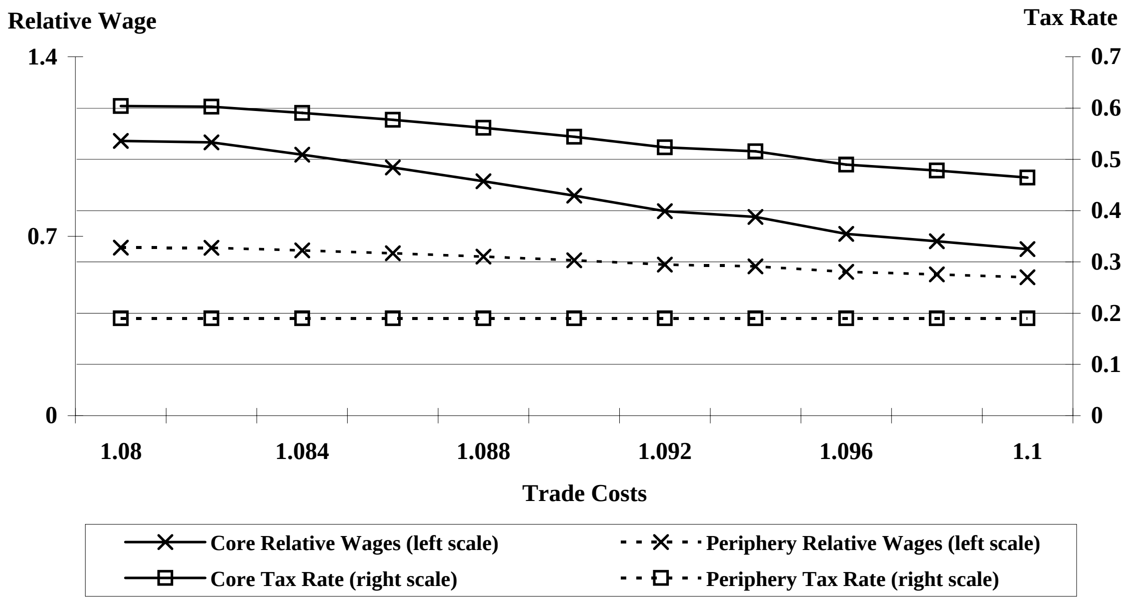


**Figure 5: Trade Liberalization: Relative Wages and Tax Rates**

***Asymmetric Migration Costs***

I assume that only immigration of skilled labor from the periphery to the core country is accompanied with migration costs $(m_1 > 0, m_2 = 0)$. Or to put it differently, one can imagine factor mobility restrictions as quotas or qualitative requirements imposed by the industrialized countries in order to control migration flows. Once migration takes place, monetary costs such as the physical movement, the inclusion in social systems and even money transfers to relatives at home are sunk cost to domestic consumption of the destination country. Figure 6 plots equilibrium tax rates $t_1^{eq}$ and $t_2^{*un}$ on the right scale and the number of firms in the core country on the left scale against diminishing migration costs (i.e. migration cost reduction from $m_1 = 0.1$ to $m_1 = 0$).

First, the higher the migration costs are, the higher the tax rate by the core country is. The core country has to increase nominal wages in order to compensate for migration costs and therefore raise the incentive for skilled labor to immigrate. In contrast, the tax rate chosen by the periphery as an agricultural hinterland remains unchanged. As shown by Figure 6, diminishing migration costs leads to lower income taxes in the core country. Second, such migration costs are sunk costs to the industrialized countries. The share of imposed taxes used as a wage compensation for the occurred migration costs is lost to overall national consumption by equation (21). Consequently, the core's number of firms and products is higher the lower the migration costs are; shown on the left scale in Figure 6.

