Do Countries Compete over Corporate Tax Rates?*

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Abstract

This paper investigates whether OECD countries compete with each other over corporation taxes. We develop a model in which multi-national firms choose their capital stock in response to an effective marginal tax rate (EMTR), and simultaneously choose the location of their profit in response to differences in statutory tax rates. Governments engage in two-dimensional tax competition: they simultaneously compete over EMTRs for capital and over statutory rates for profit. We estimate the parameters of their reaction functions using data from 21 countries between 1982 and 1999. We find evidence that countries compete over both measures, and moreover, that the estimated slopes of reaction functions are consistent with our theoretical predictions. We find that - consistent with our model, but not some other forms of competition - evidence of strategic interaction is present only between open economies (i.e. those without capital controls in place). The Nash equilibrium statutory rates implied by the empirical model fall substantially over the period, in line with falls in actual statutory rates.

Keywords: tax competition, corporate taxes, transfer pricing

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1. Introduction

Statutory rates of corporation tax in developed countries have fallen substantially over the last two decades. The average rate amongst OECD countries in the early 1980s was nearly 50%; by 2001 this had fallen to under 35%. In 1992, the European Union's Ruding Committee recommended a minimum rate of 30% - then lower than any rate in Europe (with the exception of a special rate for manufacturing in Ireland). Ten years later, one third of the members of the European Union had a rate at or below this level. It is commonly believed that the reason for these declining rates is a process of tax competition: countries have increasingly competed with each other to attract inward flows of capital by reducing their tax rates on corporate profit. Such a belief has led to increased attempts at international coordination in order to maintain revenue from corporation taxes. Both the European Union and the OECD introduced initiatives in the late 1990s designed to combat what they see as "harmful" tax competition.

The notion that there is increasing competitive pressure on governments to reduce their corporation tax rates has been the subject of a growing theoretical literature - surveyed by Wilson (1999), and Fuest, Huber and Mintz (2003). But there have been no detailed attempts to examine whether there is any empirical evidence of such international competition in taxes on corporate income.[1] In this paper we extend the theoretical literature to provide testable predictions about country reaction functions in corporation taxes, and we provide a rigorous test of those predictions.

Existing theory, in our view, suffers from important weaknesses. First, the vast majority[2] of existing theory does not adequately deal with the fact that governments have *two* instruments for determining corporate income taxes: the rate and the base. In the standard model in the literature, developed by Zodrow and Mieszkowski (1986) and Wilson (1986), denoted here the ZMW model, governments have only one instrument, a tax on capital income. However, as shown below, if a corporate tax of the simplest possible form - with a statutory rate and a capital allowance - is introduced in the ZMW model, this is equivalent to a tax on capital income *plus* a tax on rent accruing to the fixed factor. More precisely, the fixed factor is taxed at the statutory tax rate, and capital income is taxed at a rate which depends on both the statutory rate and

[1] In an unpublished paper, Altshuler and Goodspeed (2002) investigate competition between countries, and test whether the US is a Stackelberg leader, using data on tax revenue.

[2] An exception is Haufler and Schjelderup (2000), in the context of a model which incorporates mobile capital and profit shifting. This paper is discussed further below.

the value of capital allowances (usually called the *effective marginal tax rate*, or EMTR).[3] In this version of the ZMW model, there is no strategic interaction in the setting of the statutory tax rate since it is effectively a lump sum tax. Moreover, if countries are symmetric, the EMTR at equilibrium is zero[4], which is of course, highly unrealistic.

A second weakness of the ZMW model is that it assumes mobility *only* of capital, thus ignoring other forms of mobility[5]. One empirically important form which we focus on in this paper is that of profit: that is, conditional on where real activity takes place, multinational firms are able to shift profits from one country to another in order to reduce overall tax liabilities.[6] There are a number of opportunities for doing so, including appropriate use of financial policy (in the simplest case, lending by an affiliate in a low tax country to an affiliate in a high tax country) and setting appropriate transfer prices on intermediate goods exchanged within the corporation. The fundamental incentive for profit-shifting is a difference in the statutory rate between jurisdictions. Firms can take advantage of any allowances available in each jurisdiction; having done so, the tax rate applied to a marginal increase in taxable profit is the statutory rate. Moreover, there is considerable empirical evidence of multinational firms taking advantage of differences in statutory tax rates to shift profits between countries.[7].

Motivated by these two problems with the standard ZMW model, we develop a model which combines mobile capital with a model of profit-shifting via transfer pricing, and we study competition over corporate tax systems in this model. The model is related to contributions by Eliztur and Mintz (1996) and Haufler and Schjelderup (2000), in that in all three models, at the

[3] A tax on the fixed factor only could be achieved through a cash flow tax, which would generate revenue with a zero effective marginal tax rate.

[4] This is shown in Section 2.5 below.

[5] A third form of mobility, which we do not consider in this paper is mobility of firms. Multinational firms make discrete choices as to where to locate their foreign affiliates, and these choices depend on how taxes affect the post-tax level of profit available in each potential location; the impact of tax on such decisions is measured by the *effective average tax rate* (EATR). Devereux and Griffith (1998, 2003) provide evidenceof the impact of the EATR on discrete location decisions. We neglect this issue here for two reasons. First, including three forms of mobility simultaneously would make the theoretical model intractable. Second, the EATR is strongly correlated with the statutory rate; it is therefore difficult to identify separately competition in these two forms of tax rate.

[6] There is a considerable theoretical literature on multinational firms shifting profit through the misuse of transfer prices, although not usually in the context of tax competition. Recent relevant papers include Elitzur and Mintz (1996), Haufler and Schjelderup (2000), Raimondos-Moller and Scharf (2002), Neilsen, Raimondos -Moller and Schjelderup (2003), and Mintz and Smart (2004).

[7] For example, two recent papers use different approaches and data to investigate international profit shifting. Bartelsman and Beetsma (2003) use OECD industry level data to infer profit shifting by relating rates of value added to corporate tax differences between countries. Their baseline estimate is that more than 65% of the additional revenue which would otherwise result from a unilateral tax increase is lost because of profit shifting. Clausing (2003) tests the impact of taxes on transfer pricing directly with data on prices used in US intra-firm trade. She finds that a statutory tax rate 1% lower in the destination country is associated with intra-firm export prices 1.8% higher, and that a statutory tax rate 1% lower in origin country is associated with intra-firm import prices 2% higher. A number of earlier papers also provide evidence of profit shifting. See, for example, Hines and Hubbard (1990), Grubert and Mutti (1991), Hines and Rice (1994), Grubert and Slemrod (1998) and the survey by Hines (1999).

first stage, the governments choose taxes, and at the second, firms choose a transfer price for an input given the choice of taxes. Our contribution differs from the other two, however, in that we allow for two-dimensional tax competition (over both the statutory rate and the EMTR) and also in our modelling of transfer-pricing incentives, which is both micro-founded and realistic[8].

In our model, we show that the statutory rate, rather than being lump-sum, is used competitively by each country to shift profits into its jurisdiction. This generates strategic interaction in the setting of statutory rates. Moreover, because the statutory rate is no longer a lump-sum tax, the tax on capital income (EMTR) is positive in equilibrium. Finally, in an advance on the previous literature (see e.g. Bruekner, 2003), we are able to establish some quite precise predictions about the properties of reaction functions. In particular, the model has *two-dimensional* reaction functions: in the home country, the optimal choice of both statutory rate and the EMTR react to changes in each of these taxes in the foreign country, and vice-versa. We evaluate these responses in the neighborhood of symmetric Nash equilibrium. We are able to prove generally that the response of the home statutory rate (EMTR) to the foreign statutory rate is positive (negative), and for a calibrated version of the model, the response of both the home EMTR and statutory rate to the foreign EMTR rate is positive, although the response of the statutory rate to the foreign EMTR is numerically very small.

Having developed this model, we confront it with data. Part of the reason for the lack of empirical evidence to date on this topic may be the difficulty in developing appropriate measures of the EMTR. Although there have been striking changes to statutory tax rates, there have also been important changes to the definitions of tax bases; very broadly, tax bases have been broadened as tax rates have fallen. Our measure of the EMTR is based on applying the rules of the tax system to a hypothetical investment project (Devereux and Griffith, 2003). We use information on tax rules from 21 OECD countries over the period 1982 to 1999. This type of measure has been used for other purposes[9], but not for investigating strategic interactions between countries: this paper is the first, to our knowledge, to estimate tax reaction functions based on detailed measures of corporate taxes.

Our empirical work builds on two small, but growing empirical literatures. The first, mostly

[8]Haufler and Schjelderup (2000) simply assume an ad hoc cost of transfer pricing of a discrete input, which is increasing and convex in the difference between the true cost of the input and the price. In Eliztur and Mintz (1996), the manager of the subsidiary chooses the level of the input, and the parent chooses the transfer price to induce the manager to choose an effeicent level of the input. In our model, the costs of transfer-pricing are fully micro-founded, and reflect the emprical fact that firms are prinarily deterred from transfer-pricing by the threat of audit by the tax authorities.

[9]For example, constructed measures of the EMTR have been used elsewhere to make international comparisons of corporate income taxes (see, for example, King and Fullerton (1984), OECD (1991), Devereux and Pearson (1995), Chennells and Griffith (1997), European Commission (2001)). Devereux and Freeman (1995) provide evidence that flows of foreign direct investment depend on differences in the EMTR across countries.

in political science, has regressed either corporation tax revenues or rates on measures of capital controls and other control variables, primarily to test whether relaxation of exchange controls, especially on the capital account, lowers either corporate tax revenues or rates.[10] Slemrod (2004) uses a similar approach to investigate whether corporate tax rates and revenues rise in response to greater revenue needs and a the degree of openness of the economy. However, this literature has not directly tested for strategic interactions between fiscal authorities.

Second, a pioneering study by Case, Rosen and Hines (1993) has stimulated a growing empirical literature on estimation of tax reaction functions, surveyed recently by Brueckner(2003). However, existing empirical work has employed data on local (business) property tax rates,[11] or on local or state income taxes,[12] rather than investigating competition at a national level. This is significant, because, while local property taxes may determine business location within a region, corporate taxes are the most obvious taxes in determining location of investment between countries.

Our findings are as follows. We find evidence consistent with our prediction that countries compete both over the statutory tax rate (to attract mobile profit) and the EMTR (to attract capital). The size of these effects is both large and consistent with theoretical predictions. For example, a 1 percentage point fall in the weighted average statutory rate in other countries tends to reduce the tax rate in the home country by around 0.7 percentage points. A similar effect is found for the EMTR. However, the evidence suggests that these two forms of competition are distinct in the sense that we do not find an effect of the EMTR in country j on the statutory rate in country i, nor do we find an effect of the statutory rate in country j on the EMTR in country i. This is broadly consistent with our theoretical model in the sense that theoretical analysis of reaction function slopes suggests that these "cross-tax effects" will be smaller than the "own-tax effects".

It is of course possible that observed strategic interaction in tax setting may also be due to yardstick competition. The latter occurs when voters in a tax jurisdiction use the taxes (and expenditures) set by their own political representative relative to those in neighboring jurisdictions to evaluate the performance of their representative (Besley and Case, 1995, Besley and Smart, 2003 and Bordignon, Cerniglia, and Revelli, 2003). It is also possible that countries follow each other in setting tax policy, not because of any kind of competition, but because of common intellectual trends. Finding an empirical relationship between tax rates in different

[10] See Hallerberg and Basinger (1998), Garrett (1998), Quinn (1997), Rodrik (1997), Swank and Steinmo (2002), and Slemrod (2004).

[11] See Brueckner (1998), Brett and Pinkse (2000), Heyndels and Vuchelen (1998).

[12] See Besley and Case (1995), Heyndels and Vuchelen (1998).

countries may not necessarily therefore imply competition of the kind analysed in our theoretical model.

We address this as follows. In our model, there is mobility of capital and profit between countries, and governments compete over these mobile flows. However, the yardstick model does not require any flows between the two competing countries - it is as likely to take place between two completely closed (but otherwise similar) countries as between two open economies. Similarly, common intellectual trends can apply to countries which are closed. We therefore differentiate observations in our data depending on whether countries had significant capital controls in place at that time. We take the existence of significant capital controls as severely restricting mobility of capital and profit. Specifically, we would only expect tax competition between two countries when neither country had significant capital controls in place. We find evidence for strategic interaction is much stronger in the cases where none of the countries analysed have capital controls in place. In fact, arguably interaction is present *only* in this case. Our findings thus strongly support the predictions of the theoretical model, and are not consistent with the main alternatives.

Finally, we return to our motivation in the first paragraph of this paper: does our empirical model explain the significant reduction in statutory rates of corporation tax over the last twenty years? To investigate this, we use the estimated coefficients from the empirical model and the values of the control variables, to infer the year-by-year mean of the Nash equilibrium statutory rates for our sample of countries. We show that these estimated Nash equilibrium means fall substantially over the period considered.

The layout of the rest of the paper is as follows. Section 2 provides a theoretical framework for the empirical approach. Section 3 presents the empirical specification and data, and Section 4 presents the results. Section 5 briefly concludes.

2. A Theoretical Framework

2.1. A Model of Corporate Tax Competition

There are two countries, home, and foreign. Following the usual convention in the international trade literature, home country variables are unstarred, and foreign country variables are starred. Each country is populated by a unit measure of agents, each of whom owns (i) an endowment of capital, κ, and (ii) a share (normalized to unity) of a multinational firm whose parent is located in that country. That is, the home (foreign) multinational is 100% owned by agents in the home (foreign) country, although nothing important depends on this.

Every agent resident in the home country has preferences over consumption of a private good produced by the two firms and of a country-specific public good of the quasi-linear form:

$$u(x, g) = x + v(g) \tag{2.1}$$

where the function v is strictly increasing and concave, and x and g are the consumption levels of the private and public goods. The government can transform one unit of the private consumption good into one unit of the public good. We assume that $v'(0) \geq 1$ which implies that some provision of the public good is (weakly) desirable if lump-sum taxation is available. Preferences in the foreign country are of the same form, over consumption levels x^* and g^* .

