Competition in corporate and personal income taxation

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18th April 2007

Abstract

Focussing on international tax competition, this paper pays specific attention to the stylized fact that multinational firms are typically incorporated whereas national firms are typically not. Accordingly, we model international tax competition as a two stage game with two tax instruments for each government. We derive testable hypotheses about the slope of the reaction functions and their shifters. We contrast these hypotheses with the data and estimate tax reaction functions for both corporate and personal income tax rates in a panel of 30 OECD countries between 1985 and 2005.

JEL classification: C33, H25, H77
Keywords: Tax competition; Spatial econometrics; Generalized moments (GM) estimation

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1 Introduction

Theoretical research on tax competition suggests that jurisdictions interact strategically in capital tax rate setting to attract mobile capital (see Wilson, 1999, for a comprehensive survey). The empirical research generally finds supportive evidence for this hypothesis (see Devereux, 2007, for a recent survey). One important study in this regard is Devereux, Lockwood and Redoano (2004), who estimate tax reaction functions for a panel of 21 OECD economies between 1982 and 1999. They find positively sloped reaction functions in statutory corporate tax rates and effective marginal corporate tax rates (EMTR),[1] indicating that countries compete strategically with their corporate tax instruments. In a similar vein, Altshuler and Goodspeed (2002) test whether the OECD countries respond to the tax rate setting of the U.S. Their findings lend support to this hypothesis, although the measurement of company tax burden is based on tax revenues instead of (statutory and effective) tax rates.[2]

The previous empirical research almost exclusively focuses on corporate taxation. This, however, is in sharp contrast to the observation that only a minority of firms is incorporated. At least in the industrialized countries, the majority of firms, especially national companies, are single entrepreneurs or private partnerships. But it is reasonable that governments attempt to attract non-incorporated firm activity using a favorable personal income tax system. In this case, one would expect not only a strategic competition in corporate taxation but also an

[1]In contrast to statutory tax rates, effective (marginal and average) tax rates consider the definition of the tax base (e.g., depreciation allowances, investment credits, etc.). The method to calculate effective corporate tax rates is well established in the literature and, for instance, described in Devereux and Griffith (2003).

[2]Apart from the reaction function approach, there is an alternative strand of research testing the above mentioned tax competition hypothesis more indirectly by regressing (statutory and/or effective) capital and corporate tax rates on a measure of capital mobility and other controls (Devereux, 2007, provides a survey over this literature). By and large, the empirical findings of these studies are in line with the reaction function approach.

interaction in personal income taxation and an interaction between personal and corporate income taxation. This paper analyzes these strategic tax interactions and attempts to estimate the response of a country's corporate and personal income tax rates to the corresponding tax changes of its neighbors. We propose a theoretical model with a multinational, incorporated enterprise (MNE) and a national (non-exporting), non-incorporated enterprise (NE). The two firm types are faced with a different tax treatment, i.e., corporate taxation for MNEs and personal income taxation for NEs. Further, the MNE is allowed to shift profits across borders via transfer pricing (see Haufler and Schjelderup, 2000; Devereux, Lockwood, and Redoano, 2004). The theoretical model enables us to derive empirically testable hypotheses about the above mentioned strategic interactions between corporate and personal income taxation. Empirically, we employ data from 30 OECD countries between 1985 and 2005. Following Devereux, Lockwood and Redoano (2004), we use statutory and effective rates for both types of taxes. Our findings suggest that there a strategic interaction in corporate and personal income taxation within the OECD countries. In particular, we observe that tax rates of the same type (corporate and personal income taxes) are used as strategic complements, while corporate and personal income taxes work as strategic substitutes.

The remainder of the paper is organized as follows. In Section 2 we presents the theoretical model. Section 3 gives a brief description of the data, discusses the econometric approach and presents the empirical results. Section 4 concludes.

2 The model

We consider a model of a single (industrial) sector and two countries. Each of the economies hosts a single national, unincorporated, non-exporting enterprise (NE). Furthermore, there is a multinational enterprise (MNE), which runs a plant in both countries. The multinational is horizontally organized (producing the same product across countries, but serving consumers in a market locally), and it is footloose so that plant-specific profits accrue to the plant and are not repatriated across borders.

Demand is assumed to be linear and represented by an inverse demand schedule for market $p_i = a_i - (s_i^N + s_i^M)$, $i = 1, 2$. For the sake of notational simplicity, the slope of the inverse demand schedule are normalized to unity. Consequently, the preference parameter a_i becomes a measure of the size of market i, reflecting the quantity sold at a price of zero. We normalize the marginal cost of production across markets to unity for all firms and assume that NEs do not incur any fixed costs of production. Under these assumptions, the profits of NEs are determined as:

$$\begin{aligned} \pi_i^N &= (1-\tau_i)[p_i s_i^N - \delta_i s_i^N], \qquad (1) \\ \delta_i &= \tfrac{(1-\alpha\tau_i)}{(1-\tau_i)}. \end{aligned}$$

s_i^N denotes the production of the NE in i, τ_i is the corresponding tax rate on the unincorporated NE's profits (to be associated with the personal income tax rate in the subsequent empirical analysis), and $1 > \alpha > 0$ is a cost deduction parameter, accounting for tax base allowances such as depreciation or investment credits (see also Janeba, 1996; Haufler and Schjelderup, 2000; Devereux, Lockwood, and Redoano, 2004).

Following Haufler and Schjelderup (2000), we assume that the MNE incurs higher fixed costs than the NEs (recall that we assumed zero fixed costs for NEs). In particular, the MNE requires a fixed amount F of additional services with costs of 1 per unit. These services can be provided either by the plant in market 1 or by that in market 2. Rather than charging the true costs for the services, the firm is able to set a transfer price q per unit of the service.[3] The latter enables avoidance of the MNE's tax payments by implicitly shifting the tax base from a high-tax country to a low-tax country. The transfer price q is not observed by tax authorities. However, we assume that transfer pricing can not be applied deliberately since the MNE has to bear additional fixed costs $\frac{1}{2\rho}\left(q-1\right)^2 F$ for hiding transfer pricing practices and avoiding the risk of disclosure (see also Haufler and Schjelderup, 2000). Unlike other production costs, the service-related variable costs are not tax deductible. In contrast, the service-related fixed transfer pricing costs are not subject to taxation at all, since they are unobservable to the tax authorities. Under these assumptions, the profits of the MNE are determined by

$$\begin{aligned} \pi^M &= (1-t_1)\left[p_1 s_1^M + (q-1)F - \theta_1 s_1^M\right] \\ &\quad +(1-t_2)\left[p_2 s_2^M - (q-1)F - \theta_2 s_2^M\right] - \tfrac{1}{2\rho}\left(q-1\right)^2 F, \\ \theta_i &= \tfrac{(1-\alpha t_i)}{(1-t_i)} \quad \forall \quad i = 1,2, \end{aligned} \tag{2}$$

where s_i^M is the quantity sold by the MNE in market i. The MNE is assumed to be incorporated, facing a statutory corporate tax rate of t_i in country i, which may be different from the tax rate of the unincorporated NEs (τ_i).

In this setting, transfer prices for the services are determined by cost mini-

[3]Of course, NEs can not apply transfer pricing, since they only operate in a single market.

mization:

$$\begin{aligned}
\frac{\partial \pi^M}{\partial q} &= (1-t_1)F - (1-t_2)F - \frac{1}{\rho}(q-1)F = 0 \Rightarrow \\
q^* &= 1 + \rho(t_2 - t_1) \qquad (3) \\
Q^* &= (1-t_1)(q^*-1)F - (1-t_2)(q^*-1)F - \tfrac{1}{2\rho}\left(q^*-1\right)^2 F \\
&= \rho(t_2-t_1)^2 F - \tfrac{1}{2\rho}\rho^2(t_2-t_1)^2 F = \tfrac{\rho}{2}(t_2-t_1)^2 F
\end{aligned}$$

Following the tax competition literature, we envisage a two-stage game. In the first stage, each country sets its tax rates (τ_i, t_i, $i = 1, 2$) to maximize its objective function. We assume that countries maximize their tax revenue, which is given by

$$\begin{aligned}
T_i &= \tau_i(p_i - 1)s_i^N + (1-\alpha)\tau_i s_i^N \qquad (4) \\
&\quad + t_i(p_i-1)s_i^M + (1-\alpha)t_i s_i^M + t_i\rho(t_j - t_i)F,
\end{aligned}$$

where $i, j = 1, 2$ and $i \neq j$. In the second stage, firms engage in Cournot competition to determine their supplies for market i, s_i^N and s_i^M, respectively.

We can solve the game through backward induction. Starting with the second stage, the firm's first order conditions are

$$\begin{aligned}
\frac{\partial \pi_i^N}{\partial s_i^N} &= (1-\tau_i)\left[a_i - 2s_i^N - s_i^M - \delta_i\right] = 0 \\
\frac{\partial \pi^M}{\partial s_i^M} &= (1-t_i)\left[a_i - 2s_i^M - s_i^N - \theta_i\right] = 0 \qquad (5)
\end{aligned}$$

At given tax rates, the Nash-equilibrium in market i is characterized by

$$s_i^{N*} = \tfrac{a_i - 2\delta_i + \theta_i}{3}; \quad s_i^{M*} = \tfrac{a_i - 2\theta_i + \delta_i}{3}; \quad p_i^* = \tfrac{a_i + \delta_i}{3} + \theta_i. \qquad (6)$$

The corresponding firm profits amount to

$$\pi_i^{N*} = (1-t_i)(p_i^* - \delta_i)s_i^{N*} = (1-t_i)(s_i^{N*})^2,\ i=1,2 \tag{7}$$
$$\pi^{M*} = (1-t_1)(p_1^* - \theta_1)s_1^{M*} + (1-t_2)(p_2-\theta_2)s_2^{M*} + \tfrac{\rho}{2}(t_2-t_1)^2F$$

As indicated before, countries set tax rates to maximize tax revenue in the first stage. For this, it is useful to define the personal income tax base (B_{τ_i}) and the corporate income tax base (B_{t_i}) in country i, respectively:

$$B_{\tau_i} = (p_i^* - \alpha)s_i^{N*} = \left(s_i^{N*}\right)^2 + \tfrac{1-\alpha}{(1-\tau_i)}s_i^{N*} \tag{8}$$
$$B_{t_i} = (p_i^* - \alpha) + \rho t_i(t_j - t_i)F$$
$$= \left(s_i^{M*}\right)^2 + \tfrac{1-\alpha}{(1-t_i)}s_i^{M*} + \rho t_i(t_j-t_i)F \tag{9}$$

Accordingly, the tax revenues of country i are given by

$$T_i = \tau_i B_{\tau_i} + t_i B_{t_i} + \rho t_i(t_j - t_i)F \tag{10}$$

Proposition 1 *The two-stage game exhibits a symmetric Nash-equilibrium with* $\tau_1 = t_1 = \tau_2 = t_2$.

