Royalty Taxation under Tax Competition and Profit Shifting

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Abstract. Multinational corporations increasingly use royalty payments for intellectual property rights to shift profits globally. This not only threatens the tax base of countries worldwide but also affects the nature of tax competition. Against this background, our theoretical analysis suggests a surprising solution to the problem of curbing profit shifting without suffering major outflows of capital: A strictly positive withholding tax on royalty payments is both the Pareto-efficient solution under international coordination *and* the optimal unilateral response. If internal debt is sufficiently responsive, governments can even implement optimal targeting. Then, the royalty tax closes the profit-shifting channel, while all competition for mobile capital is relegated to internal-debt regulation. Our results question the ban on royalty taxes in double tax treaties and the EU Interest and Royalty Directive.

Résumé. If you do not provide a French abstract, the English abstract will be translated into French and inserted here.

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1. Introduction

At present, current economic is characterized by complex multinational business models with substantial intrafirm trade flows.[1] Moreover, there is a growing digital economy that is heavily knowledge based and requires relatively few physical activities. The importance of the underlying innovation activities and intellectual properties is mirrored in the enormous growth of global royalty payments (see Table 1 and recent studies, e.g., Arkolakis et al., 2018). Both trends together affect the nature of tax competition. Governments provide tax incentives to attract capital to benefit from not only positive labor market effects (Hijzen et al., 2013) but also technological spillovers (Haskel et al., 2007; Keller and Yeaple, 2009).

However, on the darker side of the rise of multinationals and the spread of intellectual property rights, international tax avoidance became a major challenge for nearly all countries worldwide, with the exception of tax havens. The Organisation for Economic Co-operation and Development (OECD) states in its "Base Erosion and Profit Shifting" (BEPS) report that "at stake is the integrity of the corporate income tax" (OECD, 2013, p. 8), and strategic (mis-)pricing of intellectual property amplifies the issue. The emergence of patent boxes within the European Union (EU) in recent years and the effective patent box in the U.S. since its 2018 tax reform ("Tax Cut and Jobs Act") further fuel the challenge because they provide preferential tax treatment for royalty income derived from intellectual property (e.g., patents and trade marks).[2]

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1 One-third of global exports (Antrás, 2003; UNCTAD, 2016) and 40% of U.S. trade flows (Egger and Seidel, 2013) happen within multinationals.

2 Empirical evidence documents that taxes indeed have a significant effect on where multinational firms locate the ownership of their intellectual property (e.g., Karkinsky and Riedel, 2012; Griffith et al., 2014).

TABLE 1
World multinational production, exports and royalties

	1990	2005-2007	2010	2019
GDP				
current US dollars; billion	22 617	52 291	66 049	85 931
FDI outward stock				
current US dollars; billion	2 255	15 196	21 130	31 508
index in % (1990=100)	100	674	937	1 397
percent of GDP	10.0	29.1	32.0	36.7
Exports				
current US dollars; billion	4 308	15 055	19 044	25 132
index in % (1990=100)	100	349	442	583
percent of GDP	19.0	28.8	28.8	29.2
Royalties and license fee receipts				
current US dollars; billion	31	172	215	397
index in % (1990=100)	100	555	694	1 281

Sources: Sales of foreign affiliates; royalties and license fee receipts: UNCTAD (2013, 2020); GDP and Exports: World Bank Open Data

The enlarged possibilities to shift profits not only pose a direct threat for the corporate tax base of countries but also have implications for tax competition. Governments are constrained in their instruments to provide targeted tax incentives to mobile capital. Reducing the statutory tax rate is expensive because it also benefits domestic (immobile) investors. Directly differentiated corporate tax rates would be ideal but are denied by most tax codes and multilateral agreements. Therefore, a common way to implement lower *effective* corporate tax rates on mobile capital is to allow multinationals to shift part of their profits, either by transfer pricing, i.e., mispricing their intrafirm trade in tangible or intangible goods (Kant, 1988), or by debt shifting, i.e., replacing nondeductible equity with tax-deductible internal debt from related affiliates (Collins and Shackelford, 1997; Mintz and Smart, 2004). Although unilaterally optimal, such a strategy still results in an equilibrium with a standard tax-competition prisoners' dilemma, i.e., hardly any effect on investment but globally inefficiently low tax rates and excessive profit shifting.[3] Enlarged possibilities to shift profits with royalties foster the latter outcome.

Against this background, our aim is to answer the following question: How can a country unilaterally defend its tax base against the new profit shifting challenges, but still maintain its position in the race for mobile capital? Relying on a tax competition model, we find a surprising answer

3 Throughout the paper, investment refers to capital investment.

that has far-reaching policy implications. Despite the negative perception of withholding taxes and the fact that they usually are competed away in equilibrium (Bucovetsky and Wilson, 1991), we find that a strictly positive withholding tax on (intrafirm) royalty payments is an effective *unilateral* instrument against profit shifting in intellectual property without severely harming capital investment. Combining strictly positive withholding taxes with more lenient thin capitalization rules allows for a better targeting of investment incentives, whereas the unproductive component of excessive profit shifting can be curbed. Our findings provide support to recent policy actions in the Netherlands and Norway, where royalty taxes became effective in 2021.

To derive our results, we set up a model where two large countries with domestic and multinational firms compete for capital investment. All firms can respond to tax policies by adjusting their level of external debt, and multinational firms can additionally use internal debt to further reduce their after-tax capital costs. In addition, we incorporate intellectual property through a capital-enhancing technology that renders multinational firms more productive. The existence of the intellectual property enables multinational firms to overcharge on transfer prices for (intrafirm) royalties and shift profits, in addition to arm's-length payments, to a tax haven. For the government, the simultaneously available policy instruments are statutory tax rates, thin capitalization rules and withholding taxes on royalty payments. While thin capitalization rules are used to limit the tax deductibility of internal debt, withholding taxes on royalties target profit shifting through abusive transfer prices for royalties.

We find that whenever internal debt financing is sufficiently responsive, the optimal royalty tax equals at least the corporate tax rate and exceeds it whenever countries want to tax 'quasi-economic rents' related to royalty payments. Then, the optimal policy package grants investment incentives by allowing for more deductibility of internal interest expenses (i.e., by relaxing thin capitalization rules). Intuitively, the main driving force behind our finding is the interaction of the withholding tax and the thin capitalization rule. Because firms balance marginal tax savings against marginal concealment costs, the decision on abusive profit shifting with royalties does not affect the intensive investment margin (for a given quality of technology). Hence, the royalty payment decision is fully independent of the investment level and has no behavioral effect on effective capital costs. Therefore, when setting withholding taxes on royalties, countries do not need to trade off reduced profit shifting against reduced capital investment, beyond the mechanical effect via the standardized arm's-length payment.[4] If internal debt is sufficiently

4 In our main analysis, we treat R&D investment and the quality of the intangible good as exogenous. We discuss the relevance of this assumption and potential effects on capital investment and optimal royalty taxes in Section 5.2.

responsive, a lax(er) thin capitalization rule can fully compensate for the negative mechanical effect on capital investment.

We also show that there can be a tradeoff between capital investment and profit shifting with a medium-range royalty tax if agency costs related to internal debt are high and quasi-economic rents are sufficiently low. Such a solution, however, requires that the motive for tax competition be substantial, relative to the other effects at play. Importantly, even if agency costs of internal debt are high, the royalty tax still has a better ratio of tax revenue relative to distortions created than any other withholding tax or anti-avoidance measure. This explains why the optimal royalty tax always is positive and likely features a medium range as a lower bound.

Our paper contributes to the literature in three ways. First, we challenge both the dominant view that withholding taxes are always poor instruments and the standard result in public finance that optimal withholding taxes equal zero under tax competition because countries face a race to the bottom (e.g., Bucovetsky, 1991; Bucovetsky and Wilson, 1991). We note that both arguments do not apply to the case of royalty payments, even if the costs of internal debt are prohibitively high. If the costs of internal debt are sufficiently low, all competition for capital investment is relegated to thin capitalization rules that are relaxed to neutralize adverse investment effects. Hence, profit shifting can be eliminated without harming investment and efficiency.

Second, we provide new insights on thin capitalization rules. Haufler and Runkel (2012) find that it is optimal to grant some deductibility for internal debt in multinationals to lower their effective capital costs.[5] Our findings generalize this result to a setting that also features shifting of paper profits, intellectual property, differences in the productivity of domestic and multinational firms, and an extended tool set for the government. Notably, thin capitalization rules become an even more important instrument to compete for capital investment and represent a crucial complement to curb excessive profit shifting in intangibles. By weakening thin capitalization rules, multinationals can be compensated for the overshooting effect of royalty taxes that do not differentiate between arm's-length remuneration for intellectual property and abusive profit shifting.

Third, this paper adds to the scarce literature on royalty taxes. Fuest et al. (2013, Section 5) propose withholding taxes on royalty payments that are creditable in the residence country as one policy option to reduce BEPS. In a brief statement, the authors verbally discuss the scope of such a measure.[6]

5 Hong and Smart (2010) argue that some debt shifting to implement discrimination between domestic and multinational firms is always optimal. Gresik et al. (2015), however, show that adding transfer pricing to such a model questions this view.

6 In 2014, a Norwegian government committee on capital taxation in a small open economy voiced mixed opinions on royalty taxation (NOU, 2014, chapter 7.3). In contrast, Finke et al. (2014) estimate that most countries would benefit from a

For a small open economy without strategic interaction, Juranek et al. (2018) provide a comprehensive positive analysis of the effects of royalty taxation on firms' investment and profit shifting behavior, depending on various different OECD methods to regulate transfer pricing. One main finding is that transfer pricing in intellectual property does not have any effect on the intensive investment margin. In all these papers, however, government policies are exogenous. Our analysis confirms that there is no behavioral ('intensive-margin') effect and the arm's-length component only triggers a mechanical investment effect, and it brings the argument to a rigorous normative level. Royalty taxes are an efficient instrument to curb profit shifting and can be maintained under tax competition, particularly when they are accompanied by (lax) thin capitalization rules.

In addition to contributing to the scientific literature, our theoretical results offer potential explanations for the empirically observed variety in royalty tax rates among the 41 countries that were members of either the EU or the OECD in 2017 (see Table 2). Almost 42% of these countries set their royalty tax rate above or equal to their corporate tax rate or undercut the corporate tax by less than one percentage point. These countries, therefore, are well suited to our main scenario. For another 39% of countries, the royalty tax is positive but significantly undercuts the corporate tax, which our model explains with high agency costs of internal debt and a substantial weight of tax competition, respectively.[7] Only a minority, i.e., 19 %, of countries do not impose a royalty tax and seem to operate a suboptimal policy. Among them are mainly well-known tax havens and conduit countries, such as Cyprus, Luxembourg, the Netherlands, and Switzerland, for which our results likely do not apply because the latter countries follow a different business model in their tax policies.

