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Capital Taxation and Imperfect Competition: ACE vs. CBIT*

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Abstract

This paper sets up an imperfect-competition model of a small open economy, and undertakes a welfare comparison of the Corporate Business Income Tax (CBIT) and the Allowance for Corporate Equity tax (ACE). A main result is that a small open economy should levy a positive source tax on capital in a market with free firm entry. Our analysis also shows that the well known neutrality property of the ACE tax is no longer true when firms are mobile and can enter the market. Which tax system is better from a welfare point of view, CBIT or ACE, is shown to depend on assumptions about production technology and entry.

Keywords: Optimal corporate taxation, Corporate tax reform, Imperfect competition, ACE, CBIT

JEL classification: D58, H25

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1 Introduction

The analysis of corporate tax reform under imperfect competition in a small open economy is a non-existing field in the corporate tax literature. This paper sets up an imperfect-competition model of a small open economy and undertakes a welfare comparison of the two most favored candidates for a corporate tax reform, the Corporate Business Income Tax (CBIT) and the Allowance for Corporate Equity tax (ACE). We show that the benchmark result in the optimal tax literature that a small open economy should not levy any source based taxes on capital,¹ is no longer valid under imperfect competition, since the corporate tax rate plays a key role in regulating competition and avoiding a wasteful use of resources on (socially) excessive market entry.

In a second set of results, we show that the ACE tax is equal to a lump sum tax that does not distort prices when the number of firms is fixed. This results has a parallel to Boadway and Bruce (1984) who pointed out that the ACE tax works like a lump sum tax, since it offsets the investment distortions caused by deviations between true economic depreciation and depreciation for tax purposes. In a market with free entry, however, we show that the neutrality of the ACE tax no longer is true. As a matter of fact, both ACE and CBIT distort the market equilibrium.

Which tax system is better from a welfare point of view, CBIT or ACE, depends on assumptions about production technology, entry and the level of taxation. Under both systems, the optimal corporate tax rate is positive in order to reduce excessive entry. Though consumer prices are always lower under an ACE system, a CBIT system promotes less entry under increasing returns to scale. The reason is that CBIT avoids a subsidy on average capital costs that, under increasing returns to scale, would overcompensate the intensified strategic price competition driven by the marginal-cost effect. Results are reversed under decreasing returns to scale. Empirical evidence points to the importance of multinational companies in all economies worldwide and shows that such companies are operating under increasing returns to scale (e.g., Carr et al., 2001; Antweiler and Treffer, 2002). Accordingly, the policy recommendation from our findings can be: A CBIT should be implemented if the corporate tax rate falls short of its socially optimal level (e.g., due to tax competition) and if the economy is predominantly characterized by markets under imperfect competition that are dominated by multinationals. Taxing capital costs is a second-best instrument in order to mitigate excessive entry, then.

The expressed preferences for either an ACE or a CBIT tax reform has been motivated by current distortions in national tax systems. Most countries allow for a deduction of debt interest when computing the profit tax base, but disallow equity to deduct its opportunity cost. Debt finance, therefore, is at an advantage compared to financing an investment via retained earnings or equity. Thus, tax-deductible debt as preferred mode

¹See, e.g., Gordon (1986).

of financing leads to tax avoidance by debt shifting (see, e.g., Mintz and Weichenrieder, 2010, for a survey). Moreover, thin capitalization induces a moral hazard problem leading either to excessive risk taking or to suboptimal investment due to a debt-overhang problem (Myers, 1977). In order to avoid such problems and to equalize the opportunity cost of debt and equity, CBIT and ACE taxation came into being.² CBIT was developed by the US Treasury Department at the beginning of the nineties (see US Department of Treasury, 1992), whereas the ACE was elaborated by the IFS Capital Taxes Group (see Institute for Fiscal Studies, 1991). The CBIT makes the corporation tax neutral towards the financing structure by disallowing the exemption of interest paid for corporate income tax purposes. ACE obtains the same result by granting equity holders an allowance equal to a notional risk-free return on equity (e.g., the market interest rate for long-term government bonds). Neither the comprehensive business income tax nor the allowance for corporate equity distort the liability side of corporations. One key difference between the two systems is that CBIT has a wider tax base (since interest expenses are non-deductible), but distorts marginal investment decisions compared to ACE.

Previous studies of these two tax systems have been undertaken in a perfectly competitive setting. Radulescu and Stimmelmayer (2007) compare ACE and CBIT using computable general equilibrium (CGE). They show that welfare is higher under an ACE type of reform even if the loss of tax revenue is financed by an increase in the VAT. De Moij and Devereux (2011) use an applied general equilibrium model for the EU calibrated with recent empirical estimates of elasticities to study a balanced budget reform. They focus on investment and profit shifting incentives following a tax reform and find that most European countries would benefit from a unilateral CBIT type of reform. A coordinated tax reform within the EU, however, would work in favor of an ACE reform.

The model used in this paper is the circular city model of Salop. In the subsequent sections, we set up the model and analyze the equilibrium with and without free entry of firms. In the final section of the paper, a welfare comparison of the two tax systems is undertaken.

2 Model

Consider a market with $n \geq 2$ firms symmetrically located on a (Salop) circle with circumference equal to 1. Each firm offers a product at price p_i , $i = 1, \dots, n$. There is a continuum of consumers uniformly located on the circle with total mass normalized to one. Each consumer buys one or zero units of the product. The utility to consumer

²Recently, also the Mirrless Report argued in favor of achieving a tax system that is neutral with respect to the financing decision. See Mirrlees et al. (2011), particularly chapter 17.

located at $x \in [0, 1]$ of buying product i is given by

$$u_i = v - \tau d_i + \phi, \quad (1)$$

where v is the gross utility of consuming the product (reservation price), τ is the transport cost per unit of distance, $d_i = |z_i - x|$ is the distance to firm i 's location $z_i \in [0, 1]$, and ϕ is a numeraire good. Distance is, as usual, interpreted either in physical or product space.³

Each consumer has income $m = r\kappa + w$, where $r\kappa$ is capital income, with r denoting the interest rate and κ the capital endowment, and w is non-capital (e.g., labor) income. We assume a small, open economy, which implies that r is exogenous and the firms' demand for capital is not constrained by the domestic capital endowment. Normalizing the price of the numeraire good to unity, and inserting the budget constraint into (1), we can write the net utility of consumer x as follows

$$u_i = v - \tau d_i - p_i + m. \quad (2)$$

We assume v is sufficiently large, so that all consumers buy one unit of the product from the most preferred firm (full market coverage). The consumer that is indifferent between buying from firm i and firm $i + 1$ is located at

$$\hat{x}_+ = \frac{1}{2\tau} [\tau (z_{i+1} + z_i) - p_i + p_{i+1}],$$

whereas the consumer indifferent between buying from firm i and firm $i - 1$ is located at

$$\hat{x}_- = \frac{1}{2\tau} [\tau (z_i + z_{i-1}) + p_i - p_{i-1}].$$

Firm i 's demand is then given by

$$y_i = \int_{\hat{x}_-}^{\hat{x}_+} dx = \frac{1}{n} - \frac{2p_i - p_{i-1} - p_{i+1}}{2\tau}. \quad (3)$$

The firms have identical technology. For simplicity, we assume capital is the only input in production and define the relationship between capital and production by the following inverse production function $k_i = g(y_i)$.⁴ The inverse production function $g(\cdot)$ is assumed to be continuous and twice differentiable, where $g(0) = 0$ and $g'(\cdot) > 0$. We allow for technology to exhibit different scale properties. A constant returns to scale

³In the latter case, τ is often referred to as the mismatch cost measuring the cost related to the distance between the consumer's most preferred product (defined by the consumer's location x) and the products offered in the market (defined by the firm location z).