In both countries, governments finance the provision of a public good though a source-based corporation tax levied on the profit of both firms. We now describe the operation of the corporation tax in more detail. Consider first the parent company of the home multinational, which is located in the home country. It produces output $f(k)$ using k units of the capital input, and a discrete input which it purchases at price q from an affiliate located in the foreign country. The capital input is purchased from households at price r. So, tax paid by the parent in the home country is $\tau(f(k) - ark - q)$, where $0 \leq \tau \leq 1$ is the statutory rate of tax, and $a \geq 0$ is the rate of allowance on the cost of capital.[13] In addition, the cost to the affiliate of producing the input is normalized to zero, so the foreign affiliate of the home parent makes a pre-tax profit of q and is taxed at the foreign tax rate τ^*.

The overall post-tax profit of the multinational is therefore

$$\begin{aligned} \Pi &= f(k) - rk - q - \tau(f(k) - ark - q) + (1 - \tau^*)q \\ &= (1 - \tau)(f(k) - zrk - q) + (1 - \tau^*)q \end{aligned} \tag{2.2}$$

where the effective marginal tax rate (EMTR) is $z - 1 = (1 - a\tau)/(1 - \tau) - 1 = \tau(1 - a)/(1 - \tau)$. Given τ, the government can choose a in order to set a value of this EMTR. In what follows, we treat the government as choosing z directly.

Now consider the foreign multinational whose parent is located in the foreign country. It has an affiliate in the home country which also sells a discrete input (again at a cost normalized to zero) at price q^* to the parent in the foreign country. The parent combines this input with capital input k^* to produce revenue $f(k^*)$. So, global post-tax profits of the foreign multinational are

$$\Pi^* = (1 - \tau^*)(f(k^*) - z^* r k^* - q^*) + (1 - \tau)q^*. \tag{2.3}$$

[13] The allowance rate a partly reflects relief for the cost of finance: for example, in the case of a wholly debt-financed investment (and in the absence of depreciation) the interest payment would be deductible from tax, and hence $a = 1$. More generally, although we do not model depreciation explicitly, a might also reflect the value of depreciation allowances. A cash flow tax would imply that $a = 1$ We do not impose $a \leq 1$.

In our model, the price of r is determined competitively in the market for the capital input. On the other hand, we assume that there is no competitive market for the discrete inputs: this is realistic in many circumstances, for example where the input is a commercial intangible, such as a patent or trademark (OECD, 2001). Rather, we suppose that the multinationals themselves choose q and q^* to maximise global profits Π and Π^*. If they do so in an unrestrained way, however, it is clear that the multinationals will choose corner solutions[14] for q and q^*. This is both unrealistic and unhelpful for generating testable predictions, as it generates discontinuities in the tax reaction functions.

In practice, the scope of firms for transfer-pricing is limited by the threat of audit by the tax authorities, and a subsequent fine if the transfer price chosen deviates too much from the correct price as determined by the tax authorities (the *audited value*). We model this as follows. Assume that the home and foreign country governments can costlessly audit either company. When audited, with probability p - a parameter that measures the effectiveness of the audit process, assumed to be the same for both governments - an audit of a given multinational by either government reveals an audited value of the input, θ, where θ is uniformly distributed on $[0,1]$. Note that this audited value is the same for the inputs of both multinationals. The interpretation of θ is that it is the value of the input as determined by the government using an "arms-length" valuation method (OECD, 2001). For example, θ may be the price of a similar input in a competitive market[15] (the comparable uncontrolled price method). We are thus assuming that both governments agree on the valuation method, and thus no double-taxation occurs in equilibrium[16].

If the home multinational is found to have been overcharging for the input ($q > \theta$), the home government charges a fine F. If the home multinational is found to have been undercharging for the input ($q < \theta$), the foreign government can charge a fine F^*. We assume that fines are proportional to the difference[17] between q and θ that is:

$$F = \alpha \max\{(q-\theta), 0\},\ \ F^* = \alpha^* \max\{(\theta - q), 0\} \tag{2.4}$$

where $\alpha > \tau,\ \alpha^* > \tau^*$. An equivalent fine applies to the foreign multinational. In what follows, we take α, α^* to be fixed and equal i.e. we do not allow governments compete over fines. This is for two reasons. First, our focus is on tax competition, rather than competition in fines.

[14] For example, the home multinational will choose $q = 0$ if $\tau < \tau^*$, and $q = f(k) - zrk$ if $\tau > \tau^*$.
[15] Other methods for assessing value include the resale price method and the cost-plus method (OECD, 2001).
[16] In our model, this manifests itself in the fact that in equilibrium, a given multi-national is fined by at most one government.
[17] An attractive assumption would be that the fines are proportional to the tax lost by incorrect transfer pricing e.g. $F = \alpha \max\{\tau(q-\theta), 0\}$. It turns out that with this specification, the Nash equilibrium statutory tax rate is not well-defined.

Secondly, in practice, the financial penalties for incorrect transfer pricing are normally closely related to the tax avoided, with discretionary choice of α being limited by the legal system (OECD, 2001).

The multinationals then choose their transfer prices q, q^*, taking this audit and fine structure as given, as well as the structure of corporate taxation in both countries. We assume that θ is unknown to either multinational when q, q^* are chosen but that the distribution of θ is common knowledge to both governments and firms.[18]

So, to summarise, we have assumed the following order of events:

1. Governments choose corporation tax parameters, τ and z.

2. Firms choose investments k, k^* and transfer prices q, q^*.

3. The price of capital, r, is determined, and production and consumption take place.

As is usual, we solve the model backwards.

2.2. Choice of Investments and Transfer Prices

From (2.4), the expected fines paid to home and foreign governments by the home multinational, given an input price q, are

$$P(\theta < q)E[F \mid \theta < q] = \alpha\frac{q^2}{2} = EF,\ P(\theta > q)E[F^* \mid \theta > q] = \alpha\frac{(1-q)^2}{2} = EF^*. \tag{2.5}$$

Hence the overall expected fine that the home multinational pays, given q, is

$$\Phi = p(EF + EF^*) = \frac{\alpha p}{2}[q^2 + (1-q)^2]. \tag{2.6}$$

The home multinational chooses q and k to maximise profit Π, defined in (2.2), less the expected fine Φ, defined in (2.6). The first order condition for q is thus

$$\tau - \tau^* = \alpha p[q - (1-q)] \tag{2.7}$$

which easily solves to give the profit-maximising value of q as a linear function of the difference between the two statutory tax rates, $\tau - \tau^*$:

$$q = q(\tau - \tau^*) = \frac{\tau - \tau^* + \alpha p}{2\alpha p}. \tag{2.8}$$

[18] In this way, we avoid the complications that occur when the multinational has private information about the value of the input (or the cost of producing the input). Optimal transfer pricing rules in the presence of such asymmetric information have been analysed by Gresik and Nelson (1994).

Thus, the home firm's optimal transfer price shifts profit in the usual way: when τ rises, q rises to shift profit to the foreign affiliate, and when τ^* rises, q falls to shift profit to the parent company. At a symmetric tax equilibrium ($\tau = \tau^*$), then $q(0) = 0.5$. The foreign firm's choice of q^* is entirely symmetric. In particular, the foreign multinational chooses a transfer price

$$q^* = q^*(\tau^* - \tau) = \frac{\tau^* - \tau + \alpha p}{2\alpha p}. \tag{2.9}$$

Now consider the home multinational's choice of capital input, k. This choice maximises Π in (2.2), implying a first order condition for k

$$f'(k) = zr. \tag{2.10}$$

which simply says that the marginal value product of capital is equal to the cost of capital, given the corporate tax system[19]. This solves to give demand for capital by the home multinational of $k(zr)$, and in the same way, $k(z^*r)$ is demand for capital of the foreign multinational. So, the capital market equilibrium condition is

$$k(zr) + k(z^*r) = 2\kappa \tag{2.11}$$

It is easily seen that an increase in z, z^* depresses the demand for capital and thus reduces r. So (2.8) and (2.11) jointly determine q and r. Note that q only depends on the statutory tax rates, and r only on the EMTRs.

2.3. Choice of Corporate Taxes

Here, we characterise the symmetric Nash equilibrium in the corporate tax game between countries. This is the first step in studying the reaction functions, as due to the non-linearity of the model, we cannot study the reaction functions generally, but only linear approximations to these reaction functions around the Nash equilibrium.

The home country government is assumed to choose τ and z to maximise the sum of utilities of its residents, given τ^* and z^* fixed. Given quasi-linearity of preferences, the government maximand is thus just the total surplus

$$W = r\kappa + \Pi - \Phi + v(g). \tag{2.12}$$

[19] We are implicitly assuming here that each multinational takes the price of capital r as given when choosing k. This assumption is made for analytical tractability: treating multinationals as oligopsonistic buyers of capital would considerably complicate the analysis, without adding any new insights. The assumption could be justified (without much change to the details of the model) by supposing that there are large numbers of multinationals of each "type".

which is simply the total income[20] $r\kappa + \Pi - \Phi$ of a resident plus his utility from the public good. Now define the profit function $\pi(zr) = \max_k\{(f(k) - zrk\}$.

Then, revenue in the home country from taxes and expected fines from both the home and foreign multinational can be written

$$g = \tau(\pi(zr) - q) + (z-1)rk(zr) + \tau q^* + \frac{\alpha p}{2}[q^2 + (1-q^*)^2] \tag{2.13}$$

This formula for g has three components: (i) the tax revenue from the home multinational, $\tau(\pi(zr) - q) + (z-1)rk(zr)$; (ii) the tax revenue from the foreign multinational, τq^*; and (iii) the expected fines levied by the home government on both multinationals. Note also that tax revenue from the home multinational is expressed as the sum of (i) the statutory tax base $\pi(zr) - q$ times the rate, τ; plus (ii) the EMTR base $rk(zr)$ times the rate, $z - 1$.

The home government chooses τ, z to maximise (2.12), taking τ^*, z^* as fixed, but taking into account (i) the fact that $\Pi - \Phi, g$ depend not only on τ, z but also on the input prices r, q, q^*; and (ii) the fact that r, q, q^* depend on τ, z. Let these first-order conditions be denoted

$$W_\tau = 0, \ W_z = 0 \tag{2.14}$$

where W_x denotes the partial of W with respect to $x = \tau, z$ *taking into account all the effects on the input prices.* These first-order conditions for τ, z simplify considerably, mainly because q, q^* only depends on τ, and r only depends on z. Indeed, after some manipulation, we can prove (proofs of all Propositions are in Appendix A):

Proposition 1. *At a symmetric Nash equilibrium,* $(\tau = \tau^* = \hat{\tau}, \ z = z^* = \hat{z})$, *then (assuming an interior solution for* $\hat{\tau}$*),* $\widehat{\tau}, \hat{z}$ *solve*

$$\widehat{\tau} = \alpha p\left(1 + \frac{(v'-1)(\pi - 0.5)}{v'}\right) \tag{2.15}$$

$$\frac{\hat{z}-1}{\hat{z}} = \frac{(v'-1)(1-\hat{\tau})}{v'\varepsilon} - \frac{\partial W}{\partial r}\frac{1}{2v'\varepsilon\kappa\hat{z}}, \ \varepsilon = -\frac{k'r\hat{z}}{k} > 0 \tag{2.16}$$

where

$$\frac{\partial W}{\partial r} = \kappa - (1-\tau)\hat{z}\kappa + v'(-\tau\hat{z}\kappa + (\hat{z}-1)(\kappa + r\hat{z}k')). \tag{2.17}$$

In the proposition, primes denote derivatives, and π and k' are $\pi(zr)$ and $k'(zr)$ evaluated at the equilibrium values of z and r. These are interesting and easily interpretable formulae for

[20] Note that each resident in the home country receives the post-tax global profit of the home multinational Π, (2.2), net of expected fines paid Φ, defined in (2.6), as the home multinational is 100% owned by home residents.

$\hat{\tau},\ \hat{z}$. First, note from (2.8) that $2q' = 1/\alpha p$ measures the sensitivity of the tax base, $\pi(zr)-q+q^*$, to the statutory tax. So, (2.15) says that $\hat{\tau}$ is inversely proportional to this. A further feature of $\hat{\tau}$ is that it is positive even where there is no revenue-raising motive for government e.g. where $v(g) = g$ (one can think of this case as one where any revenue is returned in lump-sum form to consumers). In this case, as $v' = 1$, $\hat{\tau} = \alpha p > 0$. The intuition for this is that an increase in the statutory tax by the home government increases both tax revenue and the expected fine that the home country government collects from the foreign multinational, and this benefits domestic residents (this is a form of *tax exporting*).

Second, (2.16) says that the optimal EMTR, $\hat{z}-1$, is set with regard to both revenue-raising incentives (the first term), and with regard to any incentive the government has to manipulate the price of capital (the second term). For example, if the government wants to lower the price of capital ($\frac{\partial W}{\partial r} < 0$), then other things equal, the EMTR will be higher, as a higher z .lowers r. It is interesting to note that if the government has no revenue-raising motive, then in equilibrium, the incentive to manipulate r vanishes, and so the equilibrium $\hat{z} = 1$. To see this, let $v(g) = g$, implying $v' = 1$. Then, from (2.17), if $z = 1$, $\frac{\partial W}{\partial r} = 0$. So, $\hat{z} = 1$ solves (2.16). So, to conclude, without a revenue-raising motive, $\hat{\tau} = \alpha p,\ \hat{z} = 1$.