Finally, we challenge not only the limitations for the use of withholding taxes set by many double tax treaties and multinational agreements but also the complete ban of royalty taxes for multinational corporations within the European Economic Area (EEA) following from the EU Interest and Royalty Directive.[8] This directive was justified by facilitating capital investment within the EU Common Market and has a clear objective of removing obstacles from withholding taxes on interest. However, in a period when the importance of intellectual property is rapidly increasing, the royalty part of the directive

withholding tax on royalty payments, whereas the U.S., which receives the largest royalty income worldwide, would lose a significant share of its revenue.

7 Note that many double tax treaties and multinational agreements limit the scope of the royalty tax rate. The EU Interest and Royalty Directive even completely bans royalty taxes for within-EU transactions by multinational corporations.

8 Our findings also support proposals in the legal literature that argue in favor of withholding taxes on the digital economy; see, e.g., Báez Moreno and Brauner (2015, 2018).

TABLE 2
Corporate tax rates and withholding taxes (WHT) on royalties for EU and OECD countries in 2017.

Country	**CIT**[1]	**WHT on Royalties**[2]	**Country**	**CIT**	**WHT on Royalties**
Australia	30.0	30.0	Korea	24.2	20.0
Austria	25.0	20.0	Latvia	15.0	0.0[6]
Belgium	34.0	30.0	Lithuania	15.0	10.0
Bulgaria	10.0	10.0	Luxembourg	27.1	0.0
Canada	26.7	25.0	Malta	35.0	0.0
Chile	25.0	30.0	Mexico	30.0	30.0
Croatia	18.0	15.0	Netherlands	25.0	0.0
Cyprus	12.5	0.0	New Zealand	28.0	15.0
Czech Republic	19.0	15.0[3]	Norway	24.0	0.0
Denmark	22.0	22.0	Poland	19.0	20.0
Estonia	20.0	10.0	Portugal	29.5	25.0[7]
Finland	20.0	20.0	Romania	16.0	16.0
France	34.4	33.33	Slovak Republic	21.0	19.0[8]
Germany	30.2	15.0	Slovenia	19.0	15.0
Greece	29.0	20.0	Spain	25.0	24.0
Hungary	10.8[4]	0.0	Sweden	22.0	22.0
Iceland	20.0	20.0	Switzerland	21.2	0.0
Ireland	12.5	20.0	Turkey	20.0	20.0
Israel	24.0	24.0	United Kingdom	19.0[9]	20.0[10]
Italy	27.8	30.0[5]	United States	38.9	30.0
Japan	30.0	20.0			

Sources: CIT: Eurostat (2017) and OECD (2017b); WHTs: PWC (2017) and EY (2017)
[1] Statutory corporate income tax rate. Combined tax rate, i.e., central and federal level.
[2] WHT on royalties refer to general rates; special double taxation treaty (DTT) may apply in addition.
[3] 35.0% if payments are to countries with which no enforceable double taxation treaty (DTT) or tax information exchange agreement (TIEA) exists.
[7] The rate increases to 35% when the income is paid or due to entities resident in black-listed jurisdictions.
[8] A 35% rate applies on payments to taxpayers from noncontracting states.
[9] Since 1 April 2017, previously 20.0%.
[10] Some types of royalties are not subject to UK WHT, incl. film royalties and equipment royalties.

denies governments an important instrument to combat profit shifting, while there are other instruments to maintain free capital flows. Finally, as the results demonstrate that there is no need for the optimal royalty tax to differentiate between arm's-length and abusive payments, the problem of measuring the fair payment and implementing a tractable concept of arm's-length pricing (see Action 1 in the OECD Action Plan, OECD, 2015b) vanishes.

The remainder of the paper proceeds as follows. Section 2 develops the model. In Section 3, the Pareto-optimal solution where policy instruments are chosen in coordination is derived as a benchmark. Section 4 analyzes the noncooperative symmetric equilibrium. In Subsection 4.1, we discuss the equilibrium for the scenario that captures the EU Interest and Royalty Directive and the current situation within the EEA, that is, the absence of royalty taxes. In Subsection 4.2, we then derive the equilibrium for the full set of policy instruments. Subsection 4.3 discusses the direct policy implications of our findings. Finally, Section 5 evaluates the external validity of our results by discussing generalizations of simplifying assumptions and relevant extensions. Section 6 concludes the paper.

2. The model

We outline the general setup of the model and the structure of the capital market. Then, we solve for optimal firm behavior and analyze the capital market equilibrium. Finally, we derive the responses of private and public consumption to changes in tax policy.

2.1. General setup

There are two symmetric countries $i \in \{A, B\}$ engaging in tax competition. In each country, corporations produce either in a domestic sector or a multinational sector, (superscript n and m, respectively) using capital as the unique production input. The outputs of the sectors are perfect substitutes in consumption. Each country is inhabited by $1 + n$ individuals that own one unit of productive capital k each.

Becoming internationally active and entering the multinational sector requires the successful development of an intellectual property (e.g., production technology), and only a minority of companies is successful in developing such an asset. We normalize the number of multinational firms per country to one. The remaining n firms have sufficient skills to produce but serve their local market only. Domestic firms face an inelastic capital investment of $k_i^n = 1$, and the total investment of domestic firms per country is given by n. In contrast, multinational firms invest in country A or B. Thus, there is a total stock of one unit of mobile capital in each country, and total investment into a multinational in country i is given by $0 < k_i^m < 2$.

In our analysis, we assume that all governments apply the tax-exemption method in the case of foreign-earned income, i.e., territorial income taxation applies.[9] We follow the main tax competition literature in modeling a capital tax per unit of capital input denoted by t_i instead of a (proportional) corporate

9 Nearly all major OECD countries operate a territorial tax system and the tax-exemption method. The exceptions in the OECD are Chile, Israel, Mexico, and South Korea.

tax rate on firms' taxable profits (see, e.g., Haufler and Runkel, 2012, p. 1090).[10]

Firms choose to invest via equity or debt. Thus, all firms actively choose their (external) leverage. Following most tax codes worldwide, debt is tax deductible, while equity is not. Hence, all firms can reduce their effective tax rate by choosing their external leverage $\alpha_i \in [0,1]$, i.e., the extent to which investment is financed by external debt. As is well known from tradeoff theory in the finance literature, external debt causes additional non-tax benefits and costs.[11] In line with the standard finance literature (e.g., Huizinga et al., 2008), we summarize the costs of external debt by a U-shaped function $C_\alpha(\alpha_i - \bar{\alpha})$, where $\bar{\alpha}$ denotes the optimal external leverage ratio in the absence of taxation (i.e., the cost-minimizing level of external debt). Any deviation from $\bar{\alpha}$ causes marginal agency costs with $C_\alpha(0) = 0$, $C'_\alpha(\alpha_i - \bar{\alpha}) \cdot (\alpha_i - \bar{\alpha}) > 0$, and $C''_\alpha(\alpha_i - \bar{\alpha}) > 0 \; \forall \; \alpha_i$.

In addition to their productive affiliate, multinational firms host an affiliate in a tax haven that, for simplicity, charges a zero tax rate on capital and corporate income.[12] By investing equity in the tax haven, the multinational can turn this affiliate into an internal bank that passes on the equity as internal debt to the productive affiliate in country i. Internal leverage (or the internal debt-to-asset ratio) is denoted by γ_i. Because internal debt is – per se – tax deductible, the additional debt financing further lowers the effective tax rate in country i.[13]

Internal debt might, however, cause additional costs. Operating internal debt and claiming tax deductions can require costly tax-planning effort. Similarly to external debt, high internal leverage might affect bankruptcy risk and cause agency costs. We capture these costs by a convex cost function over internal leverage γ_i, $C_\gamma(\gamma_i)$ that features the properties $C'_\gamma > 0$ if $\gamma_i > 0$, $C'_\gamma = 0$ if $\gamma_i = 0$, and $C''_\gamma > 0$. In addition, multinational firms face a thin capitalization rule λ_i that denotes the maximum internal leverage (i.e., the

10 We show in an external appendix, available upon request, that the comparative-static effects remain qualitatively unchanged in a model with a corporate income tax.

11 Tradeoff theory dates back to Kraus and Litzenberger (1973). See Hovakimian et al. (2004) and Aggarwal and Kyaw (2010) for overviews and Van Binsbergen et al. (2010) for recent empirical support.

12 This assumption corresponds with, e.g., Hong and Smart (2010), Haufler and Runkel (2012), and Gresik et al. (2015, 2017). A positive tax rate in the tax haven would not affect our results as long as tax payments on royalty income in the tax haven can be credited against potential royalty tax payments in the productive affiliates.

13 For simplification, we neglect that some national firms might use a trustee solution to reroute equity. Our main results are robust as long as 'internal debt' is costlier for national firms than for multinationals. Importantly, empirical evidence documents scale effects in that large multinational firms are more likely to operate in tax havens (Desai et al., 2006) and only large multinationals host separate internal banks (Goldbach et al., 2021). See also Section 5.1.

internal-debt-to-asset ratio) that is tax deductible.[14] We assume that this rule is a strict limit. Hence, in equilibrium, $\gamma_i \leq \lambda_i$.

Finally, the multinational's affiliate in country i has access to intellectual property (e.g., a capital-enhancing technology) owned by the tax-haven affiliate. In the international trade literature, multinationals are regularly assumed to be more productive than domestic firms (e.g., Helpman et al., 2004; Bauer and Langenmayr, 2013). To capture this technological advantage of multinational firms, we assume that the intellectual property implies a proportional shift in the production technology by $\kappa > 1$. The production functions of domestic and multinational firms are $f(k_i^n)$ and $\kappa f(k_i^m)$, respectively, with $f'(\cdot) > 0$ and $f''(\cdot) < 0$.