⁴This production function can be generalized to encompass non-capital inputs (labor) when these inputs are used either in fixed proportions with or independently of capital.

(CRS) technology implies constant marginal productivity of capital, $g'' = 0$, and marginal capital costs equal to average capital costs, $g' = g/y$. Moreover, a decreasing returns to scale (DRS) technology implies a decreasing marginal productivity of capital, $g'' > 0$, and marginal capital costs exceeding average capital costs, $g' > g/y$, whereas the opposite is true for an increasing returns to scale (IRS) technology.⁵

We assume a perfectly competitive capital market and, for simplicity, that neither equity nor debt are risky. This implies that the interest rates of debt and equity must be equalized in a capital market equilibrium. Thus, the firms are indifferent between raising capital through debt or equity. The cost of capital is therefore given by the interest rate in the capital market. Using the above-mentioned production technology, we can write firm i 's gross (before-tax) profits as

$$\pi_i = p_i y_i - r g(y_i) - f, \quad (4)$$

where $p_i y_i$ is the sales revenues, $r g(y_i)$ is the capital costs, and $f > 0$ is the fixed set-up (entry) cost assumed without loss of generality to be identical across firms.⁶

The corporate tax scheme is set by the government. We will consider two different regimes: (i) Comprehensive Business Income Tax (CBIT) and (ii) Allowance for Corporate Equity (ACE). The two regimes differ according to whether they allow for tax deduction of capital costs. While ACE allows for tax deductions of both debt and equity, CBIT does not allow for any tax deductions of capital costs. Assuming that the government bases the possible tax deductions on costs of equity on the interest rate in the capital market, firm i 's after-tax profits are given by

$$\pi_i = (1 - t) p_i y_i - r (1 - \alpha t) g(y_i) - f, \quad (5)$$

where $t \in [0, 1)$ is the corporate tax rate and $\alpha \in [0, 1]$ is the share of the capital costs that are tax deductible by the firms. Notice that $\alpha = 0$ corresponds to a pure CBIT scheme with no tax deductions for capital costs, whereas $\alpha = 1$ corresponds to ACE with complete tax deduction for capital costs.

We consider the following timing structure. At stage 1, the tax authority decides on

⁵To see this more clearly, consider the production function $y = f(k) = k^{1/\theta}$, where $\theta > 0$. Clearly, if $\theta = 1$, technology is CRS with constant marginal productivity of capital, whereas if $\theta < (>) 1$, technology is IRS (DRS) with increasing (decreasing) marginal capital productivity. Inverting the production function above, we get $k = g(y) = y^\theta$, where

$$g' = \theta y^{\theta-1}, \quad g'' = \theta(\theta - 1) y^{\theta-2}, \quad \text{and} \quad g' - g/y = y^{\theta-1}(\theta - 1).$$

Thus, a CRS technology ($\theta = 1$) implies $g'' = 0$ and $g' = g/y$, a DRS technology ($\theta > 1$) implies $g'' > 0$ and $g' > g/y$, and an IRS technology ($\theta < 1$) implies $g'' < 0$ and $g' < g/y$.

⁶Allowing for different fixed costs would imply that only firms with sufficiently low fixed costs would enter. However, since the fixed costs do not influence the price decisions directly, but only entry decision, our results would be robust to such a generalization.

the corporate tax rate and the tax deductions for capital costs. At stage 2, the firms simultaneously decide to enter the market. Entry takes place as long as expected profits exceed a fixed (sunk) entry cost. Finally, at stage 3, the firms that entered the market compete in prices à la Bertrand. The game is as usual solved by backward induction.

3 Price equilibrium

Given that $n \geq 2$ firms have entered the market, each firm sets the price in order to maximize profits taking the other firms' prices as given. The profit-maximizing price of firm i is given by the following first-order condition:⁷

$$\frac{\partial \pi_i}{\partial p_i} = (1-t) \left(p_i \frac{\partial y_i}{\partial p_i} + y_i \right) - r(1-\alpha t) g'(y_i) \frac{\partial y_i}{\partial p_i} = 0, \quad (6)$$

where $\partial y_i / \partial p_i = -1/\tau$ from equation (3).

Imposing symmetry, i.e., $p_i = p_{i-1} = p_{i+1} = p$ for all $i = 1, \dots, n$, and solving (6) for p , we get the following candidate for a symmetric Nash price equilibrium

$$p^* = \frac{\tau}{n} + r g'(y_i) \left(\frac{1-\alpha t}{1-t} \right). \quad (7)$$

The last term can be interpreted as the (effective) marginal capital costs, which is increasing in the corporate tax rate, but decreasing in the level of tax deductions. Inserting (7) into (5), we get the following equilibrium after-tax profits

$$\pi^* = (1-t) \frac{\tau}{n^2} + r(1-\alpha t) \left(g' \frac{1}{n} - g \right) - f. \quad (8)$$

From these expressions, we can establish the following:

Lemma 1 *The price equilibrium in (7) exists and is unique if and only if $\tau > \max\{\tau_1, \tau_2\}$, where*

$$\tau_1 := -\frac{r}{2} \frac{1-t\alpha}{1-t} g'' \quad (9)$$

ensures that the profit function is strictly concave, and

$$\tau_2 := \frac{n^2}{1-t} \left(r(1-\alpha t) \left(g - g' \frac{1}{n} \right) + f \right) \quad (10)$$

ensures that each firm's equilibrium after-tax profits are non-negative.

⁷The second-order condition requires

$$\frac{\partial^2 \pi_i}{\partial p_i^2} = -\frac{1}{\tau} \left[2(1-t) + r(1-\alpha t) g'' \frac{1}{\tau} \right] < 0.$$

All proofs are provided in the Appendix.

The effects of corporate taxation and deduction of capital costs follow straightforward from (7)

$$\frac{\partial p^*}{\partial t} = rg' \frac{1 - \alpha}{(1 - t)^2} \geq 0, \quad (11)$$

$$\frac{\partial p^*}{\partial \alpha} = -rg' \frac{t}{1 - t} < 0, \quad (12)$$

and can be summarized in the following proposition:

Proposition 1 *In a Salop model with a fixed number of firms,*

(i) *a higher corporate tax rate increases product prices, except when complete tax deductions for capital costs are allowed (ACE) in which corporate taxation has no distortionary price effects;*

(ii) *a higher level of tax deduction for capital costs always reduces product prices.*

If the tax authority introduces CBIT in its pure form with no tax deductions ($\alpha = 0$) or only allows for limited deductions of capital costs ($\alpha < 1$), we obtain the standard result that the corporate tax distorts firm behavior and thus product prices. The effect of corporate taxation on product prices can be decomposed into a direct and a strategic effect. The direct effect is that the corporate tax increases the (effective) marginal cost of capital, which in turn shifts up the product prices.⁸ The strategic effect is due to prices being strategic complements and reinforces the direct effect of corporate taxation on product prices.⁹ Thus, corporate taxation has a stronger (positive) impact on product prices in markets with imperfect price competition than in markets without any strategic interaction between firms.

