Evidence for profit-shifting with tax sensitive capital stocks

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Abstract

This paper contributes to the literature providing indirect evidence for profit shifting within multinational companies. In contrast to the previous studies we account for the tax responsiveness of the capital stock and analyse the impact of corporate taxes on both pre- and post-tax profitability. Evidence from our large panel dataset of European subsidiaries supports the profit shifting hypothesis. We find that a 10 percentage point decrease in the tax rate increases post-tax profitability by up to 1.1 percentage points. Further, our results suggest that financial profits and losses are particularly responsive to taxes, which indicates that a large part of profit shifting takes places via debt shifting.

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1 Introduction

Policy makers have been concerned about differences in corporate tax rates worldwide for some time, because these differences create incentives for multinational companies to move real activity to countries with lower taxes. Furthermore, even if multinationals do not move real capital in response to tax differentials, they may shift income to low-tax countries, by manipulating the geographical distribution of their taxable profits. Multinational groups can shift income among affiliates resident in different countries in two main ways, namely through transfer pricing, i.e. strategic mispricing of internal transactions, and through debt shifting, i.e. financial transactions between affiliated subsidiaries. Although policy makers are targeting such strategies by setting limits to intra-firm borrowing and lending and by applying the arm's length principle in intra-group trade, there is widespread belief that multinationals succeed in transferring profits via tax planning.

Profit shifting activities by multinational companies have been in the focus of a growing empirical literature. For example Huizinga and Laeven (2008) and Weichenrieder (2009) investigate the effects of corporate taxes on profit levels. While this provides indirect evidence for profit shifting, the profits level might at the same time be affected by tax-induced relocation of capital. Therefore we extend the work of Grubert and Mutti (1991) and model the effects of taxes on profitability, defined as the ratio of profits over assets. However, in order to derive empirically testable predictions about profitability one should look at capital movements as well as at profit movements. In our model we show that in the absence of profit shifting *pre-tax* profitability should be positively associated with corporate tax rates, whereas *post-tax* profitability should be equalised across countries. If, on the other hand, profit shifting is important, then *post-tax* profitability will be unambiguously negatively associated with the tax rate.

We use a large sample consisting of 253,106 observations on 39,110 firms from 2002-2009 from the Amadeus dataset to test our theoretical predictions. Our results favour the profit shifting hypothesis over the non-profit shifting hypothesis. The firm fixed effects estimates show that a 10 percentage point increase in the tax rate decreases *post-tax* profitability between 0.6 and 1.1 percentage points depending on the measure of profit used. Profit measures including financial profits and losses, most notably interest deductions are more responsive to tax rate changes, which indicates that profit shifting is to a large extent done via debt shifting. This finding is strengthened by the large influence of debt on reported profitability.

The remainder of the paper is structured as follows. Section 2 provides a short review of related literature. Section 3 develops a stylized theoretical model to motivate the empirical estimation. Section 4 describes the data, and Section 5 presents and discusses the results and some robustness analysis. Section 6 concludes.

2 Related Literature

Empirical profit shifting literature can be broadly distinguished into studies providing direct and indirect evidence. Direct evidence in this context refers to the fact that a specific channel of profit shifting, i.e. debt shifting or transfer pricing, is

analyzed. In contrast, indirect evidence describes the approach where the outcome of profit shifting, i.e. tax induced differences in profits, is interpreted as evidence for the existence of profit shifting. Whereas studies providing direct evidence can shed more light on the different channels of profit shifting and rule out some alternative explanations, these studies typically demand more detailed data on intra-group transactions.[1] More importantly, direct evidence for profit shifting by its nature analyses only particular aspects of profit shifting, and therefore can never capture the full impact of taxation on profit shifting activities. We therefore follow the strand of literature providing indirect evidence for profit shifting.[2]

The earliest study directly related to our approach is Grubert and Mutti (1991). They use country level aggregate data for foreign affiliates of US parents and find strong evidence of a negative relationship between the statutory corporate tax rate and post-tax profitability. Similarly Hines and Rice (1994) use country-level aggregate data of US non-bank affiliates for a larger set of host countries including tax havens. Analysing the profit levels in the host countries a one percentage point higher host country tax rate is associated with a reduction of reported profits by 3 percent. In a more recent paper, Bartelsman and Beetsma (2003) suggest that profit-shifting activity is also significant within the OECD countries. Using industry level aggregate data they disentangle the effects of profit shifting from changes in productivity and real economic activity.

More recent contributions make increasingly use of firm level data. Two early studies are motivated by the observation of near zero profitability of foreign-controlled US domestic corporations. Collins et. al. (1997) use data from the wholesale sector but fail to find a significant difference in profitability between domestically and foreign owned companies. Grubert (1997) finds a significant difference in profitability, however, the effect vanishes over time and can not be attributed to profit shifting. In contrast Mintz and Smart (2004) find evidence for profit shifting using Canadian data. The identification strategy of Mintz and Smart (2004) is to compare the tax elasticity of firms which choose not to consolidate their accounts with firms electing formula apportionment. One common feature of these papers is that they treat differences in profitability between domestic and multinational companies as evidence for profit shifting. However, this approach can be compromised by the fact that more productive firms are more likely to become multinationals. See Maffini and Mokkas (2011) for an empirical analysis of measured profitabilities in domestic and multinational companies.

A number of recent papers overcomes this problem with international datasets, which allows them to use the cross-country variation in the tax rates to identify profit shifting. Huizinga and Laeven (2008) for example use the Amadeus database to find the profit levels of multinational subsidiaries negatively affected by a weighted tax differential. Weichenrieder (2009) uses confidential data on German inbound and

[1] While there is an increasingly large number of international studies on debt shifting, the literature providing direct evidence for transfer pricing is typically based on confidential US data. Examples include Swenson (2001) using US Department of Census trade data, Clausing (2003) using Bureau of Labour Statistics data and Bernard et al. (2006) using the Linked/Longitudinal Firm Trade Transactions Database.

[2] For a comprehensive survey of the other strands of empirical profit shifting literature see Devereux (2007).

outbound FDI to find a significant effect of host country tax rates on after tax profitability. However, due to data restrictions he can not analyse pre-tax profitability. Finally, Dischinger (2010) is also related to our approach investigating the impact of tax differentials between parent and subsidiaries on the pre-tax profitability in the subsidiary. Scaling profitability by the number of employees he finds evidence for profit shifting.

Interestingly, Dischinger (2010) also argues in line with our paper stating '[...] tax rate effects on pre-tax profits might not be confined solely to profit shifting activities, as the incentive to invest in a given country also decreases with the corporate tax rate' (p. 4). Given the widespread and conclusive empirical evidence that firms investment decisions are affected by corporate taxation, we think that it is important to incorporate the impact of the investment decision into the analysis of profit shifting.[3] Therefore the next section introduces a stylized model which allows us to derive predictions about the impact of tax rates on both *pre-* and *post-tax profitability*.

3 Theoretical Background

This section presents a stylized model of a multinational enterprise (MNE) to motivate the subsequent empirical analysis. The algebra and proofs of the equations are included in the appendix.[4]

Consider a MNE consisting of two entities $1, 2$, which operate in two different countries $1, 2$. Without loss of generality we assume that the statutory tax rate in country 1 is higher than in country 2, i.e. $\tau_1 > \tau_2$. Denote the profit functions of the two subsidiaries as F_1, F_2, which are a function of capital K_1, K_2 respectively and are assumed to be homogeneous of degree a.[5] Further the MNE can transfer a part of its profits $S < F_1$ from subsidiary 1 to subsidiary 2. However, this profit shifting activity comes at a cost of:

$$C = \frac{b}{2}\left(\frac{S}{F_1}\right)^2 F_1 \tag{1}$$

Although the real costs of profit shifting are not known, we follow the literature (Hines and Rice (1994), Huizinga and Laeven (2008)) in approximating the profit shifting cost by a convex function of S so that additional profit shifting becomes more costly. Further, the costs depend only on F_1 for simplicity. An intuitive explanation for this can be, that the MNE needs to defend the level of profits in particular in the high tax country. More generally, costs of profit shifting may be resource costs, such as hiring tax and transfer price experts to allocate efficiently accounting profits, or they can represent costs that the firm pays only if they are caught by the tax authorities. A consequence of this functional form is that the bigger the operation of an MNE in country 1, the cheaper it is to shift a given level of profits between the

[3] See De Mooij and Ederveen (2008 and 2003) for a comprehensive overview of the empirical literature.

[4] The theoretical model in this paper, and the general idea of this paper, builds on Chapter 3 from Mokkas (2009).

[5] If a function $F(K)$ is homogeneous of degree a, then $\frac{\partial F(K)}{\partial K}K = aF(K)$. In addition, it is assumed that $a < 1$, otherwise the model does not have a solution for optimal levels of capital in the absence of taxation.

two subsidiaries; and that the higher the level of profits already shifted, the more costly it is to shift the next unit of profits.