For the use of the intellectual property, the tax-haven affiliate charges a royalty payment $R_i(a_i, b, k_i^m) = R_i^a(a_i, k_i^m) + R_i^b(b, k_i^m)$ that is tax deductible in the productive affiliate in country i. $R_i^b(\cdot)$ captures the arm's-length payment that mirrors the actual (or imputed) value created and depends on capital investment and an exogenous parameter b that denotes the corresponding arm's-length rate where $\partial R_i^b/\partial b > 0$ and $\partial^2 R_i^b/(\partial k_i^m \partial b) > 0$.[15] In contrast, $R_i^a(\cdot)$ measures the amount of profit shifting that is achieved by the tax-haven affiliate charging a surcharge above the arm's-length royalty payment. This surcharge depends on capital investment and some variable a_i that allows for adjustment of the arm's-length rate. Hence, the abusive part of the royalty payment is given by $R_i^a(a_i, k_i^m)$. We assume that the royalty payments $R_i^b(\cdot)$ and $R_i^a(\cdot)$ are increasing and concave in k_i^m.

The (additive) structure of the royalty payment can be rationalized in two related ways. First, the true arm's-length payment is private information of the multinational, and its exact value is unobservable by tax authorities. Therefore, the multinational has leeway to deviate from the arm's-length payment, for example, by adding the abusive surcharge a to the arm's-length royalty rate b such that the total rate (per unit of sales or capital) is $a + b$. To implement the surcharge, the multinational has to exert effort to disguise the true arm's-length price to the tax authority (and potentially a fiscal court and its experts). Moreover, it faces the risk of being fined when deviating from the arm's-length price and losing the case against the tax authority in court.

Second, the intellectual property right (i.e., the patent) might be so unique that hardly any arm's-length pricing is obtainable from objective appraisal.

14 Note that the general definition of 'thin capitalization' refers to companies that are highly geared in total and replace equity with a high level of internal and external debt. The main focus of policy makers, however, is on internal debt. Indeed, most (safe harbor) thin capitalization rules are either defined over the internal debt-to-asset ratio or effectively restrict the deductibility of internal debt only. In what follows, we will rely on such a setup and neglect rules that also restrict external debt.

15 As discussed in San Martín and Saracho (2010), most royalty payments are made relative to sales revenue, units sold, or as a combination of a fixed payment and payments relative to sales.

That gives the multinational freedom in choosing the royalty payment and shifting profits. Nevertheless, the choice is not fully unrestricted. Although the tax authority cannot directly observe any arm's-length price, it will still postulate a price that it perceives as the acceptable arm's-length price. For example, the tax authority can rely on average profitability or average cost markups across all firms in related markets to develop a notion of what the arm's-length payment and the arm's-length rate b should be.[16] The multinational can argue against this choice and exert effort (e.g., via lawyers and consultants) to achieve a deviation a from what the tax authority imposes as the arm's-length rate. For some deviation a, the related costs might be very low, but for large deviations from the tax authority's perception, the costs (and transfer pricing risk in court) will increase steeply.

These considerations show that arm's-length prices are difficult to observe or simply postulated by tax authorities. This leaves multinationals with the possibility to shift profits if they exert effort or take transfer pricing risk. The resulting concealment costs can be interpreted as the use of lawyers and accountants to justify the chosen rates with a given leeway and disguise the abusive part of the royalty payment or as non-tax-deductible fines related to abusive pricing.[17] Taking the functioning of OECD transfer pricing guidelines and methods into account, these concealment costs depend on the level of mispricing, and the more profits are shifted, the higher these costs become.[18] Therefore, applying OECD standard methods, we define concealment costs as $C_R(R_i^a)$ with $C_R(0) = 0$, $C'_R R_i^a > 0$ and $C''_R > 0$.

The government has three tax instruments at its disposal. It charges a statutory capital tax rate t_i per unit of capital k_i^n and k_i^m that is invested in country i. The thin capitalization rule sets the maximum internal leverage λ_i that is tax deductible. Finally, it can impose a withholding tax τ_i on royalty payments. Total tax revenue is used to finance a public consumption good g_i. While all three instruments can be used to compete for mobile

16 A prominent, alternative option in many countries is to apply 'Something of Value' (SOV) clauses, embedded into transfer pricing rules related to intangibles. These SOV rules specify that there is an underlying asset that generates an income stream and requires an arm's-length price (which the tax authority then can set 'opportunistically'). Surveys among managers in tax units and practitioners in consulting firms show that these rules are perceived as a considerable source of transfer pricing risk (see Mescall and Klassen, 2018, p. 831). The criteria used by tax authorities are soft, and the claims are difficult to refute.

17 See, e.g., Kant (1988) and Haufler and Schjelderup (2000). Whether concealment costs are tax deductible does not matter for the qualitative results to come.

18 Juranek et al. (2018) show that the OECD standard transfer pricing methods, i.e., the Controlled Unrelated Price Method, Transactional Net Margin Method and Cost Plus Method (cf. OECD, 2015c, 2017a), imply a functional form of royalty-related concealment costs that defines its argument over the deviation from the arm's-length payment.

capital, thin capitalization rules and withholding taxes additionally allow for discrimination between domestic and multinational firms.

2.2. Capital market

There are two types of investors. In each country, n inhabitants are domestic investors that can only invest in national firms, via either corporate bonds or stocks. The remaining inhabitants can invest multinationally. Hence, total capital endowment per country is given by $\bar{k} = 1 + n$ and the global capital supply is exogenously given by $2\bar{k}$, equally divided between the two countries.

The distinction between domestic and multinational investors finds various motivations in the literature. Investors might have strong home bias in equity investment (see Lewis, 1999, for an overview) that results from information asymmetries (e.g., Coval and Moskowitz, 1999; Van Nieuwerburgh and Veldkamp, 2009) or might differ in their financial literacy (see, e.g., van Rooij et al., 2011). For simplicity, we assume that domestic investors can only invest in their home country and are confined to purely national firms. In contrast, multinational investors can invest in corporate bonds of either firm in either country and hold stocks from any multinational firm.

Furthermore, we restrict all investors from short-selling stocks. In addition, domestic investors cannot short-sell corporate bonds, whereas multinational investors can hold any position in all corporate bonds.[19] This implies that both types of investors face the same capital market interest rate r that is equal to the return on corporate bonds. If returns were to differ, multinational investors could arbitrage between corporate bonds, triggering return adjustments until the equilibrium with uniform returns is reached. Although the market interest rate is equal for both types of investors, the net returns on investment realized in national and multinational firms differ, in general, due to differences in productivity and tax treatment. As domestic investors are confined to national firms and multinational investors invest in the more productive multinational firms, the differences in stock returns are not arbitraged away, differently from the bond market.

In the capital-market equilibrium, the gross return before financing costs in all multinational firms, across countries A and B, needs to be equalized and needs to meet the rate of return r of corporate bonds. In Subsection 2.3, we discuss differences in firm returns in detail and formally derive the capital market equilibrium and the rate of return r.

19 Short-selling restrictions have a long tradition and are currently in place in multiple jurisdictions, including the European Union (see Regulation (EU) No 236/2012). The assumption of no short sales has also been used in previous research, see, for example, the (finance) literature on the 'Miller equilibrium', originally outlined in Miller (1977). Note that the assumption is insofar innocuous as it only simplifies our analysis. Our results continue to hold in a setting with segregated national and multinational capital markets that then feature different interest rates.

2.3. Firm behavior and capital market equilibrium

We assume that all firms produce a homogenous output good and normalize its price to unity, i.e., $p = 1$. Given the described tax system, the net profit of a domestic firm in country i is as follows:

$$\pi_i^n = f(k_i^n) - rk_i^n - t_i k_i^n(1 - \alpha_i^n) - C_\alpha(\alpha_i^n - \bar{\alpha})k_i^n, \tag{1}$$

where $k_i^n = 1$ is a fixed amount of capital investment and r denotes the interest rate that is endogenously determined on the capital market.

The net profit of the multinational firm in country i is

$$\begin{aligned}\pi_i^m(k_i^m) = {} & \kappa f(k_i^m) - rk_i^m - t_i k_i^m(1 - \alpha_i^m - \gamma_i) - C_\alpha(\alpha_i^m - \bar{\alpha})k_i^m \\ & - C_\gamma(\gamma_i)k_i^m + \mu_i R_i(a_i, b, k_i^m) - C_R(R_i^a(a_i, k_i^m)),\end{aligned} \tag{2}$$

where we define $\mu_i \equiv t_i - \tau_i$ as the net deductibility rate for royalties.

For a given level of capital investment, the net profits of multinational firms are higher than those of domestic firms for three reasons. First, capital invested in multinational firms is more productive due to the use of the intellectual property (captured by $\kappa > 1$). Second, multinationals can reroute equity via the internal bank and declare some capital as internal debt (denoted by γ_i). This reduces their effective tax rate and, therefore, their user costs of capital but also leads to agency costs $C_\gamma(\gamma_i)$. Third, multinationals can lower their effective tax rate via the deduction of royalty payments (captured by $\mu_i R_i(a_i, b, k_i^m)$). To do so, the multinational incurs concealment costs $C_R(R_i^a)$ for the part of royalties that is abusive. For optimal behavior, the net tax savings from internal debt, $(t_i\gamma_i - C_\gamma(\gamma_i))\, k_i^m$, and royalty payments, $\mu_i R_i(a, b, k_i^m) - C_R(R_i^a(a, k_i^m)$, are positive.