Proof. See the Appendix. ■

The slope of the tax reaction functions can be derived using the total differential about the first order conditions around the Nash-equilibrium. The results can be summarized with the following proposition.

Proposition 2 *(Slopes of the reaction functions at the symmetric Nash-Equilibrium):* $\frac{d\tau_i}{dt_i}|_{Nash} = -\frac{\partial T_i}{\partial\tau_i\partial t_i}/\frac{\partial^2 T_i}{\partial\tau_i^2} > 0$, $\frac{d\tau_i}{d\tau_j}|_{Nash} = 0$, $\frac{d\tau_i}{dt_j}|_{Nash} = -\frac{1}{D}\frac{\partial^2 T_i}{\partial\tau_i\partial t_i}\frac{\partial T_i}{\partial t_i\partial t_j} > 0$, $\frac{dt_i}{d\tau_j}|_{Nash} = 0$, $\frac{dt_i}{dt_j}|_{Nash} = -\frac{1}{D}\frac{\partial T_i}{\partial t_i\partial t_j}/\frac{\partial^2 T_i}{\partial t_i^2} > 0$.

Proof. See the Appendix. ■

This proposition shows that (i) τ_i and t_i are complementary strategies and (ii) the tax reactions curves are both upward sloping, i.e., there is tax competition in terms of both tax rates.

Proposition 3 *(Shift of the reaction functions at the symmetric Nash-Equilibrium): As long as* $D\left|_{Nash}\right. > 0$ *we obtain the following effects of country size on the equilibrium tax rates:* $\frac{d\tau_i}{da_i}\left|_{Nash}\right. = -\frac{1}{D}\left(\frac{\partial^2 T_i}{\partial t_i^2} - \frac{\partial^2 T_i}{\partial \tau_i \partial t_i}\right)\frac{\partial^2 T_i}{\partial \tau_i \partial a_i} > 0$, $\frac{dt_i}{da_i}\left|_{Nash}\right. = -\frac{1}{D}\left(-\frac{\partial^2 T_i}{\partial \tau_i \partial t_i} - \frac{\partial^2 T_i}{\partial \tau_i^2}\right)\frac{\partial^2 T_i}{\partial \tau_i \partial a_i} > 0$, $\frac{d\tau_i}{da_j}\left|_{Nash}\right. = 0$, *and* $\frac{dt_i}{da_j}\left|_{Nash}\right. = 0$.

Proof. See the Appendix. ■

3 Empirical analysis

3.1 Data

Our sample includes data for 30 OECD economies between 1985 and 2005 (a set of descriptive statistics is presented in Table 1). Following Devereux, Lockwood, and Redoano (2004), we use statutory and effective corporate and (top) personal income tax rates in our empirical application. The statutory tax rates are available from the *OECD Tax Database* and the *World Tax Database* of the *Office of Tax Policy Research* at the University of Michigan. The effective personal income tax rate is approximated by the tax burden of an average industrial worker as collected in the *OECD*'s *Taxing Wages* (2006). It is defined as the tax burden of a single person with no children and includes personal income taxes, employee and employer contributions less cash benefits. Regarding corporate taxation, this tax burden should be compared to the effective average corporate tax rate (EATR) as developed by Devereux and Griffith (1999, 2003). To calculate the EATR on corporate profits, we follow their approach. Finally, the data for our control variables (GDP, unemployment) are taken from the *OECD Statistical Compendium* 2006-2.

−− Table 1 −−

Figure 1 illustrates the OECD-average of statutory and effective corporate and personal income tax rates between 1985 and 2005. Clearly, there is a downward trend in the statutory tax rates. This pattern is also observed for effective corporate tax rates but not for the ones of the personal income tax.

−− Figure 1 −−

In Figures 2-5 we plot the tax rates for the year 1995 against those of the year 2005.[4] For Denmark, Norway, Sweden and Switzerland, we only include personal income taxes collected at the federal level instead of the compound rate consisting of federal and regional (cantonal) taxes. This explains the low statutory personal income tax rate for Switzerland in Figure 2.[5] Entries above the black line in the figure indicate that countries have reduced their tax rates within the considered time span. As can be seen from the figures, both corporate as well as personal income tax rates declined substantially in most of the OECD economies within the considered time window. Yet, this change is less pronounced for personal income tax rates.

−− Figures 2 to 5−−

[4] We do not use a reference year prior to 1995 to cover the largest possible number of countries. For instance, using the 1985 instead of 1995 would reduce the cross-section substantially (for instance, recall that the Eastern European countries became independent and entered the OECD only in the 1990s). However, the picture emerging from such comparisons would be more or less the same as in the figures presented here.

[5] In our estimation approach we include fixed country effects, so that this measurement error is not critical.

One question emerging from the figures is whether domestic and foreign corporate and/or personal income tax rates are strategic complements or substitutes. The previous section gave some guidance about what to expect from the model introduced above. In the sequel, we will describe and apply econometric methods suitable to shed light on the question of interest.

3.2 Econometric approach

The theoretical model in Section 2 supports a reduced-form econometric specification of (corporate and personal income) tax rates of the form:

$$\boldsymbol{\tau}_t = \rho_{11}\mathbf{W}\tau_t + \rho_{12}\mathbf{W}\mathbf{t}_t + \mathbf{X}_t\boldsymbol{\beta}_1 + \boldsymbol{\varepsilon}_{1t} \quad (11)$$

$$\mathbf{t}_t = \rho_{21}\mathbf{W}\tau_t + \rho_{22}\mathbf{W}\mathbf{t}_t + \mathbf{X}_t\boldsymbol{\beta}_2 + \boldsymbol{\varepsilon}_{2t} \quad (12)$$

where, based on Proposition 2, we hypothesize $\rho_{11} = 0$, $\rho_{12} > 0$, and $\rho_{21} = 0$ and $\rho_{22} > 0$. While we control for cross-sectional interdependence through the inclusion of $\mathbf{W}\boldsymbol{\tau}_{\mathbf{t}}$ and $\mathbf{W}\mathbf{t}_t$ and for country-size as well as country-specific effects $\mathbf{X}_t\boldsymbol{\beta}_1$ and $\mathbf{X}_t\boldsymbol{\beta}_2$, the residuals may still show autocorrelation across both space (countries) and time. To guard against this problem, we apply the variance-covariance matrix estimator for spatial panel data with cross-sectional as well as time variation suggested by Driscoll and Kraay (1998). This estimator is especially suited to account for heteroskedasticity and autocorrelation if the panel has a large time dimension as in our case.

Note that $\mathbf{W}\boldsymbol{\tau}_{\mathbf{t}}$ and $\mathbf{W}\mathbf{t}_t$ in (11) and (12) are endogenous. Kelejian and Prucha (1999) suggest using instruments $\mathbf{W}\mathbf{X}_t$, $\mathbf{W}^2\mathbf{X}_t$, $\mathbf{W}^3\mathbf{X}_t$ (and, eventually, even higher powers of spatially weighted exogenous variables) to avoid the endogeneity bias associated with the inclusion of spatially weighted endogenous variables.[6] A two-stage least squares estimator on (11) and (12), separately, obtains consistent estimates of the model parameters $\rho_{\ell m}$ and β_ℓ for $\ell, m = 1, 2$. With a large cross section N as well as a large number of time periods T, this is even true for the fixed cross-sectional (country) effects. Unlike with traditional panel data based on small T, two-stage least-squares then even provides consistent estimates of the error terms $\varepsilon_{\ell t}$.[7]

Let us define the two-stage least-squares GMM estimator and its heteroskedasticity and spatial as well as time autocorrelation-consistent (HAC) estimator of the variance-covariance matrix in the spirit of Driscoll and Kraay (1998) in the following way. First, let us refer to the cross-sectional units (countries) as $i = 1, ..., N$ and to the time periods as $t = 1, ..., T$. Furthermore, collect the K_ℓ variables in the second stage (including the the spatially weighted endogenous variables $\mathbf{W}\boldsymbol{\tau}_t$ and $\mathbf{W}\mathbf{t}_t$ and all exogenous variables as well as country dummies) into an $NT \times K_\ell$ matrix $\mathbf{X}$. Similarly, collect the $P_\ell \geq K_\ell$ instruments into the $NT \times P_\ell$ matrix $\mathbf{Z}$. Let us refer to one row of $\mathbf{X}$ and $\mathbf{Z}$ by the $1 \times K_\ell$ vector $\mathbf{x}_{it}$ and the $1 \times P_\ell$ vector $\mathbf{z}_{it}$, respectively. Define the projection $\widehat{\mathbf{X}} = \mathbf{Z}(\mathbf{Z}'\mathbf{Z})\mathbf{Z}'\mathbf{X}$. Denote the $K_\ell \times 1$ vector of two-stage least squares parameters by $\boldsymbol{\theta}_\ell$ and refer to the $R_\ell \times 1$ vector of moment conditions as $E[\mathbf{h}_{it}(\boldsymbol{\theta}_\ell)] = \mathbf{0}$, where $\mathbf{h}_{it}(\boldsymbol{\theta}_\ell) = \mathbf{h}(\widehat{\mathbf{x}}_{it}, \theta_\ell)$ and $\widehat{\mathbf{x}}_{it}$ is one row of $\widehat{\mathbf{X}}_{it}$. Let us stack the R orthogonality conditions for the N cross-sectional units to obtain an $NR \times 1$ vector of moment conditions $E[\widetilde{\mathbf{h}}_t(\boldsymbol{\theta}_\ell)] = 0$ with $\widetilde{\mathbf{h}}_t(\boldsymbol{\theta}_\ell) = [\widetilde{\mathbf{h}}_{1t}(\boldsymbol{\theta}_\ell)', ..., \widetilde{\mathbf{h}}_{Nt}(\boldsymbol{\theta}_\ell)']$ as in Driscoll and Kraay (1998). Then, the

[6] Kelejian and Prucha (1999) do so for cross-sectional problems. However, the arguments straightforwardly carry over for panel data.