The MNE maximises its overall *post-tax* profits with respect to the capital stock K_1, K_2 and profit shifting S:

$$\max_{K_1,K_2,S} \Pi = (1-\tau_1)(F_1 - S) + (1-\tau_2)(F_2 + S) - r(K_1 + K_2) - \frac{b}{2}\frac{S^2}{F_1} \tag{2}$$

where r is the cost of capital which is determined on the world market and therefore equal in both locations. The first two terms are the after tax profits made in each location after profit shifting. The third term represents the opportunity cost of capital. Finally, the fourth term catches the profit shifting costs. Note that we assume that the profit shifting costs are not deductible from the tax base of any of the subsidiaries.[6]

The first order conditions yield:

$$\frac{\partial \Pi}{\partial K_1} \stackrel{!}{=} 0 \Rightarrow F_{1K} = \frac{r}{1 - \tau_1 + \frac{b}{2}\left(\frac{S}{F_1}\right)^2} \tag{3}$$

$$\frac{\partial \Pi}{\partial K_2} \stackrel{!}{=} 0 \Rightarrow F_{2K} = \frac{r}{1 - \tau_2} \tag{4}$$

$$\frac{\partial \Pi}{\partial S} \stackrel{!}{=} 0 \Rightarrow S = \frac{\tau_1 - \tau_2}{b} F_1 \tag{5}$$

Equation (5) combined with the restriction for an internal solution ($S < F_1$) dictates that $b > \tau_1 - \tau_2$. Inspection of the first order condition for profit shifting shows that profits are shifted from the high tax country to the low tax country. In addition, the level of profits shifted is proportional to the true *pre-tax* profits of the subsidiary where profits are shifted out of, which is a direct consequence of the specific functional form chosen for the costs of profit shifting. With regard to the first order conditions for capital, the marginal product of capital in country 1 is decreasing in the ratio of profits shifted and increasing in b. Hence, in the specific model, the MNE invests more capital in the high tax country relative to the non profit shifting case, because by shifting profits to a lower tax country the MNE reduces the effective tax rate faced in the high tax country. In contrast, the first order condition for the low tax country does not include the capital stock, because we assume that profit shifting costs do not depend on F_2.

3.1 Empirical Predictions

Marginal products of capital, F_{iK}, and profit shifting levels, S, usually can not be observed. Rather, we observe total reported profits, $F_1 - S$ and $F_2 + S$, and *average* profitability, $\pi_1 = \frac{F_1 - S}{K_1}$ and $\pi_2 = \frac{F_2 + S}{K_2}$. This section describes the relative level of *average* profitability of the two subsidiaries and how changes in the tax rates affect *pre-* and *post-tax* profitability.

[6] This assumption is more plausible if one interprets profit shifting as an illegal activity and the costs involved the potential fines if caught. Alternatively the profit shifting costs might simply be borne by parent companies and are thus not included at the subsidiary level.

No profit shifting

In order to derive the alternative hypothesis of the absence of profit shifting we first consider the case where profit shifting is not possible ($b \to \infty, S \to 0$). This implies that (3) and (4) simplify to:

$$F_{1K} = \frac{r}{1-\tau_1}, F_{2K} = \frac{r}{1-\tau_2} \tag{6}$$

Given that F_1, F_2 are assumed to be homogenous of degree a then (6) yields:

$$\begin{aligned} &\text{Average } \textit{pre-tax} \text{ profitability:} && \pi_1 = \frac{r}{a(1-\tau_1)}, \pi_2 = \frac{r}{a(1-\tau_2)} \\ &\text{Average } \textit{post-tax} \text{ profitability:} && (1-\tau_1)\pi_1 = \frac{r}{a}, (1-\tau_2)\pi_2 = \frac{r}{a} \end{aligned} \tag{7}$$

Hence, *pre-tax* profitability must be higher in the high tax country 1 to to achieve the equalisation of *post-tax* profitabilities. To show the effects of a change in the tax rates on the average profitabilities we partially differentiate (6) with respect to the tax rates.

$$\begin{aligned} &\text{Average } \textit{pre-tax} \text{ Profitability Firm 1:} && \frac{\partial \pi_1}{\partial \tau_1} = \frac{r}{a(1-\tau_1)^2}, \frac{\partial \pi_1}{\partial \tau_2} = 0 \\ &\text{Average } \textit{pre-tax} \text{ Profitability Firm 2:} && \frac{\partial \pi_2}{\partial \tau_1} = 0, \frac{\partial \pi_2}{\partial \tau_2} = \frac{r}{a(1-\tau_2)^2} \\ &\text{Average } \textit{post-tax} \text{ Profitability Firm 1:} && \frac{\partial[(1-\tau_1)\pi_1]}{\partial \tau_1} = \frac{\partial[(1-\tau_1)\pi_1]}{\partial \tau_2} = 0 \\ &\text{Average } \textit{post-tax} \text{ Profitability Firm 2:} && \frac{\partial[(1-\tau_2)\pi_2]}{\partial \tau_1} = \frac{\partial[(1-\tau_2)\pi_2]}{\partial \tau_2} = 0 \end{aligned} \tag{8}$$

The derivatives in (8) highlight two direct effects of taxes on profitabilities. First the *pre-tax* profitabilities react positively to a tax rate change in the own country, because a higher tax rate reduces the capital stock and therefore increases the profitability. The second direct effect is the direct reduction of the *post-tax* profitability due to the higher tax rate. Under the non profit shifting hypothesis, this second effect exactly compensates for the increased *pre-tax* profitability to ensure the equalisation of after tax rate of return. In consequence, the level of average *post-tax* profitability is equalised (see equation 7) across subsidiaries resident in different countries no matter the tax rate. Intuitively, if entrepreneurs eliminate any differences in *post-tax* profitability, *pre-tax* profitability needs to compensate for the tax disadvantage of a high tax location.

Profit shifting

Under the alternative hypothesis of profit shifting, we can use the assumption of homogeneity of degree a to show that the reported average *pre-tax* profitabilities are:

$$\pi_1 = \frac{1}{a} F_{1K} - \frac{S}{K_1} \tag{9}$$

$$\pi_2 = \frac{1}{a} F_{2K} + \frac{S}{K_2} \tag{10}$$

While it is not possible to draw any general predictions about the relative level of reported average *pre-tax* profitability, it can be shown that *pre-tax* profitability will be higher in the low tax country under the following condition

$$\pi_2 > \pi_1 \Leftrightarrow \frac{\tau_1 - \tau_2}{2b} + \frac{1}{b}(1 - \tau_2)\left(\frac{K_1}{K_2} + 1\right) > 1 \tag{11}$$

Inequality (11) is a function of the relative capital stock $\frac{K_1}{K_2}$, the tax rates and profit shifting cost parameter b. And, if profit shifting is not too costly ($b \longrightarrow (\tau_1 - \tau_2)$),[7] then reported *pre-tax* profitability will be higher in the low tax country.

With regard to average reported *post-tax* profitability it is straightforward to show that[8]:

$$(1 - \tau_2)\,\pi_2 > (1 - \tau_1)\,\pi_1 \tag{12}$$

Therefore, if multinationals engage in profit shifting, subsidiaries in low tax countries should report higher average *post-tax* profitability than subsidiaries resident in countries with higher tax rates.

Effects on profitabilities in subsidiary 1

To illustrate the effects of a tax rate change on the average *pre-tax* profitability of subsidiary 1 we differentiate (9) with respect to the two tax rates. Some rearranging yields

$$\frac{\partial \pi_1}{\partial \tau_1} = \frac{2r\left[2b\,(b - 1 - \tau_1 + 2\tau_2) + (\tau_1 - \tau_2)^2\right]}{a\left[2b\,(1 - \tau_1) + (\tau_1 - \tau_2)^2\right]^2} \tag{13}$$

$$\frac{\partial \pi_1}{\partial \tau_2} = \frac{2r\left[2b\,(1 - \tau_2) - (\tau_1 - \tau_2)^2\right]}{a\left[2b\,(1 - \tau_1) + (\tau_1 - \tau_2)^2\right]^2} \tag{14}$$

Unfortunately, one cannot make unambiguous predictions about the sign of (13). This is due to the fact, that additionally to the direct effect of increased profitability due to the reduction in the capital invested in this subsidiary, there are now two counteracting effects. First, the capital reduction is mitigated by the fact that higher profits in subsidiary 1 are not fully subject to the higher tax rate and additionally the cost of profit shifting will be cheaper the higher the level of profit. Therefore the level of capital invested in subsidiary 1 will be higher under the profit shifting hypothesis, compared to the case without profit shifting. More directly, an increase of the tax rate in country 1 will induce more profit shifting and thereby reduces the profitability in subsidiary 1. The smaller the cost parameter of profit shifting, b, the

[7] Equation (5) combined with the restriction for an internal solution ($S < F_1$) dictates that $b > \tau_1 - \tau_2$.

[8] See appendix for all proofs.

stronger the latter effect. Hence, if profit shifting is not too costly, i.e. $b \to (\tau_1 - \tau_2)$, (13) will be unambiguously negative.

The increase of the tax rate in the low tax country has more clear cut effects. First, the incentive to shift profits out of the high tax country decreases. In addition, the reduction in the profit shifting capability increases the effective tax rate of the subsidiary in location 1 and thus, reduces the capital size. Both of these effects increase pre-tax profitability, which is evident in equation (14). Taking into account that $b > \tau_1 - \tau_2$ and $(1 - \tau_2) > (\tau_1 - \tau_2)$, it is immediate that the numerator, and therefore the whole term, is positive.

The effects of the tax changes on the average reported *after-tax* profitability, are similar, as it can be shown that:

$$\frac{\partial \left[(1 - \tau_1) \pi_1 \right]}{\partial \tau_1} = -\frac{2r \left[2b (1 - \tau_1)(1 - \tau_2) - (1 - \tau_2 - b)(\tau_1 - \tau_2)^2 \right]}{a \left[2b (1 - \tau_1) + (\tau_1 - \tau_2)^2 \right]^2} \tag{15}$$

$$\frac{\partial \left[(1 - \tau_1) \pi_1 \right]}{\partial \tau_2} = \frac{2r (1 - \tau_1) \left[2b (1 - \tau_2) - (\tau_1 - \tau_2)^2 \right]}{a \left[2b (1 - \tau_1) + (\tau_1 - \tau_2)^2 \right]^2} \tag{16}$$

In addition to the above described effects there is the direct negative effect of the tax rate change on the after tax profitability. Therefore, given that $b > \tau_1 - \tau_2$, (15) is unambiguously negative. Hence, an increase in the tax rate of country 1 decreases average reported *post-tax* profitability of subsidiary 1.