The optimal external leverage chosen by domestic and multinational firms follows from maximizing profits (1) and (2) for α_i^n and α_i^m, respectively. Both firm types balance marginal tax savings against marginal agency costs of external debt. The solution is identical because the decision regarding external debt is independent of internal debt and royalty payments. Thus, $\alpha_i^{n*} = \alpha_i^{m*} \equiv \alpha_i^*$ is given by the solution of

$$t_i = C'_\alpha({\alpha_i}^* - \bar{\alpha}). \tag{3}$$

Eq. (3) shows that the optimal level of external debt increases in the capital tax rate t_i but is not affected by changes in the thin capitalization rule λ_i or the deductibility rate for royalties μ_i, i.e.,

$$\frac{d\alpha_i^*}{dt_i} = \frac{1}{C''_\alpha(\alpha_i^* - \bar{\alpha})} > 0 \quad \text{and} \quad \frac{d\alpha_i^*}{d\lambda_i} = \frac{d\alpha_i^*}{d\mu_i} = 0. \tag{4}$$

The multinational's unconstrained first-order condition with respect to internal debt is

$$t_i = C'_\gamma(\gamma_i). \tag{5}$$

Thus, in general, when choosing the level of internal debt, multinationals trade off the marginal tax savings against the increase in tax planning and agency costs. Denoting the solution of the first-order condition (5) by $\hat{\gamma}_i$, the equilibrium level of internal debt is $\gamma_i^* = \hat{\gamma}_i$ if $\hat{\gamma}_i \leq \lambda_i$ and $\gamma_i^* = \lambda_i$ otherwise. If the marginal costs of internal debt are sufficiently high, the profit-maximizing internal leverage $\hat{\gamma}_i$ implied by the first-order condition (5) is lower than the limit given by the thin capitalization rule. Accordingly, the thin capitalization rule is not binding, and $\hat{\gamma}_i < \lambda_i$. If the marginal costs are sufficiently low, however, the thin capitalization rule is binding, the multinational is constrained, and the equilibrium level of internal debt is determined by $\hat{\gamma}_i = \lambda_i$. We introduce a binary function $\mathbf{1}_\lambda$ to distinguish the two cases:

$$\mathbf{1}_\lambda = \begin{cases} 1 & \text{if } \hat{\gamma}_i \leq \lambda_i, \\ 0 & \text{otherwise.} \end{cases} \tag{6}$$

Internal leverage is never affected by the royalty tax. If the thin capitalization rule is not binding, the level of internal debt is, however, increasing with the corporate tax rate and marginal tax savings, whereas the thin capitalization rule does not have any effect. In contrast, if the thin capitalization rule binds, it determines the level of internal debt, clearly, but then, there is no effect of the corporate tax rate on internal leverage. To summarize, we have

$$\frac{d\gamma_i{}^*}{dt_i} = \frac{\mathbf{1}_\lambda}{C''_\gamma(\gamma_i^*)} \geq 0, \quad \frac{d\gamma_i{}^*}{d\lambda_i} = (1 - \mathbf{1}_\lambda) \geq 0, \quad \text{and} \quad \frac{d\gamma_i^*}{d\mu_i} = 0. \tag{7}$$

The multinational's first-order condition with respect to the abusive royalty is

$$\begin{aligned} &\frac{\partial \pi_i^m}{\partial a_i} = \mu_i \frac{\partial R_i^{a*}(a_i, k_i^m)}{\partial a_i} - C'_R(R_i^{a*}(a_i, k_i^m)) \frac{\partial R_i^{a*}(a_i, k_i^m)}{\partial a_i} = 0 \\ &\Rightarrow \quad \mu_i = C'_R(R_i^{a*}). \end{aligned} \tag{8}$$

At the optimum, the abusive part of the royalty-payment function R_i^a is chosen such that marginal tax savings μ_i equal the marginal expected concealment costs. In the following, we assume that marginal concealment costs are always sufficiently large to ensure an interior optimum at a non-zero tax base. Then, the first-order condition also shows that the optimal abusive surcharge function $R_i^{a*}(a_i, k_i^m)$ is unambiguously determined by the inverse of the marginal concealment cost function and does not depend on the arm's-length payment. Note further that it follows from Eq. (8) that the optimal royalty payment, R_i^{a*}, is independent of capital investment k_i^m.[20] Consequently,

20 If the condition for the interior optimum does not hold and, additionally, the loss offset is imperfect, the independence of abusive royalty payments and capital investment does

$R_i^{a*}(a_i, k_i^m) = R_i^{a*}$. The reason is that any effect that comes from changes in optimal capital investment can be neutralized by an adjustment of the surcharge variable a_i to maintain the total profit shifting via royalties at its optimal level (see also Juranek et al., 2018).

In the following, we hold the deductibility rate μ_i constant whenever we analyze effects of a change in the capital tax rate t_i, that is, we assume that the royalty tax rate τ_i adjusts implicitly to hold $\mu_i = t_i - \tau_i$ unchanged. Then, abusive royalty payments are affected by neither the capital tax rate t_i nor by the thin capitalization rule λ_i; however, they increase in the deductibility rate for royalties μ_i, that is,

$$\frac{dR_i^{a*}}{dt_i} = \frac{dR_i^{a*}}{d\lambda_i} = 0 \quad \text{and} \quad \frac{dR_i^{a*}}{d\mu_i} = \frac{1}{C_R''(R_i^{a*})} > 0. \tag{9}$$

Taking the first-order conditions for the external leverage in Eq. (3) and for the abusive royalty payments in Eq. (8) into account, the first-order condition for capital investment in multinational firms reads as

$$\frac{\partial \pi_i^m}{\partial k_i^m} = \kappa f'(k_i^m) - r - t_i(1 - \alpha_i^* - \gamma_i^*) - C_\alpha(\alpha_i^* - \bar{\alpha}) - C_\gamma(\gamma_i^*) + \mu_i \frac{\partial R_i^b}{\partial k_i^m} = 0. \tag{10}$$

The capital market equilibrium requires that marginal gross returns (before financing costs) on (equity) investment across all multinationals are equalized and that these returns meet the return on corporate bonds r. Therefore, we solve Eq. (10) for financing costs r and equalize the conditions for multinationals in countries i and j to receive the arbitrage condition

$$\kappa f'(k_i^m) - t_i(1 - \alpha_i^* - \gamma_i^*) - C_\alpha(\alpha_i^* - \bar{\alpha}) - C_\gamma(\gamma_i^*) + \mu_i \frac{\partial R_i^b}{\partial k_i^m} = r$$

$$= \kappa f'(k_j^m) - t_j(1 - \alpha_j^* - \gamma_j^*) - C_\alpha(\alpha_j^* - \bar{\alpha}) - C_\gamma(\gamma_j^*) + \mu_j \frac{\partial R_j^b}{\partial k_j^m}. \tag{11}$$

Next, we apply this arbitrage condition together with the market clearing condition, i.e., the total demand for capital invested in national and multinational firms equals world capital supply,

$$(k_i^m + nk_i^n) + (k_j^m + nk_j^n) = 2\bar{k}, \tag{12}$$

and the symmetry assumption, i.e., $\alpha_j^* = \alpha_i^*$, $\gamma_j^* = \gamma_i^*$, $k_j^m = k_i^m$, $t_j = t_i$ and $\mu_j = \mu_i$. Combining these, the changes in capital demand due to changes in the corporate tax rate, the thin capitalization rule, and the deductibility

not apply. Multinationals with zero tax base have an incentive to increase their investment so that they can shift more profits (see Köthenbürger et al., 2019). Empirical evidence shows that a few large multinationals report zero taxable profits, but this does not apply to the average multinational.

rate for royalties, respectively, can be summarized as follows (for detailed derivations of Eqs. (13a)-(13c) see Appendix A1):

$$\frac{dk_i^m}{dt_i} = -\frac{dk_j^m}{dt_i} = \frac{1-\alpha_i^* - \gamma_i^*}{2\left(\kappa f''(k_i^m) + \mu_i \frac{\partial^2 R_i^b}{\partial (k_i^m)^2}\right)} < 0, \tag{13a}$$

$$\frac{dk_i^m}{d\lambda_i} = -\frac{dk_j^m}{d\lambda_i} = -\frac{t_i - C'_\gamma}{2\left(\kappa f''(k_i^m) + \mu_i \frac{\partial^2 R_i^b}{\partial (k_i^m)^2}\right)} \geq 0, \tag{13b}$$

$$\frac{dk_i^m}{d\mu_i} = -\frac{dk_j^m}{d\mu_i} = -\frac{\frac{\partial R_i^b}{\partial k_i^m}}{2\left(\kappa f''(k_i^m) + \mu_i \frac{\partial^2 R_i^b}{\partial (k_i^m)^2}\right)} \geq 0. \tag{13c}$$

An increase in the statutory capital tax decreases capital demand in multinational firms in the respective country and leads to an increase in capital demand in the other country. The result illustrates the standard tax base externality arising from tax competition. If the thin capitalization rule is binding (i.e., if $t_i > C'_\gamma$), relaxing the rule (i.e., increasing λ_i) leads to an increase in capital demand in the respective country and decreases capital demand in the other country. If the thin capitalization rule is not binding, $t_i = C'_\gamma$ holds from the first-order condition (5). Then, a change in the thin capitalization rule does not affect capital demand. The deductibility rate for royalties only has a mechanical effect on capital demand. An increase in the deductibility rate increases the marginal benefit of capital investment due to an increase in arm's-length royalty payments. Therefore, an increase in the deductibility rate for royalties has positive effects on capital demand in the respective country (and negative effects on capital demand in the other country) if and only if arm's-length royalties are positive. There is, however, no behavioral effect via profit shifting. It does not pay off to increase capital beyond the mechanical effect to improve the profit-shifting position because capital investment does not affect the tradeoff between abusive royalty payments and concealment costs. On the margin, the behavioral effects cancel out. This is analogous to the absence of an intensive-margin effect in Juranek et al. (2018, Proposition 1).

Importantly, if the thin capitalization rule is binding, the mechanical effect of the deductibility rate is proportional to the effect of the thin capitalization rule and, thus, can be offset by adjusting the thin capitalization regulation, as $\frac{dk_i^m}{d\mu_i} = \frac{dk_i^m}{d\lambda_i}\left(\frac{\partial R_i^b}{\partial k_i^m}\frac{1}{t_i - C'_\gamma}\right)$. In other words, if the thin capitalization rule is binding, the investment incentives of all instruments are linearly dependent, and the mechanical investment margin can be fully controlled by the available government instruments.

2.4. Private and public consumption

Each individual derives utility from private and public consumption and possesses a quasilinear utility function $u^l = x_i^l + v(g_i)$ where private consumption x_i^l depends on whether the individual is a multinational investor $(l = m)$ or not $(l = n)$. Utility from public consumption g_i is denoted by $v(g_i)$ with $v' > 0, v'' < 0$.[21]

In aggregate, the welfare in country i is given by

$$W_i = u(x_i, g_i) = \sum u^l = x_i + (1+n)v(g_i), \tag{14}$$

where x_i represents aggregate income. Before we analyze the optimal tax policy with coordination and under competition, we derive the effects of the three policy instruments on private and public consumption. Private consumption equals the sum of the net profits in domestic and multinational firms plus the interest realized due to capital supply, i.e.,

$$x_i = n\pi_i^n + \pi_i^m + r\bar{k}, \tag{15}$$

where the net profits are given in Eqs. (1) and (2), respectively.