Under an ACE tax scheme with complete tax deductions for capital costs ($\alpha = 1$), the corporate tax does not distort product prices. The reason is that when all capital costs can be deducted from the tax base, then corporate taxation is equivalent to a lump-sum profit tax. Consequently, the corporate tax will not have any impact on the firms' pricing decisions. This is in line with the neutrality properties that has been attributed to the ACE system.¹⁰ As will be clear later, this result is only true when the number of firms in the market is fixed.

⁸Alternatively, we can think of a higher corporate tax rate as a reduction of firms' marginal revenues, which induces the firms to increase their prices in order to balance marginal revenues and marginal cost.

⁹The individual firm response to corporate taxation is obtained by differentiating (6) with respect to t yielding:

$$\frac{\partial p_i}{\partial t} = \frac{y_i - \frac{1}{\tau} (p_i + \alpha r g')}{\frac{1}{\tau} (2(1 - t) + r(1 - \alpha t) \frac{1}{\tau} g'')}.$$

¹⁰See, e.g., Boadway and Bruce (1984) and Devereux and Freeman (1991).

What are the effects of corporate taxation and the tax deduction scheme on firm profitability? Differentiating (8) with respect to t and α , and using the equilibrium conditions (9)-(10), yields

$$\frac{\partial \pi^*}{\partial t} = -\frac{\tau}{n^2} - \alpha r \left(g' \frac{1}{n} - g \right) < 0, \quad (13)$$

$$\frac{\partial \pi^*}{\partial \alpha} = -rt \left(g' \frac{1}{n} - g \right) \geq 0. \quad (14)$$

Based on these expressions, we get the following results:

Proposition 2 *In a Salop model with a fixed number of firms,*

- (i) *a higher corporate tax rate always reduces firms' after-tax profits; the effect is stronger (weaker) with tax deductions and DRS (IRS) technology;*
- (ii) *a higher level of tax deduction for capital costs increases (reduces) firms' after-tax profits if the technology is IRS (DRS), but has no effect on after-tax profits if technology is CRS.*

Proposition 2 makes it clear that a higher corporate tax rate reduces firms' after-tax profits. The reason is that the firms cannot shift the full burden of the corporate tax onto consumers. A higher corporate tax rate increases the price to consumers, but the rise is not sufficient to recover the loss in profit from the corporate tax payment. The fall in profit holds for any production technology (IRS, DRS or CRS).

If the tax authority disallows tax deductions of capital costs, as under CBIT ($\alpha = 0$), then from (13) we see that the production technology does not play a role for the effect of the corporate tax on firms' profits. If tax deductions are allowed ($\alpha > 0$), the technology relating capital and production matters. More precisely, the higher (lower) are the marginal capital costs relative to the average capital costs, the stronger (weaker) is the negative impact of corporate taxation on firms' after-tax profits. In other words, corporate taxation is particularly harmful to firms' profits when the tax authority allows for tax deductions and production involves DRS. However, if technology involves IRS, then the negative effect on profits of corporate taxation is partly mitigated by the reduction in capital costs due to tax deductions.

To see why scale in production matters for profit, it is useful to decompose the effect of the corporate tax into three separate effects; (i) a loss in sales revenues ($-tp^*y^*$); (ii) an increase in prices ($\partial p^*/\partial t$) $(1-t)y^*$; and (iii) a reduction in capital costs ($\alpha rg(y^*)$) due to tax deductions. The two first effects depend on the size of the marginal cost of capital (scaled with the production level), whereas the latter effect depends on the total capital costs. Thus, the smaller the marginal costs are relative to the average costs, the stronger is the capital cost gain from tax deductions.

The effect of tax deductions of capital costs on firms' after-tax profits crucially hinges on the production technology, as shown in Proposition 2. Surprisingly, a higher level of tax deductions may result in lower after-tax profits to the firms if the technology is DRS. To understand this result, we can decompose the total effect of the tax deduction into two separate effects: (i) a profit loss due to lower prices, $(1-t)y^*(\partial p^*/\partial \alpha)$, and (ii) a profit gain due to lower capital costs, $(rt)g(\cdot)$. The latter effect is the direct tax saving effect of the tax deduction, whereas the former effect is a strategic effect due to price competition. If the technology is CRS, these two effects cancel each other, and the net effect of tax deductions is zero and the choice of ACE versus CBIT does not matter for firms' profitability. On the other hand, if the technology is IRS, the direct effect (capital cost gain) dominates, and the net effect of tax deductions on profits is positive. Thus, a ACE scheme would be more beneficial to the firms than CBIT. If the technology is DRS, however, the strategic (price) effect dominates, and the effect of tax deductions on profits is negative, suggesting that CBIT is more beneficial to firms than ACE.

4 Free entry equilibrium

We now consider stage 2 where $n \geq 2$ firms simultaneously decide whether or not to enter the market. Each firm i enters the market if the expected profits exceed the fixed (sunk) entry cost $f > 0$. Firms enter the market until the equilibrium after-tax profits equal zero (up to the integer problem); hence, the equilibrium number of firms $n^*(t, \alpha; \tau, f, r)$ is given by

$$\pi^* = (1-t) \frac{\tau}{(n^*)^2} + r(1-\alpha t) \left(g' \frac{1}{n^*} - g \right) - f = 0. \quad (15)$$

How do the corporate tax and tax deductions affect the number of firms in the market? The answer to this question follows qualitatively from the results in Proposition 2. Quantitatively, by applying the implicit function theorem on (15), and using the equilibrium conditions (9)-(10), we obtain the following tax effects on the number of firms

$$\frac{\partial n^*}{\partial t} = - (n^*)^3 \frac{\frac{\tau}{(n^*)^2} + r\alpha \left(g' \frac{1}{n^*} - g \right)}{(1-t)2\tau + r(1-\alpha t)g''} < 0, \quad (16)$$

$$\frac{\partial n^*}{\partial \alpha} = - (n^*)^3 \frac{rt \left(g' \frac{1}{n^*} - g \right)}{(1-t)2\tau + r(1-\alpha t)g''} \geq 0. \quad (17)$$

Based on these expressions, we get the following results:

Proposition 3 *In a Salop model with free entry,*

- (i) *a higher corporate tax rate always reduces the number of firms in the market, irrespective of technology and tax deduction scheme (ACE or CBIT);*

- (ii) a higher level of tax deductions of capital costs increases (reduces) the number of firms in the market when technology is IRS (DRS), but has no effect when technology is CRS.

As expected, Proposition 3 shows that corporate taxation always reduces firm entry and therefore the intensity of competition in the market. The magnitude of this effect depends on the scale properties and whether tax deductions for capital costs are allowed or not. More interesting, Proposition 3 shows that the effect of tax deductions crucially relies on the production technology. If technology is CRS, then tax deductions have no impact on market entry, and the choice of ACE or CBIT has no competitive effect. However, if technology is DRS, then allowing for tax deductions reduces the number of firms in the market, which means that CBIT would be more pro-competitive than ACE. The opposite is true when technology is IRS. To understand this result, note that tax deductions have two opposing effects on profits. On one hand, tax deductions directly increases profits, all else equal. On the other hand, tax deductions shifts down prices and thus profit margins, which reduces profits. Proposition 3 shows that the latter effect is stronger than the direct effect when technology is DRS, whereas with CRS the two effects exactly cancel out.