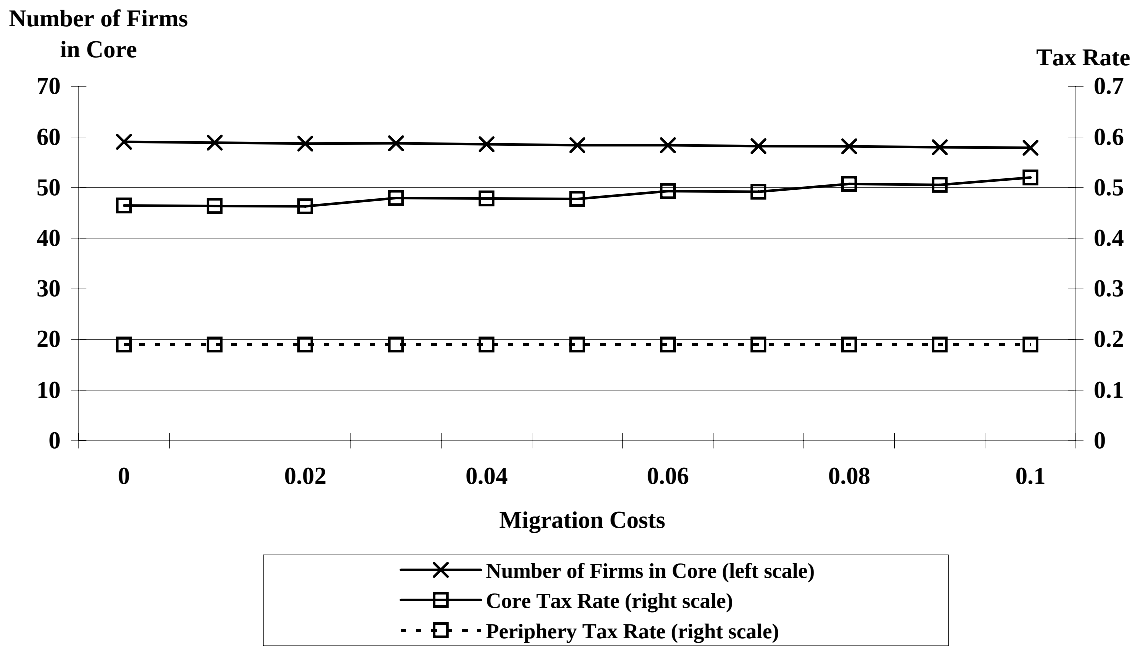


**Figure 6: Tax Competition and Asymmetric Migration Costs**

## 5. Conclusion

Increasing tax competition as a direct consequence of further economic integration obliges industrialized countries to adapt their taxes. If countries are equal in their industry shares, the outcome will be income tax rates that are too high from a social perspective. If not and in the case of a core-periphery pattern, core countries try to offset the impact of tax competition on production location and migration flows. As agglomeration rents are taxed without changing the status quo, the standard result of a "race to the bottom" does not apply. Moreover, if factor owners move with their factors and account for public goods governments are more likely to enhance the provision of such goods. In increasing the attractiveness of the country, mobile factors immigrate to countries even when income taxes are high or about to be increased.

As outlined above, tax-setting is not only constrained by tax competition but also by the extent of economic integration and factor mobility restrictions. As economic integration continues, it may be worthwhile for periphery countries to not engage in strategic tax-setting but to set a socially optimized tax rate. As factor mobility restrictions are relaxed, periphery countries suffer a brain drain towards core countries and loose skilled workforce as a valuable input for self-determining growth. In contrast, core countries, whose economic prosperity is partly based on the presence of such mobile factors, are willing to offer higher incentives. If such incentives are financed or subsidized by a lump-sum income tax, tax competition in economically integrating regions ends up as a higher tax burden for immobile factors. As integration continues, skilled labor is always favored at the expense of unskilled labor.

As outlined by Baldwin and Krugman (2004), during the first stages of European integration average taxes were increased in all participating countries but to a higher extent in the industrialized core nations such as Germany or France than in the lesser industrialized Southern countries or in Ireland. In general, it is difficult to conclude whether increased economic integration and further political enlargement of the EU should be accompanied by tax harmonization within member countries. Our analysis shows, that at least for equally industrialized countries the adoption of common tax rates would be socially desirable. Particularly as core countries implemented full factor mobility of people inside their territories according to the Schengen Agreements of 1985/1991. However, if countries are different in size and economic power, a temporary factor mobility restriction for skilled labor may serve as an adequate migration policy option for prospective members. Therefore, Central and Eastern European countries would profit from factor mobility restrictions for skilled labor at the first stages of economic integration. In preventing the described brain drain towards the industrialized countries in the EU, such countries sustain at least the opportunity for self-determining growth.

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## Appendix

Specific details for parameters and numerical simulation are given in appendix (A). Further information about the derivatives in equation (28) is listed in appendix (B).

### (A) Numerical Simulation: The Choice of Parameters and the Methodology

Numerical simulations are calculated in Gauss. Programming codes are freely available upon request. The parameters for numerical simulation are set to $\mu = 0.6$, $\sigma = 6$, $\iota = 0.6$, $\gamma = 0.3$ and $\theta = 0.8$. Original total factor endowment of unskilled and skilled labor as well as of agricultural land is assumed to be the same for both countries. Both countries have the same technology. The spillover effect is fixed to $\Gamma = 0.5$ and $\beta$ is normalized to $\beta = \rho = (\sigma - 1)/\sigma$. The technology parameter for firms' fix costs is set to $A = 1/8$.

The methodology used for numerical simulation follows Baldwin et al. (2003) and Puga (1999). To analyze the impact of government taxation on economic development, tax rates are set first, followed by migration and production decisions until economies reach steady state equilibria. Once the tax rates have been set as a result of optimization or of strategic tax settings, the following procedures and adjustment processes are applied: based on the prior determined number of operating firms ($N_i$), the price index ($q_i$) and nominal wages ($w_{A,i}$) of unskilled labor is calculated for a short-run equilibrium. Concurrently, the share of unskilled labor in manufacturing ($L_{M,i}$) and in agriculture ($L_{A,i}$) as well as of skilled labor ($H_i$) in public R&D sector is determined. The number of firms is varied and migration and production decisions are adjusted until equation (25) is satisfied.