Analogously, the provision of public goods is determined by tax revenue and reads as

$$g_i = t_i(1-\alpha_i^*)n + t_i(1-\alpha_i^* - \gamma_i^*)k_i^m - \mu_i R_i^*(a, b, k_i^m), \tag{16}$$

where we used $R_i^*(a_i, b, k_i^m) \equiv R_i^{a*} + R_i^b(b, k_i^m)$ and $k_i^n = 1$. Considering the optimal solutions for external debt, internal debt, royalties and capital demand, i.e., Eqs. (3), (5), (8) and (10), the partial derivatives of private consumption with respect to the three policy instruments in a symmetric situation are

$$\frac{dx_i}{dt_i} = -(1-\alpha_i^*)n - (1-\alpha_i^* - \gamma_i^*)k_i^m < 0, \tag{17a}$$

$$\frac{dx_i}{d\lambda_i} = \left(t_i - C'_\gamma\right) k_i^m \frac{\partial \gamma_i^*}{\partial \lambda_i} \geq 0, \tag{17b}$$

$$\frac{dx_i}{d\mu_i} = R_i^*(a_i, b, k_i^m) > 0. \tag{17c}$$

A higher statutory capital tax reduces private consumption, while a higher deductibility rate for royalties increases private consumption. A laxer thin capitalization rule will increase private consumption whenever the thin capitalization rule is binding. If the thin capitalization rule is not binding, $\frac{\partial \gamma_i^*}{\partial \lambda_i} = 0$ and there is no effect on private consumption. The three policy

21 An alternative setup would be to follow Haufler and Runkel (2012) in assuming that a representative household owns one unit of internationally mobile capital and n units of immobile capital and possesses a general utility function. Our quasilinear utility function delivers the same outcomes because both approaches end up in a standard tax-competition setting where intracountry redistribution does not matter.

instruments do not have any effect on private consumption in the other country, i.e., $\frac{\partial x_j}{\partial t_i} = \frac{\partial x_j}{\partial \lambda_i} = \frac{\partial x_j}{\partial \mu_i} = 0$.

For public consumption, we obtain, using $\frac{\partial R_i^{a*}}{\partial k_i^m} = 0$, in a symmetric equilibrium

$$\frac{dg_i}{dt_i} = (1-\alpha_i^*)n + (1-\alpha_i^*-\gamma_i^*)k_i^m - t_i(n+k_i^m)\frac{d\alpha_i^*}{dt_i} - t_i k_i^m \frac{\partial \gamma_i^*}{\partial t_i} + \Delta_k \frac{dk_i^m}{dt_i}, \tag{18a}$$

$$\frac{dg_i}{d\lambda_i} = -t_i k_i^m \frac{\partial \gamma_i^*}{\partial \lambda_i} + \Delta_k \frac{\partial k_i^m}{\partial \lambda_i}, \tag{18b}$$

$$\frac{dg_i}{d\mu_i} = -R_i^*(a_i, b, k_i^m) - \mu_i \frac{\partial R_i^{a*}}{\partial \mu_i} + \Delta_k \frac{\partial k_i^m}{\partial \mu_i}, \tag{18c}$$

with

$$\Delta_k \equiv t_i(1-\alpha_i^*-\gamma_i^*) - \mu_i \frac{\partial R_i^b}{\partial k_i^m} \geq 0 \tag{19}$$

denoting the tax wedge of capital investment. The tax wedge is positive whenever the deductibility of royalty payments μ_i is not too large.[22]

In general, the effects of the policy instruments on the public good in the same country are ambiguous in sign. At its optimum, however, the government will never choose a tax rate on the decreasing side of the Laffer curve so that $\frac{\partial g_i}{\partial t_i} \geq 0$. An increase in the capital tax rate has a direct positive effect through an increase in tax revenue. In addition, there are three negative effects because, first, external debt increases so that tax revenue is reduced, second, if the thin capitalization rule is not binding, internal debt increases so that tax revenue is reduced further, and third, capital demand decreases whenever the tax wedge of capital investment is positive.

A laxer thin capitalization rule has two effects on public consumption if the thin capitalization rule is binding. On the one hand, there is a direct reduction in tax revenue. On the other hand, tax revenue increases due to a positive investment effect. If the thin capitalization rule is not binding, there is no effect on the public good at all.

The effects of an increase in the deductibility rate for royalties on public consumption are threefold: First, there is a negative, direct effect on tax revenue. Second, an increase in the deductibility rate of royalties increases the royalty through an increase in the abusive part. This response reduces tax revenue. Finally, there is a positive effect via capital demand, analogous to the capital-demand effect of the thin capitalization rule.

22 In an equilibrium with optimal government strategies, $\Delta_k \geq 0$ will always hold. Otherwise, the government would have incentives to drive capital out of the country to increase tax revenue and public consumption. However, this implies that it would reduce the deductibility rate μ_i (i.e., increase the withholding tax τ_i) or the thin capitalization limit λ_i until $\Delta_k = 0$.

The effects of the policy instruments chosen by country i on the provision of public goods in country j arise due to changes in capital demand and are unambiguous for positive tax wedges:

$$\frac{\partial g_j}{\partial t_i} = -\Delta_k \frac{\partial k_i^m}{\partial t_i} > 0, \tag{20a}$$

$$\frac{\partial g_j}{\partial \lambda_i} = -\Delta_k \frac{\partial k_i^m}{\partial \lambda_i} \leq 0, \tag{20b}$$

$$\frac{\partial g_j}{\partial \mu_i} = -\Delta_k \frac{\partial k_i^m}{\partial \mu_i} < 0. \tag{20c}$$

An increase in the statutory capital tax, a stricter thin capitalization rule (i.e., a lower λ_i) and a reduced deductibility rate of royalty payments (i.e., a lower μ_i) have positive external effects on the other country because such policies foster capital demand in the other country.

3. The constrained Pareto-optimal solution

As a benchmark, we derive the optimal tax policy with coordination of policies in the two countries. A country's welfare is determined by Eq. (14). Under coordination, the countries maximize aggregate welfare $W^c = u(x_i, g_i) + u(x_j, g_j)$ (where the superscript c refers to coordinated tax policies). In this situation, the tax base externalities are internalized so that the Pareto-optimal levels of the policy instruments are determined. Nevertheless, the deductibility of external debt acts as a constraint on the Pareto-optimal solution. The optimization problem can be stated as

$$\max_{t_i,\lambda_i,\mu_i,t_j,\lambda_j,\mu_j} W^c = u(x_i, g_i) + u(x_j, g_j) \quad \text{s.t.} \quad (15), \text{ and } (16) \tag{21}$$

where the market clearing condition and the arbitrage condition must hold.

Proposition 1 summarizes the result, where $\varepsilon_{\alpha t}$ denotes the elasticity of external leverage with respect to the capital tax rate.

PROPOSITION 1. *With symmetric countries, the constrained Pareto-optimal tax policy is characterized by underprovision of the public good, i.e.,*

$$\frac{u_g}{u_x} = \frac{1}{1 - \varepsilon_{\alpha t}} > 1, \tag{22}$$

with $\varepsilon_{\alpha t} \equiv \frac{\partial \alpha_i^*}{\partial t_i} \frac{t_i}{1-\alpha_i^*} > 0$*, a zero thin capitalization rule* $\lambda_i^c = 0$*, and a zero deductibility rate* $\mu_i^c = 0$ *(i.e., a withholding tax* $\tau_i^c = t_i^c$ *).*

Proof. See Appendix A2. ∎

Even for a Pareto-efficient tax policy, the marginal rate of substitution between public and private consumption is greater than one, that is, greater than the marginal rate of transformation. Consequently, there is underprovision of public goods compared to a fully undistorted decision. This result is driven by the deductibility of external debt that allows firms to avoid the capital tax by strategically distorting their capital structure. Hence, the increasing external leverage constrains the level of the capital tax rate, and the elasticity of external leverage becomes a measure of the underprovision with public consumption. The faster agency costs increase with external leverage (i.e., the more convex the agency cost function is), the less tax-responsive leverage will be and the higher the Pareto-optimal tax rate becomes.[23]

Furthermore, internal debt is not tax deductible, because a positive thin capitalization rule would further foster the excessive leverage and, therefore, would lower the tax base even further. Equivalently, nondeductibility of royalty payments, i.e., a withholding tax on royalties equal to the capital tax rate, avoids any tax-revenue loss from transfer pricing. Consequently, in a Pareto-efficient equilibrium, abusive royalties are fully prevented and all profit shifting is eliminated.[24]

4. Tax competition

We now turn to the optimal tax system under competition where each country maximizes the welfare $W_i = u(x_i, g_i)$ of its residents only. As we have assumed identical countries, we focus on the symmetric equilibrium. Thus, choosing all instruments simultaneously, the noncooperative optimization problem is

$$\max_{t_i,\lambda_i,\mu_i} W_i = u(x_i, g_i) \quad \text{s.t.} \quad (15), \text{ and } (16) \tag{23}$$

where the market clearing condition and the arbitrage condition must hold.

The first-order condition for the statutory capital tax reads as

$$\frac{\partial u(x_i, g_i)}{\partial t_i} = u_x \frac{\partial x_i}{\partial t_i} + u_g \frac{\partial g_i}{\partial t_i} = 0. \tag{24}$$

Using Eqs. (17a) and (18a), we can rewrite the condition as

$$\frac{u_g}{u_x} = \frac{(1-\alpha_i^*)n + (1-\alpha_i^* - \gamma_i^*)k_i^m}{(1-\alpha_i^*)n + (1-\alpha_i^* - \gamma_i^*)k_i^m - t_i(n + k_i^m)\frac{\partial \alpha_i^*}{\partial t_i} - t_i k_i^m \frac{\partial \gamma_i^*}{\partial t_i} + \Delta_k \frac{\partial k_i^m}{\partial t_i}} > 1. \tag{25}$$

The term $-t_i(n + k_i^m)\frac{\partial \alpha_i^*}{\partial t_i} - t_i k_i^m \frac{\partial \gamma_i^*}{\partial t_i} + \Delta_k \frac{\partial k_i^m}{\partial t_i} < 0$ implies that $u_g > u_x$. Consequently, in each country, there is always underprovision of public goods

23 As usual in public finance, the 'optimal-tax expression' does not represent an explicit solution for the optimal tax rate (or other instruments). The elasticity in Eq. (22), for example, is not constant and depends on the tax rate. However, the optimal-tax expressions highlight relevant tradeoffs.