The effect of a tax change in the low tax country on the *post-tax* profitability in country 1 is in line with the effect on the *pre-tax* profit. In fact, the derivative in (16) is just scaled down by the factor $(1 - \tau_1)$ and therefore unambiguously positive like (14). This is due to the fact the increased profit shifting incentives apply to the pre-tax profits in subsidiary 1. Consequently they are equally applicable to the post tax profits, only reduced because of the higher tax rate in country 1. Thus, the average reported *after-tax* profitability of subsidiary 1 is positively affected by an increase in the tax rate of country 2.

Effects on profitability in subsidiary 2

The profitability of the subsidiary in country 2 depends on the capital stock there, the profits shifted into the country and consequently also on the capital stock in country 1 which determines the cost of profit shifting. Hence, in order to make progress with respect to the comparative statics of the reported profitability of subsidiary 2 one needs to to solve for the capital in both countries K_1, K_2 and substitute into (10). We assume profit functions are of the functional form $F_i = A_i K_i^a$, where A_i is the total factor productivity of the subsidiary.[9] Differentiation of (10) with

[9] Using (3), (4) and (5) one can solve for the relative capital stock

$$\frac{K_1}{K_2} = \left(\frac{A_1}{A_2} \right)^{1/1-a} \left[\frac{1 - \tau_1 + \frac{(\tau_1 - \tau_2)^2}{2b}}{1 - \tau_2} \right]^{1/1-a}$$

respect to τ_1 then yields:

$$\frac{\partial \pi_2}{\partial \tau_1} = \frac{r}{ab\left(1-\tau_2\right)^{\frac{1}{1-a}}}\left(\frac{A_1}{A_2}\right)^{\frac{1}{1-a}}\left[1-\tau_1+\frac{\left(\tau_1-\tau_2\right)^2}{2b}\right]^{\frac{a}{1-a}} \left[1+\frac{a\left(\tau_1-\tau_2\right)}{1-a}\frac{2(\tau_1-\tau_2-b)}{2b(1-\tau_1)+\left(\tau_1-\tau_2\right)^2}\right] \tag{17}$$

The most intuitive effect of a tax rate change in country 1 on the profitability in subsidiary 2 is via profit shifting. A higher tax rate in the high tax country ceteris paribus leads to more profit shifted to the subsidiary in the low tax country and therefore increases profitability there. However, at the same time the increased tax in country 1 will reduce the capital stock invested and therefore decreases the total amount of profit and consequently the profit which will be shifted to the low tax subsidiary. The latter effect will be mitigated because the costs of profit depend on the profits made in subsidiary 1 which will increase the capital stock relative to the no profit shifting case. The overall effect of a tax rate in country 1 on the *pre-tax* profitability of subsidiary 2 will be positive if profit shifting is not very expensive, as can be seen in equations (17), which will be unambiguously positive if $b \longrightarrow (\tau_1 - \tau_2)$.

Given that the unambiguous sign for the effect of a tax rate change for *pre-tax* profitability, the effect of a tax rate change in country 1 on the *post-tax* profitability in country 2 will be equally unambiguously positive. This is evident from (18) which is identical to (17) but scaled down with $(1-\tau_2)$.

$$\frac{\partial\left[\left(1-\tau_2\right)\pi_2\right]}{\partial \tau_1} = \frac{r}{ab\left(1-\tau_2\right)^{\frac{a}{1-a}}}\left(\frac{A_1}{A_2}\right)^{\frac{1}{1-a}}\left[1-\tau_1+\frac{\left(\tau_1-\tau_2\right)^2}{2b}\right]^{\frac{a}{1-a}} \left[1+\frac{a\left(\tau_1-\tau_2\right)}{1-a}\frac{2(\tau_1-\tau_2-b)}{2b(1-\tau_1)+\left(\tau_1-\tau_2\right)^2}\right] \tag{18}$$

The effect of a tax rate change in country 2 on the *pre-tax* profitability of subsidiary 2 is ambiguous. On the one hand there is the direct positive effect via the reduced capital, while at the same time reduced profit shifting lower profitability in the subsidiary. The latter effect will be reinforced because of less capital invested in country 1 because, the effective tax burden increases. A different explanation for the same effect is that the incentive to lower costs for profit shifting is reduced. Consequently the effect of a tax rate change in country 2 will directly increase *pre-tax* profitability in subsidiary 2 which is captured in the first term in (19) and indirectly reduce profitability which is captured in the second term.

$$\frac{\partial \pi_2}{\partial \tau_2} = \frac{r}{a(1-\tau_2)^2} - \frac{r}{ab(1-\tau_2)}\left(\frac{A_1}{A_2}\right)^{\frac{1}{1-a}}\left[\frac{1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}}{1-\tau_2}\right]^{\frac{a}{1-a}} \left[1+\frac{1}{1-a}\left(\frac{2a(\tau_1-\tau_2)^2}{2b(1-\tau_1)+(\tau_1-\tau_2)^2}-\frac{\tau_1-\tau_2}{1-\tau_2}\right)\right] \tag{19}$$

In contrast, the ambiguity disappears in the effect of a tax rate change in country two on the reported *post-tax* profitability of subsidiary 2. This is due to the fact that

the reduction in capital and the resulting increase in *pre-tax* profitability exactly compensates for the higher tax burden. This effect is the one described in non profit shifting case above. Hence we are left with the effects an increase in τ_2 has on profit shifting. There is the direct effect of reduced profit shifting, because of the smaller tax differential and the indirect effect of less capital in subsidiary 1. Both reduce the level of profits in subsidiary 2. At the same time, because of the reduced capital in subsidiary 2, the denominator also decreases which could increase the overall profitability. However, equation (20) shows that the negative effect of the reduced profit shifting dominates, since the last term in the brackets can be never larger than -1 for $\tau_1 < 1$.

$$\begin{aligned}\frac{\partial\left[\left(1-\tau_2\right)\pi_2\right]}{\partial\tau_2} &= -\frac{r}{ab}\left(\frac{A_1}{A_2}\right)^{1/1-a}\left[\frac{1-\tau_1+\frac{\left(\tau_1-\tau_2\right)^2}{2b}}{1-\tau_2}\right]^{\frac{a}{1-a}} \\ &\quad \left[1+\frac{a}{1-a}\left(\frac{2\left(b-\tau_1+\tau_2\right)\left(\tau_1-\tau_2\right)}{2b\left(1-\tau_1\right)+\left(\tau_1-\tau_2\right)^2}-\frac{\tau_1-\tau_2}{1-\tau_2}\right)\right] \qquad (20)\end{aligned}$$

To sum up, if profit shifting is possible, then a reduction in the host country tax rate will bring an ambiguous change to average reported *pre-tax* profitability, although the model suggests that if profit shifting is not very costly it will reduce *pre-tax* profitability. On the other hand, a reduction in the host country tax rate will unambiguously increase average reported *post-tax* profitability.

The predictions of the model are summarized in Table 1. In the empirical analysis, we will be focusing on the effects of the tax rate on reported *pre-* and *post-tax* profitability, which are the shaded areas in the Table 1. We restrict our analysis on these direct effects of tax rates on profitabilities of subsidiaries located there, because the data does not necessarily cover all subsidiaries of multinational groups. In consequence we do not have reliable information on the distribution of the tax rates in other countries where the group has affiliates.

Table 1: Comparative Statics of Average Profitabilities

	No Profit Shifting		Profit Shifting	
	Tax Rate τ_1	Tax Rate τ_2	Tax Rate τ_1	Tax Rate τ_2
Pre-tax average profitability of Subsidiary 1	positive	independent	ambiguous (-)	positive
Pre-tax average profitability of Subsidiary 2	independent	positive	ambiguous (+)	ambiguous
Post-tax average profitability of Subsidiary 1	independent	independent	negative	positive
Post-tax average profitability of Subsidiary 2	independent	independent	ambiguous (+)	negative

Signs in parentheses hold if profit shifting is not a costly option for multinationals.

The stylized model presented in this section highlights that, if one is to test

empirically the effect of the tax rate on average profitability, then both the numerator (profits) and the denominator (assets) should be taken into account. If the tax rate increases then profits decrease due to profit shifting and because less capital is located there. However, because capital decreases, due to the marginal conditions, *pre-tax* profitability may increase or decrease. The predictions for *post-tax* profitability are unambiguous, hence a negative coefficient can be interpreted as evidence for profit shifting. If in addition, *pre-tax* profitability is negatively affected by the tax rate, then this is a signal of profit shifting being relatively cheap, and strictly inconsistent with the alternative predictions of this model in the absence of profit shifting.

4 Data Description

The data on subsidiaries of multinational companies are taken from the Amadeus database provided by Bureau van Dijk (BvD). Since Bureau van Dijk database has been used extensively in this strand of research, for example in Huizinga and Laeven (2008) and Dischinger (2010) we do not present the data in detail, but rather highlight where we use the data differently.[10]

We start with a download of the large and very large companies from the online version of Amadeus dataset. The use of the online version allows us to use more recent data, with ownership information updated up to February 2011 and full data coverage up to the end of 2009. At the time of the download the Amadeus sample of large and very large companies included 540,832 companies in 44 European countries. We then identify the group structures using information about immediate shareholder with more than 50 percent ownership and the reported global ultimate shareholders. Table 2 splits the downloaded sample into different categories according to the group structure. The first column lists the total number of firms in each country of our final sample and sums the number of firms in other European countries.[11] The next three columns show the number of firms we exclude for the purpose of this study. First there are *standalone companies*, i.e. firms which report neither a corporate subsidiary nor a majority corporate shareholder. Further we exclude *parent companies*, because for most of them we only have the consolidated accounts. Further even if we have the unconsolidated accounts parent companies very often perform mostly holding activities, which might imply very different profit shifting possibilities. We also exclude *subsidiaries in domestic groups* because they do not have the profit shifting opportunities we want to investigate in this empirical analysis.