Generally, with a revenue-raising motive, we expect that the EMTR would be positive, consistently with what we observe in reality. This is difficult to prove in general, as from (2.17), $\frac{\partial W}{\partial r}$ need not be negative. A positive equilibrium EMTR can however be shown in the special *linear-quadratic case,* where[21] utility is linear in the public good, $v(g) = \gamma g$, with $\gamma \geq 1$, and there is a quadratic production function, $f(k) = \frac{1}{\beta}(\sigma k - \frac{k^2}{2})$. Here, γ parameterizes the demand for the public good, and $\sigma,\ \beta$ are the slope and intercept in the demand for capital i.e. $k(zr) = \sigma - \beta zr$. In this case, $\hat{\tau}, \hat{z}$ can also be solved for in closed form, which will be useful below when we calibrate the model. In fact, we have:

Proposition 2. *If $v(g) = \gamma g$, with $\gamma \geq 1$, and $f(k) = \frac{1}{\beta}(\sigma k - \frac{k^2}{2})$, then a symmetric Nash equilibrium $\widehat{\tau}, \hat{z}$ exists for all $\kappa \leq \underline{\kappa} = \frac{\gamma\sigma}{\gamma+(\gamma-1)(1-\hat{\tau})}$. Moreover, assuming an interior solution for $\hat{\tau},\ \widehat{\tau}, \hat{z}$ solve*

$$\widehat{\tau} = \alpha p \left\{ 1 + \frac{(\gamma-1)(\kappa^2-\beta)}{2\gamma\beta} \right\} \tag{2.18}$$

$$\widehat{z} = \frac{\gamma\sigma - \kappa}{\gamma(\sigma-\kappa) - (\gamma-1)(1-\tau)\kappa} \tag{2.19}$$

Moreover, in equilibrium $\widehat{\tau} > 0$, $\widehat{z} \geq 1$ with $\widehat{z} > 1$ when $\gamma > 1$.

[21] In this case, it is easily calculated from (2.11) that in equilibrium, $r = 2(\sigma-\kappa)/\beta(z+z^*)$, so we will assume $\kappa < \sigma$ to ensure a positive price of capital.

As remarked above, when there is no demand for public good provision (in this case, when $\gamma = 1$), $\widehat{z} = 1$ so the equilibrium EMTR is zero. Note also that $\widehat{\tau}$ only depends on the slope of the demand for capital, whereas $\widehat{z}$ only depends on the intercept. Our analysis of reaction functions, to which we now turn, will be partly based on this linear-quadratic case.

2.4. Reaction Functions

Our main objective in developing this theoretical model is to generate testable predictions about the nature of reaction functions. This is complicated by the fact that each government has two instruments, τ and z, and (in principle) reacts to both τ^*, z^*, so generally, the reaction functions are of the form $\tau = \phi(\tau^*, z^*)$, $z = \eta(\tau^*, z^*)$. Nevertheless, we can linearize the reaction functions around the Nash equilibrium by totally differentiating (2.14) to get:

$$\begin{pmatrix} W_{\tau\tau} & W_{\tau z} \\ W_{\tau z} & W_{zz} \end{pmatrix} \begin{pmatrix} d\tau \\ dz \end{pmatrix} = - \begin{pmatrix} W_{\tau\tau^*} & W_{\tau z^*} \\ W_{z\tau^*} & W_{zz^*} \end{pmatrix} \begin{pmatrix} d\tau^* \\ dz^* \end{pmatrix}. \quad (2.20)$$

Our general strategy is then to solve the system (2.20) for the four reaction function "slopes" $\frac{d\tau}{d\tau^*}, \frac{dz}{d\tau^*}, \frac{d\tau}{dz^*}, \frac{dz}{dz^*}$ and based on the coefficients of the matrices in (2.20), to sign these four slopes, at least under certain conditions. A useful simplification is that the first–order condition for z, $W_z = 0$, is independent of τ^*, as shown in the Appendix. Hence we can set $W_{z\tau^*} = 0$ in (2.20).

Following the game-theory literature, say that $x = \tau, z$ and $y = \tau^*, z^*$ are *strategic complements* if $W_{xy} > 0$, and *strategic substitutes* $W_{xy} < 0$. So, for example, τ, τ^* are strategic complements if (holding z, z^* fixed, but allowing all endogenous variables q, q^*, r to vary) an increase in the foreign statutory rate τ^* would induce the home country to raise its own statutory rate. In games with two players, each with only one strategic variable, it is well-known that the two variables being strategic complements (substitutes) is *equivalent* to positively sloped (negatively sloped) reaction functions. In games with more than one strategic variable, this equivalence no longer holds. Generally, this is because following (say) a change in τ^*, the home government re-optimizes z as well as τ, meaning that $W_{\tau\tau^*}$ is now not sufficient to sign the reaction of τ to τ^* : the effect of a change in z is now also relevant. (For example, in Proposition 3, there is a negative relationship between z and τ^* even though $W_{z\tau^*} = 0$ i.e. z and τ^* are strategically independent.) Nevertheless, we can show the following:

Proposition 3. *(i) Assume that utility is linear i.e.* $v(g) = \gamma g$. *Then* τ, τ^* *are strategic complements while* z, τ^* *are strategically independent, and moreover,* $\frac{d\tau}{d\tau^*} > 0$, $\frac{dz}{d\tau^*} < 0$.

So, we find an unambiguous prediction about the responses of the home country's taxes τ, z to the *statutory* tax in the foreign country: τ responds positively, and z negatively. Moreover, the explanation for $\frac{d\tau}{d\tau^*} > 0$ is simply that τ, τ^* are strategic substitutes - as in shown in the proof of Proposition 3, $\frac{d\tau}{d\tau^*}$. is signed by $W_{\tau\tau^*}$. The intuition for why τ, τ^* are strategic substitutes is simply that an increase in τ^* will decrease q, thus increasing the base $\pi - q$ of the statutory tax in the home country, and thus increasing the incentive for government to rase the statutory rate, τ.

However, we do not find an unambiguous prediction about the response of the home country statutory rate τ and EMTR z, to the foreign EMTR, z^*. In the case of τ, it is possible to show[22] that if $v(g)$ is linear, then τ and z^* are strategic complements i.e. $W_{\tau z^*} > 0$, but this is not enough to sign $\frac{d\tau}{dz^*}$ generally. In the case of z, assuming not only linear utility but also a quadratic production function as above, it is possible to show[23] that under a wide range of parameter values - but not all - z, z^* are strategic complements, but again, this is not sufficient to sign $\frac{dz}{dz^*}$. In fact, for $\frac{dz}{dz^*} > 0$ strategic complementarity has to be "strong enough" to offset feedback effects through changes in τ induces by the change in z^*, and similarly for $\frac{d\tau}{dz^*} > 0$.

Noting that if we set $\tau = 0$ in our model we have a version of the ZMW model, this is consistent with the existing literature e.g. Brueckner(2001) which finds that the slope of the reaction function cannot be signed in the ZMW model even with a quadratic production function. So, in this sense, our ability to make analytical predictions about *some* of the reaction function slopes is an advance over the existing literature.

Further, although dz/dz^*, $d\tau/dz^*$cannot be signed analytically, we can investigate their signs in a calibrated version of the model.[24] We use the sample means for τ and z (0.393 and 1.775 respectively) and a baseline value of the elasticity of the demand for capital with respect to r, denoted ε, of 0.25 (from Chirinko, Fazzari, and Meyer, 1999). In the calibration, all the remaining parameters of the model except for x (i.e. $\beta, \kappa, \gamma, \sigma$) can then be determined from the data, plus a value of x. We choose x to ensure that other parameters take on non-negative values and that $\gamma > 1$.[25]

This way of calibrating the model is natural, as the exogenously specified parameters ε, x can be interpreted as in some sense measuring the mobility of capital and profit respectively. Some illustrative results[26] are then:

[22] This result is included in the proof of Proposition 3.

[23] It can be shown that z, z^* are strategic complements if (i) $\sigma \geq 2\kappa$ or (ii) $\sigma < 2\kappa$ and $\gamma < \kappa/(2\kappa - \sigma)$, .and τ, z^* are strategic complements. The proof is available on request.

[24] The details of the calibration are explained in an Appendix available on request from the authors.

[25] The slopes of the reaction functions are all independent of r.

[26] We also found that variation in x leads to almost no change in the slopes of the reaction functions, and an increase in ε tends to increase the absolute value of all reaction function derivatives.

Table 1: Illustrative Simulations

ε	x	$d\tau/d\tau^*$	$dz/d\tau^*$	$d\tau/dz^*$	dz/dz^*
0.25	0.39	0.045	-0.019	0.002	0.199
0.45	0.39	0.077	-0.032	0.007	0.208
0.25	0.41	0.045	-0.019	0.0002	0.200
0.45	0.41	0.077	-0.032	0.003	0.210

For a range of simulations (in addition to those reported) we found that (i) $d\tau/dz^*, dz/dz^*$ are both positive; (ii) dz/dz^* is several orders of magnitude larger than $d\tau/dz^*$. Also, note that $d\tau/d\tau^*$ and $dz/d\tau^*$ are positive and negative respectively as predicted by Proposition 2.

Given Proposition 3 and the robustness of these calibration results, we regard our theoretical predictions as being the following. First, the "own-tax" effects are positive i.e.$d\tau/d\tau^* > 0$, $dz/dz^* > 0$. Second, the "cross-tax" effects are smaller in absolute value than the own-tax effects: in the case of $d\tau/dz^*$, several orders of magnitude smaller than dz/dz^*. Finally, the cross-effects $dz/d\tau^*$ and $d\tau/dz^*$ are negative and positive respectively.

2.5. Discussion

At this point, several issues are worth raising. First, would our results would be changed by the addition of other taxes to the model? As $f(k)$ is strictly concave, there is a fixed factor in each country (say labour) which is the recipient of income $\pi(rz)$. Of course, this income is taxed though the statutory rate of corporate tax, τ. But suppose that that net labour income $(1-\tau)\pi(rz)$ could also be taxed at a rate of income tax t. Then it is easily seen that this is a non-distortionary tax (as households are assumed immobile), so that if t is chosen optimally from the individual country's point of view, the marginal benefit of the public good, v' will be set equal to the marginal cost, 1. In this case, as discussed above, $\tau = \alpha p$, and $z = 1$, implying that there is no strategic interaction in taxes. So allowing for taxation of the fixed factor though the personal tax system does not allow us to make meaningful predictions about reaction functions.

Taxation of labour could be introduced into the analysis without destroying strategic interaction between countries by supposing that the supply of labour is elastic, as in Bucovetsky and Wilson (1991). We know from that paper that as long as the number of countries is finite (as here) the capital tax will be used in equilibrium, even when the labour tax is set optimally, and this would also be true in our model. It can also be shown that there would still be a role for the corporate tax, as it allows for some tax exporting. But this would make the analysis of the two-dimensional reaction functions (Proposition 3 above) yet more complex.

A second point worth making is that we can now confirm the claims, made in the Introduction, about the role of a corporate tax in the ZMW model. A version of that model is a special case of ours where the parent companies have no subsidiaries. In this case, profit of the parent is simply $\pi(rz)$, which is taxed at rate τ. The first-order condition for τ then implies that $v'(g) = 1$. But then the argument following Proposition 1 implies that $z = 1$.

3. Testing the Theory

3.1. Empirical Specification of the Tax Reaction Functions

The theoretical analysis in Section 2, which assumed two symmetric countries, generated symmetric reaction functions of the form $\tau = \phi(\tau^*, z^*)$ and $z = \eta(\tau^*, z^*)$. Allowing for n countries that may be different, and introducing time subscripts, the reaction functions can be written more generally as

$$\tau_{i,t} = R_i\left(\boldsymbol{\tau}_{-i,t},\ \mathbf{z}_{-i,t},\ \mathbf{X}_{it}\right) \qquad i = 1, ...n \qquad (3.1)$$

$$z_{i,t} = R_i\left(\boldsymbol{\tau}_{-i,t},\ \mathbf{z}_{-i,t},\ \mathbf{X}_{it}\right) \qquad i = 1, ...n \qquad (3.2)$$

where $\boldsymbol{\tau}_{-i,t}$ and $\mathbf{z}_{-i,t}$ denote the vectors of statutory tax rates and EMTRs of all countries other than i at time t, and $\mathbf{X}_{it}$ is a vector of other control variables that may affect the setting of the tax in country i at time t. Note that we are economizing on notation by allowing z to denote the EMTR, whereas in the theory it denoted one plus the EMTR.

However, (3.1) and (3.2) cannot be estimated as they stand. The first issue is that of degrees of freedom. In principle, each country could respond differently to the tax rates in every other country, leading to a large number of parameters to be estimated. We follow the existing literature by replacing the vectors $\boldsymbol{\tau}_{-i,t}$ and $\mathbf{z}_{-i,t}$ by the weighted averages

$$\overline{\tau}_{i,t} = \sum_{j \neq i} \omega_{ij} \tau_{jt} \quad \text{and} \quad \overline{z}_{i,t} = \sum_{j \neq i} \omega_{ij} z_{jt}$$

That is, we suppose that every country responds in the same way to the weighted average tax rate of the other countries in the sample.

In our case, the appropriate choice of weights $\{\omega_{ij}\}$ is not obvious. In principle, we would like the weights to be large when tax competition between countries i and j is likely to be strong. In the case of local property taxes, the obvious choice (and one that works well in practice, see e.g. Brueckner, 2000) is to use geographical weights, where ω_{ij} is inversely related to the distance between jurisdictions i and j. However, in our case, the degree of tax competition between two countries may depend not on geographic proximity of countries, but on their relative size and the degree to which they are open to international flows. In our empirical work, we focus on size and openness, but also report results using uniform weights. In any case, the two equations to be estimated become:

$$\tau_{i,t} = R_i\left(\overline{\tau}_{i,t},\ \overline{z}_{i,t},\ \mathbf{X}_{it}\right) \qquad i = 1, ...n \tag{3.3}$$

$$z_{i,t} = R_i\left(\overline{\tau}_{i,t},\ \overline{z}_{i,t},\ \mathbf{X}_{it}\right) \qquad i = 1, ...n. \tag{3.4}$$

A final issue is whether the current or lagged value of other countries' tax rates should be included in the empirical model. Following most[27] of the existing applied work in this area (Brueckner(2003)) we use the current values of $\overline{\tau}_{i,t}$ and $\overline{z}_{i,t}$, in (3.3),(3.4). The restriction of this approach is that it effectively assumes that taxes are at their Nash equilibrium values in every year. The advantage of this approach is that is consistent with the theory: at Nash equilibrium, every country correctly predicts the current tax rates of the other countries.