### (B) Optimal Tax-Setting: Benthamite Objectives

To analyze the effect of a tax change on taxable income *Y* by equation (12) and on state utility *W* by equation (15), differentiation of (*Y/q*) with respect to $t$ at the proposed symmetric equilibrium, where $t = \psi$ and $S_H = H_1/(H_1 + H_2) = 1/2$, yields to:

$$\left.\frac{d(Y/q)}{dt}\right|_{S_H=1/2} = \left(\frac{L}{q}\frac{dw_A}{dN} + \frac{B}{q}\frac{dr(w_A)}{dL_A}\frac{dL_A}{dN} - \frac{Y}{q^2}\frac{dq}{dN}\right)V + \frac{w_H}{q}\left(1 + \frac{H}{w_H}\frac{dw_H}{dH}\right)\frac{dH}{dt}, \tag{28}$$

where $\frac{d(\int \pi_M(h)dh)}{dt} = 0$ and $V = \frac{dN}{dF}\frac{dF}{dH}\frac{dH}{dt}$.

A further look at equation (18) leads to the following conclusions:

(1) $\frac{dH}{dt} > 0$: A higher tax rate leads to a higher inflow of skilled labor. Substituting equation (11) in equation (18) and using $Y_1 = Y_i^{GDP}/(1-t_i)$, total differentiation at the proposed symmetric equilibrium leads to following equation:

$$g[1/2]\frac{\partial f[t]}{\partial t}dt + f[t]\frac{\partial g[H]}{\partial H}dH = 0,$$

with $f[t] = t_1$ and $g[H] = \frac{q_1^{-\gamma}(1-m_1)Y_1^{GDP}/H_1}{q_2^{-\gamma}t_2(1-m_2)Y_2^{GDP}/H_2}$ as sub-functions, or to:

$$\frac{dH}{dt} = -\frac{g[1/2]}{\frac{\partial g[H]}{\partial H}t}. \qquad \text{(B.1)}$$

Rearranging $g[H]$ by the use of $S_H = H_1/(H_1+H_2)$ and with $D = \frac{q_1^{-\gamma}(1-m_1)Y_1^{GDP}}{q_2^{-\gamma}t_2(1-m_2)Y_2^{GDP}}$ leads to: $g[H] = D\frac{1-S_H}{S_H}$. Equation (B.2) can be calculated as:

$$\left.\frac{dH}{dt}\right|_{t=\psi} = -\frac{D}{-\frac{D}{S_H{}^2}\psi} = \frac{S_H{}^2}{\psi} = \frac{1}{4\psi} > 0. \qquad \text{(B.2)}$$

(2) $V = \frac{dN}{dF}\frac{dF}{dH}\frac{dH}{dt} > 0$: A higher tax rate leads to an increase of skilled labor by equation (B.2) and therefore to a higher research output by equation (8). The availability of research results is restricted by the technology spillover effect: a shift of skilled labor from abroad also increases the national research level by equation (9). Hence, fix costs at firm level are reduced by equation (10). This leads by equation (26) to a higher number of firms. The sign of $V$ is therefore positive.

(3) $\left.\frac{d(w_A)}{dN}\right|_{V>0} > 0$: *V > 0* leads to a higher demand for unskilled labor in the industrial sector and raises therefore nominal wages for unskilled labor.

(4) $\left.\frac{dr(w_A)}{dL_A}\frac{dL_A}{dn}\right|_{V>0} < 0$: *V > 0* results in a higher share of unqualified labor employed in manufacturing and therefore in a loss of labor shares in agriculture: $L_A = L - L_M$. Higher wages in the agricultural sector due to increased productivity of unskilled labor lead to a lower profit rate per unit of land by equation (3).

(5) $\left.\frac{dq}{dN}\right|_{V>0} < 0$: *V > 0* decreases the price index by equation (20) as more firms and products are concentrated within one country.

(6) $\varepsilon_{W_H,H} = \frac{H}{w_H}\frac{dw_H}{dH} = -1$: All other things constant, a one percent increase in skilled labor decreases wage rates by one percent. Wage elasticity with respect to skilled labor and the use of equation (11) can be stated as:

$$\varepsilon_{W_H,H} = \frac{H}{w_H}\frac{dw_H}{dH} = \frac{H}{w_H}\left(-\frac{tY}{H^2}\right). \tag{B.3}$$

Re-substitution of equation (11) in equation (B.3), the wage elasticity can then be written as:

$$\varepsilon_{W_H,H} = \frac{H}{w_H}\left(-\frac{Hw_H}{H^2}\right) = -1. \tag{B.4}$$