What are the tax effects on product prices in a market with free entry of firms? Taking the partial derivative of (7) with respect to t and α , and imposing the equilibrium level of firms $n^*(t, \alpha; \tau, r, f)$ given by (15), we get the following (implicit) comparative static results

$$\frac{\partial p^*}{\partial t} = rg' \frac{1-\alpha}{(1-t)^2} - \frac{1}{n^2} \left(\tau + r \frac{1-\alpha t}{1-t} g'' \right) \frac{\partial n^*}{\partial t} > 0, \quad (18)$$

$$\frac{\partial p^*}{\partial \alpha} = -rg' \left(\frac{t}{1-t} \right) - \frac{1}{n^2} \left(\tau + r \frac{1-\alpha t}{1-t} g'' \right) \frac{\partial n^*}{\partial \alpha} < 0. \quad (19)$$

Based on these expressions, we get the following results:

Proposition 4 *In a Salop model with free entry,*

- (i) a higher corporate tax rate always leads to higher product prices, irrespectively of technology and tax deduction scheme (ACE or CBIT);
- (ii) a higher level of tax deductions of capital costs always reduces product prices irrespectively of technology.

When accounting for entry, corporate taxation always leads to higher prices in the product market, even with ACE and complete tax deduction of capital costs ($\alpha = 1$). The reason is that corporate taxation has both a direct effect on prices (as shown in Proposition 1) and an indirect effect through the change in entry and thus competition intensity. In equation (18), these two effects are captured by the first and second term,

respectively. While ACE eliminates the direct distortionary effect on firms' pricing, the indirect effect through competition prevails. Since firms' after-tax profits are inevitably affected by corporate taxation, intensity of competition will be reduced. Thus, corporate taxation has distortionary effects on product prices irrespective of whether ACE or CBIT is introduced.

The indirect effect of corporate taxation, as given by the second term in (18), consists of two elements; (i) a standard competition effect (τ/n^2), and (ii) a capital cost effect ($rg''(1 - \alpha t)/(1 - t)$). With a CRS technology, the cost effect vanishes, whereas with an IRS (a DRS) technology the cost effect strengthens (dampens) the competition effect on prices.

Tax deductions of capital costs always reduce product prices, even when accounting for entry. We know from Proposition 1 that tax deductions reduce product prices for a given number of firms. However, as shown in Proposition 3, the competition effects of tax deductions are ambiguous and depend on the production technology. Indeed, if technology exhibits DRS, then higher levels of tax deductions reduce entry and shift up product prices. However, we find that this potentially countervailing competition effect only partially mitigates the direct effect, and that tax deductions always lead to lower product prices.

Based on the previous results, we may sum up the findings related to the choice of the tax deduction regime in the following way:

Corollary 2 *In a Salop model with free entry,*

- (i) *CBIT (ACE) promotes more entry of firms when technology exhibits DRS (IRS);*
- (ii) *both ACE and CBIT distort product prices, but ACE induces lower product prices than CBIT, irrespective of technology.*

5 Social welfare and corporate taxation

Social welfare, assuming a utilitarian (unweighted) welfare function, is given by the sum of consumers' surplus, producers' profits, and (in this setting) the corporate tax income, i.e.,

$$W = CS + \Pi + T. \tag{20}$$

CS represents the consumers' surplus given by

$$CS = \sum_{i=1}^n \int_{\hat{x}_{i-1}}^{\hat{x}_{i+1}} (v - \tau d_i - p_i + m) dx, \tag{21}$$

Π is the producers' profits given by

$$\Pi = \sum_{i=1}^n \pi_i = \sum_{i=1}^n [(1-t)p_i y_i - r(1-\alpha t)g(y_i) - f], \quad (22)$$

and T is the corporate tax income given by

$$T = \sum_{i=1}^n [tp_i y_i - \alpha r t g(y_i)]. \quad (23)$$

Using this specification of social welfare, we derive the first-best outcome, as a benchmark. After that, we study the tax authority's optimal choice of corporate taxation and deductions (ACE or CBIT), and the corresponding effects on entry and pricing in the product market. Finally, we analyze the welfare properties of ACE and CBIT under tax income neutrality, i.e., the two schemes have to generate the same tax income level.

5.1 First-best outcome

Consider a social planner that directly decides the number of firms and their production levels using the available technology. Since firms are symmetric, the first-best outcome implies that each firm produces $1/n$ units of the product. Inserting (21)-(23) into and imposing symmetry, the social welfare function in (20) simplifies to

$$W^{fb} = m + v - \frac{\tau}{2n} - nrg(y) - nf, \quad (24)$$

where the first three terms are the (gross) consumers' surplus, and the two last terms are the production (capital) costs and the fixed costs of setting up n firms, respectively.

The social planner chooses the number of firms that maximizes social welfare in (24), yielding¹¹

$$\frac{\partial W^{fb}}{\partial n} = \frac{\tau}{2(n^{fb})^2} + r \left(g' \frac{1}{n^{fb}} - g \right) - f = 0, \quad (25)$$

where $n^{fb}(\tau, r, f)$ is the first-best number of firms in the market. The first term of (25) is the social marginal benefit of a new firm due to the reduction in transport costs, the second term measures the net welfare effect of technology (i.e., returns to scale) on production costs, whereas the last term is the cost of setting up one additional firm.

With a CRS technology, the marginal capital costs are equal to the average capital costs, and the socially optimal number of firms depends only on the reduction in trans-

¹¹The second-order condition requires

$$\frac{\partial^2 W}{\partial n^2} = -\frac{1}{n^3} (\tau + rg'') < 0,$$

which is always fulfilled if $g'' \geq 0$. However, if $g'' < 0$, we need to assume that $\tau > -rg''$.

portation costs relative to the increase in fixed costs. In this case, the first-best number of firms is given by $n_{CRS}^{fb} = \sqrt{\tau/2f}$. Moreover, if technology is IRS ($g' < ng$), it follows from (25) that the first-best number of firms is lower than with a CRS technology, whereas if technology is DRS ($g' > ng$), the first-best number of firms is higher than with CRS technology. Thus, we have the following ranking

$$n_{IRS}^{fb} < n_{CRS}^{fb} < n_{DRS}^{fb}.$$

This ranking is also intuitive because with IRS technology, each firm should produce more output in order to exploit the scale properties so that overall production costs fall, all else equal. However, with DRS technology, it is optimal with more firms that each produces a lower volume.

5.2 Socially optimal corporate tax

In a second-best world, the number of firms is determined by the market equilibrium defined by the zero-profit condition in (15). In this case, second-best welfare is simply the sum of consumers' surplus and corporate tax income. Imposing symmetry, the second-best social welfare simplifies to the following

$$W^{sb} = m + v - \frac{\tau}{2n^*} - p^* + t(p^* - \alpha r g n^*), \quad (26)$$

where p^* and n^* are given by (7) and (15), respectively. The first four terms define the net consumers' surplus, whereas the last term is the corporate tax income net of the tax deductions for capital costs.