24 The nondeductibility of internal debt is in line with Haufler and Runkel (2012). In addition, we find that a Pareto-optimal solution also requires strict nondeductibility of royalty payments.

and the optimal capital tax rate t_i^* is inefficiently low. This inefficiency is driven by two effects: First, an increase in the capital tax rate fosters the distortion in firms' capital structure. The resulting increase in external and internal leverage triggers a decrease in tax revenue, all else being equal. This effect also appears with policy coordination as shown in the proof of Proposition 1. Note that the effect on internal debt is only present if the thin capitalization rule is not binding. Second, there is an additional negative effect on tax revenue caused by a reduced capital investment. That effect is not present in an equilibrium with coordination but emerges from unilateral competition for mobile capital. Country i neglects the positive externality on welfare in country j that is created by shifting capital from country i to j. In sum, the underprovision is stronger than under cooperation and can be measured as

$$\frac{u_g - u_x}{u_g} = \frac{t_i(n + k_i^m)\frac{\partial \alpha_i^*}{\partial t_i} + t_i k_i^m \frac{\partial \gamma_i^*}{\partial t_i} - \Delta_k \frac{\partial k_i^m}{\partial t_i}}{(1-\alpha_i^*)n + (1-\alpha_i^* - \gamma_i^*)k_i^m} > 0. \tag{26}$$

In contrast to the statutory tax rate, the thin capitalization rule and the withholding tax on royalties are targeted instruments to compete for mobile capital. They only affect multinationals and their capital demand. The respective first-order conditions are

$$\frac{\partial u(x_i,g_i)}{\partial \lambda_i} = u_x \frac{\partial x_i}{\partial \lambda_i} + u_g \frac{\partial g_i}{\partial \lambda_i} = (u_x - u_g) t_i k_i^m \frac{\partial \gamma_i^*}{\partial \lambda_i} - u_x C'_\gamma k_i^m \frac{\partial \gamma_i^*}{\partial \lambda_i} + u_g \Delta_k \frac{\partial k_i^m}{\partial \lambda_i} \leq 0, \tag{27}$$

$$\frac{\partial u(x_i,g_i)}{\partial \mu_i} = u_x \frac{\partial x_i}{\partial \mu_i} + u_g \frac{\partial g_i}{\partial \mu_i} = (u_x - u_g) R_i^* - u_g \left(\mu_i \frac{\partial R_i^{a*}}{\partial \mu_i} - \Delta_k \frac{\partial k_i^m}{\partial \mu_i}\right) \leq 0. \tag{28}$$

We start our analysis by capturing the EU Interest and Royalty Directive and the current situation within the EEA where royalty taxation is absent. Then, we derive the optimal combination of the instruments when both the thin capitalization rule and the withholding tax on royalties are available.

4.1. The case of a thin capitalization rule only

If the government in country i cannot impose a withholding tax on royalty payments, we have $\tau_i = 0$ so that $\mu_i = t_i$. In such a scenario, an increase in the statutory tax rate leads to an identical increase in the net deductibility rate for royalties, i.e., $d\mu_i/dt_i = 1$. Hence, in this subsection, a change in the statutory tax rate has a direct effect on capital demand (e.g., $\partial k_i^m/\partial t_i$) and an indirect effect via the royalty rate (e.g., $\partial k_i^m/\partial \mu_i$).

The government will use the thin capitalization rule $\lambda_i > 0$ and discriminate between domestic and multinational firms to attract mobile capital whenever $\left.\frac{\partial u(x_i,g_i)}{\partial \lambda_i}\right|_{\lambda_i=0,\mu_i=t_i} > 0$. This condition transforms into the requirement that capital demand is sufficiently elastic with respect to debt financing, that is, the incentives to engage in competition for mobile capital are sufficiently strong. More precisely, $\lambda_i^* > 0$ requires (see Appendix A3 for the derivation)

$$\varepsilon_{kt} > \frac{1-\alpha_i^*}{1-\alpha_i^* - \frac{\partial R_i^b}{\partial k_i^m}} \frac{n+k_i^m}{n} \left(\xi_n \, \varepsilon_{\alpha t} + \frac{n}{n+k_i^m} \, \xi_R \, \varepsilon_{R\mu} \right), \tag{29}$$

where $\varepsilon_{kt} \equiv -\frac{\partial k_i^m}{\partial t_i} \frac{t_i}{k_i^m} > 0$ is the (positively defined) tax elasticity of capital and $\varepsilon_{\alpha t} > 0$ represents the leverage elasticity (see Proposition 1) measuring the extent of underprovision of the public good. $\varepsilon_{R\mu} \equiv \frac{\partial R_i^{a*}}{\partial \mu_i} \frac{\mu_i}{R_i^*}$ is the elasticity of royalty payments with respect to their deductibility rate. Furthermore, we define $\xi_n \equiv \frac{(1-\alpha_i^*)n}{(1-\alpha_i^*)n - \left(R_i^* - \frac{\partial R_i^b}{\partial k_i^m} k_i^m\right)} \geq 1$ and $\xi_R \equiv \frac{R_i^*}{(1-\alpha_i^*)n - \left(R_i^* - \frac{\partial R_i^b}{\partial k_i^m} k_i^m\right)} \geq 0$.

A first insight is that condition (29) collapses to $\varepsilon_{kt} > \frac{n+k_i^m}{n} \varepsilon_{\alpha t}$ in the absence of royalty payments, that is, for $R_i^* = 0$ and $\frac{\partial R_i^b}{\partial k_i^m} = 0$. Then, the condition is equivalent to Proposition 2 in Haufler and Runkel (2012): Capital investment needs to be sufficiently elastic to overcompensate for revenue losses from subsidizing existing investment and worsening the underprovision problem (captured by $\varepsilon_{\alpha t}$).

In the more general case with royalty payments but no royalty taxes ($\mu_i = t_i$), however, the condition for engaging in competition for mobile capital is tighter. Additional capital investment generates less tax revenue relative to the setting in Haufler and Runkel (2012) because part of the generated tax base is deducted as royalty payment and avoids taxation in the domestic country. This effect is captured by $(1-\alpha_i^*) / \left(1-\alpha_i^* - \frac{\partial R_i^b}{\partial k_i^m}\right) > 1$ and, all else being equal, makes competition for mobile capital less attractive. In addition, the underprovision problem caused by leveraging affiliates is strengthened by the royalty payments. The additional capital investment needs to compensate for subsidizing existing investment ($\varepsilon_{\alpha t}$) and leakage via transfer pricing in royalties ($\varepsilon_{R\mu}$). Finally, these two effects become more important in the extent to which the presence of royalty payments worsens the original underprovision problem, that is the larger $\xi_n > 1$ and $\xi_R > 0$ are. Technically, $R_i^* - \frac{\partial R_i^b}{\partial k_i^m} k_i^m > 0$ captures a 'quasi-economic rent' that is created by the royalty payments. For a royalty payment R_i^*, only the part $\frac{\partial R^b}{\partial k_i^m} k_i^m$ matters for incentivizing (further) capital investment. The remaining part $R_i^* - \frac{\partial R_i^b}{\partial k_i^m} k_i^m$ constitutes a 'quasi-economic rent', i.e., a distortion-free tax base. This tax base is lost without any compensation when a multinational makes a royalty payment R_i^* to the tax-haven affiliate. Therefore, the denominator shrinks and inflates the weights ξ_n and ξ_R. Intuitively, the fact that valuable tax base (the quasi-economic rent) is lost via royalty payments further tightens the condition for welfare-improving internal debt shifting (i.e., $\lambda_i^* > 0$).

If condition (29) is fulfilled, the optimal thin capitalization rule in the absence of royalty taxation will be inefficiently lax, and we conclude as follows:

PROPOSITION 2a. *In a noncooperative symmetric Nash equilibrium where withholding taxes on royalty payments are not available* ($\mu_i = t_i$)*, the government will set the thin capitalization rule to be inefficiently lax* ($\lambda_i^* > 0$) *whenever mobile capital is sufficiently elastic, i.e., when* $\varepsilon_{kt} > \frac{1-\alpha_i^*}{1-\alpha_i^*-\frac{\partial R_i^b}{\partial k_i^m}} \frac{n+k_i^m}{n} \left(\xi_n \, \varepsilon_{\alpha t} + \frac{n}{n+k_i^m} \, \xi_r \, \varepsilon_{R\mu}\right)$.

Next, we analyze the optimal level of deductible internal debt λ_i^* whenever the government has incentives to engage in competition for mobile capital and uses its thin capitalization rule, $\lambda_i > 0$. If there are substantial costs of internal debt and the (optimal) thin capitalization rule is not binding, i.e., $\hat{\gamma}_i < \lambda_i^*$, a change in the thin capitalization rule has no effect on welfare. Then, the government can arbitrarily set a thin capitalization rule $\lambda_i \geq \hat{\gamma}_i$ and effectively only has the statutory tax rate t_i as a tax-competition instrument.

The more interesting *and* the empirically relevant case, however, is a binding thin capitalization rule with $\hat{\gamma}_i > \lambda_i$, i.e., low (or no) costs of internal debt. Empirical research on thin capitalization rules indicates that the capital structure of multinationals' affiliates reacts to changes in thin capitalization rules (e.g., Büttner et al., 2012, Blouin et al., 2018). Furthermore, available data suggests that total debt-to-asset ratios are not 'excessively' high, not even in affiliates doing internal borrowing. Hence, multinationals should be willing to respond with increased gearing when governments relax thin capitalization rules.[25] Both observations together make a strong case for binding thin capitalization rules and that governments can affect multinationals' debt policy.[26] Therefore, $\gamma_i^* = \lambda_i^*$.

Then, we can implicitly describe the optimal level of deductible internal debt λ_i^* by the optimal ratio of debt financing ($d_i = \alpha_i^* + \lambda_i^*$) relative to

25 Most data sets do not allow for disentangling the information on internal and total debt-to-asset ratios between internal banks, providing internal debt, and related affiliates, borrowing internal debt. One of the very few exceptions is the MiDi data by Deutsche Bundesbank. For affiliates of German multinationals, the total debt-to-asset ratio in the period 1996 to 2006 was 62% and the differences between internal banks (i.e., the lowest-taxed affiliates) and the other, internally borrowing affiliates was not very large (Møen et al., 2019, Table 2). Furthermore, the gearing rather decreased over time. In the period between 1999 and 2017, the affiliates of German multinationals featured a total debt-to-asset ratio of below 50%, no matter whether their corporate tax rate was below 25% or above 35% (Goldbach et al., 2021, Table 2). In all cases, total lending from related companies amounted to about one third of total debt.