[10] A detailled description of the construction of the sample is available from the authors upon request.

[11] For some important countries, e.g. Switzerland, Norway or Ireland, we end up with insufficient firms to include them in our regressions. This is due to missing information in key variables like tax payments and/or profits.

Table 2: Geographical Distribution of Firms/Observations

Country	Total Download	Standalones	Parents	Subsidiaries in domestic groups	Subsidiaries in MNE groups	Final Sample Firms	Final Sample Observations
Belgium	16,387	6,751	943	3,416	5,277	2,679	18,760
Bulgaria	3,041	1,504	101	901	535	342	2,067
Croatia	1,927	939	95	337	556	384	2,846
Czech Republic	10,469	6,831	238	677	2,723	1,001	6,759
Denmark	7,159	2,572	824	1,798	1,965	887	3,869
Estonia	1,765	313	38	539	875	368	2,640
Finland	7,367	1,867	804	2,298	2,398	513	2,673
France	71,535	12,804	3,714	32,537	22,480	6,281	42,487
Germany	55,616	18,999	2,925	18,073	15,619	2,215	10,991
Greece	3,855	2,032	289	603	931	531	3,871
Hungary	3,972	3,161	22	49	740	109	320
Italy	54,365	26,917	4,056	15,962	7,430	3,431	24,212
Latvia	1,635	789	50	235	561	144	958
Lithuania	2,132	1,042	81	380	629	120	754
Netherlands	18,177	9,013	1,270	3,065	4,829	137	793
Poland	19,731	10,470	605	2,708	5,948	1,579	10,373
Portugal	8,428	3,118	450	2,785	2,075	1,099	4,417
Romania	6,458	5,625	49	170	614	350	2,325
Russia	39,406	17,979	979	13,641	6,807	1,949	10,348
Serbia	3,181	2,208	95	367	511	275	1,824
Slovak Republic	3,231	2,147	51	85	948	252	1,416
Spain	45,085	19,250	2,690	13,334	9,811	2,870	20,240
Sweden	23,488	2,995	2,758	11,322	6,413	3,332	23,895
Ukraine	12,733	10,074	161	1,328	1,170	852	5,559
United Kingdom	71,325	20,286	6,255	20,908	23,876	7,410	48,709
Other countries[a]	48,364	24,254	3,013	11,017	10,080	n.a.	n.a.
Total	540,832	213,940	32,556	158,535	135,801	39,110	253,106

Notes: [a] The sum of 19 other European countries, most notably Norway, Switzerland and Ireland. Final sample only includes unconsolidated accounts.

Column five reports the number of *subsidiaries in MNE groups*. This includes all companies which report a corporate owner, which owns more than 50 percent. Further the corporate group must have subsidiaries in at least two different countries, in order to allocate the subsidiary to this category. Note, that this also includes subsidiaries in the same country as the headquarter. Finally, the last two columns compare the number of firms and the corresponding number of observations, which remain in our final sample.[12] At the first glance the drop to 39,460 firms appears dramatic. However, to the best of our knowledge, this is one of the largest samples - both in terms of firms and countries - used for an empirical study of this type.

This study investigates the effects of host country corporate tax rates on *pre-* and *post-tax* profitability. The model outlined in section 3 predicts that under the hypothesis of profit shifting *post-tax* profitability should be unambiguously negatively affected by a tax rate increase in the subsidiary country. We use two measures of *post-tax* profitability. The first measure of *post-tax* profitability is the ratio of earnings before interest and after taxes over total assets (EBI/TA). For robustness, we use profits and losses after taxes over total assets ($PLAT/TA$) as a second measure of *post-tax* profitability, which is a measure of *net-of-tax* return on assets. The numerator of the latter measure is equal to the the earnings before interest and taxation ($EBIT$) plus the net financial profits and losses minus taxation. The net financial profits include interest payments and receipts, thus $PLAT/TA$, unlike EBI/TA, subtracts interest payments from the measure of the profits. Since this is the profit attributable to shareholders, one may argue that the denominator of the latter measure of *post-tax* profitability should have been equity capital, which would make the ratio a measure of *after-tax* return on equity. We do not do this here in order for the results to be comparable with other studies (e.g. Weichenrieder (2009)). Regarding *pre-tax* profitability, we use the ratio of earnings before interest and taxes over total assets ($EBIT/TA$). Alternatively we also use the reported profit before taxation over total assets ($PLBT/TA$), which includes financial profits and losses and therefore corresponds to the $PLAT/TA$ measure.

In the descriptive statistics in Table 3 one can see that both measures of *pre-tax* profitability are on average close to 0.09 and range from -0.55 to 0.71. This indicates that we include negative profitabilities in our analysis.[13] It is not a priori clear whether profit shifting remains an issue if a subsidiary is in a loss making position, but we prefer to initially include loss making subsidiaries to restrict the censoring of the data. We will return to the issue of loss making companies in the robustness checks. After tax profitabilities are above 0.06 on average and range from -0.51 to 0.61. This lower average and the reduced variation primarily on the positive side appears plausible because the part of profits which is taxed away is larger for profit making firms.

The primary regressor we are interested in is the host country tax rate. This includes the top corporate tax rate plus local profit taxes. For the local taxes we

[12] The detailled description of the data cleaning criteria are available from the authors upon request.

[13] We treat observations which deviate more than one half of the standard deviation from the mean as outliers. Admittedly, this criteria is rather arbitrary, but the results do not change much with alternative cut off points.

use the unweighted average of the local profit tax rates.[14] Over the sample period from 2002 to 2009 corporate tax rates were significantly reduced. The extent of tax rate reductions varies from minor reductions in France due to the abolition of the tax professionelle to significant drops from 23.5% to 10% in Bulgaria or from 31% to 20% in the Czech Republic.

Table 3: Descriptive Statistics

Variable	Observations	Mean	St. Dev	Min	Max
EBI/TA	265,717	0.063	0.105	-0.512	0.617
$PLAT/TA$	265,717	0.062	0.109	-0.517	0.619
$EBIT/TA$	265,717	0.089	0.132	-0.554	0.713
$PLBT/TA$	265,717	0.088	0.137	-0.559	0.716
$log(TA)$	265,717	9.668	1.666	0.000	22.147
$log(EMP)$	253,704	4.494	1.539	0.000	12.471
Leverage	265,717	0.627	0.241	0.000	1.000
Growth rate	265,717	1.246	3.524	-17.616	12.954
Interest rate	265,717	4.065	3.064	0.398	27.310
Inflation	265,717	102.987	10.004	70.417	178.605

Notes: Leverage is defined as the current plus non-current liabilities over total assets. Growth rate is the annual growth rate of GDP per capita. Interest rate denotes the 3-month money market rate. Inflation is the consumer price index.

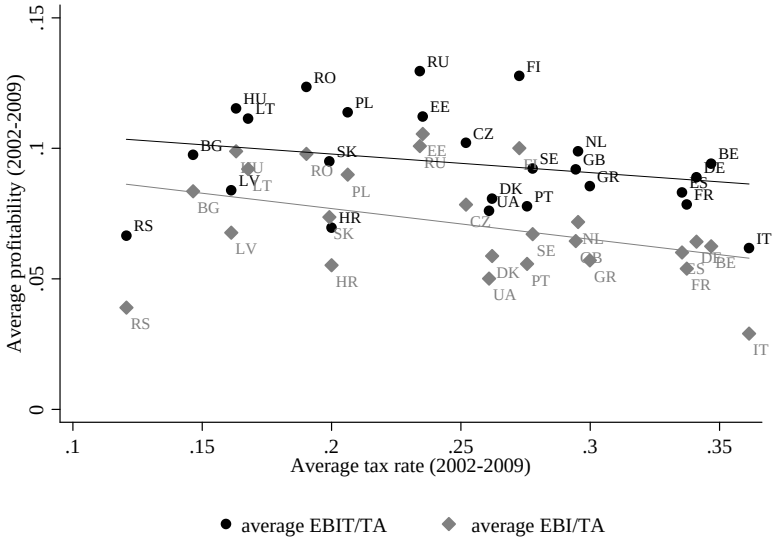
Apart from the host country tax rate we will use several control variables to capture the effects of observed factors that might be related to profitability. The control variables are the logarithm of total assets ($log(TA)$) and several country variables. The logarithm of total assets may reflect that larger companies are more mature and less risky and hence, have lower profitability. On the other hand, it may capture that larger companies have superior technology and market power and thus, higher profitability. We also include the logarithm of the number of employees ($log(EMP)$) as an alternative measure of firm size. The country control variables include GDP per capita growth, which is expected to be positively related to profitability. In addition, the inflation rate as measured by the consumer price index is included to control for the impact of general price inflation on measured profits and assets. Financial statements are prepared on the historical basis accounting. This method does not take into account the level of prices when valuing assets. Ignoring changes in the general price level may understate the economic value of assets to a firm as well as overstate firms' profits. Thus, inflation is expected to be positively related to firm profitability (cf. Feldstein and Summers (1979)). Finally, the money market interest rate is included, which may capture the effects of credit conditions in a country. This is the annual average of the 3-month interest rate for the domestic money market. A higher interest rate means that firms will only undertake projects with higher returns and thus the money market interest rate is expected to be positively related to profitability. Data on GDP per capital growth and inflation is provided by the World Bank, and the money market interest rate by Eurostat and the national banks of the countries in question.

[14]The information on the tax rates is an extension of the data used in Loretz (2008). Additional information stems mostly from the Global Tax Surveys of the International Bureau of Fiscal Documentation (IBFD), and the KPMG corporate tax rates surveys.