Finally, we assume that the functions (3.3) and (3.4) are linear. Allowing for fixed effects and country-specific time trends, and adding in error terms, the system of equations to be estimated is

$$\tau_{i,t} = \alpha_1 + \beta_1\overline{\tau}_{i,t} + \gamma_1\overline{z}_{i,t} + \boldsymbol{\eta}_1'\mathbf{X}_{it} + \eta_{1i} + T_{1it} + \varepsilon_{1it},\ i = 1, ..n \tag{3.5}$$

$$z_{i,t} = \alpha_2 + \beta_2\overline{\tau}_{i,t} + \gamma_2\overline{z}_{i,t} + \boldsymbol{\eta}_2'\mathbf{X}_{it} + \eta_{2i} + T_{2it} + \varepsilon_{2it},\ i = 1, ..n \tag{3.6}$$

where η_{1i} and η_{2i} are country-specific fixed effects, and T_{1it} and T_{2it} are country-specific time trends, discussed below. The theoretical predictions are that $\beta_1, \gamma_1, \gamma_2 > 0$, and $\beta_2 < 0$, with β_1, γ_2 large relative to γ_1, β_2.

3.2. Data

The empirical approach in this paper is to estimate (3.3) and (3.4) using data on the corporation tax regimes of 21 OECD countries over the period 1982 to 1999. Data definitions, sources, and summary statistics are given in Table A1 of the Appendix. We first comment on our measures of corporate tax rates.

[27] An alternative approach used, by a few authors, for example by Hayashi and Boadway(2001), is to use lagged values, say $\overline{\tau}_{i,t-1}$ and $\overline{z}_{i,t-1}$. We do not follow this approach on the grounds that this is a further step away from the theory. In effect it assumes a particular form of myopic behavior in which each country responds to the tax rates set in the previous period by other countries.

There are two broad approaches to the measurement of effective tax rates on capital income. One, proposed for example by Mendoza et al (1994), is based on the ratio of tax payments to a measure of the operating surplus of the economy. This approach is not ideal for analyzing the competition between jurisdictions over taxes on corporate income described in our theoretical model, for several reasons. First, at best it is a measure only of an effective average tax rate, and so does not measure either the statutory rate or the EMTR. Second, it does not necessarily reflect the impact of taxes on the incentive to invest in a particular location, because tax revenues depend on the history of past investment and profit and losses of a firm, and also the aggregation of firms in different tax positions. Third, this measure can vary considerably according to underlying economic conditions, even when tax regimes do not change; the variation is therefore due to factors outside the immediate control of the government.

The tax rate measures used in this paper are therefore based instead on an analysis of the legislation underlying different tax regimes. In our dataset, the statutory rate is typically the headline rate of corporation tax, with an adjustment for "typical" local statutory rates of taxes where appropriate. For the EMTR, we use the measure proposed by Devereux and Griffith (2003), which is the additional tax paid following a hypothetical unit perturbation to the capital stock. The cost of the increased capital stock is offset by tax allowances, defined by the legislation and the additional revenue is taxed under the statutory tax rate. Using this approach, we have derived our measure of the EMTR. Further details are available on request from the authors, but here we describe some of the main issues involved.

First, this approach gives several measures of the EMTR, depending on the source of finance (equity, debt) and the type of asset (plant and machinery, industrial buildings). To avoid working with four different measures of this tax variable, we take an average of the four rates, using standard weights[28].

Second, from (2.10)), in the theory, the EMTR can be written $z-1 = (f'(k)-r)/r$, which is a indeed a standard definition of the EMTR. However, in our main empirical work below, we do not use this measure, because there are cases where the value of r is close to zero, which generates very high values of the EMTR. Instead, we therefore use the numerator of this expression, which refer to as the *tax wedge*, $f'(k) - r$. Clearly, this is a simple transformation of z, multiplying it by r. In the case where r is held constant across all observations, this clearly makes no difference to the results. However, there is a difference when r varies across observations. We have run regressions using the tax wedges and the full EMTR. In general, larger standard errors arise in the second case due to the large variation in $z - 1$. Below we present results using the tax

[28] Following Chennells and Griffith(1997), The proportions of each are asumed to be: plant and machinery 64% and industrial buildings 36%; equity 65%, debt 35%.

wedge, although again to economize on notation, we denote this z.

Third, another issue is that in constructing the EMTR or the tax wedge, some assumption must be made about economic parameters (the interest rate and the inflation rate) by country and year in order to calculate the post-tax return to a hypothetical investment project (and thus the EMTR). In the data we use[29], we allow the interest rate and the inflation rate to vary both across years and countries; this approach is gives a best estimate of the EMTR for each observation.[30]

We have constructed the EMTR and the tax wedge, using data[31] on the statutory tax rate, τ, and allowance rules, between 1982 and 1999 for 21 high income OECD countries. Figures 1-4 below show key features of our tax rate variables. As shown in Figure 1, which presents the statutory rate for each country in both 1982 and 1999, almost all countries have reduced their statutory rates, many significantly. It is interesting to note that Germany, essentially the last country in 1999 with a high tax rate, has subsequently cut its tax rate substantially. Ireland is the only country which stands out from the others - here we have used the special 10% rate for manufacturing used in Ireland throughout the period analysed.

Figure 2 presents data on our estimated tax wedges in the same format. In contrast to Figure 1, the tax wedge has risen in several countries as a result of a broadening of the tax base. For example, the 1984 tax reform in the UK substantially reduced capital allowances on both types of asset analysed here; in computing the tax wedge this outweighs the very substantial reduction in the statutory rate which occurred at the same time. In general, these two Figures suggest that the statutory rate and the tax wedge are not highly correlated. This is indeed the case. Out of 20 countries for which there is variation in both forms of tax rate, 7 have a negative correlation between the statutory tax rate and the tax wedge; the average correlation coefficient over these 20 countries is 0.13. (The correlation between the statutory rate and the EMTR is even lower).

Figures 3 and 4 present time series for the mean statutory rate and tax wedge. The upper and lower lines in each Figure show the mean plus and minus one standard deviation. Overall, the mean statutory rate fell from 46.5% in 1982 to 34.7% in 1999. At the same time the dispersion of rates also fell substantially; the standard deviation fell from 12.3% to 8.0%. By contrast, the

[29] However, we have also re-run the regressions for the case in which these parameters are fixed over all observations, so that the only variation in the EMTR is due to changes in tax parameters; this does not affect the qualitative results.

[30] Interest rate and inflation rate data are from World Development Indicators of the World Bank. We use the "lending interest rate" and the "GDP implicit deflator".

[31] These data were collected from a number of sources. Chennells and Griffith (1997) provide information for 10 countries up to 1997. These data have been extended to other countries and later years using annual summaries from accounting firms, notably Price Waterhouse tax guides (Price Waterhouse, 1983 to 1999).

mean tax wedge actually rose slightly over the same period, from 4.3% to 4.5%. However, there was also a reduction in the dispersion of tax wedges - the standard deviation fell from 2.2% to 1.1%.[32]

Finally, it is worth noting that we do not incorporate international aspects of tax, such as taxes levied by the residence country of the multinational on repatriation of profit. One reason is that such taxes vary with the residence country and so to do so would introduce variation in the tax rates which would need to be applied to activity arising in any country. A more fundamental reason is that there is plenty of evidence that multinational companies are skilled at tax planning (some of the evidence is discussed in the Introduction). This implies that the straightforward calculation of effective tax rates taking into account additional taxes at an international level may be seriously misleading. We believe that a more reasonable approach is to assume that multinational firms typically avoid any further tax at an international level: so, we include only the taxes levied in the source country.

Table A1 also lists and defines the country-specific control variables that we included in the regressions determining the tax rate variables. The control variables chosen which we use are based on existing theoretical and empirical literature. It has frequently been argued that corporation tax is a necessary "backstop" for income tax: that is, in the absence of corporation tax, individuals could potentially escape tax on their earnings by incorporating themselves. One important control variable is therefore the highest domestic income tax rate, TOPINC_{it}. A second potentially important factor is the revenue needs of the government; we proxy this using the proportion of GDP accounted for by public consumption. In addition, we control for the openness of each country using lagged data on inward and outward foreign direct investment, and size, using GDP. Finally, we also include some demographic variables. We have also experimented with various measures of political control. However, these proved to be insignificant in the estimation and are therefore not reported.

3.3. Econometric Issues

The system to be estimated is (3.5),(3.6). Since the model predicts that all tax rates are jointly determined, it clearly indicates endogeneity of $\overline{\tau}_{i,t}$ and $\overline{z}_{i,t}$. We use an instrumental variable approach to address this. As a first stage, we first regress $\tau_{i,t}$ on $\mathbf{X}_{it}$, the control variables for country i. We estimate this as a panel, and derive predicted values of $\tau_{i,t}$, denoted $\hat{\tau}_{i,t}$.

[32] A thorough description of the development of these taxes is provided in Devereux, Griffith and Klemm (2002).

Assuming the weights $w_{i,t}$ to be exogenous, we then generate

$$\widehat{\overline{\tau}}_{i,t} = \sum_{j \neq i} \omega_{ij} \hat{\tau}_{jt} \quad \text{and} \quad \widehat{\overline{z}}_{i,t} = \sum_{j \neq i} \omega_{ij} \hat{z}_{jt}$$

the weighted average of the predicted values, and use $\widehat{\overline{\tau}}_{i,t}$, $\widehat{\overline{z}}_{i,t}$ in place $\overline{\tau}_{i,t}$ and $\overline{z}_{i,t}$ in estimating the regression.

An alternative approach, common in the literature, is to generate instruments as the weighted average of the control variables in other countries. That is for each element of $\mathbf{X}_{it}$, denoted x_{it}, it is possible to construct a weighted average for other countries: $\overline{x}_{i,t} = \sum_{j \neq i} \omega_{ij} x_{jt}$ These weighted averages can be used directly as instruments for $\overline{\tau}_{i,t}$ and $\overline{z}_{i,t}$. We have experimented with both approaches. However, our approach tends to generate better instruments in the sense that they are more highly correlated with the endogenous variables. As a result the standard errors tend to be smaller. A drawback of our approach is that we are not able to construct a test of over-identifying restrictions. However, the two approaches do not generally result in significantly different estimates of the coefficients.

A second issue is that in practice, our tax rates are serially correlated, perhaps because abrupt changes in the tax system are likely to be costly to governments, either because such changes impose costs of adjustment on the private sector, or because such changes may be blocked at the political level by interest groups who stand to lose from the change. There may also be spatial correlation in the error terms. We present t-statistics based on clustered standard errors which are robust to both spatial correlation and serial correlation (see Bertrand, Duflo and Mullainathan, 2004).

A third issue is that while we would want to include time dummies, to capture shocks in each period which are common to all countries, this is not generally feasible. To see this, consider for example the case of uniform weights. Then (3.5) can be rewritten[33] as an equation where τ_{it} depends on only the average of *all* statutory rates $\overline{\tau}_t = \frac{\sum_{j=1}^{n} \tau_{jt}}{n}$, plus $\overline{z}_{i,t}$, $\mathbf{X}_{it}$, and thus the effect of $\overline{\tau}_t$ cannot be identified separately from a time dummy. However, we do allow for unobserved factors varying over time as far as possible by also including country-specific time trends. We also include country-specific fixed effects.

Finally, although we generally treat the control variables as exogenous, we have estimated the model also allowing the top income tax rate to be jointly determined with the corporation tax rate, and therefore endogenous. In this case we note that in a first stage regression the three demographic variables - the proportion of the population that is young, old and urban

[33] To see this, note that we can write $\overline{\tau}_{i,t}$ in the uniform weighted case, for example, as $\overline{\tau}_{i,t} = \frac{\sum_{j \neq i} \tau_{jt}}{n-1} = \frac{\sum_{j=1}^{n} \tau_{jt}}{n-1} - \frac{\tau_{it}}{n-1}$. Substituting into (3.5) and rearranging yields the result.

- are jointly significant in determining the top income tax rate. However, as shown in Table 1 below, they are not significant in determining either form of corporate tax rate, conditional on the other variables in the model. As a robustness check we have therefore used these three variables as instruments for the top income tax rate. Since in this case they are being used as instruments, we do not include them in the second stage regression.

4. Empirical Results

4.1. Regression Results

The results for our base case are presented in Table 1. This contains three columns (1 to 3) with the statutory rate as the dependent variable and three (columns 4 to 6) with the effective tax wedge as the dependent variable. In each case, we include as regressors the predicted values of both $\overline{\tau}_{i,t}$ and $\overline{z}_{i,t}$, as described above, as well as a number of control variables, described above, and country fixed effects and country-specific time trends. For each form of tax rate, we present results based on three weighting schemes: (a) uniform weights, (b) weights based on the size of the economy, measured by GDP, and (c) weights intended to capture the openness of the economy, measured by the sum of inward and outward FDI over the three preceding years, expressed as a proportion of GDP. In fact, the results are remarkably consistent across all three weighting schemes.

First consider the control variables. Treating the top income tax rate as exogenous, it has a significant effect on the statutory rate, but not on the tax wedge. This is exactly what would be expected if the corporation tax were being used as a "backstop" to income tax[34]. This form of income shifting does not depend on the EMTR or tax wedge; consistently with this, we find that the top income tax rate is not significant in the tax wedge regressions. These results mirror those in Slemrod (2004). So, too, do the results for the role of public spending on the statutory rate. Here, we find that increases in public consumption relative to GDP - which require at some stage a higher tax revenue - do not effect the statutory rate (or the effective tax wedge) at the margin. There is evidence that country size has a positive effect on the statutory rate, but again, not on the effective tax wedge. This may reflect the possibility that in a larger economy, a higher proportion of economic activity is purely domestic. If the government prefers to tax such activity at high rates, it would be effectively constrained by competitive pressures from abroad. It is plausible that the more important the domestic part of the economy, the higher the government would set the overall tax rate. By contrast, however, our measure of the openness

[34] The further the statutory rate from the income tax rate, the greater the incentive to classify income in the lower-taxed form.

of the economy plays no role in determining either form of tax rate, conditional on the other variables in the model. One of the demographic variables is marginally significant, but overall these three variables are not jointly significant in determining the statutory tax rate, although they are marginally significant in determining the tax wedge.