The socially optimal corporate tax is given by the following first-order condition

$$\frac{\partial W^{sb}}{\partial t} = p^* - \alpha n^* r g - (1-t) \frac{\partial p^*}{\partial t} + \left[\frac{\tau}{2(n^*)^2} + \alpha t r \left(g' \frac{1}{n^*} - g \right) \right] \frac{\partial n^*}{\partial t}. \quad (27)$$

The two first terms define the direct welfare effect of corporate taxation keeping prices and the number of firms fixed. The third term defines the negative welfare effect of higher prices, whereas the last set of terms defines the indirect welfare effects on transport and capital costs due to changes in market entry. As shown in Proposition 3, a higher corporate tax reduces the number of firms ($\partial n^*/\partial t < 0$), and has therefore an adverse effect on consumers' surplus, whereas the impact on capital costs depend on the production technology and level of tax deductions.

Using the equilibrium price and market entry in (7) and (15), respectively, and the comparative statics results in (18) and (16), the first-order condition in (27) simplifies to

$$\frac{\partial W^{sb}}{\partial t} = \frac{[\tau + n^* r \alpha (g' - g n^*)] [\tau (1 - 2t) - 2n^* r t \alpha (g' - g n^*)]}{2n^* [2\tau (1 - t) + r (1 - \alpha t) g'']} = 0,$$

which yields the following socially optimal corporate tax

$$t^* = \frac{1}{2} \left(\frac{\tau}{\tau + \alpha r n^* (g' - n^* g)} \right) > 0. \quad (28)$$

From this expression, we obtain the following results:

Proposition 5 *In a Salop model with free entry,*

- (i) *there exists a strictly positive (and unique) corporate tax rate t^* defined by (28) that implements first-best entry ($n^* = n^{fb}$).*
- (ii) *If $t < (>) t^*$, then the market equilibrium implies excessive (suboptimal) entry.*
- (iii) *If tax deductions are not allowed (CBIT) and/or technology involves CRS, the first-best corporate tax rate is exactly $1/2$;*
- (iv) *If tax deductions are allowed (ACE) and technology involves IRS (DRS), the first-best corporate tax rate is higher (lower) than $1/2$.*

In contrast to the optimal tax literature to date, Proposition 5 shows that a small open economy under imperfect competition should levy a positive corporate (source) tax on capital. In our setting, such a positive tax implies that the tax also falls on the normal return on mobile capital. The benchmark result in the optimal tax literature is that a small open economy should not apply a source-based tax on the normal rate of return on mobile capital (see Gordon, 1986). Since capital is perfectly elastic, such a source-based tax is fully shifted onto immobile factors of production via an outflow of capital which drives up the pre-tax return to capital. This result is recognized as an open-economy version of Diamond and Mirrlees' (1971) production efficiency theorem, but is derived under the assumption of perfect competition. Under imperfect competition the welfare maximization problem must balance the gains and costs of tougher competition.

In our model a zero corporate tax would result in excessive entry. This result, which is often referred to as the "excess entry theorem", is standard in spatial competition models (e.g., Vickery, 1964, Salop, 1979).¹² The social planner balances, as described above, the marginal benefit to consumers (reduction in transport costs) relative the marginal costs (fixed entry cost and change in capital costs due to scale properties). The firms, on the other hand, consider the profitability of entry. However, they do not internalize the negative impact of entry on rival firms' profit through increased price competition. Since total demand is inelastic, competition is purely business-stealing, which is the main

¹²Matsumura and Okamura (2006) show that this theorem holds for a large set of transportation costs and production technologies. However, Gu and Wenzel (2009) relax the assumption of inelastic demand and show that there is insufficient entry if demand is sufficiently elastic.

reason for excessive entry (see e.g., Gu and Wenzel, 2009). From a social point of view, the marginal costs of entry exceeds the marginal benefit to consumers.

We show that in markets with corporate taxation, firm entry can be excessive or suboptimal depending on the level of the corporate tax. Since the corporate tax directly reduces firms' profits, the incentive to enter the market is reduced. Thus, corporate taxation mitigates the market failure due to excessive entry, and transforms the wasteful use of resources spent on market entry into tax revenues, which can be returned to households via lump-sum transfers or by financing a public good.¹³

Proposition 5 makes it clear that the tax authorities can always implement the first-best by selecting the appropriate corporate tax rate. The socially optimal tax rate is exactly 1/2 if the technology involves CRS. In this case, tax deductions for capital costs do not influence the market equilibrium (market entry). Thus, if there is a need to raise tax income, a CBIT scheme, which disallows for tax deductions is preferable. However, if technology is IRS or DRS, then the choice of ACE or CBIT will influence the market outcome and therefore also the optimal corporate tax rate. More precisely, if technology involves IRS, then the first-best number of firms is lower than with CRS, therefore the optimal corporate tax rate is higher. The reverse is true when technology involves DRS.

Note that positive corporate taxation is optimal for any kind of tax system, i.e., for any level of α . In a Salop world, welfare is fully determined by the competition intensity, i.e., by the number of firms in the market. The government has two instruments, the tax rate t and capital-cost deductions α in order to enforce the optimal number of firms in the market. Because price effects are welfare-neutral redistributive effects between consumers and producers in such an imperfect-competition model, the choice of the tax system (i.e., of α) does not provide any additional benefits and we are left with two instruments for adjusting one margin. The choice of α then is redundant as soon as the optimal corporate tax rate is adjusted according to equation (28). Under constant returns to scale, it is also important to note that corporate taxation is the only instrument available as cost deductions do not affect market entry anymore.

5.3 Socially optimal tax deduction scheme

Usually the corporate tax rate is not set in order to induce the first-best number of firms across product markets. In this section, we therefore study the welfare effects of tax deduction schemes assuming any given corporate tax $t \in (0, 1)$. Maximizing the second-best social welfare function in (26) with respect to the level of tax deduction for capital costs yields the following first-order condition

¹³Note that equilibrium profits are zero due to free market entry. Therefore, our results are not driven by the fact that economic rents should be taxed away in an optimal tax setting.

$$\frac{\partial W^{sb}}{\partial \alpha} = -tn^*rg - \frac{\partial p^*}{\partial \alpha} (1-t) + \left[\frac{\tau}{2(n^*)^2} - \frac{\partial p^*}{\partial n} (1-t) + \alpha tr \left(g' \frac{1}{n} - g \right) \right] \frac{\partial n^*}{\partial \alpha}. \quad (29)$$

The impact of tax deductions on social welfare consists of a direct effect (first two terms) and an indirect effect through the change in entry (last set of terms). For a given number of firms, allowing for tax deductions reduces the corporate tax income both directly (tn^*rg) and through the price reduction ($t^* \cdot \partial p^*/\partial \alpha$). However, the price reduction benefits consumers, implying that the net direct welfare effects of tax deductions are a priori ambiguous.

The indirect welfare effects crucially relies on the impact of tax deductions on market entry. We showed in Proposition 3 that a higher level of deductions increases (reduces) the number of firms in the market when technology is IRS (DRS), but has no effect when technology is CRS. Thus, with a CRS technology, the last term in (29) disappears and we are left with only the direct effect. However, with an IRS technology, ACE will trigger more market entry. In this case, tax deductions have a positive impact on consumers' surplus due to lower transport costs and lower prices, but a negative impact on tax income through lower prices and higher average capital costs due to lower production at each firm. The opposite is true for DRS technology or CBIT tax scheme.