5 Results

This section presents the econometric results. First, we present our baseline regression of the four profitability measures on corporate tax rates and several control variables in detail. We will use a panel fixed effect approach as our workhorse model. We then run several robustness checks to account for the potential impact of debt, loss making companies or different circumstances in transition countries.

Before starting the presentation and the discussion of the results, we illustrate the relationship between the tax rate and each of the profitability measures, using average values of the firm-level measures in each host country averaged over all eight years. Figure 5 is the scatter plot of each country's average *pre-tax* profitability ($EBIT/TA$) and *post-tax* profitability (EBI/TA) versus the average tax rate over the period of 2002-2009.



The black circles displaying *pre-tax* profitability and the gray diamonds representing *post-tax* profitability show considerable variation across countries. Apart from the outlier Serbia (including Montenegro before 2008) Figure 5 indicates that subsidiaries in high tax countries tend to be less profitable than those in low tax countries. In addition, the slope of the relationship in the *post-tax* profitability graph is slightly steeper than that of the *pre-tax* profitability. Although the graphs do not control for characteristics of affiliates or country characteristics that are unrelated to tax rates, there is indicative evidence that favours the profit shifting hypothesis.

5.1 Baseline Results

The benchmark for our empirical study are the fixed effects regressions for all countries. The dependent variables presented are $EBIT/TA$ and $PLBT/TA$ as measures for *pre-tax* profitability and EBI/TA, and $PLAT/TA$ for *post-tax* profitability. In addition to the host country tax rate, which is our regressor of primary interest we include several control variables. The logarithm of total assets and the logarithm of the number of employees are intended to capture the impact of the size of the firm. GDP per capita growth, the inflation rate, and the money market interest rate

further control for the investment opportunities in the host countries. Given some of our control variables vary only at a higher level, all the standard errors correct for clustering of errors across country/industry cells. Table 4 reports the results for four baseline regressions.

Table 4: Baseline Results

	pre-tax profitability		*post-tax* profitability	
Dependent variable	EBIT/TA	PLBT/TA	EBI/TA	PLAT/TA
Host Tax	0.020	-0.036	-0.056***	-0.108***
	(0.027)	(0.032)	(0.021)	(0.026)
Log Total Assets	-0.002	-0.001	0.001	0.002*
	(0.001)	(0.002)	0.001	(0.001)
Log Number of Employees	0.006***	0.003**	0.003***	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
GDP Growth	0.001***	0.001***	0.002***	0.001***
	(0.000)	0.000	(0.000)	0.000
Log Inflation	0.025**	0.022	0.028***	0.012
	(0.013)	(0.014)	(0.010)	(0.012)
Money Rate	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Time Dummies	Y	Y	Y	Y
Firm Fixed effects	Y	Y	Y	Y
Firms	39,110	39,110	39,110	39,110
Observations	253,106	253,106	253,106	253,106
R^2	0.015	0.016	0.011	0.014

Notes: All regressions are estimated by panel data within groups estimators and includeyear dummies. Host Tax is the country's statutory tax rate including local taxes. GDP Growth is the GDP per capita growth rate provided by the World Bank. Inflation is the logarithm of the consumer price index provided by the World Bank. Money Rate is the annual average of the 3 month interest rate for the domestic money market provided by Eurostat. Robust standard errors that correct for clustering of errors within country/industry cells are presented in the parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

Starting with *pre-tax* profitability, Table 4 shows that the coefficient on the tax rate is ambiguous and insignificant for both measures of profitability. This is in stark contrast to the regressions on *post-tax* profitability where the coefficient for the host country tax rate has a significant negative sign. Further the coefficient almost doubles in size from -0.056 for EBI/TA to -0.108 for $PLAT/TA$, which hints at a special role for financial profits and losses. We will return to the role of debt instruments for profit shifting in the robustness checks below. Overall, the effect of a change in the tax rate on reported profitability is negative for *after-tax* profitability and ambiguous for *pre-tax* profitability. This is consistent with the profit shifting hypothesis, under which the reported *post-* and possibly *pre-tax* profitability of subsidiaries in high tax countries should be lower than that of subsidiaries in low tax countries. Furthermore, it is certainly inconsistent with the alternative theory of no profit shifting under which the tax rate should have a positive impact on *pre-tax* profitability and no impact on *post-tax* profitability.

The size of the company measured by the number of employees is found to have a significant positive impact for most *pre-* and *post-tax* profitability measures, while the log of total assets is only significant for $PLAT/TA$. The fact that at most one of the size measures turns out to be significant is mostly due to the positive correlation between the two variables. Further the division bias (Borjas (1980)) potentially contributes to the employees being significant rather than the total assets.[15] Out of the coefficients on the country controls the GDP growth rate has the expected positive sign in all regressions. Further the inflation turns out to be significant in both regressions using profitability measures excluding the financial profits.

5.2 The role of debt

The fact that the tax effect on reported *post-tax* profitability is twice as large for the measure of profitability including financial profits and losses indicates that the use of debt as a mean of profit shifting is potentially very important. To control for the use of debt as a mean of profit shifting we include the firm leverage as an additional control variable. First, there is the non-tax related impact of profitability on the financing decision of the firm. According to the pecking order theory (cf. Myers and Majluf (1984)), companies will finance investment projects first with retained earnings and then with debt. Thus, one expects less profitable firms to finance investment using debt and thus the leverage ratio and profitability should be negatively associated. However, there may be a limit to the above channel. There is now a growing literature on the use of debt to shift profits, which indicates that firms with high pre-tax profitabilities may strategically use debt in order to benefit from the deduction of interest for tax purposes.[16] Both arguments imply that causality runs from profitability to leverage.[17] Before discussing the results, we want the reader to be aware that there may be a degree of simultaneity in one of our regressions. Specifically, the level of leverage may affect the concurrent measure of post-tax profitability, $PLBT/TA$, through interest deductions, i.e. causality may also run from leverage to profitability. However, we believe that the level of leverage drives primarily the level of future interest deductions and thus simultaneity should be weak.

[15] For example, if the value of total assets is over-estimated in the reported accounts, this would tend to reduce each of the profitability measures.

[16] Early empirical studies based on Canadian data (Jog and Tang (2001)) or US data (Desai et al. (2004)) indicate that debt plays an important role in profit shifting. Using an international dataset Huizinga et al (2008) provide further evidence for debt reacting to tax differentials. For more recent evidence on the role of internal debt in profit shifting and a review of the literature see Buettner and Wamser (2009).

[17] This assumption is supported by recent evidence for a one-way Granger causality from profitability to leverage by Bartoloni (2011).

Table 5: The role of debt

	pre-tax profitability		*post-tax* profitability	
Dependent variable	EBIT/TA	PLBT/TA	EBI/TA	PLAT/TA
Host Tax	0.070**	0.026	-0.017	-0.056**
	(0.029)	(0.032)	(0.023)	(0.026)
Debt ratio	-0.160***	-0.200***	-0.126***	-0.166***
	(0.004)	(0.005)	(0.004)	(0.004)
Log Total Assets	0.004***	0.007***	0.006***	0.009***
	(0.002)	(0.002)	(0.001)	(0.001)
Log Number of Employees	0.007***	0.004***	0.004***	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
GDP Growth	0.001***	0.001***	0.002***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Log Inflation	0.032**	0.030**	0.033***	0.019
	(0.013)	(0.014)	(0.011)	(0.012)
Money Rate	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Time Dummies	Y	Y	Y	Y
Firm Fixed effects	Y	Y	Y	Y
Firms	39,110	39,110	39,110	39,110
Observations	253,106	253,106	253,106	253,106
R^2	0.059	0.080	0.051	0.014

Notes: All regressions are estimated by panel data within groups estimators and include year dummies. Host Tax is the country's statutory tax rate including local taxes. GDP Growth is the GDP per capita growth rate provided by the World Bank. Inflation is the logarithm of the consumer price index provided by the World Bank. Money Rate is the annual average of the 3 month interest rate for the domestic money market provided by the Eurostat. Debt ratio is the sum of current and non-current liabilities over total assets. Robust standard errors that correct for clustering of errors within country/industry cells are presented in the parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

The results in Table 5 are rather strong. The newly included debt variable is highly significant in all specifications. Additionally, accounting for the strong negative effect of the debt level on profitability the signs of the tax rate in the regressions with the EBIT profitability measures change. Controlling for the level of debt the tax rate now has a positive effect on $EBIT/TA$ and no effect on EBI/TA. These signs are in line with the prediction of the no profit shifting case in our stylized model. Put differently, this would indicate that debt shifting is the primary form of profit shifting. However, the results for the regressions which use profitability measures after financial profits and losses remain unaffected by the inclusion of the debt level as an additional control. The host country tax rate still has a significant negative sign for *post-tax* profitability and no effect on *pre-tax* profitability. This is in line with our predictions for the presence of profit shifting. Hence, the inclusion of the debt level indicates that while profit shifting may to a large extent be organized through debt shifting, there are other potential ways to reallocate profits via financial transactions. One of the potential channels, which has recently gained some considerable attention is the use of royalty payments.[18]

[18]See for example Dischinger and Riedel (2011) and Karkinsky and Riedel (2009).

5.3 Robustness checks

One immediate concern which may arise is the role of loss making subsidiaries. Arguably firms have little incentive to shift profits out of a country if they are already in a loss making position there. Furthermore, if the subsidiary has been in a significant loss position it may also have the possibility to reduce its tax burden by means of loss carry forward. Therefore we might also expect firms which were in a loss position in previous years to be less inclined to use profit shifting. The first two robustness checks in Table 6 address this issue. The top block excludes the observations, which have a loss in the current year. This reduces the sample size by roughly 50,000 observations, but affects the number of firms much less with a reduction of only about 2,000 firms. In contrast the second block in Table 6 excludes all firms which have a loss in any of the periods we observe. This reduces the number of firms rather dramatically to only 15,617. This reflects that a very large number of companies reported losses in the recent economic crises.