[7] With small T, two-stage least-squares would only obtain consistent estimates of the within-transformed (i.e., country-demeaned) residuals.

GMM estimator of θ_ℓ is defined as

$$\boldsymbol{\theta}_\ell = \arg\min_{(\boldsymbol{\theta}_\ell)} \left[\tfrac{1}{T}\sum_{t=1} \widetilde{\mathbf{h}}_t(\boldsymbol{\theta}_\ell)\right]' (\widehat{\widetilde{\mathbf{S}}}_T)^{-1} \left[\tfrac{1}{T}\sum_{t=1} \widetilde{\mathbf{h}}_t(\boldsymbol{\theta}_\ell)\right], \tag{13}$$

where $\widehat{\widetilde{\mathbf{S}}}_T$ is a consistent estimator of the $NR \times NR$ matrix

$$\widetilde{\mathbf{S}}_T = \frac{1}{T}\sum_{t=1}^{T}\sum_{s=1}^{T} E[\widetilde{\mathbf{h}}_t(\boldsymbol{\theta}_\ell)\widetilde{\mathbf{h}}_s(\boldsymbol{\theta}_\ell)']. \tag{14}$$

With N being relatively large, a consistent estimate of this $NR\times NR$ matrix is not available. However, Driscoll and Kraay (1998) suggest replacing this estimator by one that is based on $\mathbf{h}_t(\boldsymbol{\theta}_\ell) = \frac{1}{N}\sum_{i=1}^{N} \mathbf{h}_{it}(\boldsymbol{\theta}_\ell)$ instead of $\widetilde{\mathbf{h}}_t(\boldsymbol{\theta}_\ell)$.

$$\mathbf{S}_{\ell T} = \frac{1}{T}\sum_{t=1}^{T}\sum_{s=1}^{T} E[\mathbf{h}_{\ell t}\mathbf{h}'_{\ell s}],$$

where $\mathbf{z}_{\ell it}$ is a $K_\ell \times 1$ matrix of instruments (including the exogenous variables of the second stage with the fixed country effects among them) with equation $\ell = 1, 2$. Furthermore, note that

$$\mathbf{h}_{\ell t} = \tfrac{1}{N}\sum_{i=1}^{N} \mathbf{z}_{\ell it}\varepsilon_{\ell it}; \quad \mathbf{h}_{\ell s} = \tfrac{1}{N}\sum_{i=1}^{N} \mathbf{z}_{\ell is}\varepsilon_{\ell is}.$$

Hence, $E[\mathbf{h}_{\ell t}\mathbf{h}'_{\ell s}] = \frac{1}{N^2}\sum_{i=1}^{N} \mathbf{z}_{\ell it}\mathbf{z}'_{\ell is}E[\varepsilon_{\ell it}\varepsilon_{\ell is}]$. Then, the variance-covariance matrix of the two-stage least-squares estimator is defined as $\mathbf{V}_{\ell T} = (\mathbf{D}'_{\ell T}\mathbf{S}^{-1}_{\ell T}\mathbf{D}_{\ell T})^{-1}$. An estimator of this variance-covariance matrix is

$$\widehat{\mathbf{V}}_{\ell T} = (\widehat{\mathbf{D}}'_{\ell T}\widehat{\mathbf{S}}^{-1}_{\ell T}\widehat{\mathbf{D}}_{\ell T})^{-1}; \quad \widehat{\mathbf{D}}_{\ell T} = \sum_{t=1}^{T}\sum_{i=1}^{N} \mathbf{z}_{\ell it}\mathbf{x}'_{\ell it}, \tag{15}$$

where $\mathbf{x}_{\ell it}$ is a $P_\ell \times 1$ vector of exogenous variables in the second stage (note that

$P_\ell < K_\ell$ whenever the estimator is over-identified; $\mathbf{x}_{\ell it}$ corresponds to one row of $\mathbf{X}_{\ell t}$). Driscoll and Kraay (1998) prove that this Newey and West (1987)-type estimator of the variance-covariance matrix relies on fairly weak assumptions.

3.3 Estimation results

Table 2 summarizes the findings of the specifications as outlined in (11) and (12), using the statutory personal and corporate income tax rates on the left-hand-side and country size in terms of log gross domestic product (GDP) as well as the unemployment rate in percent as the two continuous exogenous variables in the second stage. To account for the presence of fixed country effects all estimates are based on within two-stage least-squares (see Baltagi, 2005).[8] According to the chosen notation, the continuous variables are collected in the matrix $\mathbf{X}_t$, for each year t.

Let us start with a general evaluation of the estimated models before turning to the discussion of the parameter estimates. Since all subsequently presented results rely on two-stage least-squares, there are two prerequisites for unbiased parameter estimates. First, the instruments need to be *relevant* in the first-stage models, and they need to be exogenous and, hence *adequate*. Instrument relevance can be determined by means of F-tests or, as we do, by means of partial R^2 (see Shea, 1997). The latter attributes the 'marginal' contribution of the identifying instruments to the explanatory power in the first stage model(s). Since we have two endogenous variables (namely, $\mathbf{W}\boldsymbol{\tau}_t$ and $\mathbf{W}\mathbf{t}_t$ in our application) there are two first-stage models and, accordingly, two partial R^2s for each of the equations (i.e., for $\boldsymbol{\tau}_t$ and $\mathbf{t}_t$). Instrument adequacy can be inferred from a test on over-identifying restrictions (see Sargan, 1958), provided that the number of

[8]Hence, all variables in the model are country-'demeaned'.

identifying instruments is larger than the number of endogenous variables (i.e., as long as $P_\ell > K_\ell$ according to the chosen notation).

In our application, the relevance of the identifying instruments is exceptionally high (see the corresponding footnote in Table 2 for details on the included instruments) in both of the first-stage equations, irrespective of which model we look at. Furthermore, the test of over-identifying restrictions does never reject the null hypothesis of exogenous instruments. Finally, the explanatory power of the estimated models is fairly high. Since both the variation across periods and the overall R^2 are larger for corporate tax rates than it is for personal income tax rates, it is not surprising that the (centered) within R^2 is also higher for that model than for the one for personal income tax rates.

−− Table 2 −−

The parameter estimates in Table 2 suggest that domestic and foreign (top) personal income tax rates and, even more so, domestic and foreign corporate tax rates are strategic complements. Hence, a country will be inclined towards lowering, say, its corporate tax rate in response to corporate tax cuts in adjacent economies (see Devereux, Lockwood, and Redoano, 2004, for similar evidence). Under the assumptions adopted in the theoretical model, we did not expect (top) personal income tax rates to respond to a change in the corresponding foreign counterpart.[9] The point estimates for $\rho_{\ell m}$ in the table suggest that corporate tax rates react marginally more sensitively to a change abroad than personal income tax rates. However, we would have expected the domestic personal income tax rate to be a strategic complement to the foreign corporate tax rate. Empirically, it turns out that countries use them as strategic substitutes. Hence, a typical

[9]It should be emphasized that this relationship does not emerge in our theoretical model, since national firms are not allowed to serve foreign markets via exports.

OECD country increased its personal income tax rate in response to a foreign cut of the corporate tax rate.

In Table 3, we use effective average tax rates for personal income and corporate profits instead of the statutory rates. In particular, effective rates capture other arguments of tax burden beyond the statutory tax rates (e.g., the definition of the tax base). In terms of the model characteristics (explanatory power as well as instrument relevance and adequacy), the effective tax rate-based specifications work similarly well as the ones based on the statutory rate.

−− Table 3 −−

Also the parameter estimates are qualitatively similar to the original ones in Table 2. The results in Table 2 suggest that effective rates react less sensitively to changes abroad than statutory ones. In general, this may have to do with the fact that statutory rates are easier to control than effective ones, since they also depend on entrepreneurial decisions (such as the extent, timing, and type of partially deductible investments).

4 Conclusions

In most of the OECD member countries, the lion's share of firms is not incorporated. However, these firms are typically national in scope: neither doe they export nor do they run foreign subsidiaries. Hence, national and multinational firms face different tax rates. This paper analyzes a simple model with national and one multinational firm to explore the normative dimension about taxing unincorporated versus incorporated firms. We then proceed to implement an empirical approach that is suited to analyze the strategic interaction between personal income tax rates (i.e., ones that unincorporated firms are typically faced with) and corporate tax rates (i.e., ones that typically pertain to incorporated, multinational firms).

We find that domestic and foreign tax rates of the same kind (corporate versus personal income) work as strategic complements. Hence, if a typical country's neighbors lower their corporate tax rates, the country tends to respond by a corporate tax cut as well. We would have expected to see this pattern from the theoretical model. Countries use their personal income tax rates in a similar way. With regard to the latter, we would have expected no or only a small response (based on a fairly restrictive set of assumptions in the theoretical model). Moreover, foreign corporate tax rates and domestic personal tax rates turn out to be strategic substitutes in the empirical analysis, while we would have expected them to be strategic complements against the theoretical background.