26 Based on the EY Worldwide Corporate Tax Guide 2018 (Ernst & Young, 2018), 99 countries do *not* operate thin capitalization rules; hence, they do not face binding rules either. Importantly, however, a set of 82 countries that includes the economically most relevant countries, has thin capitalization rules in place and these rules are binding then. Our analysis mainly focuses on the latter set of countries.

taxable profit per unit of capital $\left(1-\alpha_i^*-\lambda_i^*-\frac{\partial R_i^b}{\partial k_i^m}\right)$, which is given by the elasticity rule (see Appendix A4)

$$\frac{\alpha_i^*+\lambda_i^*}{1-\alpha_i^*-\lambda_i^*-\frac{\partial R_i^b}{\partial k_i^m}}=\frac{n}{n+k_i^m}\cdot\frac{t_i}{t_i-C_\gamma'}\cdot\frac{(\omega_n+\omega_{RR})\varepsilon_{kd}}{\omega_n\;\varepsilon_{\alpha t}+\frac{n}{n+k_i^m}\;\omega_R\;\varepsilon_{R\mu}+\frac{n}{n+k_i^m}\;\frac{C_\gamma'}{t_i-C_\gamma'}},\quad(30)$$

where $\varepsilon_{kd}\equiv\frac{\partial k_i^m}{\partial\lambda_i}\frac{\alpha_i^*+\lambda_i^*}{k_i^m}>0$ is the elasticity of capital demand with respect to total leverage $d_i=\alpha_i^*+\lambda_i^*$, $\omega_n\equiv\frac{(1-\alpha_i^*)n}{(1-\alpha_i^*)n+(1-\alpha_i^*-\lambda_i^*)k_i^m-R_i^*}$ represents the share of domestic firms' tax base in the total capital tax base of the economy, $\omega_R\equiv\frac{R_i^*}{(1-\alpha_i^*)n+(1-\alpha_i^*-\lambda_i^*)k_i^m-R_i^*}\geq 0$ is the share of royalties in the tax base, and $\omega_{RR}\equiv-\frac{R_i^*-\frac{\partial R_i^b}{\partial k_i^m}k_i^m}{(1-\alpha_i^*)n+(1-\alpha_i^*-\lambda_i^*)k_i^m-R_i^*}\leq 0$ is the share of quasi-economic royalty rents in the domestic capital tax base.

Eq. (30) is a classic Ramsey rule, and each of its three factors on the right-hand side represents a welfare-relevant effect. First, competition for mobile capital via the statutory tax rate becomes more expensive in the extent to which domestic firms benefit from a lower tax rate. Hence, discrimination of multinationals becomes more attractive, and the thin capitalization rule weakens with the share of domestic firms in total investment $\frac{n}{n+k_i^m}$. Note that if there are no domestic firms, in contrast, there is no need to discriminate, and all competition for mobile capital is done via the tax rate. Consequently, $\lambda_i^*=0$ for $n=0$.

Second, a higher corporate tax rate indicates greater distortions and a larger need for compensating measures. Moreover, t_i-C_γ' measures the marginal tax savings and the marginal investment effect from weakening the thin capitalization rule. The higher the tax rate and the lower the marginal investment effect from the thin capitalization rule, the more internal debt needs to be allowed to mitigate the tax distortions.

Finally, the last term captures the classic tradeoff in generated distortions. The more investment responds to financial incentives (ε_{kd}), the weaker the thin capitalization rule should be to exploit the positive investment effect. This effect in the numerator matters more in a world with few multinationals and a large tax base from domestic firms (i.e., large ω_n). It suffers, however, from the fact that larger investment by multinationals allows for shifting more quasi-economic rents via royalties to the tax haven; see the effect via $\omega_{RR}<0$. The denominator captures the effects that reduce welfare. A larger underprovision problem (i.e., a higher $\varepsilon_{\alpha t}$ – see Proposition 1) renders the subsidy on capital costs more expensive. The reason is that weakening the rule provides windfall gains to existing multinational investment that are paid by valuable tax revenue. Therefore, a larger tax-base-weighted leverage elasticity ($\omega_n\;\varepsilon_{\alpha t}$) tightens the thin capitalization rule. Similarly, the tax-base-weighted royalty elasticity ($\omega_R\;\varepsilon_{R\mu}$) represents transfer pricing in royalties and additional revenue losses from investment. Thus, it leads to an even stricter thin capitalization rule. In addition, allowing for internal debt can create additional agency costs that are a waste of resources from a society's perspective. The more marginal agency costs are created relative to the marginal investment effect, that is, the higher $\frac{C'_\gamma}{t_i - C'_\gamma}$ is, the less internal leverage should be tax deductible.

Therefore, and similarly to condition (29), the presence of royalty payments reduces the incentive to engage in competition for mobile capital. This relationship mirrors the fact that shifting of paper profits dampens competition for physical capital.

PROPOSITION 2b. *If the agency costs of internal debt are sufficiently low so that the thin capitalization rule is binding, the optimal thin capitalization rule trades off tax-revenue gains from attracting capital investment against losses in revenue from subsidizing existing investment and transfer pricing in royalties. The presence of royalty payments works in favor of stricter thin capitalization rules, i.e., less competition for mobile capital, because royalties reduce the gains from capital investment.*

4.2. Combining thin capitalization rules and royalty taxation

Finally, we derive the optimal setting of royalty taxes and thin capitalization rules when both instruments are available and can be chosen simultaneously. As in Section 4.1, we distinguish between the case where the thin capitalization rule is binding in equilibrium (i.e., $\hat{\gamma}_i > \lambda_i^*$ so that $\gamma_i^* = \lambda_i^*$) and the case where the thin capitalization rule is slack and multinational firms can realize their preferred, profit-maximizing internal leverage ratio (i.e., $\gamma_i^* = \hat{\gamma}_i < \lambda_i$).

Binding thin capitalization rule. When the thin capitalization rule is binding and the first-order condition (27) holds with equality, we can exploit the fact that both instruments, i.e., the thin capitalization rule and the deductibility of royalties, are linearly dependent with respect to attracting capital investment. From Eqs. (13b) and (13c), it follows that $\frac{\partial R_i^b}{\partial k_i^m}\frac{\partial k_i^m}{\partial \lambda_i} = (t_i - C'_\gamma)\frac{\partial k_i^m}{\partial \mu_i} > 0$. By applying this relationship in the first-order condition for the optimal thin capitalization rule λ_i, Eq. (27), and inserting the resulting expression into the first-order condition for the optimal deductibility rate μ_i^*, Eq. (28), straightforward rearrangements lead to (see Appendix A5)

$$\mu_i^* = -\frac{\frac{\Delta_k k_i^m}{R_i^*}\left(\frac{1}{\varepsilon_{Rk}} - 1\right)\varepsilon_{k\mu}}{\varepsilon_{R\mu} - \frac{C'_\gamma}{t_i - C'_\gamma}}, \tag{31}$$

where $\frac{1}{\varepsilon_{Rk}} - 1 = \frac{R_i^*}{\frac{\partial R_i^b}{\partial k_i^m} k_i^m} - 1 = \frac{1}{\frac{\partial R_i^b}{\partial k_i^m} k_i^m} \left(R_i^* - \frac{\partial R_i^b}{\partial k_i} k_i^m \right) > 0$ captures the 'quasi-economic rents', discussed before Proposition 2a, once again.

Having the concept of 'quasi-economic rents' in mind, we can interpret the optimal tax rule in Eq. (31) using standard intuition. The positive numerator on the right-hand side captures the benefits from royalty taxation. Higher 'quasi-economic rents', that is a lower elasticity $\varepsilon_{Rk} < 1$, work in favor of a higher royalty tax rate, all else being equal. The aim is to confiscate the supernormal profits embedded in the royalty payments. This effect is fostered to the extent that reducing deductibility of royalties reduces capital investment ($\varepsilon_{k\mu} > 0$), which will further increase the rent component. Hence, given a positive denominator, we have a force that pushes for a high royalty tax rate ($\tau_i^* \to 1$) and triggers a negative deductibility rate $\mu_i^* < 0$ because we also have $\Delta k > 0$.

The denominator represents the costs involved with using the royalty tax. First, any deductibility rate $\mu_i^* \neq 0$ provides transfer-pricing incentives to shift profits to lower-taxed tax bases. Larger distortions induced by profit shifting ($\varepsilon_{R\mu} > 0$) buffer the deductibility rate around zero (i.e., $\mu_i^* \to 0$ for $\varepsilon_{R\mu} \to \infty$). Finally, the second term in the denominator captures the costs of using a relaxed thin capitalization rule to mitigate the investment distortions of a royalty tax $\mu_i < t_i$. A high royalty tax distorts capital investment because the tax also falls on the arm's-length component. To mitigate these distortions, a weaker thin capitalization rule and a higher level of internal debt are required. If the marginal agency costs of internal debt, however, are high relative to its investment effect, $\frac{C'_\gamma}{t_i - C'_\gamma} > 0$ (cf. Eq. (30)), compensating for the investment distortion is very expensive. Hence, a royalty tax becomes less attractive, all else being equal.

In most cases, agency costs of internal debt should be low, but if the internal leverage that is necessary to compensate for investment distortions implies a total leverage close to one, agency costs of internal debt will become substantial and turn the denominator negative. Then, substantial costs of internal debt work in favor of a positive deductibility rate $\mu_i^* > 0$ and $\tau_i^* < t_i^*$. This also reduces investment distortions and saves agency costs.

Note that a negative deductibility rate $\mu_i^* < 0$ might be impracticable and has severely negative effects on the incentives to generate R&D. Furthermore, multinationals might simply stop invoicing royalty payments to avoid the tax. Thus, a cap at $\mu_i = 0$ appears likely. That implies, however, that the royalty tax will be equal to the corporate tax rate for a wide range of agency costs. In other words, condition (31) implies that it can well be optimal to ban any deductibility of royalties, i.e., $\mu_i^* = 0$. This boundary solution gains support with quasi-economic rents embedded in the royalty payments and with a decrease in the marginal costs of internal debt. Then, strict nondeductibility implies that the government fully prevents profit shifting ($R_i^{a*} = 0$).

To maintain an efficient position in the competition for mobile capital, however, further measures are necessary. Therefore, when does the government want to use its thin capitalization rule to compete for capital investment given that it does not allow for any deduction of royalties? When we evaluate the first-order condition (27) at $\mu_i^* = 0$ and utilize the underprovision measure in Eq. (26), we find that (see Appendix A6)

$$\left.\frac{\partial u(x_i, g_i)}{\partial \lambda_i}\right|_{\lambda_i=0,\mu_i=0} > 0 \quad \Leftrightarrow \quad \varepsilon_{kt} > \frac{n + k_i^m}{n}\, \varepsilon_{\alpha t}. \tag{32}$$

This condition and its interpretation effectively are analogous to a simplified version of condition (29) in the case of a thin capitalization rule only the absence of royalty payments.