Table 6: Robustness checks

	pre-tax profitability		*post-tax* profitability	
Dependent variable	EBIT/TA	PLBT/TA	EBI/TA	PLAT/TA
Excluding observations with a loss in this period				
Host Tax	0.034	0.002	-0.057***	-0.098***
	(0.026)	(0.028)	(0.019)	(0.021)
Firms	37,819	37,811	37,753	37,726
Observations	209,647	207,634	205,286	203,117
Excluding firms with a loss in any period				
Host Tax	0.013	-0.029	-0.103***	-0.145***
	(0.032)	(0.033)	(0.023)	(0.025)
Firms	15,617	15,617	15,617	15,617
Observations	99,119	99,119	99,119	99,119
Excluding firms in transitions countries				
Host Tax	-0.000	0.006	-0.065***	-0.059***
	(0.029)	(0.030)	(0.022)	(0.023)
Firms	31,385	31,385	31,385	31,385
Observations	204,917	204,917	204,917	204,917
Only firms in transitions countries				
Host Tax	0.038	-0.070	-0.114***	-0.212***
	(0.041)	(0.048)	(0.036)	(0.045)
Firms	7,725	7,725	7,725	7,725
Observations	48,189	48,189	48,189	48,189

Notes: All regressions are estimated by panel data within groups estimators and include the same control variables (including the debt ratio) as the previous regressions. Robust standard errors that correct for clustering of errors within country/industry cells are presented in the parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%.

The results for the subsamples without loss making observations or loss making firms confirm the finding of the baseline results. When excluding only the observations with losses the results closely resemble our benchmark results, both in terms of

sign and magnitude of the tax effects. This is a striking result since these robustness checks also include the debt level as an additional control. The previous result of no profit shifting once the debt level is controlled for disappears, if we exclude the observations with negative profits. Further, when excluding all the firms with a loss arising in any period the magnitude of the coefficient for tax rate increases substantially. Excluding all the companies which have losses at some point during 2002 and 2009 implies using only the most profitable companies. It certainly appears consistent with the general concept of profit shifting that these companies react stronger to tax rate changes.

The second concern we are addressing in the robustness checks is the fact that the transition countries made the most aggressive tax cuts. At the same time the transition process could have been an important factor leading to higher profitability. While the inclusion of country fixed effects accounts for the country specific characteristics, it could still be the case that the negative sign for the host country tax rate is primarily driven by a few subsidiaries in the transition economies. To overcome these concerns we split the sample into the transition economies and the developed economies.[19] The results in the third block of Table 6 show the effects for the subsidiaries in the developed economies and the fourth block for the subsidiaries in the transition. The results confirm the suspicion that the tax effect is larger in the transition countries. However, the results are still line with the predictions for the profit shifting hypothesis, even after excluding the transition economies from the sample. One interesting feature of this final robustness check is that the tax effect on the EBI/TA profit measure is roughly in line with the coefficient for tax in the $PLAT/TA$ regression once we only use the developed economies. In contrast using only the transition countries we can see a stronger effect of a tax rate change on the $PLAT/TA$ measure. A tentative conclusion can be that the use of financial instruments plays a more important role in the transition countries.

6 Conclusion

This paper investigates the extent to which subsidiaries of multinational firms in 25 countries engage in profit shifting. In contrast to the preceding theoretical literature, which has modelled the effects of taxes on the level of reported profits, we model the effects of corporate taxes on profitability measured as the ratio of profits to total assets. It becomes apparent that theoretical predictions in the case of profit shifting are not clear cut with regard to *pre-tax* profitability. If a country increases its tax rate, then the affiliate will decrease its capital stock to satisfy the marginal condition, which will tend to raise *pre-tax* profitability. In addition, it will transfer profits to lower-taxed affiliates. Hence, *pre-tax* profitability, which is the ratio of reported *pre-tax* profits over total assets, may not decrease if profit shifting is a sufficiently costly activity and the former effect dominates. On the other hand, if there is profit shifting, then reported *post-tax* profitability should definitely be reduced in reaction to an increase in the tax rate.

The empirical work extends the existing literature by looking at both *pre-* and

[19] For the purpose of this paper we define the following countries as transition countries: Bulgaria, Croatia, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Serbia, Slovak Republic and the Ukraine.

post-tax profitability of the same sample of multinational subsidiaries, as opposed to the papers which look at either *pre-* or *post-tax* profitability but not in conjunction. The primary results come from a sample on 39,110 firms over the period of 2002-2009 inclusive. Results are consistent with the hypothesis that multinationals transfer profits between their foreign subsidiaries for tax reasons. Our results suggest that a 10 percentage point increase in the host country corporate tax rate decreases *post-tax* profitability excluding financial profits by 0.6 percentage points. For profits measures including financial profits the tax elasticity is even higher with a 1.1 percentage point increase. Extensive robustness checks show that profitable firms tend to shift more profits and that debt shifting appears to be a key channel for profit shifting. The latter is especially true with respect to the transition countries where the tax differential is larger.

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Appendix

A.1 Theoretical Model

In this section we present a stylized model of a multinational enterprise (MNE). The MNE consists of two entities $1, 2$, which operate in two different countries $1, 2$ with statutory tax rates $\tau_1 > \tau_2$. The profit functions of the two subsidiaries are given by F_1, F_2, which are a function of capital K_1, K_2 respectively and are assumed to be homogeneous of degree $a < 1$.[1] In addition, we assume that the MNE transfers profits $S < F_1$ from subsidiary 1 to subsidiary 2. We assume that the profit shifting activity comes at a cost of:

$$C = \frac{b}{2}\left(\frac{S}{F_1}\right)^2 F_1 \tag{A.1}$$

The MNE is maximising its overall *post-tax* profits with respect to the capital stock K_1, K_2 and profit shifting S:

$$\max_{K_1,K_2,S} \Pi = (1-\tau_1)(F_1 - S) + (1-\tau_2)(F_2 + S) - r(K_1 + K_2) - \frac{b}{2}\frac{S^2}{F_1} \tag{A.2}$$

where r is the cost of capital which is assumed to be equal in both locations.

The first order conditions yield:

$$\frac{\partial F_1}{\partial K_1} = F_{1K} = \frac{r}{1 - \tau_1 + \frac{b}{2}\left(\frac{S}{F_1}\right)^2} \tag{A.3}$$

$$\frac{\partial F_2}{\partial K_2} = F_{2K} = \frac{r}{1-\tau_2} \tag{A.4}$$

$$S = \frac{\tau_1 - \tau_2}{b} F_1 \tag{A.5}$$

Equation (A.5) combined with the restriction for an internal solution ($S < F_1$) dictates that $b > \tau_1 - \tau_2$.

In the case of no profit shifting ($b \to \infty, S \to 0$), from (A.3) and (A.4):

$$F_{1K} = \frac{r}{1-\tau_1}, F_{2K} = \frac{r}{1-\tau_2} \tag{A.6}$$

Given that F_1, F_2 are assumed homogeneous of degree a then (A.6) yields:

$$\begin{aligned} &\text{Average } \textit{pre-tax} \text{ Profitability:} && \frac{F_1}{K_1} = \frac{r}{a(1-\tau_1)}, \frac{F_2}{K_2} = \frac{r}{a(1-\tau_2)} \\ &\text{Average } \textit{post-tax} \text{ Profitability:} && \frac{F_1}{K_1}(1-\tau_1) = \frac{r}{a}, \frac{F_2}{K_2}(1-\tau_2) = \frac{r}{a} \end{aligned} \tag{A.7}$$

[1] If a function $F(K)$ is homogeneous of degree a, then $\frac{\partial F(K)}{\partial K} K = aF(K)$. In addition, it is assumed that $a < 1$, otherwise the model cannot have a solution for the optimal capital level of capital in the absence of taxation.

Hence, *pre-tax* profitabilities must vary with the local tax rate to achieve the equalisation of *post-tax* profitability. Partial differentiation of (A.7) with respect to the tax rates yields:

$$\text{Average } \textit{pre-tax} \text{ Profitability Firm 1:} \frac{\partial \frac{F_1}{K_1}}{\partial \tau_1} = \frac{r}{a\left(1-\tau_1\right)^2}, \frac{\partial \frac{F_1}{K_1}}{\partial \tau_2} = 0 \tag{A.8}$$

$$\text{Average } \textit{pre-tax} \text{ Profitability Firm 2:} \frac{\partial \frac{F_2}{K_2}}{\partial \tau_2} = \frac{r}{a\left(1-\tau_2\right)^2}, \frac{\partial \frac{F_2}{K_2}}{\partial \tau_1} = 0$$

$$\text{Average } \textit{post-tax} \text{ Profitability Firm 1:} \frac{\partial \left[\frac{F_1}{K_1}\left(1-\tau_1\right)\right]}{\partial \tau_1} = \frac{\partial \left[\frac{F_1}{K_1}\left(1-\tau_1\right)\right]}{\partial \tau_2} = 0$$

$$\text{Average } \textit{post-tax} \text{ Profitability Firm 2: } \frac{\partial \left[\frac{F_1}{K_1}\left(1-\tau_2\right)\right]}{\partial \tau_1} = \frac{\partial \left[\frac{F_1}{K_1}\left(1-\tau_2\right)\right]}{\partial \tau_2} = 0$$