Our analysis seems interesting in at least two regards. First, it is important to recognize that developed countries use corporate and personal income tax rates in a similar strategic way. Second, it seems overly restrictive to think of national firms as fully immobile and their profits only collected from national sales. While the consideration of mobile national and multinational firms was beyond the scope of our work, the empirical findings are suggestive of a better understanding of strategic company taxation: countries seem to compete in more than just a single instrument, and they seem to react as sensitively to tax instruments targeted towards the profits of unincorporated firms as to ones of incorporated firms. Ignoring the role of personal income tax competition for corporate tax competition could lead to biased inference about the intensity of competition in one dimension. Moreover, one could be inclined towards attributing some relevance to corporate tax competition which in fact should be attributed to other dimensions of the multidimensional system of tax competition.

Acknowledgements

Peter Egger gratefully acknowledges financial support from the Austria Science Fund through Grant nr. P17713-G05. Michael Pfaffermayr and Hannes Winner gratefully acknowledge financial support from the Austria Science Fund through Grant nr. P17028-G05. All authors gratefully acknowledge funding by the European Tax Policy Forum.

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Appendix

Some supplementary derivations

To derive the corresponding first order conditions observe that

$$\begin{aligned}
\frac{\partial \delta_i}{\partial \tau_i} &= \tfrac{-\alpha(1-\tau_i)+(1-\alpha\tau_i)}{(1-\tau_i)^2} = \tfrac{1-\alpha}{(1-\tau_i)^2} > 0 \\
\frac{\partial \theta_i}{\partial t_i} &= \tfrac{-\alpha(1-t_i)+(1-\alpha t_i)}{(1-t_i)^2} = \tfrac{1-\alpha}{(1-t_i)^2} > 0
\end{aligned}$$

$$\begin{aligned}
\frac{\partial s_i^{N*}}{\partial \tau_i} &= -\tfrac{2}{3}\tfrac{\partial \delta_i}{\partial \tau_i} = -\tfrac{2}{3}\tfrac{1-\alpha}{(1-\tau_i)^2} < 0 \\
\frac{\partial^2 s_i^{N*}}{\partial \tau_i^2} &= -\tfrac{4}{3}\tfrac{1-\alpha}{(1-\tau_i)^3} = \tfrac{2}{(1-\tau_i)}\tfrac{\partial s_i^{N*}}{\partial \tau_i} < 0 \\
\frac{\partial s_i^{N*}}{\partial t_i} &= \tfrac{1}{3}\tfrac{\partial \theta_i}{\partial t_i} = \tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^2} > 0 \\
\frac{\partial^2 s_i^{N*}}{\partial t_i^2} &= \tfrac{2}{3}\tfrac{1-\alpha}{(1-t_i)^3} > 0 \\
\frac{\partial s_i^{M*}}{\partial \tau_i} &= \tfrac{1}{3}\tfrac{\partial \delta_i}{\partial \tau_i} = \tfrac{1}{3}\tfrac{1-\alpha}{(1-\tau_i)^2} = -\tfrac{1}{2}\tfrac{\partial s_1^{N*}}{\partial \tau_1} > 0 \\
\frac{\partial^2 s_i^{M*}}{\partial \tau_i^2} &= \tfrac{2}{3}\tfrac{1-\alpha}{(1-\tau_i)^3} = -2\tfrac{\partial^2 s_1^{N*}}{\partial \tau_1^2} = \tfrac{2}{(1-\tau_i)}\tfrac{\partial s_i^{M*}}{\partial \tau_i} > 0 \\
\frac{\partial s_i^{M*}}{\partial t_i} &= -\tfrac{2}{3}\tfrac{\partial \theta_i}{\partial t_i} = -\tfrac{2}{3}\tfrac{1-\alpha}{(1-t_i)^2} = -2\tfrac{\partial s_1^{N*}}{\partial t_1} < 0 \\
\frac{\partial^2 s_i^{M*}}{\partial t_i^2} &= -\tfrac{4}{3}\tfrac{1-\alpha}{(1-t_i)^3} < 0 \\
\frac{\partial p_i}{\partial \tau_i} &= \tfrac{1}{3}\tfrac{\partial \delta_i}{\partial \tau_i} = \tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^2} = \tfrac{\partial s_i^{M*}}{\partial \tau_i} > 0 \\
\frac{\partial^2 p_i}{\partial \tau_i^2} &= \tfrac{2}{3}\tfrac{(1-\alpha)}{(1-t_i)^3} > 0 \\
\frac{\partial p_i}{\partial t_i} &= \tfrac{1}{3}\tfrac{\partial \theta_i}{\partial t_i} = \tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^2} = \tfrac{\partial s_i^{N*}}{\partial t_i} > 0 \\
\frac{\partial^2 p_i}{\partial t_i^2} &= \tfrac{2}{3}\tfrac{1-\alpha}{(1-t_i)^3} > 0
\end{aligned}$$

Use the definitions of the tax bases for personal income and corporate taxes in country i given in (8) and (9) to determine

$$\begin{aligned} B_{\tau_i} - B_{t_i} &= (p_i^* - \alpha)\left(s_i^{N*} - s_i^{M*}\right) \\ &= (p_i^* - \alpha)(\theta_i - \delta_i) + \rho(t_j - t_i)F \end{aligned}$$

with $i, j = 1, 2$ and $i \neq j$, as before.

Recall the definition of country i's tax income from (10) to determine the following set of first and second derivatives:

$$\begin{aligned} \frac{\partial T_i}{\partial \tau_i} &= B_{\tau_i} + \tau_i \frac{\partial B_{\tau_i}}{\partial \tau_i} + t_i \frac{\partial B_{t_i}}{\partial \tau_i} = 0 \\ \frac{\partial^2 T_i}{\partial \tau_i^2} &= 2\frac{\partial B_{\tau_i}}{\partial \tau_i} + \tau_i \frac{\partial^2 B_{\tau_i}}{\partial \tau_i^2} + t_i \frac{\partial^2 B_{t_i}}{\partial^2 \tau_i} < 0?? \\ &= \frac{1}{3}\frac{1-\alpha}{(1-\tau_i)^2}\left(-2s_i^{N*} - 4\frac{1-\alpha}{1-\tau_i}\right) \\ &\quad + \frac{\tau_i}{3}\frac{1-\alpha}{(1-\tau_i)^3}\left(-s_i^{N*} - \frac{10}{3}\frac{1-\alpha}{1-\tau_i}\right) \\ &\quad \frac{t_i}{3}\frac{1-\alpha}{(1-\tau_i)^3}\left(2s_i^{M*} + \frac{1-\alpha}{1-t_i} + \frac{2}{3}\frac{1-\alpha}{1-\tau_i}\right) \\ \frac{\partial T_i}{\partial t_i} &= B_{t_i} + \tau_i \frac{\partial B_{\tau_i}}{\partial t_i} + t_i \frac{\partial B_{t_i}}{\partial t_i} = 0 \\ \frac{\partial^2 T_i}{\partial^2 t_i} &= 2\frac{\partial B_{t_i}}{\partial t_i} + \tau_i \frac{\partial^2 B_{\tau_i}}{\partial t_i^2} + t_i \frac{\partial^2 B_{t_i}}{\partial t_i^2} < 0?? \\ &= \frac{2}{3}\frac{1-\alpha}{(1-t_i)^2}\left(-s_i^{M*} - 2\frac{1-\alpha}{1-t_i}\right) - 2\rho F \\ &\quad + \frac{\tau_i}{3}\frac{1-\alpha}{(1-t_i)^3}\left(2s_i^{N*} + \frac{1-\alpha}{1-\tau_i} + \frac{2(1-\alpha)}{3(1-t_i)}\right) \\ &\quad + t_i \frac{1}{3}\frac{1-\alpha}{(1-t_i)^3}\left(-s_i^{M*} - \frac{10}{3}\frac{1-\alpha}{1-t_i}\right) \\ \frac{\partial^2 T_i}{\partial \tau_i \partial t_i} &= 2\frac{\partial B_{\tau_i}}{\partial t_i} + \tau_i \frac{\partial^2 B_{\tau_i}}{\partial \tau_i \partial t_i} + t_i \frac{\partial^2 B_{t_i}}{\partial \tau_i \partial t_i} \\ \frac{\partial^2 T_i}{\partial t_i \partial t_j} &= \frac{\partial B_{t_i}}{\partial t_j} + t_i \frac{\partial^2 B_{t_i}}{\partial t_i \partial t_j} = \rho F > 0 \end{aligned}$$

Therefore, we obtain

$$\frac{\partial T_i}{\partial \tau_i} - \frac{\partial T_i}{\partial t_i} = B_{\tau_i} - B_{t_i} + \tau_i\left(\frac{\partial B_{\tau_i}}{\partial \tau_i} - \frac{\partial B_{\tau_i}}{\partial t_i}\right) + t_i\left(\frac{\partial B_{t_i}}{\partial \tau_i} - \frac{\partial B_{t_i}}{\partial t_i}\right) - \rho\left(t_j - 2t_i\right)F = 0.$$