Imputing the equilibrium values in (7) and (15) and the comparative statics in (19) and (17), the first-order condition simplifies to

$$\frac{\partial W^{sb}}{\partial \alpha} = \frac{rt(g' - gn^*) \left[\frac{\tau}{2}(1-2t) - \alpha tn^*r(g' - gn^*) \right]}{2\tau(1-t) + rg''(1-t\alpha)} = 0, \quad (30)$$

which yields the following optimal tax deduction level for capital costs

$$\alpha^* = \frac{\tau(1-2t)}{2n^*rt(g' - gn)}. \quad (31)$$

Based on these expressions, we get the following results:

Proposition 6 *In a Salop model with free entry, then*

- (i) *with CRS technology the choice of tax scheme has no effect on welfare;*
 - (ii) *with IRS technology CBIT is socially optimal if $t \leq 1/2$, ACE is socially optimal if $t > \tilde{t}$, and an intermediate scheme is socially optimal if $t \in (1/2, \tilde{t})$;*
 - (iii) *with DRS technology CBIT is socially optimal if $t \geq 1/2$, ACE is socially optimal if $t < \tilde{t}$, and an intermediate scheme is socially optimal if $t \in (\tilde{t}, 1/2)$;*
- where $\tilde{t} := \tau/2(\tau + n^*r(g' - gn))$ yields $\alpha^* = 1$.

The proposition shows that the choice of tax scheme crucially relies on the production technology and the competitive effects of ACE and CBIT. In case of a CRS technology,

tax deductions have no impact on market entry (cf. Proposition 3) and the choice of tax scheme is welfare neutral. However, if technology is IRS, then CBIT is welfare improving if corporate tax is sufficiently low. In this case, the number of firms in the market is too high, and allowing for tax deductions (ACE) would trigger even more entry. Thus, with IRS technology, ACE is only welfare improving for high corporate tax levels where market entry is suboptimal. The opposite is true when technology is DRS.

5.4 Tax income neutrality

In this section we analyze the welfare properties of ACE and CBIT in the case of tax income neutrality. Imposing symmetry the corporate tax income in (23) simplifies to¹⁴

$$T^* = t(p^* - \alpha rgn^*), \quad (32)$$

where the equilibrium price p^* and number of firms n^* are given by (7) and (15), respectively. From this we can make two observations. First, for a given number of firms, allowing for tax deductions generates lower tax income partly through the deduction itself and partly through lower prices and before-tax profits, implying a higher corporate tax under ACE than CBIT. Second, for a given tax scheme, more firms in the market reduces the tax income. Fiercer competition reduces prices and before-tax profits, which in turn leads to lower tax income, all else equal. Thus, when CBIT triggers less entry than ACE, the competition effect reinforces the direct effect, and it is clear that ACE requires a higher corporate tax under tax income neutrality. However, when CBIT triggers more entry than ACE then the competition effect counteracts the direct effect, and it is a priori unclear which regime that requires a higher corporate tax under tax income neutrality. Below we investigate this further both by considering the effect of a change in the corporate tax and the level of tax deductions on the equilibrium corporate tax income.

Differentiating (32) with respect to the corporate tax rate yields

$$\frac{\partial T^*}{\partial t} = p^* - \alpha rgn^* + t \left(\frac{\partial p^*}{\partial t} + \alpha r \left(g' \frac{1}{n} - g \right) \frac{\partial n^*}{\partial t} \right) > 0, \quad (33)$$

where the first two terms are the direct, positive effect of an increase in the corporate tax, whereas the second set of terms are the indirect, competitive effect on prices and capital costs due to changes in market entry. We know from Proposition 3 and 4 that a higher corporate tax reduces market entry ($\partial n^*/\partial t < 0$) but increases equilibrium prices ($\partial p^*/\partial t > 0$). From (33) it is then evident that corporate tax income is always increasing

¹⁴Notice that equilibrium tax income is always strictly positive as long as firms' equilibrium (before-tax) profits are positive, which is ensured by the equilibrium condition τ_2 , as reported in Lemma 1.

in the corporate tax rate when technology is CRS or IRS. However, if technology is DRS, then fewer firms in the market means higher capital costs, which in turn increases the tax deductions. Notice that this effect vanishes if tax deductions are not allowed as in the case of CBIT. This effect is a second-order effect, and we can show that it never offsets the positive effect of an increase in the corporate tax on total corporate tax income.¹⁵

What is the effect of tax deductions on tax income? Differentiating (32) with respect to α we get

$$\frac{\partial T^*}{\partial \alpha} = -trgn^* + t \left(\frac{\partial p^*}{\partial \alpha} + \alpha r \left(g' \frac{1}{n} - g \right) \frac{\partial n^*}{\partial \alpha} \right) < 0. \quad (34)$$

The first term reflects the direct, negative effect of allowing for deductions for capital costs. The second set of terms are the indirect effects on prices and capital costs due to changes in market entry. We know from Proposition 4 that more tax deductions induces lower equilibrium prices ($\partial p^*/\partial \alpha < 0$). This effect reinforces the negative, direct effect. The effect on market entry depends on technology. From Proposition 3 we know that if technology is CRS, then tax deductions have no impact on market entry ($\partial n^*/\partial t = 0$). In this case ACE will always generate lower tax income than CBIT. If technology is IRS ($g' < ng$), then tax deductions triggers market entry ($\partial n^*/\partial \alpha > 0$), whereas the opposite ($\partial n^*/\partial \alpha < 0$) is true when technology is DRS ($g' > ng$). This implies that the last term in (34) is negative, which means that the competition effect always reinforces the direct, negative effect of tax deductions on total corporate tax income. Based on (33) and (34) we can make the following conclusion:

Lemma 3 *In a Salop model with free entry, tax deductions for capital costs leads to lower corporate tax income, and implies a higher corporate tax under ACE than CBIT when tax income neutrality is required.*

We now proceed with analyzing the welfare properties of ACE and CBIT under tax income neutrality. This analysis is quite demanding since it involves comparing welfare levels conditional on tax income being identical in the two schemes. Using (26), welfare under CBIT ($\alpha = 0$) and ACE ($\alpha = 1$) are given by

$$W_c^{sb} = m + v - \frac{\tau}{2n_c^*} - p_c^*(1 - t_c),$$

and

$$W_a^{sb} = m + v - \frac{\tau}{2n_a^*} - p_a^*(1 - t_a) - t_a r g_a n_a^*,$$

where subscript a and c denote ACE and CBIT, respectively. Based on this we can write

¹⁵See proof of Lemma 2 in the Appendix.

the welfare difference as follows

$$\Delta W := W_c^{sb} - W_a^{sb} = \frac{\tau}{2} \left(\frac{1}{n_a^*} - \frac{1}{n_c^*} \right) + p_a^* (1 - t_a) - p_c^* (1 - t_c) + t_a r g_a n_a^*,$$

where $\Delta W > (<) 0$ implies that CBIT (ACE) is socially desirable. We see that CBIT is welfare improving unless ACE involves stronger competitive effects (more entry and lower prices) simply because CBIT generates higher tax income by disallowing tax deductions for capital costs. From Proposition 3 we know that ACE (CBIT) induces more entry than CBIT (ACE) when technology is IRS (DRS), whereas with CRS technology entry is unaffected by tax deductions. Moreover, from Proposition 4 we know that ACE leads to lower prices than CBIT. These results are derived assuming a constant corporate tax rate. However, assuming tax income neutrality, the pro-competitive effects of ACE may be offset by the higher corporate tax rate ($t_a > t_c$). Thus, the scope for CBIT to be welfare improving increases under tax income neutrality due to the adverse effects of corporate taxation on entry and pricing.