Under the alternative hypothesis of profit shifting ($\tau_1 - \tau_2 < b < \infty$, $S > 0$), the reported average *pre-tax* profitabilities are:

$$\frac{F_1 - S}{K_1} = \frac{1}{a}F_{1K} - \frac{S}{K_1} \tag{A.9}$$

$$\frac{F_2 + S}{K_2} = \frac{1}{a}F_{2K} + \frac{S}{K_2} = \frac{1}{a}F_{2K} + \frac{S}{K_1}\frac{K_1}{K_2} \tag{A.10}$$

Pre-tax profitability in country 2 is higher than *pre-tax* profitability in country 1 if:

$$\begin{aligned}
\frac{F_2 + S}{K_2} &> \frac{F_1 - S}{K_1} \Leftrightarrow \\
\frac{1}{a}F_{2K} + \frac{S}{K_1}\frac{K_1}{K_2} &> \frac{1}{a}F_{1K} - \frac{S}{K_1} \Leftrightarrow \\
\frac{1}{a}\left(F_{2K} - F_{1K}\right) &> -\frac{S}{K_1}\left(\frac{K_1}{K_2} + 1\right) \Leftrightarrow \\
\frac{F_{1K}}{a}\left(\frac{F_{2K}}{F_{1K}} - 1\right) &> -\frac{\tau_1 - \tau_2}{b}\frac{F_1}{K_1}\left(\frac{K_1}{K_2} + 1\right) \Leftrightarrow \\
\frac{1 - \tau_1 + \frac{b}{2}\left(\frac{S}{F_1}\right)^2}{1 - \tau_2} - 1 &> -\frac{\tau_1 - \tau_2}{b}\left(\frac{K_1}{K_2} + 1\right) \Leftrightarrow \\
\frac{1 - \tau_1 + \frac{b}{2}\left(\frac{\tau_1 - \tau_2}{b}\right)^2}{1 - \tau_2} + \frac{\tau_1 - \tau_2}{b}\left(\frac{K_1}{K_2} + 1\right) &> 1 \Leftrightarrow \\
\frac{1}{1-\tau_2} - \frac{\tau_1}{1-\tau_2} + \frac{1}{2b}\frac{\left(\tau_1 - \tau_2\right)^2}{1-\tau_2} + \frac{\tau_1 - \tau_2}{b}\left(\frac{K_1}{K_2} + 1\right) &> 1 \Leftrightarrow \\
\left(\tau_1 - \tau_2\right)\left[\frac{1}{2b}\frac{\tau_1 - \tau_2}{1-\tau_2} + \frac{1}{b}\left(\frac{K_1}{K_2} + 1\right)\right] &> \frac{\tau_1 - \tau_2}{1-\tau_2} \Leftrightarrow \\
\frac{\tau_1 - \tau_2}{2b} + \frac{1}{b}\left(1-\tau_2\right)\left(\frac{K_1}{K_2} + 1\right) &> 1
\end{aligned} \tag{A.11}$$

With regard to average reported *post-tax* profitabilities of the two subsidiaries:

$$
\begin{aligned}
(1-\tau_2)\frac{F_2+S}{K_2}-(1-\tau_1)\frac{F_1-S}{K_1} &> 0 \Leftrightarrow \\
(1-\tau_2)\left[\frac{1}{a}F_{2K}+\frac{S}{K_1}\frac{K_1}{K_2}\right]-(1-\tau_1)\left[\frac{1}{a}F_{1K}-\frac{S}{K_1}\right] &> 0 \Leftrightarrow \\
\frac{r}{a}-(1-\tau_1)\frac{r}{a}\frac{1}{1-\tau_1+\frac{b}{2}\left(\frac{S}{F_1}\right)^2}+\frac{S}{K_1}\left[(1-\tau_2)\frac{K_1}{K_2}+(1-\tau_1)\right] &> 0 \Leftrightarrow \\
\frac{r}{a}\left[1-\frac{1-\tau_1}{1-\tau_1+\frac{b}{2}\left(\frac{S}{F_1}\right)^2}\right]+\frac{S}{K_1}\left[(1-\tau_2)\frac{K_1}{K_2}+(1-\tau_1)\right] &> 0 \quad \text{(A.12)}
\end{aligned}
$$

Both terms of inequality (A.12) are positive and thus *after-tax* profitability in the low tax country 2 is unambiguously higher than in the high tax country, 1.

Passing on to comparative statics, we differentiate (A.9) with respect to the two tax rates:

$$
\begin{aligned}
\frac{\partial\frac{F_1-S}{K_1}}{\partial\tau_1} &= \frac{\partial\left[\frac{1}{a}F_{1K}-\frac{S}{K_1}\right]}{\partial\tau_1}\Rightarrow \\
\frac{\partial\frac{F_1-S}{K_1}}{\partial\tau_1} &= \frac{\partial\left[\frac{1}{a}F_{1K}-\frac{\tau_1-\tau_2}{b}\frac{F_1}{K_1}\right]}{\partial\tau_1}\Rightarrow \\
\frac{\partial\frac{F_1-S}{K_1}}{\partial\tau_1} &= \frac{\partial\left[\frac{1}{a}F_{1K}\left(1-\frac{\tau_1-\tau_2}{b}\right)\right]}{\partial\tau_1}\Rightarrow \\
\frac{\partial\frac{F_1-S}{K_1}}{\partial\tau_1} &= \frac{r}{a}\frac{\partial\left[\frac{1}{1-\tau_1+\frac{1}{2b}(\tau_1-\tau_2)^2}\left(1-\frac{\tau_1-\tau_2}{b}\right)\right]}{\partial\tau_1}\Rightarrow \\
\frac{\partial\frac{F_1-S}{K_1}}{\partial\tau_1} &= \frac{r}{a}\frac{\partial\left[\frac{2(b-\tau_1+\tau_2)}{2b(1-\tau_1)+(\tau_1-\tau_2)^2}\right]}{\partial\tau_1}\Rightarrow \\
\frac{\partial\frac{F_1-S}{K_1}}{\partial\tau_1} &= \frac{2r}{a}\frac{\left[-\left(2b(1-\tau_1)+(\tau_1-\tau_2)^2\right)-(b-\tau_1+\tau_2)\left(-2b+2(\tau_1-\tau_2)\right)\right]}{\left[2b(1-\tau_1)+(\tau_1-\tau_2)^2\right]^2}\Rightarrow \\
\frac{\partial\frac{F_1-S}{K_1}}{\partial\tau_1} &= \frac{2r\left[2b(b-1-\tau_1+2\tau_2)+(\tau_1-\tau_2)^2\right]}{a\left[2b(1-\tau_1)+(\tau_1-\tau_2)^2\right]^2} \quad \text{(A.13)}
\end{aligned}
$$

If costs of profit shifting are not too high ($b \Rightarrow (\tau_1-\tau_2)$ it can be shown that (A.13) will be unambiguously negative:

$$
\begin{aligned}
\frac{2r\left[2b\left(b-1-\tau_1+2\tau_2\right)+\left(\tau_1-\tau_2\right)^2\right]}{a\left[2b\left(1-\tau_1\right)+\left(\tau_1-\tau_2\right)^2\right]^2} &< 0 \Leftrightarrow \\
2b\left(b-1-\tau_1+2\tau_2\right) &< -\left(\tau_1-\tau_2\right)^2 \Rightarrow \\
2\left(\tau_1-\tau_2\right)\left(\tau_1-\tau_2-1-\tau_1+2\tau_2\right) &< -\left(\tau_1-\tau_2\right)^2 \Rightarrow \\
2\left(\tau_1-\tau_2-1-\tau_1+2\tau_2\right) &< -\left(\tau_1-\tau_2\right) \Rightarrow \\
-2\left(1-\tau_2\right) &< -\left(\tau_1-\tau_2\right) \Rightarrow \\
2\left(1-\tau_2\right) &> \left(\tau_1-\tau_2\right) \Rightarrow \\
2 &> \left(\tau_1+\tau_2\right)
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial \frac{F_1-S}{K_1}}{\partial \tau_2} &= \frac{r}{a}\frac{\partial\left[\frac{2(b-\tau_1+\tau_2)}{2b(1-\tau_1)+(\tau_1-\tau_2)^2}\right]}{\partial \tau_2} \Rightarrow \\
\frac{\partial \frac{F_1-S}{K_1}}{\partial \tau_2} &= \frac{2r}{a}\frac{\left(2b\left(1-\tau_1\right)+\left(\tau_1-\tau_2\right)^2\right)-\left(b-\tau_1+\tau_2\right)\left(-2\left(\tau_1-\tau_2\right)\right)}{\left[2b\left(1-\tau_1\right)+\left(\tau_1-\tau_2\right)^2\right]^2} \Rightarrow \\
\frac{\partial \frac{F_1-S}{K_1}}{\partial \tau_2} &= \frac{2r\left[2b\left(1-\tau_2\right)-\left(\tau_1-\tau_2\right)^2\right]}{a\left[2b\left(1-\tau_1\right)+\left(\tau_1-\tau_2\right)^2\right]^2}
\end{aligned} \tag{A.14}
$$