Observe that

$$\begin{aligned} \frac{\partial B_{\tau_i}}{\partial \tau_i} &= -\frac{4}{3}\frac{1-\alpha}{(1-\tau_i)^2}s_i^{N*} + \frac{3}{3}\frac{1-\alpha}{(1-\tau_i)^2}s_i^{N*} - \frac{1-\alpha}{(1-\tau_i)}\frac{2}{3}\frac{1-\alpha}{(1-\tau_i)^2} \\ &= \frac{1}{3}\frac{1-\alpha}{(1-\tau_i)^2}\left(-s_i^{N*} - 2\frac{1-\alpha}{(1-\tau_i)}\right) < 0 \end{aligned}$$

$$
\begin{aligned}
\frac{\partial^2 B_{\tau_i}}{\partial \tau_i^2} &= \tfrac{1}{3}\tfrac{1-\alpha}{(1-\tau_i)^3}\left(-s_i^{N*} - 2\tfrac{1-\alpha}{(1-\tau_i)}\right) + \tfrac{1}{3}\tfrac{1-\alpha}{(1-\tau_i)^2}\left(+\tfrac{2}{3}\tfrac{1-\alpha}{(1-\tau_i)^2} - 2\tfrac{1-\alpha}{(1-\tau_i)^2}\right) \\
&= \tfrac{1}{3}\tfrac{1-\alpha}{(1-\tau_i)^3}\left(-s_i^{N*} - 2\tfrac{1-\alpha}{(1-\tau_i)} - \tfrac{4}{3}\tfrac{1-\alpha}{(1-\tau_i)}\right) \\
&= \tfrac{1}{3}\tfrac{1-\alpha}{(1-\tau_i)^3}\left(-s_i^{N*} - \tfrac{10}{3}\tfrac{1-\alpha}{(1-\tau_i)}\right) < 0
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial B_{\tau_i}}{\partial t_i} &= \tfrac{2}{3}\tfrac{1-\alpha}{(1-t_i)^2}s_i^{N*} + \tfrac{1-\alpha}{(1-\tau_i)}\tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^2} \\
&= \tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^2}\left(2s_i^{N*} + \tfrac{1-\alpha}{(1-\tau_i)}\right) > 0 \\
\frac{\partial B_{\tau_i}}{\partial t_i \partial \tau_i} &= \tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^2}\left(-\tfrac{4}{3}\tfrac{1-\alpha}{(1-\tau_i)^2} + \tfrac{1-\alpha}{(1-\tau_i)^2}\right) \\
&= \tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^2}\left(-\tfrac{1-\alpha}{(1-\tau_i)^2}\right) < 0 \\
\frac{\partial^2 B_{\tau_i}}{\partial t_i^2} &= \tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^3}\left(2s_i^{N*} + \tfrac{1-\alpha}{(1-\tau_i)}\right) + \tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^2}\left(\tfrac{2(1-\alpha)}{3(1-t_i)^2}\right) \\
&= \tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^3}\left(2s_i^{N*} + \tfrac{1-\alpha}{1-\tau_i} + \tfrac{2(1-\alpha)}{3(1-t_i)}\right) > 0
\end{aligned}
$$

$$
\left(s_i^{M*}\right)^2 + \tfrac{1-\alpha}{(1-t_i)}s_i^{M*} + \rho(t_j - t_i)F
$$

$$
\begin{aligned}
\frac{\partial B_{t_i}}{\partial t_i} &= -\tfrac{4}{3}\tfrac{1-\alpha}{(1-t_i)^2}s_i^{M*} + \tfrac{3}{3}\tfrac{1-\alpha}{(1-t_i)^2}s_i^{M*} - \tfrac{1-\alpha}{(1-t_i)}\tfrac{2}{3}\tfrac{1-\alpha}{(1-t_i)^2} - \rho F \\
&= \tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^2}\left(-s_i^{M*} - 2\tfrac{1-\alpha}{(1-t_i)}\right) - \rho F < 0 \\
\frac{\partial^2 B_{t_i}}{\partial t_i^2} &= \tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^3}\left(-s_i^{M*} - 2\tfrac{1-\alpha}{(1-t_i)}\right) + \tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^2}\left(+\tfrac{2}{3}\tfrac{1-\alpha}{(1-t_i)^2} - 2\tfrac{1-\alpha}{(1-t_i)^2}\right) \\
&= \tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^3}\left(-s_i^{M*} - 2\tfrac{1-\alpha}{(1-t_i)} - \tfrac{4}{3}\tfrac{1-\alpha}{(1-t_i)}\right) \\
&= \tfrac{1}{3}\tfrac{1-\alpha}{(1-t_i)^3}\left(-s_i^{M*} - \tfrac{10}{3}\tfrac{1-\alpha}{(1-t_i)}\right) < 0
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial B_{t_i}}{\partial \tau_i} &= \tfrac{\partial}{\partial \tau_i}\left(\left(s_i^{M*}\right)^2 + \tfrac{1-\alpha}{1-t_i}s_i^{M*} + \rho(t_j - t_i)F\right) \\
&= \tfrac{2}{3}\tfrac{1-\alpha}{(1-\tau_i)^2}s_i^{M*} + \tfrac{1-\alpha}{1-t_i}\tfrac{1}{3}\tfrac{1-\alpha}{(1-\tau_i)^2} \\
&= \tfrac{1}{3}\tfrac{1-\alpha}{(1-\tau_i)^2}\left(2s_i^{M*} + \tfrac{1-\alpha}{1-t_i}\right) > 0
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial^2 B_{t_i}}{\partial \tau_i^2} &= \frac{1}{3}\frac{1-\alpha}{(1-\tau_i)^3}\left(2s_i^{M*}+\frac{1-\alpha}{1-t_i}\right)+\frac{1}{3}\frac{1-\alpha}{(1-\tau_i)^2}\left(\frac{2}{3}\frac{1-\alpha}{(1-\tau_i)^2}\right)\\
&= \frac{1}{3}\frac{1-\alpha}{(1-\tau_i)^3}\left(2s_i^{M*}+\frac{1-\alpha}{1-t_i}+\frac{2}{3}\frac{1-\alpha}{1-\tau_i}\right)>0\\
\frac{\partial^2 B_{t_i}}{\partial \tau_i \partial t_i} &= \frac{1}{3}\frac{1-\alpha}{(1-\tau_i)^2}\left(-\frac{4}{3}\frac{1-\alpha}{(1-t_i)^2}+\frac{1-\alpha}{(1-t_i)^2}\right)\\
&= \frac{1}{3}\frac{1-\alpha}{(1-\tau_i)^2}\left(-\frac{1-\alpha}{(1-t_i)^2}\right)<0
\end{aligned}
$$

Proof of Proposition 1

For the proof of Proposition 1, let us proceed in two steps.

Part A of the proof of Proposition 1

It is useful to note (and prove) first that $t_i < \tau_i$ if $t_j > 2t_iF - \tau_iF$ in the Nash-equilibrium. At $\tau_i = t_i$ in the Nash-equilibrium, we have $s_i^{M*} = s_i^{N*}$, $B_{\tau_i} - B_{t_i} = \rho(t_j - t_i)F$, $\frac{\partial B_{\tau_i}}{\partial \tau_i} - \frac{\partial B_{t_i}}{\partial t_i} = -\rho F$, and $\frac{\partial B_{t_i}}{\partial \tau_i} = \frac{\partial B_{\tau_i}}{\partial t_i}$. Hence, $\frac{\partial T_i}{\partial t_i} = \frac{\partial T_i}{\partial \tau_i} - \rho\left(t_j - 2t_i\right)F + \tau_i\frac{\partial B_{\tau_i}}{\partial \tau_i} - t_i\frac{\partial B_{t_i}}{\partial t_i} = -\rho\left(t_j - 2t_i\right)F - \tau_i\rho F < 0$, if $t_j > 2t_iF - \tau_iF = \tau_iF$ using $\frac{\partial T_i}{\partial \tau_i} = 0$. This contradicts the first order condition for t_i and one can conclude that $t_i < \tau_i$. Note $\frac{\partial^2 T_i}{\partial^2 t_i} = 2\frac{\partial B_{t_i}}{\partial t_i} + \tau_i\frac{\partial^2 B_{\tau_i}}{\partial t_i^2} + t_i\frac{\partial^2 B_{t_i}}{\partial t_i^2} < 0$ has to hold, which has been stated.

Part B of the proof of Proposition 1

Assume that $t_i = t_j = \tau_i = \tau_j$. Then, $B_{\tau_i} = B_{t_i}$. Let us use Part A of the proof and observe that $\frac{\partial T_i}{\partial t_i} = \rho\left(t_i - \tau_i\right)F = 0$ at $\tau_i = t_i$. Hence, there exists a symmetric Nash-equilibrium with $\tau_i = t_i = \tau_j = t_j$. The same argument shows that $t_i = t_j = \tau_i = \tau_j$ $\frac{\partial T_j}{\partial \tau_j} = \frac{\partial T_j}{\partial t_j} = 0$.

Proof of Proposition 2

Recall the definition of $\frac{\partial^2 T_i}{\partial \tau_i^2}$ from the first section of the Appendix and, for the Nash equilibrium, use $\tau \equiv \tau_i = t_i$ and $s_i^* \equiv s_i^{N*} = s_i^{M*}$ to see that

$$
\begin{aligned}
\frac{\partial^2 T_i}{\partial \tau_i^2}\Big|_{Nash} &= \frac{1}{3}\frac{1-\alpha}{(1-\tau)^3}\left(-2s_i^{N*}(1-\tau)-4\left(1-\alpha\right)-\tau s_i^* - \frac{\tau 10}{3}\frac{1-\alpha}{1-\tau}+2\tau s_i^* + \frac{5\tau}{3}\frac{1-\alpha}{1-\tau}\right)\\
&= \frac{1}{3}\frac{1-\alpha}{(1-\tau)^3}\left(-\left(2+3\tau\right)s_i^* - 4\left(1-\alpha\right) - \frac{5\tau}{3}\frac{1-\alpha}{1-\tau}\right)<0.
\end{aligned}
$$

In addition, it can easily be seen that

$$\frac{\partial^2 T_i}{\partial \tau_i \partial \tau_j}\Big|_{Nash} = \frac{\partial^2 T_i}{\partial \tau_i \partial t_j}\Big|_{Nash} = \frac{\partial^2 T_i}{\partial t_i \partial \tau_j}\Big|_{Nash} = 0.$$

Recall the definition of $\frac{\partial^2 T_i}{\partial \tau_i \partial t_i}$ from the first section of the Appendix to determine

$$\frac{\partial^2 T_i}{\partial \tau_i \partial t_i}\Big|_{Nash} = \frac{2}{3}\frac{1-\alpha}{(1-\tau)^2}\left(2s_i^* + \frac{1-\alpha}{1-\tau}\right) + \frac{2\tau}{3}\frac{(1-\alpha)^2}{(1-\tau)^4} > 0.$$