Turning to the tax variables, there is again a remarkable consistency of results across the different weighting schemes. For the statutory rate, there is clear evidence of an effect of other countries' statutory rates. In columns 1 to 3, the size of the coefficients vary from 0.67 to 0.78; that is a one percentage point reduction in the average of other countries' statutory rates would tend to reduce the rate in country i by between 0.67 and 0.78 percentage points. However, the statutory rate in country i does not depend on the effective tax wedges in other countries.

The case of the effective tax wedge is symmetric. Columns 4 to 6 present clear and consistent evidence that the effective tax wedges in other countries have a significant impact on the effective tax wedge in country i. The coefficients are positive, and their size is comparable to those for the statutory rates in columns 1 to 3. In this case, the statutory rates in other countries do not affect the effective tax wedge in country i.

How do these results relate to our theoretical predictions? First, as predicted, the "own-tax" effects are positive i.e. $\frac{d\tau}{d\tau^*} > 0$, $\frac{dz}{dz^*} > 0$. Our second prediction was that the "cross-tax" effects are smaller in absolute value than the own-tax effects: this is indeed what we find, subject to the obvious qualification that the coefficients measuring the cross-tax effects are imprecisely determined. Finally, as predicted, the cross-effects $\frac{dz}{d\tau^*}$ and $\frac{d\tau}{dz^*}$ are negative and positive respectively in the case of either GDP or FDI weights, although imprecisely determined.

We have undertaken a variety of robustness checks of this evidence. One is presented in the table - the results are consistent across weighting schemes. The results are also very similar when we use the inverse distance between countries as weights. As mentioned above, we have also estimated the model using as instruments the weighted averages of the control variables in other countries. This tends to generate slightly higher standard errors, but the results are not qualitatively different from those in Table 1. With this approach, the instruments sets generally satisfy a test of overidentifying restrictions.

One further robustness check is provided in Table 2. Here we allow for the possibility that the income tax rate and the corporation tax rate are determined jointly. As described above, we instrument the income tax rate with the demographic variables, and drop them from the corporate tax rate regressions. In this case, the income tax rate ceases to have a significant impact on the statutory corporation tax rate. Contrary to previous results, then, this calls into question the role of corporation tax as a backstop to income tax. Allowing for the endogeneity of the income tax rate has some small effects on the point estimates of the strategic interaction terms, and also on their standard errors. However, the broad conclusions from Table 1 continue to hold.

4.2. Alternative Explanations of Strategic Interaction

A central question is whether the relationship between tax rates in different countries observed in Table 1 can be attributed to the movements of capital and profit described in our theoretical model. Alternative explanations include yardstick competition and a common intellectual trend.

To investigate this, we run regressions which allow for the reaction function coefficients to vary with the strength of legal controls on capital movements in *both* the country setting the tax *and* the average of such controls across all the other countries with which that country is competing. The purpose of this exercise is the following. If the strategic interaction detected in the regressions already discussed is due to yardstick competition or common intellectual trends, the strength of capital controls should not matter. If on the other hand, the strategic interaction is truly generated by competition over mobile tax bases, then strategic interaction should be stronger, the more mobile these bases are i.e. the weaker are capital controls.

The main source for researchers on legal controls is the information in the International Monetary Fund's Exchange Arrangements and Exchange Restrictions annual. Based on this publication, Quinn (1997) offers a sophisticated coding that measures the intensity of capital controls, and which covers all our countries and observations up to 1997.[35] Quinn distinguishes seven categories of statutory measures, of which two are capital account restrictions. He codes each of these on a 0-4 scale with a higher number denoting a weaker restriction. We use an index based on Quinn's coding of capital account restrictions. We give the two capital controls equal weight, and normalize the index between zero and one, with a higher value denoting weaker control.[36]

To split the sample broadly into those observations with and without capital controls, we divide observations between those with a value of the index above 0.8 (58% of observations) and those with an index below 0.8 (42% of observations); this allows us to create a dummy variable, $c_{it} = 0$ if country i does not have controls in period t, and $c_{it} = 1$ if country i does have controls in period t.

[35] Another widely-used coding is abinary one, originally due to Grilli and Milesi-Ferretti (1995).

[36] We have also experimented with a number of other possible measures; some of these results are reported in a companion paper, Devereux, Lockwood and Redoano, (2003).

We then proceed as follows. Consider first the statutory rate. First, we calculate the weighted average of τ_{jt} across countries other than i which have capital controls separately from those which do not:

$$\overline{\tau}_{i,t}^{C} = \sum_{j \neq i} \omega_{ij} c_{jt} \tau_{jt} \quad \text{and} \quad \overline{\tau}_{i,t}^{N} = \sum_{j \neq i} \omega_{ij} (1 - c_{jt}) \tau_{jt} \tag{4.1}$$

where the weights $\omega_{ij} c_{jt}$ and $\omega_{ij}(1 - c_{jt})$ are adjusted to sum to one within each subgroup. We then run the regression

$$\tau_{i,t} = \alpha_1 + \beta_1^1 (1 - c_{it}) \overline{\tau}_{i,t}^{N} + \beta_1^2 c_{it} \overline{\tau}_{i,t}^{N} + \beta_1^3 (1 - c_{it}) \overline{\tau}_{i,t}^{C} \ + \beta_1^4 c_{it} \overline{\tau}_{i,t}^{C} + \boldsymbol{\eta}_1' \mathbf{X}_{it} + \eta_{1i} + \varepsilon_{1it} \tag{4.2}$$

This specification allows a country i to respond differently to other countries depending on whether they have significant controls or not, and moreover, allows this response to differ also depending on whether country i itself has significant controls. If strategic interaction is only being generated by tax competition, we would expect only β_1^1 to be significant: i.e. there should be strategic interaction only between countries without capital controls.

In the case of the tax wedge, we run the regression

$$z_{i,t} = \alpha_2 + \gamma_1^1 (1 - c_{it}) \overline{z}_{i,t}^{N} + \gamma_1^2 c_{it} \overline{z}_{i,t}^{N} + \gamma_1^3 (1 - c_{it}) \overline{z}_{i,t}^{C} \ + \gamma_1^4 c_{it} \overline{z}_{i,t}^{C} + \boldsymbol{\eta}_2' \mathbf{X}_{it} + \eta_{2i} + \varepsilon_{2it} \tag{4.3}$$

where $\overline{z}_{i,t}^{N}$ and $\overline{z}_{i,t}^{C}$ are constructed as in (4.1). Again, if strategic interaction is only being generated by tax competition, we would expect only γ_1^1 to be significant. Note that for simplicity we drop the tax wedge from the statutory tax rate equations, and vice versa; this does not affect the results.

The results of regressions (4.2), (4.3) are reported in Table 3 below, and provide striking support for the hypothesis that co-movements in tax rates are driven by movements of capital and possibly profit between countries. In each of the six columns in Table 3, the first coefficient - which gives an estimate of β_1^1 or γ_1^1 for each of the specifications - is both positive and significant. Further, the coefficients are all of a similar magnitude to those in Table 1. The only case in which this is not true is the case of uniform weights and the effective tax wedge.

By contrast, of the other eighteen coefficients reported in the table, only two are statistically significant; again both of these are in the case of uniform weights, and both refer to the case in which the home country has controls in place, but responds to the tax rates of those other countries which do not have controls in place. These two results seem to suggest that all countries respond to the tax rates in countries which do not have controls. However, on theoretical grounds, the case of uniform weights is probably the weakest of the cases we analyse. It seems plausible to assume that countries respond more to the tax rates in other countries which are large and open, and hence a potentially important source of capital and profit.

In the case of GDP and FDI weights, the hypothesis that there is competition only between countries without capital controls is supported - both for the statutory rate and for the effective tax wedge. For the three other possibilities in the table, there is no evidence of any role played by tax rates in other countries. These results are consistent with the models analysed in this paper. They do not appear consistent with either yardstick competition or a common intellectual trend- neither of which requires flows of capital or profit between countries.

4.3. Can the Model Explain the Evolution of Taxes over Time?

The original motivation for our work was to investigate whether falls in the statutory rate of corporate tax over the last 20 years can be explained as the outcome of a process of tax competition. We believe that our analysis so far establishes the existence of strategic interaction in tax-setting between countries, which is plausibly explained by tax competition. We now ask the question: can the degree of strategic interaction we have estimated (as measured by slopes of reaction functions), together with changes in the control variables over time, explain a significant part of the observed decline in the statutory rate of tax?

To answer this question, observe that in our empirical model, it is implicitly assumed that in any period, taxes are at their Nash equilibrium values, as all countries are "on" their tax reaction functions. So, our general approach is to (i) calculate in any time period, the Nash equilibrium tax rates, given the values of the control variables (and their estimated coefficients) in that period, and our estimates of the slopes of the reaction functions: and then (ii) take the average of those Nash equilibrium taxes across countries, and compare the cross-country averages of the Nash equilibrium taxes to the actual cross-country averages.

In more detail, the procedure is as follows. First, we look at the statutory tax only, as it has fallen much more substantially over the sample period, and this fall is of considerable interest. Observing that the "cross-tax" effect γ_1 is always insignificant, we re-estimate (3.5) with $\gamma_1 = 0$. Second, at this stage we also drop the country-specific time trends, because if they are present, they may explain much of the time-series variation in taxes. In this sense, we are setting a very stringent test for our model: evolution in the control variables *only,* combined with strategic interaction must explain the time-series variation in the statutory tax rate.

So, the Nash equilibrium statutory taxes must solve the n simultenous equations:

$$\tau_{i,t} = \hat{\beta}_1 \overline{\tau}_{i,t} + \hat{\boldsymbol{\eta}}_1' \mathbf{X}_{it} + \hat{\eta}_{1i}, \; i = 1, ..n \tag{4.4}$$

where $\hat{\beta}_1$, $\hat{\boldsymbol{\eta}}_1', \hat{\eta}_{1i}$ are the estimated coefficeints from the regression just described. Let these solutions[37] be $\hat{\tau}_{i,t}$ and let $\hat{\tau}_t = \frac{1}{n}\sum_{i=1}^{n}\hat{\tau}_{i,t}$. We compute $\hat{\tau}_t$ and refer to them as the *Nash equilibrium average statutory tax rates* across countries.

Figure 5 presents the time series for these estimated Nash equilibrium average statutory tax rates for the cases corresponding to the specifications in columns 2 and 3 of Table1, with GDP and FDI weights respectively. For comparison, it also shows the actual average statutory rate in each period. The two specifications give similar results. They both indicate a substantial reduction in Nash equilibrium average statutory tax rates over the time period considered. In fact the overall reduction is larger than that in actual tax rates - that is, the empirical model predicts a sharper fall in tax rates than actually occurred. The Nash equilibria average tax rates, in particular, the ones calculated from FDI weights, are also more volatile than the actual averages. The reason for this is that, by assumption, the Nash equilibrium taxes are assumed to adjust immediately to their equilibrium values within the period, following any change in either the control variables or the weights[38]. So, perhaps the puzzle is not that there has been such a big fall in the statutory rate over time, but that the fall has not been bigger.

5. Conclusions

Motivated by significant reforms to corporation taxes in OECD countries over the last twenty years, we have investigated the extent to which governments set such taxes in response to each other. We have found strong evidence that they do respond to changes in other countries' taxes. More specifically, we identify in our theoretical model two possible forms of tax competition: over statutory tax rates for mobile profit and over effective marginal tax rates (EMTRs) for capital. We derived testable predictions about the resulting two-dimensional reaction functions, and took these predictions to the data. In the empirical work, we did find intense strategic interaction in both forms of tax rate.

Moreover, our results indicate that this strategic interaction is probably not well-explained by other theories (such as yardstick competition or common intellectual trends), since it is generally present only between open economies: thus, it is best explained in terms of competition over mobile tax bases, as described in our theoretical model. Finally, we show that the downward trend in the average statutory tax rate across countries in our sample is quite well explained

[37] The solution is found by writing e.g. (4.4) in matrix form as $\boldsymbol{\tau}_t = B\tau_t + \hat{\boldsymbol{\eta}}_1'\mathbf{X}_t + \hat{\eta}_1$, where the ijth element of B_t is 0 if $i = j$, and ω_{ij} if $i \neq j$, and $\mathbf{X}_t$ is the $n \times k$ matrix of controls, and $\hat{\eta}_1$ is a $n \times 1$ vector of fixed effects. Matrix inversion then gives $\hat{\boldsymbol{\tau}}_t = (I - B)^{-1}(\hat{\boldsymbol{\eta}}_1'\mathbf{X} + \hat{\eta}_1)$.

[38] We could smooth this adjustment in an ad hoc way by (for example) assuming that there is only partial adjustment in any period, so that τ_{it} depends on its own lagged values. This, however, is not consistent with the theory, and would complicate the estimation of the model.

by our model, in the sense that the average Nash equilibrium taxes also fall substanitally over time.