To illustrate the welfare properties of ACE and CBIT under tax income neutrality, we construct numerical examples assuming the (inverse) production function relating capital and output is given by $k = g(y) = y^\theta$. Below we report two tables where we vary the tax rate under CBIT from a low tax level ($t_c = 0.1$) to a high tax level ($t_c = 0.5$), and compute the corresponding tax rate under ACE that generates the same tax income level as with CBIT.

Table 1. Numerical results under tax income neutrality with low tax rate.

	CRS ($\theta = 1$)		DRS ($\theta = 2$)		IRS ($\theta = 0.5$)	
	CBIT	ACE	CBIT	ACE	CBIT	ACE
Tax rate	0.100	0.159	0.100	0.106	0.100	0.265
Entry	13	12	13	13	8	7
Price	0.265	0.267	0.171	0.169	0.407	0.418
Tax income	0.027	0.027	0.017	0.017	0.041	0.041
Welfare	3.685	3.677	3.769	3.771	3.509	3.480

Parameter values: $\tau = 2; r = 0.1; m = v = 2; f = 0.01$.

Table 2. Numerical results under tax income neutrality with high tax rate.

	CRS ($\theta = 1$)		DRS ($\theta = 2$)		IRS ($\theta = 0.5$)	
	CBIT	ACE	CBIT	ACE	CBIT	ACE
Tax rate	0.500	0.700	0.500	0.514	0.500	0.780
Entry	10	7	10	9	5	4
Price	0.400	0.386	0.240	0.244	0.624	0.600
Tax income	0.200	0.200	0.120	0.120	0.312	0.312
Welfare	3.700	3.671	3.780	3.764	3.488	3.462

Parameter values: $\tau = 2$; $r = 0.1$; $m = v = 2$; $f = 0.01$.

For the low tax rate case in Table 1 we see that CBIT yields higher welfare than ACE in case of CRS and IRS technology, whereas ACE yields higher welfare in case of DRS. This is somewhat surprising since the pro-competitive effects of ACE is stronger under IRS (cf. Proposition 3). However, the reason is that tax income neutrality requires a large increase in the corporate tax rate under ACE when technology is IRS, and this has adverse effects on entry and prices. Actually, it is only in the DRS case that prices are lower and entry at the same level under ACE. In this case, tax income neutrality only requires a small increase in the corporate tax under ACE. In the case of CRS and IRS entry is higher, prices are lower and welfare is higher with CBIT.

For the high tax rate case in Table 2, ACE is never welfare improving. The reason is partly that first-best is achieved under CBIT with a corporate tax rate equal to one half and partly that tax income neutrality forces the corporate tax rate under ACE above $1/2$, which is likely to induce suboptimal entry. We observe that entry is always higher with CBIT, while prices are lower with ACE in case of CRS and IRS technology. These numerical examples illustrate that the welfare ranking of ACE and CBIT is generally ambiguous, but that tax income neutrality is likely to make CBIT more preferable to ACE due to the adverse effects of corporate taxation on entry and prices.

6 Policy implications

Contrasting the conditions in Proposition 6 with empirical evidence, the first thing to note is that the real-world corporate tax rate is rather too low. Tax rates are usually not set in order to internalize excessive market entry and there is a strong pressure on decreasing corporate tax rates due to international tax competition. For example, in the EU-27 countries, statutory corporate tax rates decreased from 35% to 23% on average, see Haufler and Mardan (2013) pointing to Eurostat (2011), Tables II-4.1 and II-4.2. For

OECD countries in general, Devereux et al. (2008) find empirical evidence for strategic tax competition reducing corporate tax rates. Hence, the case of suboptimally low taxation appears to be the more relevant case in Proposition 6. Second, while DRS or CRS should be relevant for (purely) domestic firms, multinational companies are a salient feature of all developed economies, nowadays. But, both in the theoretical analysis of multinationals (e.g., Helpman, 1984; Ethier, 1986) and in empirical evidence on multinationals' production and trade activities (e.g., Carr et al., 2001; Antweiler and Trefler, 2002), it is well established that multinationals produce under IRS. Antweiler and Trefler, for example, estimate that one third of all goods-producing industries are characterized by IRS. Putting both aspects together, it appears very likely that imperfectly competitive markets in the real world are populated by too many (multinational) firms.¹⁶

Based on these facts, the policy recommendation would be to introduce a CBIT system if the economy is characterized by imperfect-competition markets that are mainly dominated by multinationals (producing under IRS). The reason is that under IRS, any tax deduction on capital costs will increase firms' profits by the direct effect, whereas the strategic effect via price competition does not matter much. Consequently, any positive α would increase the number of firms further, see Proposition 3. Formally, the policy recommendation follows from assuming $t < 1/2$ and IRS in the first-order condition (30), since then

$$\frac{\partial W^{sb}}{\partial \alpha} < 0 \quad \forall \alpha > 0, \quad (35)$$

and CBIT ($\alpha = 0$) is the optimal corner solution.

7 Concluding remarks

In the real world, a limited number of firms compete for customers; yet tax policy is often founded on assumptions where competition is perfect and firms are price takers. This paper sheds light into how tax policy is affected by imperfect competition. In such a setting, consumer surplus is positively affected by more intense competition, whereas firms profits and tax revenue may fall if competition is too intense. Then, the corporate tax plays a role in balancing gains to consumers against the increased costs of competition. In short, a positive corporate tax serves to reduce excessive market entry and to avoid wasteful use of resources.

This paper has also investigated the two most favored candidates for a corporate tax reform, the Corporate Business Income Tax (CBIT) and the Allowance for Corporate Equity tax (ACE). Under perfect competition, the ACE is perceived as a neutral 'lump-sum' tax. In an imperfectly competitive market with free entry, however, we show that

¹⁶Remember from equation (28) and Proposition 5 that the optimal tax rate in a Salop economy under IRS should be $t^* \geq 1/2$.

the neutrality of the ACE tax no longer is true. As a matter of fact, both ACE and CBIT distort the market equilibrium. Which tax system is better from a welfare point of view, CBIT or ACE, depends on assumptions about production technology, entry and the level of the corporate tax rate.

CBIT may actually be the preferred choice in an economy characterized by imperfect-competition markets that are dominated by multinationals (producing under increasing returns to scale). Based on empirical evidence, this case seems to be the most policy-relevant one. Of course, CBIT will distort investment decisions in markets under perfect competition so that a trade-off between avoiding waste of resources in imperfect-competitive markets and distorting investment in perfectly competitive markets evolves. Analyzing this trade-off is, though important, left for further research here.