Furthermore, recall the definition of $\frac{\partial^2 T_i}{\partial t_i^2}$ from the first part of the Appendix and evaluate at the symmetric Nash equilibrium to derive

$$\begin{aligned}
\frac{\partial^2 T_i}{\partial t_i^2}\Big|_{Nash} &= \frac{1}{3}\frac{1-\alpha}{(1-\tau)^3}\left(-2s_i^*(1-\tau) - 4(1-\alpha) - 4\rho F(1-\tau)\right) \\
&\quad + \frac{1}{3}\frac{1-\alpha}{(1-\tau)^3}\left(2\tau s_i^* + \tau \frac{5}{3}\frac{1-\alpha}{1-\tau}\right) \\
&\quad + \frac{1}{3}\frac{1-\alpha}{(1-t_i)^3}\left(-\tau s_i^* - \tau \frac{10}{3}\frac{1-\alpha}{1-\tau}\right) \\
&= \frac{1}{3}\frac{1-\alpha}{(1-\tau)^3}\left(-\left(2+3\tau\right)s_i^* - 4\left(1-\alpha\right) - \frac{5\tau}{3}\frac{1-\alpha}{1-\tau} - 4\rho F(1-\tau)\right) < 0.
\end{aligned}$$

Finally,

$$\frac{\partial T_i}{\partial t_i \partial t_j} = \frac{\partial B_{t_i}}{\partial t_j} + t_i \frac{\partial^2 B_{t_i}}{\partial t_i \partial t_j} = \rho F > 0$$

Totally differentiating the reaction functions $\frac{T_i}{\partial \tau_i} = 0$ and $\frac{T_i}{\partial t_i} = 0$ gives

$$\begin{bmatrix} \frac{\partial^2 T_i}{\partial \tau_i^2} & \frac{\partial^2 T_i}{\partial \tau_i \partial t_i} & 0 & 0 \\ \frac{\partial^2 T_i}{\partial \tau_i \partial t_i} & \frac{\partial^2 T_i}{\partial t_i^2} & 0 & \frac{\partial T_i}{\partial t_i \partial t_j} \end{bmatrix} \begin{bmatrix} d\tau_i \\ dt_i \\ d\tau_j \\ dt_j \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} \frac{\partial^2 T_i}{\partial \tau_i^2} & \frac{\partial^2 T_i}{\partial \tau_i \partial t_i} \\ \frac{\partial^2 T_i}{\partial \tau_i \partial t_i} & \frac{\partial^2 T_i}{\partial t_i^2} \end{bmatrix} \begin{bmatrix} d\tau_i \\ dt_i \end{bmatrix} = -\begin{bmatrix} 0 & 0 \\ 0 & \frac{\partial T_i}{\partial t_i \partial t_j} \end{bmatrix} \begin{bmatrix} d\tau_j \\ dt_j \end{bmatrix}$$

$$\begin{bmatrix} d\tau_i \\ dt_i \end{bmatrix} = -\frac{1}{D} \begin{bmatrix} \frac{\partial^2 T_i}{\partial t_i^2} & -\frac{\partial^2 T_i}{\partial \tau_i \partial t_i} \\ -\frac{\partial^2 T_i}{\partial \tau_i \partial t_i} & \frac{\partial^2 T_i}{\partial \tau_i^2} \end{bmatrix} \begin{bmatrix} 0 & 0 \\ 0 & \frac{\partial T_i}{\partial t_i \partial t_j} \end{bmatrix} \begin{bmatrix} d\tau_j \\ dt_j \end{bmatrix}$$

$$= -\frac{1}{D} \begin{bmatrix} 0 & -\frac{\partial^2 T_i}{\partial \tau_i \partial t_i} \frac{\partial T_i}{\partial t_i \partial t_j} \\ 0 & \frac{\partial^2 T_i}{\partial \tau_i^2} \frac{\partial T_i}{\partial t_i \partial t_j} \end{bmatrix} \begin{bmatrix} d\tau_j \\ dt_j \end{bmatrix}$$

where

$$D = \frac{\partial^2 T_i}{\partial \tau_i^2} \frac{\partial^2 T_i}{\partial t_i^2} - \left(\frac{\partial^2 T_i}{\partial \tau_i \partial t_i} \right)^2 > 0$$

due to the second order condition. As a result, we have

$$\begin{aligned} \frac{d\tau_i}{d\tau_j} |_{Nash} &= 0 \\ \frac{d\tau_i}{dt_j} |_{Nash} &= -\frac{1}{D} \frac{\partial^2 T_i}{\partial \tau_i \partial t_i} \frac{\partial T_i}{\partial t_i \partial t_j} > 0 \end{aligned}$$

$$\begin{aligned} \frac{dt_i}{d\tau_j} |_{Nash} &= 0. \\ \frac{dt_i}{dt_j} |_{Nash} &= -\frac{1}{D} \frac{\partial T_i}{\partial t_i \partial t_j} / \frac{\partial^2 T_i}{\partial t_i^2} > 0 \end{aligned}$$

In the Nash-Equilibrium with $t_i = \tau_i = \tau$ and $s_i^{N*} = s_i^{M*} = s_i^*$, we have $\frac{\partial^2 T_i}{\partial t_i^2}\left|_{Nash}\right. = \frac{\partial^2 T_i}{\partial \tau_i^2}\left|_{Nash}\right. - 2\rho F$. Accordingly,

$$
\begin{aligned}
D\left|_{Nash}\right. &= \left[\left(\frac{\partial^2 T_i}{\partial \tau_i^2}\left|_{Nash}\right.\right)\left(\frac{\partial^2 T_i}{\partial t_i^2}\left|_{Nash}\right.\right) - \left(\frac{\partial^2 T_i}{\partial \tau_i \partial t_i}\left|_{Nash}\right.\right)^2\right] \\
&= \left(\frac{\partial^2 T_i}{\partial \tau_i^2}\left|_{Nash}\right.\right)^2 - 2\rho F \frac{\partial^2 T_i}{\partial \tau_i^2}\left|_{Nash}\right. - \left(\frac{\partial^2 T_i}{\partial \tau_i \partial t_i}\left|_{Nash}\right.\right)^2 \\
\left(\frac{\partial^2 T_i}{\partial \tau_i^2}\left|_{Nash}\right.\right)^2 &= \left\{-\frac{1}{3}\frac{1-\alpha}{(1-\tau)^3}\left[(2+3\tau)\, s_i^* + 4\,(1-\alpha) + \frac{5\tau}{3}\frac{1-\alpha}{1-\tau}\right]\right\}^2 > 0 \\
-2\rho F \frac{\partial^2 T_i}{\partial \tau_i^2}\left|_{Nash}\right. &= 2\rho F \left\{\frac{1}{3}\frac{1-\alpha}{(1-\tau)^3}\left[(2+3\tau)\, s_i^* + 4\,(1-\alpha) + \frac{5\tau}{3}\frac{1-\alpha}{1-\tau}\right]\right\} > 0 \\
-\left(\frac{\partial^2 T_i}{\partial \tau_i \partial t_i}\left|_{Nash}\right.\right)^2 &= -\left\{\frac{2}{3}\frac{1-\alpha}{(1-\tau)^2}\left[2s_i^* + \frac{1-\alpha}{1-\tau}\right] + \frac{2\tau}{3}\frac{(1-\alpha)^2}{(1-\tau)^4}\right\}^2 < 0.
\end{aligned}
$$

Note that $D\left|_{Nash}\right.$ will not be generally positive. However, $D\left|_{Nash}\right. > 0$ if ρF is sufficiently large.

Proof of Proposition 3

Use the definitions of B_{tau_i} and B_{t_i} given in (8) and (9) and note that

$$
\begin{aligned}
\frac{\partial^2 T_i}{\partial \tau_i \partial a_i} &= \frac{\partial}{\partial a_i}\left(B_{\tau_i} + \tau_i \frac{\partial B_{\tau_i}}{\partial \tau_i} + t_i \frac{\partial B_{t_i}}{\partial \tau_i}\right) = \frac{\partial B_{t_i}}{\partial \tau_i} + \tau_i \frac{\partial^2 B_{\tau_i}}{\partial \tau_i a_i} + \tau_i \frac{\partial^2 B_{t_i}}{\partial \tau_i \partial a_i} \\
\frac{\partial B_{\tau_i}}{\partial a_i} &= \left(2s_i^{N*} + \frac{1-\alpha}{1-\tau_i}\right)\frac{\partial s_i^{N*}}{\partial a_i} = \frac{1}{3}\left(2s_i^{N*} + \frac{1-\alpha}{1-\tau_i}\right) \\
\frac{\partial^2 B_{\tau_i}}{\partial \tau_i \partial a_i} &= \frac{\partial}{\partial a_i}\left(\frac{1}{3}\frac{1-\alpha}{(1-\tau_i)^2}\left(-s_i^{N*} - 2\frac{1-\alpha}{1-\tau_i}\right)\right) = -\frac{1}{9}\frac{1-\alpha}{(1-\tau_i)^2} \\
\frac{\partial^2 B_{t_i}}{\partial \tau_i \partial a_i} &= \frac{\partial}{\partial a_i}\left(\frac{1}{3}\frac{1-\alpha}{(1-t_i)^2}\left(2s_i^{N*} + \frac{1-\alpha}{(1-\tau_i)}\right)\right) = \frac{2}{9}\frac{1-\alpha}{(1-t_i)^2} \\
\frac{\partial B_{t_i}}{\partial a_i} &= \frac{1}{3}\left(2s_i^{M*} + \frac{1-\alpha}{1-t_i}\right) \\
\frac{\partial^2 B_{\tau_i}}{\partial \tau_i \partial a_i} &= \frac{2}{9}\frac{1-\alpha}{(1-\tau_i)^2} \\
\frac{\partial^2 B_{t_i}}{\partial t_i \partial a_i} &= -\frac{1}{9}\frac{1-\alpha}{(1-t_i)^2}
\end{aligned}
$$