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A. Appendix

A.1. Proofs of Propositions

Proof of Proposition 1. From (2.2),(2.6) and (2.13), each of $\hat{\Pi} \equiv \Pi - \Phi$ and g depends on (i) the home corporate tax system τ, z : (ii) the input prices r, q, q^*.In particular, from (2.11), (2.8), τ does not affect r, and z does not affect q or q^*. So, we see that at symmetric tax equilibrium, the two first-order conditions are

$$W_\tau = \frac{\partial W}{\partial \tau} + \frac{\partial W}{\partial q}\frac{\partial q}{\partial \tau} + \frac{\partial W}{\partial q^*}\frac{\partial q^*}{\partial \tau} = 0,\ W_z = \frac{\partial W}{\partial z} + \frac{\partial W}{\partial r}\frac{\partial r}{\partial z} = 0 \tag{A.1}$$

Evaluating (A.1) at symmetric tax equilibrium ($\tau = \tau^*$, $z = z^*$), we see that

$$\frac{\partial W}{\partial q} = \frac{\partial \hat{\Pi}}{\partial q} + v'\frac{\partial g}{\partial q} = (\tau - \tau^*) - \alpha p(2q-1) + v'(-\tau + \alpha p q) = v'(-\hat{\tau} + 0.5\alpha p) \tag{A.2}$$

$$\frac{\partial W}{\partial q^*} = \frac{\partial \hat{\Pi}}{\partial q^*} + v'\frac{\partial g}{\partial q^*} = v'[\tau - \alpha p(1-q^*)] = v'(\hat{\tau} - 0.5\alpha p) \tag{A.3}$$

Moreover, $\partial q/\partial \tau = -\partial q/\partial \tau^* = 1/2\alpha p$ from (2.8). So, from (A.2),(A.3), at symmetric equilibrium,

$$\frac{\partial W}{\partial q}\frac{\partial q}{\partial x} + \frac{\partial W}{\partial q^*}\frac{\partial q^*}{\partial x} = \frac{v'(0.5\alpha p - \hat{\tau})}{\alpha p} \tag{A.4}$$

Moreover, at symmetric equilibrium,

$$\frac{\partial W}{\partial \tau} = \frac{\partial \hat{\Pi}}{\partial \tau} + v'\frac{\partial g}{\partial \tau} = -\pi(zr) + q + v'\left(\pi(zr) + q^* - q\right) = -\pi + 0.5 + v'\pi \tag{A.5}$$

So, substituting (A.4),(A.5) in (A.1), we have

$$W_\tau = -\pi + 0.5 + v'\pi + \frac{v'(0.5\alpha p - \hat{\tau})}{\alpha p} = 0 \tag{A.6}$$

which solves to give (2.15).

Next, note that at symmetric equilibrium,

$$\frac{\partial W}{\partial z} = -(1-\tau)rk + v'\left[(1-\tau)rk + (z-1)r^2k'\right] \tag{A.7}$$

Substituting (A.7) in (A.1) , and rearranging, we get

$$\begin{aligned}(z-1) &= \frac{(v'-1)(1-\tau)z}{v'\varepsilon} + \frac{\partial W}{\partial r}\frac{\partial r}{\partial z}\frac{1}{v'r^2(-k')},\quad \varepsilon = \frac{-k'rz}{k} > 0 \qquad \text{(A.8)} \\ &= \frac{(v'-1)(1-\tau)z}{v'\varepsilon} - \frac{\partial W}{\partial r}\frac{1}{2v'k\varepsilon}\ \left(\text{using } \frac{\partial r}{\partial z} = -\frac{r}{2z} \text{ from (2.11)}\right)\end{aligned}$$

which gives (2.16). Finally, note that

$$\begin{aligned}\frac{\partial W}{\partial r} &= \kappa - (1-\tau)zk + v'\frac{\partial g}{\partial r} \\ &= \kappa - (1-\tau)zk + v'\left[-\tau zk + (z-1)k + (z-1)rzk'\right]\end{aligned} \tag{A.9}$$

which gives (2.17). □

Proof of Proposition 2. As $f = \frac{1}{\beta}(\sigma k - k^2/2)$, $v(g) = \gamma g$, then $k(zr) = \sigma - \beta zr$, so $k' = -\beta$, and so, in equilibrium. from (2.11),

$$r = \frac{2(\sigma - \kappa)}{\beta(z + z^*)} \tag{A.10}$$

so we require $\kappa \leq \sigma$ for a positive price of capital, and moreover,

$$\pi(zr) = \frac{1}{\beta}(\sigma k - k^2/2) - zrk = \frac{(\sigma - \beta zr)^2}{2\beta} \tag{A.11}$$

Then, note that at equilibrium, $\beta zr = \sigma - \kappa$ from (A.10), and so $\pi(zr) = \kappa^2/2\beta$. Substituting this, and $v' = \gamma$ in (2.15), we obtain expression (2.18) for the equilibrium statutory rate.

Also, to obtain the formula for the EMTR, it is convenient not to use formula (A.8) above, but to use a different derivation, which will be useful for the proof of Proposition 3. Using (A.7), (A.9), and the fact that $k' = -\beta$ and $\frac{\partial r}{\partial z} = -\frac{r}{(z+z^*)}$ with a quadratic production function, and $v' = \gamma$ from linear utility, we have

$$\begin{aligned}W_z &= \frac{\partial W}{\partial z} + \frac{\partial W}{\partial r}\frac{\partial r}{\partial z} \\ &= -(1-\tau)rk + \gamma\left[(1-\tau)rk - (z-1)r^2\beta\right] \\ &\quad + \{\kappa - (1-\tau)zk + \gamma\left[-\tau zk + (z-1)k - (z-1)rz\beta\right]\}\left[-\frac{r}{(z+z^*)}\right] \\ &= \frac{r}{(z+z^*)}\{-\kappa + (\gamma-1)(1-\tau)zk + \gamma k - \gamma(z-1)zr\beta\}\end{aligned} \tag{A.12}$$

At the symmetric Nash equilibrium, the term in the curly brarkets is is equal to zero. Solving the resulting equation for $\hat{z}$, using $\hat{z}r\beta = \sigma - \kappa$ from (A.10), give (2.19) above.

To show $\hat{z} > 1$ when $\gamma > 1$, we proceed as follows. As the EMTR must be greater than -1 (as the cost of capital cannot be negative), we must have $\widehat{z} > 0$ in equilibrium. As $\kappa \leq \sigma$ and $\gamma > 1$ by assumption, so $\gamma\sigma - \kappa > 0$. Then, letting $E = \gamma(\sigma - \kappa) - (\gamma - 1)\kappa(1 - \tau)$, for $\hat{z} > 0$ it is necessary and sufficient that $E > 0$, which requires $\frac{\sigma-\kappa}{\kappa} > \frac{\gamma-1}{\gamma}(1-\tau)$. This reduces to $\kappa \leq \underline{\kappa}$ as stated in the proposition: note that $\underline{\kappa} < \sigma$ so that this subsumes the earlier condition $\kappa \leq \sigma$. Finally, it is easily calculated that $\gamma\sigma - \kappa > E$ as long as $\gamma > 1$. So, from (2.19), if $\widehat{z} > 0$, then $\widehat{z} > 1$. □

Proof of Proposition 3. Note first that as none of the terms in (A.12) depends on τ^*, $W_{z\tau^*} = 0$ as claimed. Then from (2.20), we have

$$\frac{d\tau}{d\tau^*} = \frac{-W_{zz}W_{\tau\tau^*}}{D}, \ \frac{dz}{d\tau^*} = \frac{W_{\tau z}W_{\tau\tau^*}}{D}, \ D = W_{\tau\tau}W_{zz} - (W_{\tau z})^2 > 0. \tag{A.13}$$

where D is psotive from the second-order conditions. Now note from (A.2),(A.3) that in the case of linear utility

$$\begin{aligned} W_\tau &= -\pi(zr) + q + \gamma\left(\pi(zr) + q^* - q\right) + \frac{1}{2\alpha p}((\tau - \tau^*) - \alpha p(2q-1) \\ &\quad +\gamma(-\tau + \alpha p q)) - \frac{1}{2\alpha p}\gamma(\tau - \alpha p(1-q^*)) \\ &= \frac{1}{2} + (\gamma - 1)\pi(zr) - \frac{1}{\alpha p}(\gamma - \frac{1}{2})\tau + \frac{\gamma}{2}\left(q^* - q\right) - \frac{1}{2\alpha p}\tau^* \end{aligned} \tag{A.14}$$

So, from (A.14), using (2.8), (2.9), we get:

$$W_{\tau\tau^*} = \frac{\gamma - 1}{2\alpha p} > 0 \tag{A.15}$$

In addition, from (A.14), at symmetric equilibrium, using $\partial r/\partial z = -r/2z$, we have

$$W_{\tau z} = -(\gamma - 1)(rk + zk\frac{\partial r}{\partial z}) = -\frac{1}{2}(\gamma - 1)rk < 0 \tag{A.16}$$

Combining (A.13),(A.15) and (A.16), and using the fact that $W_{zz} < 0$ from the second-order conditions, completes the proof. Finally note from (A.14) that

$$W_{\tau z^*} = -(\gamma - 1)zk\frac{\partial r}{\partial z^*} = \frac{1}{2}(\gamma - 1)rk > 0. \tag{A.17}$$

which establishes that τ, z^* are strategic complements, as claimed in the text. □

B. Appendix. Description of Calibrations (not for publication)

We begin with four definitions from the theoretical model:

$$\kappa = \sigma - \beta z r. \tag{B.1}$$

$$\tau = x\left\{1 + \frac{(\gamma-1)(\kappa^2-\beta)}{2\gamma\beta}\right\} \tag{B.2}$$

$$z = \frac{\gamma\sigma - \kappa}{\gamma(\sigma-\kappa) - (\gamma-1)(1-\tau)\kappa} \tag{B.3}$$

$$\epsilon = \frac{\beta z r}{\kappa} \Rightarrow \kappa = \frac{\beta z r}{e} \tag{B.4}$$

We assume that we have data on three parameters, τ, z and ϵ; the values used are given in the text.

B.1. Solving for basic parameters

We solve these equations for $(\gamma, \beta, \kappa, \sigma)$ before using the results in quantifying the reaction functions. We demonstrate below that although these parameters depend on r, the slopes of the reaction functions do not depend on r.

From (B.4) and (B.1):

$$\kappa = \sigma - e\kappa \Rightarrow \kappa = \frac{\sigma}{1+e} \tag{B.5}$$

Substituting into (B.3) gives:

$$\begin{aligned} z &= \frac{\gamma\sigma - \frac{\sigma}{1+e}}{\gamma(\sigma - \frac{\sigma}{1+e}) - (\gamma-1)(1-\tau)\frac{\sigma}{1+e}} \\ &= \frac{\gamma(1+e)-1}{\gamma e - (\gamma-1)(1-\tau)} \end{aligned} \tag{B.6}$$

We can rearrange (B.6) to solve for γ from the three known parameter values, τ, z and ϵ:

$$\gamma = \frac{1 + z(1-\tau)}{(1+e) + z\,(1-t-e)}.$$

Also, from (B.2) and (B.4):

$$\left(\frac{\widehat{\tau}}{x}-1\right)\frac{2\gamma}{(\gamma-1)}+1=\frac{\kappa^2}{\beta}=\beta\left(\frac{zr}{e}\right)^2$$

which implies that

$$\begin{aligned}\beta &= \left\{\left(\frac{\widehat{\tau}}{x}-1\right)\frac{2\gamma}{(\gamma-1)}+1\right\}\left(\frac{e}{zr}\right)^2 \\ &= \psi\left(\frac{e}{zr}\right)^2 \end{aligned} \tag{B.7}$$

where ψ depends only on known parameter values:

$$\psi=\left(\frac{\widehat{\tau}}{x}-1\right)\frac{2\gamma}{(\gamma-1)}+1. \tag{B.8}$$

Given (B.7), we can use (B.4) to solve for κ also in terms on known parameter values, plus r:

$$\kappa=\frac{\beta zr}{e}=\psi\left(\frac{e}{zr}\right)^2\frac{zr}{e}=\frac{\psi e}{zr} \tag{B.9}$$

B.2. Slopes of Reaction Functions

We can now apply these values to find slopes of 4 reaction functions. From (A.13), we have

$$\frac{d\tau}{d\tau^*}=\frac{-W_{zz}W_{\tau\tau^*}}{D},\ \frac{dz}{d\tau^*}=\frac{W_{\tau z}W_{\tau\tau^*}}{D},\ D=W_{\tau\tau}W_{zz}-(W_{\tau z})^2>0 \tag{B.10}$$

and from (2.20) we have:

$$\frac{d\tau}{dz^*}=\frac{-W_{zz}W_{\tau z^*}+W_{\tau z}W_{zz^*}}{D},\ \frac{dz}{dz^*}=\frac{-W_{\tau\tau}W_{zz^*}+W_{\tau z}W_{\tau z^*}}{D}. \tag{B.11}$$

We have already evaluated three of the elements of these equations, $W_{\tau\tau^*}$, $W_{\tau z}$ and $W_{\tau z^*}$ at a symmetric equilibrium. Here we modify these expressions slightly, using (B.7), (B.8) and (B.9). From (A.15) we have

$$W_{\tau\tau^*}=\frac{\gamma-1}{2x}. \tag{B.12}$$

From (A.16),

$$\begin{aligned} W_{\tau z} &= -\frac{1}{2}(\gamma-1)r\kappa \\ &= -\frac{(\gamma-1)\psi e}{2z} \end{aligned} \tag{B.13}$$

and from (A.17),

$$\begin{aligned} W_{\tau z^*} &= \frac{1}{2}(\gamma-1)r\kappa \\ &= \frac{(\gamma-1)\psi e}{2z} \end{aligned} \tag{B.14}$$

In addition, from (A.14), and again using (2.8) and (2.9), we have

$$W_{\tau\tau} = -\frac{(3\gamma-1)}{2x}. \tag{B.15}$$

To evaluate the other terms, we begin with (A.12), noting again that at a symmetric equilibrium, $\partial r/\partial z = -r/2z$. This yields

$$\begin{aligned} W_{zz} &= -\frac{\beta r^2}{2z}\left\{\gamma z + \frac{1}{2}(\gamma-1)(1-\tau)z + \gamma\right\} \\ &= -\frac{\psi e^2 \phi}{2z^3} \end{aligned} \tag{B.16}$$

where

$$\phi = \gamma z + \frac{1}{2}(\gamma-1)(1-\tau)z + \gamma$$

depends only on known parameters. Using also (B.5), we can show that

$$\begin{aligned} W_{zz^*} &= \frac{r}{2z}\left\{(\gamma-1)(1-\tau)\left[\frac{(\sigma+\kappa)}{2} - \frac{\gamma(\sigma-\kappa)}{\gamma\sigma-\kappa}\kappa\right] + \gamma(\sigma-\kappa)\left[\frac{\gamma(\sigma-\kappa)}{\gamma\sigma-\kappa} - \frac{1}{2}\right]\right\} \\ &= \frac{r}{2z}\left\{(\gamma-1)(1-\tau)\left[\frac{(\kappa(2+e))}{2} - \frac{\gamma e\kappa}{\gamma(1+e)-1}\right] + \gamma\kappa e\left[\frac{\gamma e}{\gamma(1+e)-1} - \frac{1}{2}\right]\right\} \\ &= \frac{r}{2z}\left\{(\gamma-1)(1-\tau)\left[\frac{(\beta z r(2+e))}{2e} - \frac{\gamma\beta z r}{\gamma(1+e)-1}\right] + \gamma\beta z r\left[\frac{\gamma e}{\gamma(1+e)-1} - \frac{1}{2}\right]\right\} \\ &= \frac{\beta r^2 z}{2z}\left\{(\gamma-1)(1-\tau)\left[\frac{2+e}{2e} - \frac{\gamma}{\gamma(1+e)-1}\right] + \gamma\left[\frac{\gamma e}{\gamma(1+e)-1} - \frac{1}{2}\right]\right\} \\ &= \frac{\psi e^2 \lambda}{2z^2} \end{aligned} \tag{B.17}$$

where

$$\lambda = \left\{(\gamma-1)(1-\tau)\left[\frac{2+e}{2e} - \frac{\gamma}{\gamma(1+e)-1}\right] + \gamma\left[\frac{\gamma e}{\gamma(1+e)-1} - \frac{1}{2}\right]\right\}$$

again depends only on known parameters.