8 Appendix: Proofs of Propositions

Proof of Lemma 1: The second-order condition

$$\frac{\partial^2 \pi_i}{\partial p_i^2} = -\frac{1}{\tau} \left[2(1-t) + r(1-\alpha t) g'' \frac{1}{\tau} \right] < 0$$

is always fulfilled if $g'' \geq 0$. However, if $g'' < 0$, then we need $2(1-t) + r(1-\alpha t) g'' \frac{1}{\tau} > 0$, which is always true if $\tau > \tau_1$ defined in (9). In addition, for the price equilibrium in (7) to exist, we need to ensure that the equilibrium profits in (8) is non-negative for any $n \geq 2$. Since equilibrium profits are monotonically increasing in τ , i.e., $\partial \pi^* / \partial \tau = (1-t) / n^2 > 0$, we can set $\pi^* = 0$ and solve for τ , which yields the lower bound τ_2 defined in (10). Thus, for any $\tau > \tau_2$, equilibrium profits is strictly positive. QED.

Proof of Proposition 2: (i) From (13), we see that $\partial \pi^* / \partial t < 0$ is always true if $\alpha = 0$ or $g' \geq ng$. On the other hand, if $\alpha > 0$ and $g' < ng$, then $\partial \pi^* / \partial t < 0$ is true if and only if $\tau > n^2 \alpha r \left(g - g' \frac{1}{n} \right)$. Comparing this with the non-negative profit condition in (10), it is easily verified that

$$\tau_2 := \frac{n^2}{1-t} \left(\alpha r \left(g - g' \frac{1}{n} \right) + f \right) > n^2 \alpha r \left(g - g' \frac{1}{n} \right) \text{ for all valid parameter values.}$$

Thus, it follows that $\partial \pi^* / \partial t < 0$ is always true. (ii) From (14), it follows that

$$\frac{\partial \pi_i^*}{\partial \alpha} \begin{cases} > 0 & \text{if } g' < ng \\ = 0 & \text{if } g' = ng \\ < 0 & \text{if } g' > ng \end{cases} .$$

QED.

Proof of Proposition 3: (i) The second-order condition in (9) ensures that the denominator of (16) is strictly positive, and the non-negative profit constraint (10) ensures that the numerator of (16) is strictly positive. Thus, $\partial n^*/\partial t < 0$ is always true. (ii) The second-order condition in (9) ensures that the denominator of (17) is strictly positive. Thus, the sign of (17) is determined by the sign of the numerator, which implies that

$$\frac{\partial n^*}{\partial \alpha} \begin{cases} > 0 & \text{if } g' < n^*g \\ = 0 & \text{if } g' = n^*g \\ < 0 & \text{if } g' > n^*g \end{cases} .$$

QED.

Proof of Proposition 4. (i) Using the second-order condition in (9) and that $\partial n^*/\partial t < 0$ from Proposition 3, it follows from (18) that $\partial p^*/\partial t > 0$ is always true. (ii) If $\partial n^*/\partial \alpha \geq 0$, which is the case when $g' \geq n^*g$ (cf. Proposition 3), it follows from (19) that $\partial p^*/\partial \alpha < 0$ is always true by the second-order condition in (9). However, if $\partial n^*/\partial \alpha < 0$, which is the case if $g' > n^*g$ (cf. Proposition 3), then $\partial p^*/\partial \alpha$ is potentially ambiguous. Inserting (17) into (19), and simplifying the expression, we get

$$\frac{\partial p^*}{\partial \alpha} = -rt \frac{\tau(1-t)(g' + ng) + gnrg''(1-t\alpha)}{(1-t)(2\tau(1-t) + rg''(1-t\alpha))} .$$

It is straightforward to show that both the numerator and denominator are strictly positive using the equilibrium conditions in Lemma 1. Thus $\partial p^*/\partial \alpha < 0$ is always true irrespective of technology. QED.

Proof of Proposition 5. (i) Observe from (28) that $t^* > 0$ is always true if $g' \geq ng$. However, if $g' < ng$, then $t^* > 0$ holds if only if $\tau > .$ However, using the non-negative profit condition in (10), it is easily verified that $\tau_2 > nr\alpha(ng - g')$, which ensures that $t^* > 0$ is true for all valid parameter values. Inserting (28) the zero-profit condition (15), we get

$$\frac{\tau}{2(n^*)^2} + r \left(g' \frac{1}{n^*} - g \right) - f = 0,$$

which exactly coincide with the condition for the first-best number of firms in (25).

(ii) Since $\partial n^*/\partial t < 0$ from (16), it follows that $n^* < (>) n^{fb}$ when $t > (<) t^*$.

(iii) It follows from (28) that $t^* = 1/2$ if technology is CRS ($g' = ng$) and/or a CBIT scheme ($\alpha = 0$) is in place.

(iv) It follows from (28) that $t^* > 1/2$ with tax deductions ($\alpha > 0$) and IRS technology ($g' > ng$), whereas the opposite is true with a DRS technology ($g' < ng$).

Proof of Proposition 6. (i) With a CRS technology ($g' = ng$), then (29) holds for any $\alpha \in [0, 1]$.

(ii) With a IRS technology ($g' < ng$), from (31) we get

$$\alpha^* = \begin{cases} 0 & \text{if } t \leq \frac{1}{2} \\ (0, 1) & \text{if } t \in (\frac{1}{2}, \tilde{t}) \\ 1 & \text{if } t \geq \tilde{t} \end{cases}, \quad \text{where } \tilde{t} > \frac{1}{2}.$$

(iii) With a DRS technology ($g' > ng$), then from (31) we get

$$\alpha^* = \begin{cases} 1 & \text{if } t \leq \tilde{t} \\ (0, 1) & \text{if } t \in (\tilde{t}, \frac{1}{2}) \\ 0 & \text{if } t > \frac{1}{2} \end{cases}, \quad \text{where } \tilde{t} < \frac{1}{2}.$$

Proof of Lemma 2:

(i) Inserting the equilibrium price in (7) into (23) we get

$$T = t \left(\frac{\tau}{n} + r \left(g' \frac{1 - \alpha t}{1 - t} - \alpha g n \right) \right)$$

Differentiating () with respect to t yields and collecting terms, we get We have that $\partial n^*/\partial t < 0$ from Proposition 3 and $\partial p^*/\partial t > 0$ from Proposition 4. This implies $\partial T^*/\partial t > 0$ given by (33) is always true when technology is CRS ($g' = ng$) or IRS ($g' < ng$). However, if technology is DRS ($g' > ng$), then

$$\frac{\partial T^*}{\partial t} = \frac{\tau}{n} + r g' \frac{1 - 2\alpha t + \alpha t^2}{(1 - t)^2} - t \left(\frac{\tau}{n^2} + r g'' \frac{1 - \alpha t}{1 - t} \frac{1}{n^2} - \alpha r \left(g' \frac{1}{n} - g \right) \right) \frac{\partial n^*}{\partial t} > 0.$$

(ii) We have that $\partial p^*/\partial \alpha < 0$ from Proposition 4 and that

$$\frac{\partial n^*}{\partial \alpha} \begin{cases} > 0 & \text{if } g' < n^* g \\ = 0 & \text{if } g' = n^* g \\ < 0 & \text{if } g' > n^* g \end{cases},$$

from Proposition 3. From this it follows that

$$\frac{\partial T^*}{\partial \alpha} = -t r g n^* + t \left(\frac{\partial p^*}{\partial \alpha} + \alpha r \left(g' \frac{1}{n} - g \right) \frac{\partial n^*}{\partial \alpha} \right) < 0$$

must be true. QED.

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