Hence, in the Nash-equilibrium

$$
\begin{aligned}
\frac{\partial^2 T_i}{\partial \tau_i \partial a_i}\Big|_{Nash} &= \frac{\partial^2 T_i}{\partial t_i \partial a_i} = \frac{1}{3}\left(2s_i^* + \frac{1-\alpha}{1-\tau}\right) + \frac{\tau}{9}\frac{1-\alpha}{(1-\tau)^2} > 0 \\
\frac{\partial B_{\tau_i}}{\partial a_i}\Big|_{Nash} &= \frac{\partial B_{t_i}}{\partial a_i}\Big|_{Nash} = \frac{1}{3}\left(2s_i^* + \frac{1-\alpha}{1-\tau}\right) > 0 \\
\frac{\partial^2 B_{\tau_i}}{\partial \tau_i \partial a_i}\Big|_{Nash} &= \frac{\partial^2 B_{\tau_i}}{\partial t_i \partial a_i}\Big|_{Nash} = -\frac{1}{9}\frac{1-\alpha}{(1-\tau)^2} < 0 \\
\frac{\partial^2 B_{t_i}}{\partial \tau_i \partial a_i}\Big|_{Nash} &= \frac{\partial^2 B_{\tau_i}}{\partial t_i \partial a_i}\Big|_{Nash} = \frac{2}{9}\frac{1-\alpha}{(1-\tau)^2} > 0.
\end{aligned}
$$

$$
\begin{bmatrix} \frac{\partial^2 T_i}{\partial \tau_i^2} & \frac{\partial^2 T_i}{\partial \tau_i \partial t_i} & \frac{\partial^2 T_i}{\partial \tau_i \partial a_i} & 0 \\ \frac{\partial^2 T_i}{\partial \tau_i \partial t_i} & \frac{\partial^2 T_i}{\partial t_i^2} & \frac{\partial^2 T_i}{\partial t_i \partial a_i} & \end{bmatrix}
\begin{bmatrix} d\tau_i \\ dt_i \\ da_i \\ da_j \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}
$$

$$
\begin{aligned}
\begin{bmatrix} d\tau_i \\ dt_i \end{bmatrix} &= -\frac{1}{D}\begin{bmatrix} \frac{\partial^2 T_i}{\partial t_i^2} & -\frac{\partial^2 T_i}{\partial \tau_i \partial t_i} \\ -\frac{\partial^2 T_i}{\partial \tau_i \partial t_i} & \frac{\partial^2 T_i}{\partial \tau_i^2} \end{bmatrix} \begin{bmatrix} \frac{\partial^2 T_i}{\partial \tau_i \partial a_i} & 0 \\ \frac{\partial^2 T_i}{\partial t_i \partial a_i} & \end{bmatrix} \begin{bmatrix} da_i \\ da_j \end{bmatrix} \\
&= -\frac{1}{D}\begin{bmatrix} \left(\frac{\partial^2 T_i}{\partial t_i^2} - \frac{\partial^2 T_i}{\partial \tau_i \partial t_i}\right)\frac{\partial^2 T_i}{\partial \tau_i \partial a_i} \\ \left(-\frac{\partial^2 T_i}{\partial \tau_i \partial t_i} - \frac{\partial^2 T_i}{\partial \tau_i^2}\right)\frac{\partial^2 T_i}{\partial \tau_i \partial a_i} \end{bmatrix} \begin{bmatrix} da_i \\ da_j \end{bmatrix}
\end{aligned}
$$

Table 1: Descriptive Statistics

Variable	**Observations**	**Mean**	**Standard deviation**	**Minimum**	**Maximum**
Statutory personal income tax rate	567	0.430	0.127	0.115	0.800
Effective average personal income tax rate	567	0.370	0.104	0.063	0.569
Statutory corporate tax rate	567	0.353	0.093	0.100	0.614
Effective average corporate income tax rate	567	0.290	0.076	0.070	0.521
log(GDP)	567	24.252	2.572	19.409	30.006
Unemployment rate	567	7.154	3.861	0.441	19.931

Table 2: Reaction function estimation for statutory corporate and personal income tax rates

	Personal income tax rate			Corporate tax rate		
Explanatory variable	Coef.	Std.[a)]	Std.[b)]	Coef.	Std.[a)]	Std.[b)]
Spatially weighted personal income tax rate ($\mathbf{W\tau}_t$)	0.416	0.185	0.126	-0.599	0.286	0.146
Spatially weighted corporate tax rate ($\mathbf{Wt}_t$)	-0.481	0.196	0.149	0.422	0.273	0.163
Log GDP ($\mathbf{a}_{t-1}$)	-0.233	0.017	0.018	-0.202	0.014	0.003
Unemployment rate ($\mathbf{u}_t$)	-0.004	0.002	0.001	-0.011	0.001	0.001
Observations		537			567	
Countries		30			30	
Centered R^2		0.715			0.731	
Centered within R^2		0.265			0.404	
Shea's (1997) partial R^2						
$\mathbf{W\tau}_t$		0.520			0.612	
$\mathbf{Wt}_t$		0.516			0.613	
Sargan test on overidentifying restrictions (p-value)[c)]		0.767			0.675	

Notes: All two-stage least-squares models include fixed country effects. - a) Based on Huber-White sandwich estimates of the variance-covariance matrix to guard against heteroskedasticity. - b) Based on Driscoll and Kraay (1998)-type HAC estimates of the variance-covariance matrix to guard to guard against heteroskedasticity and time- as well as spatial autocorrelation. - c) The following identifying instruments have been used in the first stage: $\mathbf{Wx}_{1t}$, $\mathbf{Wx}_{2t}$, $\mathbf{Wx}_{3t}$, $\mathbf{Wx}_{4t}$, $\mathbf{W}^2\mathbf{x}_{5t}$, $\mathbf{W}^3\mathbf{x}_{2t}$ (for the top personal income tax rate on the left-hand-side); $\mathbf{Wx}_{1t}$ $\mathbf{Wx}_{2t}$, $\mathbf{Wx}_{3t}$, $\mathbf{Wx}_{4t}$, $\mathbf{W}^2\mathbf{x}_{1t}$, $\mathbf{W}^2\mathbf{x}_{4t}$, $\mathbf{W}^3\mathbf{x}_{3t}$, $\mathbf{W}^3\mathbf{x}_{4t}$ (for the corporate tax rate on the left-hand-side), where W is an N×N inverse-distance-based row-normalized spatial weighting matrix $\mathbf{x}_{1t},...,\mathbf{x}_{4t}$ are N×1 vectors of explanatory variables with $\mathbf{x}_{1t}$~log GDP, $\mathbf{x}_{2t}$~log unit labor costs, $\mathbf{x}_{3t}$~debt-to-GDP ratio; $\mathbf{x}_{4t}$~unemployment rate in percent.

Table 3: Reaction function estimation for effective average corporate and personal income tax rates

	Effective average personal income tax rate			Effective average corporate tax rate		
Explanatory variable	Coef.	Std.[a)]	Std.[b)]	Coef.	Std.[a)]	Std.[b)]
Spatially weighted personal income tax rate ($\mathbf{W\tau}_t$)	0.366	0.138	0.055	-0.387	0.236	0.054
Spatially weighted corporate tax rate ($\mathbf{Wt}_t$)	-0.227	0.122	0.052	0.232	0.192	0.054
Log GDP ($\mathbf{a}_{t-1}$)	-0.016	0.011	0.005	-0.163	0.013	0.004
Unemployment rate ($\mathbf{u}_t$)	-0.001	0.001	0.001	-0.009	0.001	0.001
Observations						
Countries						
Centered R^2		0.914			0.743	
Centered within R^2		0.034			0.419	
Shea's (1997) partial R^2						
$\mathbf{W\tau}_t$		0.444			0.419	
$\mathbf{Wt}_t$		0.468			0.437	
Sargan test on overidentifying restrictions (p-value)[c)]		0.550			0.334	

Notes: All two-stage least-squares models include fixed country effects. - a) Based on Huber-White sandwich estimates of the variance-covariance matrix to guard against heteroskedasticity. - b) Based on Driscoll and Kraay (1998)-type HAC estimates of the variance-covariance matrix to guard to guard against heteroskedasticity and time- as well as spatial autocorrelation. - c) The following identifying instruments have been used in the first stage: $\mathbf{Wx}_{1t}$, $\mathbf{Wx}_{2t}$, $\mathbf{Wx}_{3t}$, $\mathbf{Wx}_{4t}$, $\mathbf{W}^2\mathbf{x}_{5t}$, $\mathbf{W}^3\mathbf{x}_{2t}$ (for the personal income tax rate on the left-hand-side); $\mathbf{Wx}_{1t}$ $\mathbf{Wx}_{4t}$, $\mathbf{W}^2\mathbf{x}_{1t}$ $\mathbf{W}^2\mathbf{x}_{2t}$, $\mathbf{W}^2\mathbf{x}_{4t}$, $\mathbf{W}^3\mathbf{x}_{1t}$, $\mathbf{W}^3\mathbf{x}_{4t}$ (for the corporate tax rate on the left-hand-side), where W is an N×N inverse-distance-based row-normalized spatial weighting matrix $\mathbf{x}_{1t},\ldots,\mathbf{x}_{4t}$ are N×1 vectors of explanatory variables with $\mathbf{x}_{1t}$~log GDP, $\mathbf{x}_{2t}$~log unit labor costs, $\mathbf{x}_{3t}$~debt-to-GDP ratio; $\mathbf{x}_{4t}$~unemployment rate in percent.