Finally,

$$\begin{aligned} D &= \frac{(3\gamma-1)\beta r^2}{4xz}\left\{\gamma z + \frac{1}{2}(\gamma-1)(1-\tau)z + \gamma\right\} - \frac{1}{4}(\gamma-1)^2 r^2 \kappa^2 \\ &= \frac{r^2}{4xz}\left\{(3\gamma-1)\beta\phi - \theta\kappa^2 xz\right\} \\ &= \frac{\psi e^2}{4xz^3}\left\{(3\gamma-1)\phi - \theta\psi xz\right\} \end{aligned} \tag{B.18}$$

where

$$\theta = (\gamma-1)^2. \tag{B.19}$$

It follows from this analysis that all of the elements of each of the slopes of the reaction functions depend only on τ, z, ϵ and x. Each slope is independent of r.

Finally, we can evalaute the slopes themselves:

(a)

$$\begin{aligned} \frac{d\tau}{d\tau^*} &= \frac{\frac{\psi e^2 \phi}{2z^3}\frac{\gamma-1}{2x}}{\frac{\psi e^2}{4xz^3}\left\{(3\gamma-1)\phi - \theta\psi xz\right\}} \\ &= \frac{\phi(\gamma-1)}{(3\gamma-1)\phi - \theta\psi xz}. \end{aligned} \tag{B.20}$$

(b)

$$\begin{aligned} \frac{dz}{d\tau^*} &= \frac{-\frac{(\gamma-1)\psi e}{2z}\frac{\gamma-1}{2x}}{\frac{\psi e^2}{4xz^3}\left\{(3\gamma-1)\phi - \theta\psi xz\right\}} \\ &= \frac{-(\gamma-1)^2 z^2}{e\left\{(3\gamma-1)\phi - \theta\psi xz\right\}} \\ &= \frac{-\theta z^2}{e\left\{(3\gamma-1)\phi - \theta\psi xz\right\}}. \end{aligned} \tag{B.21}$$

(c)

$$\frac{d\tau}{dz^*} = \frac{\frac{\psi e^2\phi}{2z^3}\frac{(\gamma-1)\psi e}{2z} - \frac{(\gamma-1)\psi e}{2z}\frac{\psi e^2\lambda}{2z^2}}{\frac{\psi e^2}{4xz^3}\{(3\gamma-1)\phi - \theta\psi xz\}}$$
$$= \frac{\frac{\phi(\gamma-1)\psi e}{z} - \frac{(\gamma-1)\psi e\lambda z}{z}}{\frac{1}{x}\{(3\gamma-1)\phi - \theta\psi xz\}}$$
$$= \frac{\psi ex(\gamma-1)(\phi-\lambda z)}{z\{(3\gamma-1)\phi - \theta\psi xz\}}. \tag{B.22}$$

(d)

$$\frac{dz}{dz^*} = \frac{\frac{(3\gamma-1)}{2x}\frac{\psi e^2\lambda}{2z^2} - \frac{(\gamma-1)\psi e}{2z}\frac{(\gamma-1)\psi e}{2z}}{\frac{\psi e^2}{4xz^3}\{(3\gamma-1)\phi - \theta\psi xz\}}$$
$$= \frac{(3\gamma-1)\lambda - (\gamma-1)^2\psi x}{\frac{1}{z}\{(3\gamma-1)\phi - \theta\psi xz\}}$$
$$= \frac{z[(3\gamma-1)\lambda - \theta\psi x]}{(3\gamma-1)\phi - \theta\psi xz}. \tag{B.23}$$

B.3. Calibrations

In performing calibrations, our baseline values of (τ, z, ϵ) are $(0.393, 1.775, 0.25)$. We choose x to generate reasonable values of the other parameters (β, κ, σ). These also depend on r; in choosing x we use $r = 0.061$ which is the mean value in our data. It turns out that there is only a small range of reasonable values for x:

x	0.39	0.40	0.41
β	6.21	3.33	0.59
κ	2.69	1.44	0.26
σ	1.02	1.80	0.32

For values of $x < 0.38$, the values of the three parameters rise substantially. For values of x in excess of around 0.412, values of all three parameters become negative. In the text, we present the implied slopes of the reaction functions for $x = (0.39, 0.41)$.

Table 1. Basic Specification

	Statutory Rate, τ_{it}			Effective Tax Wedge, w_{it}		
weights	*uniform*	*GDP*	*FDI*	*uniform*	*GDP*	*FDI*
$\bar{\tau}_{it}$	0.778	0.668	0.683	0.01	-0.019	-0.025
	(2.90)	(2.77)	(2.67)	(0.18)	(0.43)	(0.67)
$\bar{w}_{it}$	-0.758	0.277	0.529	0.791	0.817	0.69
	(0.57)	(0.18)	(0.34)	(2.85)	(2.55)	(2.06)
Income tax rate	0.175	0.183	0.187	0.008	0.009	0.01
	(3.15)	(3.30)	(3.31)	(1.03)	(1.12)	(1.31)
Size	0.524	0.435	0.403	-0.017	-0.027	-0.033
	(2.47)	(2.10)	(1.78)	(0.24)	(0.38)	(0.51)
Openness	0.052	0.083	0.098	-0.001	-0.001	-0.001
	(0.56)	(0.84)	(0.98)	(0.05)	(0.1)	(0.07)
Public consumption /GDP	-0.052	-0.088	-0.116	0.073	0.072	0.065
	(0.19)	(0.33)	(0.42)	(1.04)	(1.05)	(0.98)
Proportion Young	-2.136	-2.227	-2.333	-0.341	-0.328	-0.365
	(1.81)	(1.78)	(1.87)	(1.57)	(1.49)	(1.8)
Proportion Old	-0.058	-0.424	-0.575	0.33	0.332	0.28
	(0.04)	(0.33)	(0.48)	(0.71)	(0.75)	(0.67)
Proportion Urban	0.327	0.269	0.208	0.045	0.049	0.038
	(0.68)	(0.56)	(0.43)	(0.23)	(0.25)	(0.19)
country dummies	yes	yes	yes	yes	yes	yes
country time trends	yes	yes	yes	yes	yes	yes
Observations	378	378	378	378	378	378
R-squared	0.93	0.93	0.93	0.93	0.92	0.92

Notes.

1. Parentheses contain t-statistics robust to serial correlation and heteroscedasticity.
2. $\bar{\tau}_{it}$ and $\bar{w}_{it}$ are the weighted averages of the predicted values of other countries' statutory tax rates and effective tax wedges respectively. The predicted values are from preliminary first stage panel regressions: in each case the tax rate is regressed on the control variables for that country, plus country dummies and time dummies.
3. Control variables are assumed to be exogenous.

Table 2. Allowing Income Tax Rates to be Endogenous

	Statutory Rate, τ_{it}			Effective Tax Wedge, w_{it}		
weights	*uniform*	*GDP*	*FDI*	*uniform*	*GDP*	*FDI*
$\overline{\tau}_{it}$	0.9	0.639	0.538	-0.018	-0.058	-0.081
	(3.22)	(1.73)	(1.14)	(0.32)	(1.28)	(1.36)
$\overline{w}_{it}$	0.22	1.662	1.781	1.048	1.038	0.931
	(0.18)	(1.14)	(0.26)	(3.62)	(3.25)	(2.61)
Income tax rate	0.071	0.146	0.217	0.013	0.018	0.031
	(0.69)	(0.95)	(1.21)	(0.55)	(0.82)	(1.12)
Size	0.682	0.501	0.394	-0.04	-0.054	-0.068
	(2.28)	(1.34)	(0.86)	(0.69)	(0.92)	(0.98)
Openness	0.074	0.104	0.115	0.006	0.003	0.002
	(0.81)	(1.08)	(1.16)	(0.45)	(0.22)	(0.18)
Public consumption /GDP	-0.158	-0.205	-0.245	0.065	0.066	0.06
	(0.45)	(0.57)	(0.67)	(0.89)	(0.9)	(0.82)
country dummies	yes	yes	yes	yes	yes	yes
country time trends	yes	yes	yes	yes	yes	yes
Observations	378	378	378	378	378	378
R-squared	0.93	0.92	0.92	0.77	0.77	0.77

Notes.

1. In this case, predicted values of the top income tax rate are found from a first stage panel regression of the income tax rate on all domestic control variables, including the three demographic variables from Table 1, country dummies and time dummies. The demographic variables are not used in the regressions reported here. plus country dummies and time dummies.

Table 3. Allowing for capital controls

	Statutory Rate, τ_{it}			Effective Tax Wedge, w_{it}		
weights	*uniform*	*GDP*	*FDI*	*uniform*	*GDP*	*FDI*
mean tax rate over countries *without* capital controls; home country *without* capital controls	0.639 (2.82)	0.672 (2.59)	0.778 (3.25)	0.387 (1.08)	0.896 (2.21)	0.876 (2.02)
mean tax rate over countries *with* capital controls; home country *without* capital controls	0.042 (0.23)	-0.103 (0.34)	-0.392 (1.08)	0.573 (1.62)	0.195 (0.43)	0.06 (0.15)
mean tax rate over countries *without* capital controls; home country *with* capital controls	0.607 (3.12)	0.215 (1.2)	0.208 (1.09)	0.548 (2.14)	0.671 (1.11)	0.567 (1.0)
mean tax rate over countries *with* capital controls; home country *with* capital controls	0.128 (0.93)	0.369 (1.7)	0.179 (0.66)	0.415 (1.16)	0.409 (1.19)	0.34 (1.18)
control variables	yes	yes	yes	yes	yes	yes
country dummies	yes	yes	yes	yes	yes	yes
country time trends	yes	yes	yes	yes	yes	yes
Observations	378	378	378	378	378	378
R-squared	0.93	0.93	0.93	0.93	0.92	0.92

Notes.

1. The full set of controls from Table 1 is included in all regressions.
2. For the statutory rate regressions, the effective tax wedge is not included; the “mean tax rate” is the weighted mean of the predicted statutory rates in countries with or without capital controls. Similarly, for the effective tax wedge regressions, the statutory rate is not included; the “mean tax rate” is the weighted mean of the predicted tax wedges in countries with or without capital controls.

Table A1. Summary Statistics

Variable	Description	Mean	Std. Dev.	Min	Max	Source
STATUTORY TAX RATE$_{IT}$		0.402	0.112	0.1	0.627	Price Waterhouse, Corporate Taxes: a Worldwide Summary
TAX WEDGE$_{IT}$	Cost of Capital minus real interest rate	0.048	.0131	0.009	0.107	Our Calculations, main data from Price Waterhouse, Corporate Taxes: a Worldwide Summary and World Bank WDI
TOPINC$_{IT}$	Highest marginal income tax rate	0.533	0.116	0.280	0.920	Primarily annual guides from accounting firms, and specifically those from Price Waterhouse
PCON$_{IT}$	Total public consumption, as a proportion of GDP$_{IT}$	0.187	.0417	0.088	0.297	OECD National Accounts, various years
Size$_{it}$	relative size of each economy, measured as GDP$_{IT}$/GD$_{JT}$ where J=USA	0.122	.217	0.007	1	OECD National Accounts, various years
OPEN$_{IT-1}$	sum of inward and outward foreign direct investment, as a proportion of GDP$_{IT}$, lagged one year	0.028	0.031	-0.005	0.314	OECD International Direct Investment Statistics Yearbook
PYOU$_{IT}$	proportion of population below 14 years old	0.196	0.027	0.145	0.302	World Bank- World Development Indicators
POLD$_{IT}$	proportion of population 65 year old	0.138	0.020	0.095	0.178	World Bank- World Development Indicators
PURB$_{IT}$	proportion of population living in urban areas	.7469694	.1250475	.3252	.97239 98	World Bank- World Development Indicators