As regards average reported *after-tax* profitability of subsidiary 1:

$$
\begin{aligned}
\frac{\partial\left[\left(1-\tau_1\right)\frac{F_1-S}{K_1}\right]}{\partial \tau_1} &= \frac{r}{a}\frac{\partial\left[\frac{2(b-\tau_1+\tau_2)(1-\tau_1)}{2b(1-\tau_1)+(\tau_1-\tau_2)^2}\right]}{\partial \tau_1} \Rightarrow \\
\frac{\partial\left[\left(1-\tau_1\right)\frac{F_1-S}{K_1}\right]}{\partial \tau_1} &= \frac{2r}{a}\frac{\left(-1-b-\tau_2+2\tau_1\right)\left[2b\left(1-\tau_1\right)+\left(\tau_1-\tau_2\right)^2\right]}{\left[2b\left(1-\tau_1\right)+\left(\tau_1-\tau_2\right)^2\right]^2}+ \\
&\quad \frac{2r}{a}\frac{-\left(b-\tau_1+\tau_2\right)\left(1-\tau_1\right)\left(-2b+2\left(\tau_1-\tau_2\right)\right)}{\left[2b\left(1-\tau_1\right)+\left(\tau_1-\tau_2\right)^2\right]^2} \\
\frac{\partial\left[\left(1-\tau_1\right)\frac{F_1-S}{K_1}\right]}{\partial \tau_1} &= -\frac{2r}{a\left[2b\left(1-\tau_1\right)+\left(\tau_1-\tau_2\right)^2\right]^2} \\
&\quad \left[b\left(2-\left(2-\tau_1\right)\tau_1-\left(2-\tau_2\right)\tau_2\right)-\left(1-\tau_2\right)\left(\tau_1-\tau_2\right)^2\right]
\end{aligned} \tag{A.15}
$$

$$
\begin{aligned}
\frac{\partial\left[(1-\tau_1)\frac{F_1-S}{K_1}\right]}{\partial\tau_2} &= \frac{r}{a}\frac{\partial\left[\frac{2(b-\tau_1+\tau_2)(1-\tau_1)}{2b(1-\tau_1)+(\tau_1-\tau_2)^2}\right]}{\partial\tau_2} \Rightarrow \\
\frac{\partial\left[(1-\tau_1)\frac{F_1-S}{K_1}\right]}{\partial\tau_2} &= \frac{2r}{a}\frac{(1-\tau_1)\left[2b(1-\tau_1)+(\tau_1-\tau_2)^2\right]}{\left[2b(1-\tau_1)+(\tau_1-\tau_2)^2\right]^2} + \\
&\quad \frac{2r}{a}\frac{-(b-\tau_1+\tau_2)(1-\tau_1)(-2(\tau_1-\tau_2))}{\left[2b(1-\tau_1)+(\tau_1-\tau_2)^2\right]^2} \\
\frac{\partial\left[(1-\tau_1)\frac{F_1-S}{K_1}\right]}{\partial\tau_2} &= \frac{2r(1-\tau_1)\left[2b(1-\tau_2)-(\tau_1-\tau_2)^2\right]}{a\left[2b(1-\tau_1)+(\tau_1-\tau_2)^2\right]^2}
\end{aligned} \tag{A.16}
$$

With regard to equation (A.15), given that $b > \tau_1 - \tau_2$ then for the numerator to be positive it suffices to prove that:

$$
\begin{aligned}
2-2\tau_1+\tau_1^2-2\tau_2+\tau_2^2 &> (1-\tau_2)(\tau_1-\tau_2) \Rightarrow \\
2(1-\tau_1)+\tau_1^2-2\tau_2+\tau_2^2 &> \tau_1-\tau_2-\tau_2\tau_1+\tau_2^2 \Rightarrow \\
2(1-\tau_1)+\tau_1^2-\tau_2 &> \tau_1-\tau_2\tau_1 \Rightarrow \\
2(1-\tau_1) &> \tau_1(1-\tau_1)+\tau_2(1-\tau_1) \Rightarrow \\
2 &> \tau_1+\tau_2
\end{aligned}
$$

which holds for any conceivable tax rates. Equally, in equation (A.16) the numerator is positive since $b > \tau_1 - \tau_2$ and $(1-\tau_2) > (\tau_1 - \tau_2)$.

In order to make progress with respect to the comparative statics of the reported profitability of subsidiary 2 one needs to solve for the ratio of K_1/K_2 using (A.3)-(A.5) and substitute into (A.10). We, firstly, assume profit functions of the form $F_i = A_i K_i^a$, where A_i is the total factor productivity for each of the subsidiaries. Combinations of equations (A.3), (A.4) and (A.5) yield:

$$
\frac{K_1}{K_2} = \left(\frac{A_1}{A_2}\right)^{1/1-a}\left[\frac{1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}}{(1-\tau_2)}\right]^{1/1-a}
$$

Equation (A.10) then yields:

$$
\frac{F_2+S}{K_2} = \frac{r}{a}\left[\frac{1}{1-\tau_2}+\left(\frac{A_1}{A_2}\right)^{1/1-a}\frac{\tau_1-\tau_2}{b}\frac{\left[1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}\right]^{a/1-a}}{(1-\tau_2)^{1/1-a}}\right] \tag{A.17}
$$

Differentiation of (A.17) with respect to τ_1, τ_2 yields:

$$
\begin{aligned}
\frac{\partial \frac{F_2+S}{K_2}}{\partial \tau_1} &= \frac{r}{ab\left(1-\tau_2\right)^{1/1-a}}\left(\frac{A_1}{A_2}\right)^{1/1-a} \\
&\left[\begin{array}{c}\left[1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}\right]^{a/1-a}+ \\ \frac{a(\tau_1-\tau_2)}{1-a}\left[1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}\right]^{\frac{a}{1-a}-1}\left(\frac{\tau_1-\tau_2}{b}-1\right)\end{array}\right] \\
\frac{\partial \frac{F_2+S}{K_2}}{\partial \tau_1} &= \frac{r}{ab\left(1-\tau_2\right)^{1/1-a}}\left(\frac{A_1}{A_2}\right)^{1/1-a}\left[1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}\right]^{a/1-a} \\
&\left[1+\frac{a\left(\tau_1-\tau_2\right)}{1-a}\left(\frac{\tau_1-\tau_2}{b}-1\right)\frac{1}{1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}}\right] \qquad \text{(A.18)}
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial \frac{F_2+S}{K_2}}{\partial \tau_2} &= \frac{r}{a\left(1-\tau_2\right)^2}-\frac{r}{ab}\left(\frac{A_1}{A_2}\right)^{1/1-a}\frac{\left[1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}\right]^{a/1-a}}{\left(1-\tau_2\right)^{1/1-a}}+ \\
&\frac{r}{a}\left(\frac{A_1}{A_2}\right)^{1/1-a}\frac{\tau_1-\tau_2}{b}\frac{\left(1-\tau_2\right)^{1/1-a}\frac{a}{1-a}\left[1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}\right]^{\frac{a}{1-a}-1}\left(-\frac{\tau_1-\tau_2}{b}\right)}{\left(1-\tau_2\right)^{2/1-a}}+ \\
&\frac{r}{a}\left(\frac{A_1}{A_2}\right)^{1/1-a}\frac{\tau_1-\tau_2}{b}\frac{\left[1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}\right]^{\frac{a}{1-a}}\frac{1}{1-a}\left(1-\tau_2\right)^{a/1-a}}{\left(1-\tau_2\right)^{2/1-a}} \qquad \text{(A.19)}
\end{aligned}
$$

Below are the partial derivatives of the average reported *post-tax* profitability of subsidiary 2 with respect to the tax rates:

$$
\begin{aligned}
\frac{\partial\left[\left(1-\tau_2\right)\frac{F_2+S}{K_2}\right]}{\partial \tau_1} &= \frac{r}{ab\left(1-\tau_2\right)^{a/1-a}}\left(\frac{A_1}{A_2}\right)^{1/1-a} \\
&\left[\begin{array}{c}\left[1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}\right]^{a/1-a}+ \\ \frac{a(\tau_1-\tau_2)}{1-a}\left[1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}\right]^{\frac{a}{1-a}-1}\left(\frac{\tau_1-\tau_2}{b}-1\right)\end{array}\right] \\
\frac{\partial\left[\left(1-\tau_2\right)\frac{F_2+S}{K_2}\right]}{\partial \tau_1} &= \frac{r}{ab\left(1-\tau_2\right)^{a/1-a}}\left(\frac{A_1}{A_2}\right)^{1/1-a}\left[1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}\right]^{a/1-a}* \\
&\left[1+\frac{a\left(\tau_1-\tau_2\right)}{1-a}\left(\frac{\tau_1-\tau_2}{b}-1\right)\frac{1}{1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}}\right] \qquad \text{(A.20)}
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial\left[(1-\tau_2)\,\frac{F_2+S}{K_2}\right]}{\partial\tau_2} &= -\frac{r}{ab}\left(\frac{A_1}{A_2}\right)^{1/1-a}\left[\frac{1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}}{1-\tau_2}\right]^{a/1-a} + \\
&\quad \frac{r}{a}\left(\frac{A_1}{A_2}\right)^{1/1-a}\frac{\tau_1-\tau_2}{b}\frac{\frac{a}{1-a}\left[1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}\right]^{\frac{a}{1-a}-1}\left(\frac{\tau_1-\tau_2}{b}-1\right)}{(1-\tau_2)^{\left(\frac{2a}{1-a}\right)-\left(\frac{a}{1-a}\right)}} + \\
&\quad \frac{r}{a}\left(\frac{A_1}{A_2}\right)^{1/1-a}\frac{\tau_1-\tau_2}{b}\frac{\frac{a}{1-a}\left[1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}\right]^{\frac{a}{1-a}}(1-\tau_2)^{\frac{a}{1-a}-1}}{(1-\tau_2)^{2a/1-a}} \\
\frac{\partial\left[(1-\tau_2)\,\frac{F_2+S}{K_2}\right]}{\partial\tau_2} &= -\frac{r}{ab}\left(\frac{A_1}{A_2}\right)^{1/1-a}\left[\frac{1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}}{1-\tau_2}\right]^{a/1-a} \\
&\quad \left[1+\frac{\frac{a}{1-a}(\tau_1-\tau_2)\left(1-\frac{\tau_1-\tau_2}{b}\right)}{1-\tau_1+\frac{(\tau_1-\tau_2)^2}{2b}}-\frac{\frac{a}{1-a}(\tau_1-\tau_2)}{(1-\tau_2)}\right] \qquad \text{(A.21)}
\end{aligned}
$$

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