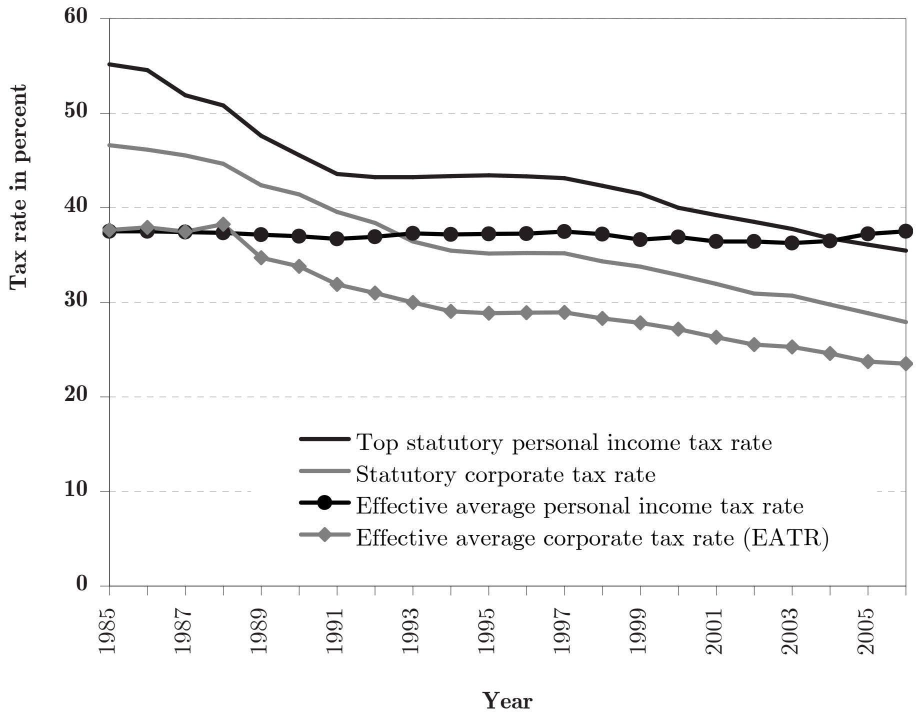

Figure 1: **Corporate and personal income taxation in OECD countries (average), 1985-2005**

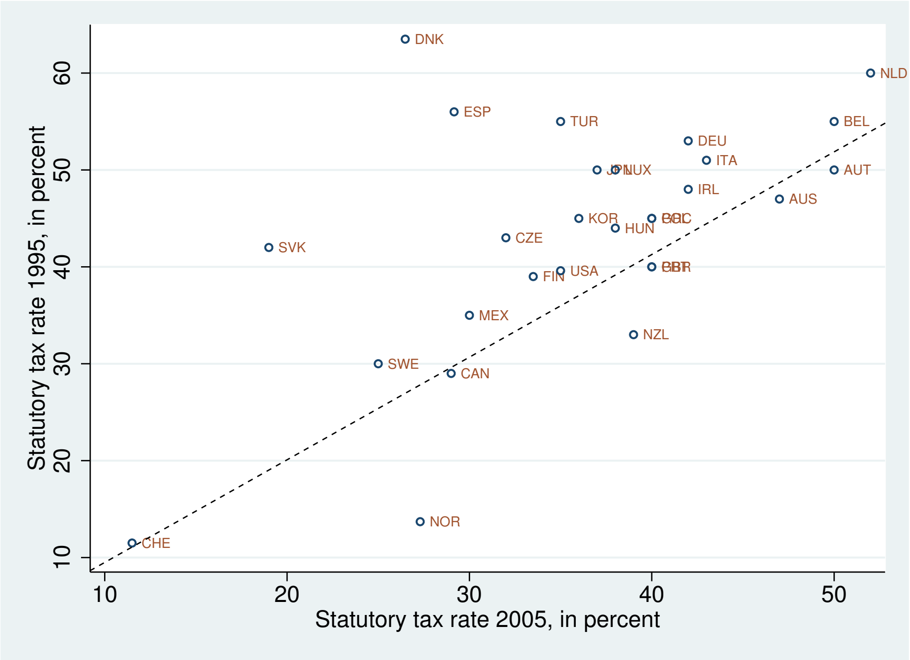

Figure 2: **Statutory (top) personal income tax rates in OECD countries, 1995 vs. 2005**

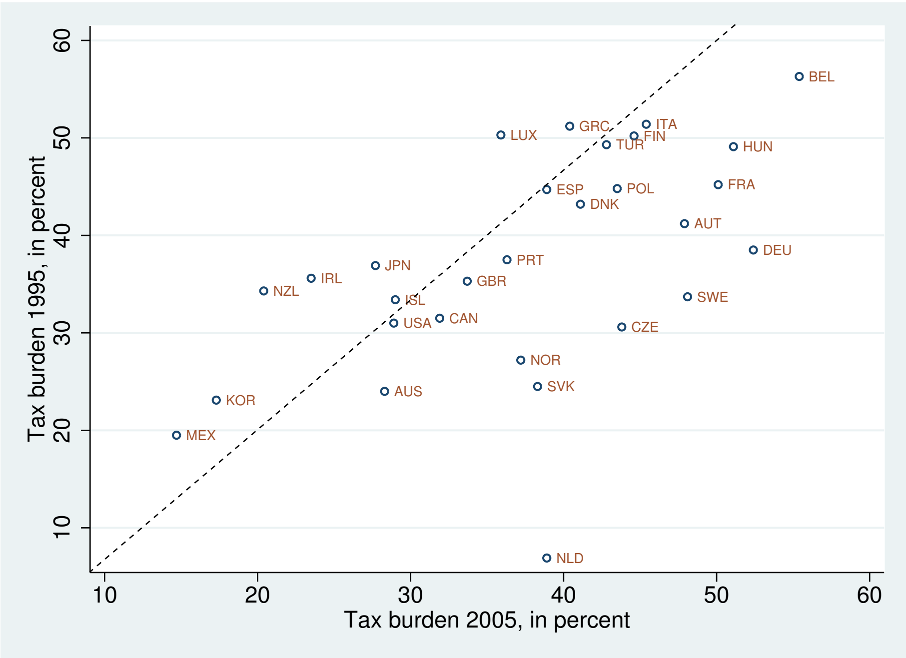

Figure 3: **Effective average personal income tax rates in OECD countries, 1995 vs. 2005**

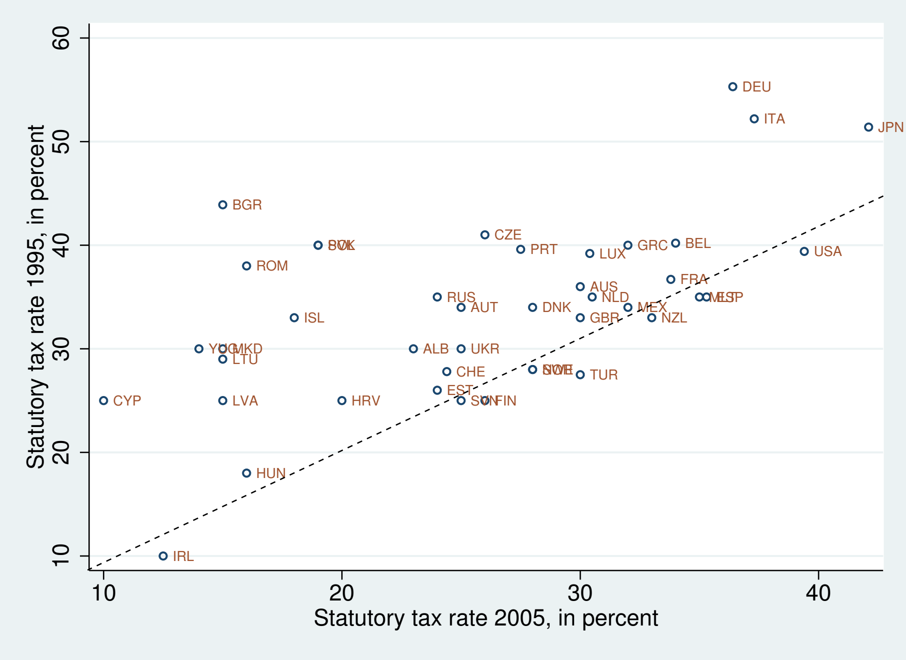

Figure 4: **Statutory corporate tax rates in OECD countries, 1995 vs. 2005**

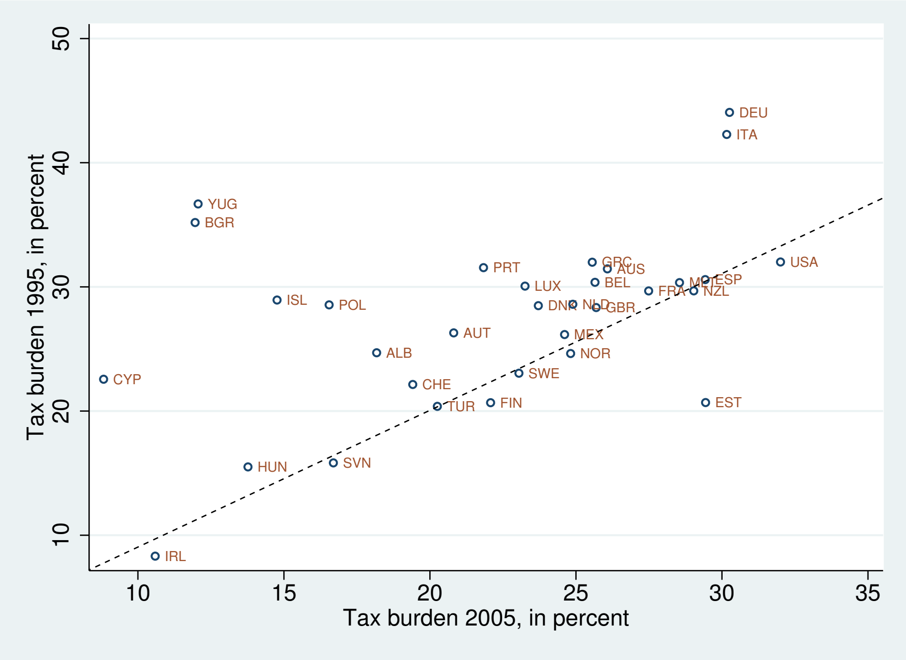

Figure 5: **Effective average corporate tax rates in OECD countries, 1995 vs. 2005**