Figure 1 – Statutory Tax Rates in 1982 and 1999

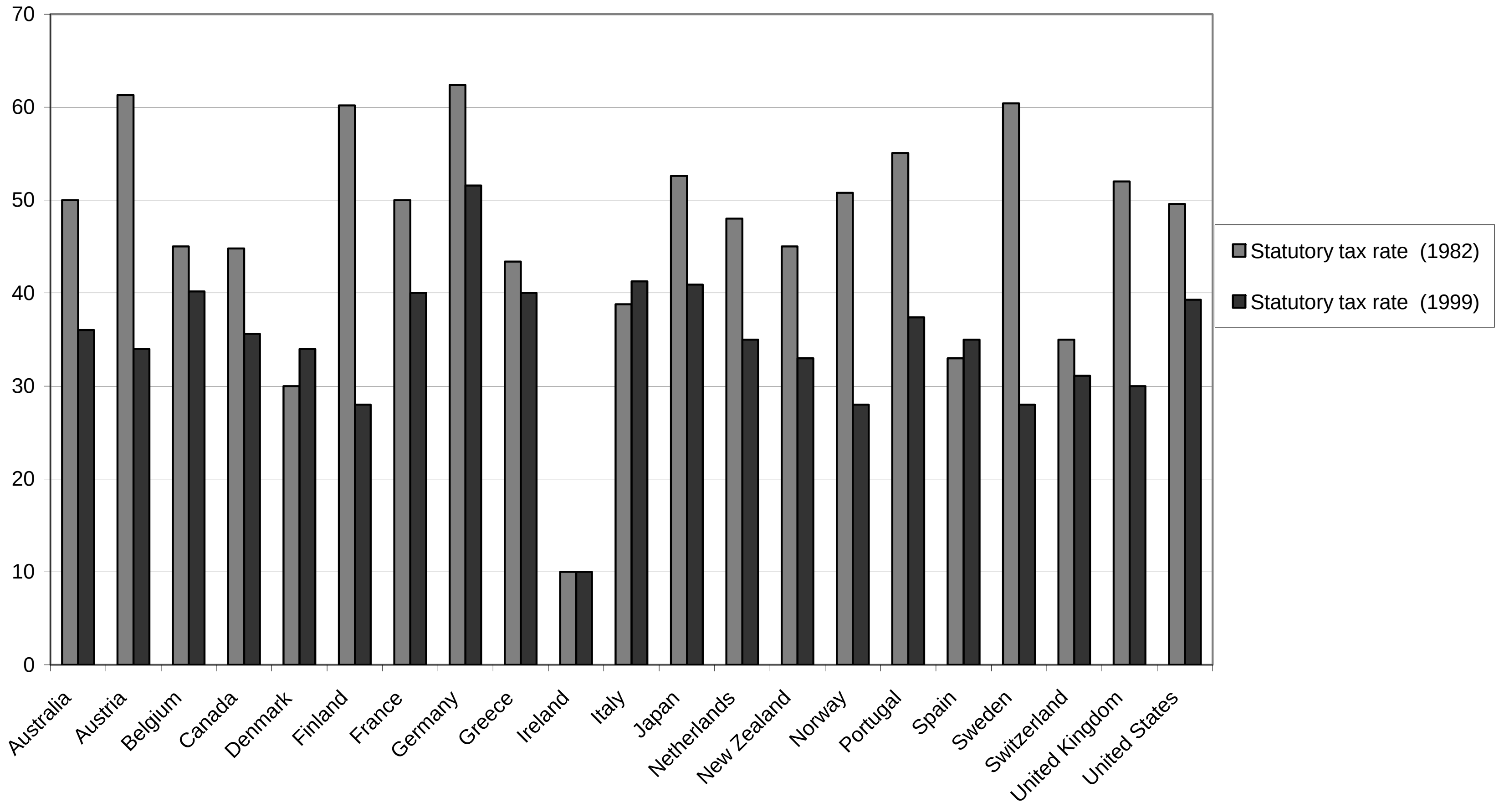
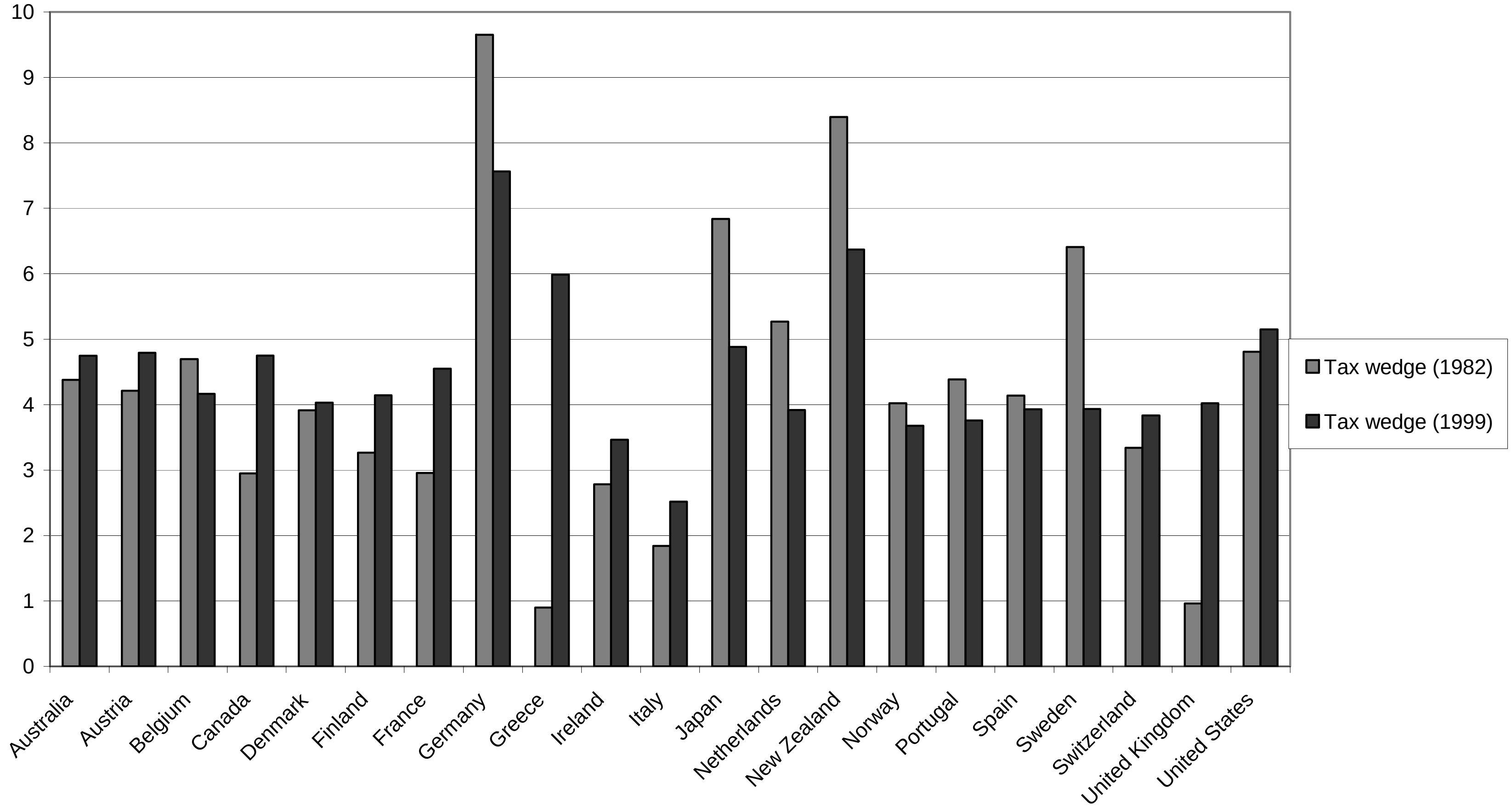


Figure 2 –EffectiveTax Wedges in 1982 and 1999



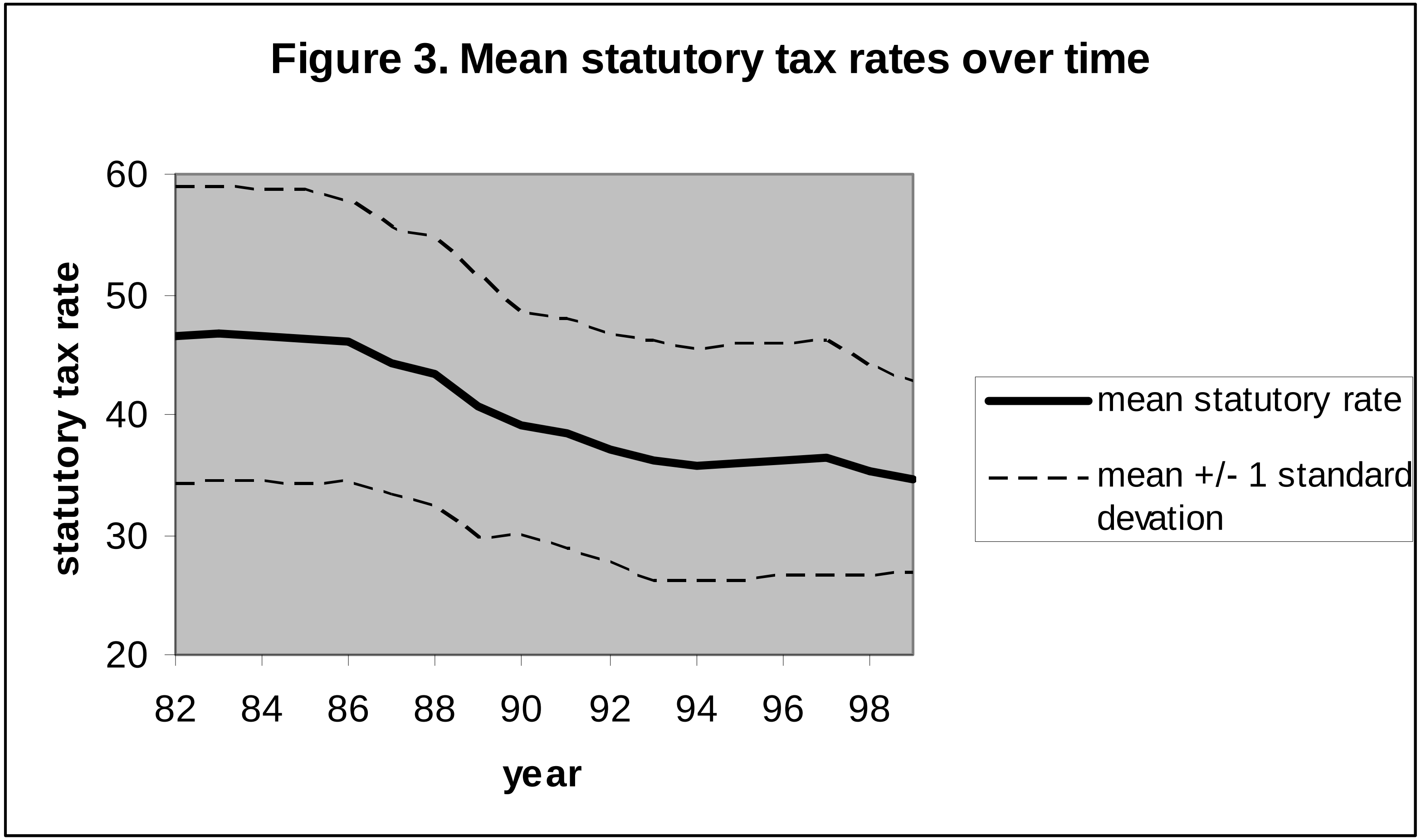


Figure 3. Mean statutory tax rates over time
statutory tax rate
60
50
40
30
20
82
84
86
88
90
92
94
96
98
year
mean statutory rate
mean +/- 1 standard devation

Figure 4. Mean effective tax wedges over time

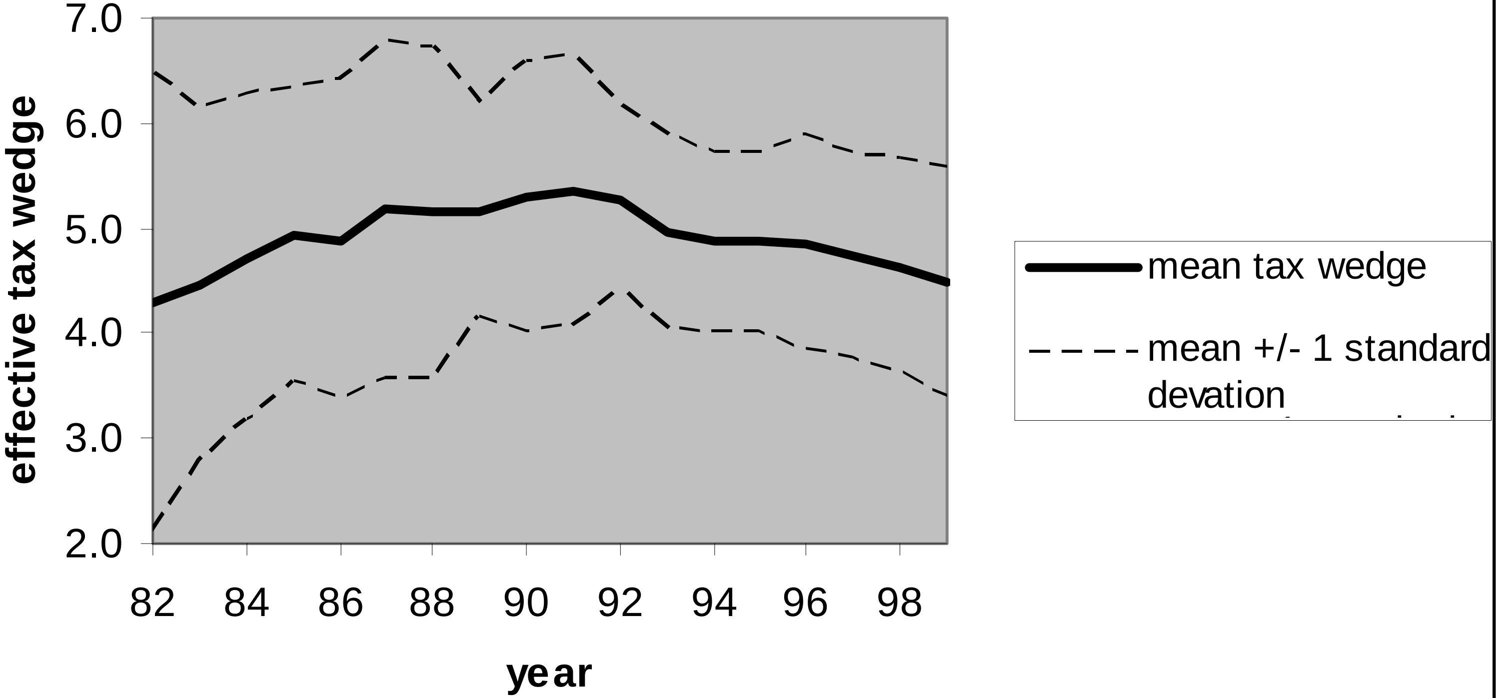


Figure 5. Average Statutory Rates:
Actual and Estimated Nash Equilibria