More generally, by applying $\mu_i = \mu_i^*$ instead of $\mu_i = t_i$, we can use the derivation in Section 4.1 to identify the optimal thin capitalization rule as

$$\frac{\alpha_i^* + \lambda_i^*}{1 - \alpha_i^* - \lambda_i^* - \frac{\mu_i^*}{t_i}\frac{\partial R_i^b}{\partial k_i^m}} = \frac{n}{n + k_i^m} \cdot \frac{t_i}{t_i - C'_\gamma} \cdot \frac{\omega_n \varepsilon_{kd}}{\omega_n \varepsilon_{\alpha t} + \frac{n}{n+k_i^m}\frac{C'_\gamma}{t_i - C'_\gamma}}. \tag{33}$$

The interpretation of the right-hand side is largely equivalent to that in Eq. (30), but an optimally set royalty tax avoids leakages via quasi-economic rents (cf. the ω_{RR} term in (30)) and via transfer pricing in royalties (cf. the $\varepsilon_{R\mu}$ term in (30)). Consequently, attracting additional capital investment leads to higher tax revenue relative to the case in Section 4.1. Furthermore, there is an important difference on the left-hand side. The more royalties are taxed, the more investment distortions are created and the laxer the thin capitalization rule needs to be. In sum, the optimal λ_i^* increases with a decrease in the deductibility rate μ_i^*, all else being equal, to foster tax revenue and reduce investment distortions.

For the boundary solution of denying tax deducibility for royalty payments ($\mu_i^* = 0$), this implies that the government unilaterally eliminates profit shifting by intellectual property and relegates all competition for mobile capital to the thin capitalization rule. The latter is set inefficiently lax, whenever the underprovision of public goods is not too severe and capital investment reacts sufficiently to tax incentives (i.e., when $\varepsilon_{kt} > \frac{n+k_i^m}{n}\varepsilon_{\alpha t}$). Thereby, compensating for the negative mechanical effect that the royalty tax exerts on capital investment further weakens the thin capitalization rule. Assuming a symmetric Nash equilibrium with a complete set of instruments, we summarize

Proposition 3a. *If agency costs are sufficiently small that the thin capitalization rule is binding, the optimal policy is characterized by an efficient royalty tax* $\tau_i^* \geq t_i^*$ *and an inefficiently lax thin capitalization rule* $\lambda_i^* > 0$. *The capital tax rate* t_i^* *is inefficiently low compared to the constrained Pareto-optimum.*

If the marginal costs of internal debt are sufficiently high, but not too large, such that the thin capitalization rule still is binding, the second term on the right-hand side of the optimal tax expression in Eq. (31) dominates, and compensation for the investment distortions via higher internal debt alone is too expensive. Consequently, there will be an interior solution for the deductibility rate. A higher μ_i^* reduces the negative investment effect and improves the position in the competition for capital investment. Importantly, the optimal royalty tax remains positive, i.e., $\mu_i^* < t_i^*$ even if not all distortionary effects can be compensated for by a laxer thin capitalization rule. The optimal thin capitalization rule continues to follow from Eq. (33), but since the deductibility rate μ_i and the marginal costs of debt C'_γ are higher than in the case summarized in Proposition 3b, the thin capitalization rule will be stricter, i.e., λ_i^* will be lower.

PROPOSITION 3b. *If agency costs are in a medium range and the thin capitalization rule is still binding, the optimal policy is characterized by an inefficiently low royalty tax $0 < \tau_i^* < t_i^*$ and an inefficiently lax thin capitalization rule $\lambda_i^* > 0$. The thin capitalization rule, however, is stricter than in the case of an efficiently set royalty tax. The capital tax rate t_i^* is inefficiently low compared to the constrained Pareto-optimum.*

To summarize our findings for a binding thin capitalization rule as an empirical prediction, countries that either face a significant portion of 'quasi-economic rents' in the royalty payments or observe low costs of internal debt should feature a deductibility rate of zero or even slightly below zero. In contrast, countries with very high marginal costs of internal debt will set intermediate to no royalty taxes.

Nonbinding thin capitalization rule. Let us finally analyze the case in which marginal costs of internal debt are so high that the thin capitalization rule is not binding, $\hat{\gamma}_i < \lambda_i$. Then, the first-order condition (27) for the thin capitalization rule is always fulfilled. This instrument cannot be used to attract capital investment and does not compensate for distortions created by royalty taxation.[27] It does not affect welfare either and can be set at any arbitrary level $\lambda_i > \hat{\gamma}_i$. Effectively, the only available instrument is the royalty tax.

27 This scenario also captures the corner solution in the case of binding thin capitalization rules when the necessary level of internal debt to compensate for investment distortions becomes so high that the optimal total leverage would exceed one, $d_i^* = \alpha_i^* + \lambda_i^* > 1$. The resulting corner solution with $d = d^{max}$ is equivalent to the case of a nonbinding thin capitalization rule that we analyze now.

Rearranging Eq. (28), the optimal deductibility rate of royalties when the thin capitalization rule has slack can be expressed as (see Appendix A7)

$$\mu_i^* = -\frac{\frac{\Delta_k k_i^m}{R_i^*}\left(\left(\frac{1}{\varepsilon_{Rk}} - 1\right) - \frac{\omega_n}{\varepsilon_{Rk}}\right)\varepsilon_{k\mu}}{\varepsilon_{R\mu} + \omega_\alpha\ \varepsilon_{\alpha t} + \omega_\gamma\ \varepsilon_{\gamma t}}, \tag{34}$$

where $\omega_\alpha \equiv \frac{(1-\alpha_i^*)(n+k_i^m)}{(1-\alpha_i^*)n+(1-\alpha_i^*-\gamma_i^*)k_i^m}$ is the after-external-leverage share in the economy's total equity and $\omega_\gamma \equiv \frac{(1-\gamma_i^*)k_i^m}{(1-\alpha_i^*)n+(1-\alpha_i^*-\gamma_i^*)k_i^m}$ is the after-internal-leverage share in total equity.

The resulting Ramsey rule is very similar to that in the previous scenario with a binding thin capitalization rule. In the denominator, the royalty elasticity $\varepsilon_{R\mu}$ captures the costs of setting $\mu_i^* \neq 0$ and inducing profit shifting to other tax bases. Furthermore, the thin capitalization rule can no longer be used to balance competition for capital investment against the underprovision of public goods. Thus, the measure for the relative agency costs of internal debt (cf. Eq. (31)) is replaced by a measure for the underprovision problem. The latter is, as usual, captured via the equity-weighted tax responsiveness of external and internal leverage; see the second and third term in the denominator. Both costs from profit shifting and underprovision buffer the deductibility rate μ_i^* around zero, i.e., work in favor of $\tau_i = t_i^*$.

In the numerator, the benefits from royalty deductibility are now twofold. First, one still wants to set a negative deductibility rate, i.e., $t_i^* < \tau_i^*$, to tax quasi-economic rents; see the term $\left[\frac{1}{\varepsilon_{Rk}} - 1\right]$ and its interpretation in Eq. (31). However, the royalty tax is the only instrument in this scenario that allows for positive discrimination of multinationals on the margin. Hence, all else being equal, to target competition for capital investment and subsidize mobile capital only, a lower royalty tax and granting a positive deductibility rate $\mu_i^* > 0$ is optimal; see the term related to $\frac{\omega_n}{\varepsilon_{Rk}}$. Again, discriminating in favor of multinationals and mobile capital becomes more important the larger the share of domestic firms in the tax base is, i.e., the higher ω_n is.

To summarize, there are once more strong incentives to use the royalty tax and significant potential for an optimally low or negative deductibility rate. A nonbinding thin capitalization rule should imply that the total leverage is already high, unless one focuses on a developing country with strong inefficiencies and frictions in both its external capital market and the internal capital markets of multinationals operating in this country.[28] A high total leverage then implies severe underprovision of public goods in our model. Hence, both the share of domestic firms in the equity tax base (ω_n) and the effect driving competition for mobile capital ($\varepsilon_{k\mu} > 0$) need to

28 De Mooij and Hebous (2018, Table 2 and Figure 1) report an average (consolidated) total debt-asset ratio of 62.09% with a range from approximately 45% to 75%, increasing with the statutory corporate tax rate.

be strong to generate a situation in which the royalty tax is substantially lower than the corporate tax rate, even if the thin capitalization rule cannot be used to mitigate investment distortions. Assuming a symmetric Nash equilibrium with a complete set of instruments, we summarize our findings for a nonbinding thin capitalization rule as follows:[29]

Proposition 3c. *If agency costs are high and the thin capitalization rule is not binding, the thin capitalization rule does not affect welfare. The royalty tax is determined as a tradeoff among attracting mobile capital, taxing quasi-economic rents in royalties, and preventing profit shifting. An inefficiently low royalty tax* $\tau_i^* < t_i^*$ *requires both a sufficiently strong need to discriminate in favor of multinationals (*ω_n *high) and a sufficiently strong elasticity of capital investment (*$\varepsilon_{k\mu} > 0$*). The capital tax rate* t_i^* *is inefficiently low compared to the constrained Pareto-optimum.*

To summarize our findings as an empirical prediction again, even with ineffective thin capitalization rules, one should observe high royalty tax rates with basically no deductions of royalties in countries that either face a substantial underprovision of public goods or feature significant 'quasi-economic rents' in the royalty payments made to third countries.

4.3. Policy implications

Our results call into question provisions in many bilateral and multilateral tax treaties that waive royalty taxes on cross-border payments. The most prominent example of the latter is the EU Interest and Royalty Directive that bans royalty taxation for all payments between member states in the EEA. The background of this ban is the notion that a withholding tax on royalty payments has similar effects as a withholding tax on interest payments with negative consequences for free trade and capital investment.

We show that the case of a withholding tax on royalties differs from the case of withholding taxes on interest (see, e.g., Johannesen, 2012). First, profit shifting via intangibles does not foster investment. Hence, there is no direct incentive to lower the tax falling on abusive transfer pricing.[30] Second, analyzing the two main profit-shifting channels, debt shifting and royalties, together shows that governments should use their thin capitalization rules to compete for capital investment via debt shifting while maintaining their

29 The results for pure transfer pricing in absence of any internal debt are analogous to the case of an ineffective thin capitalization rule. See section 5.2 in Juranek et al. (2020) for a detailed analysis.

30 For a few large multinationals (in the digital economy), there might be an investment effect from abusive transfer pricing when they reach a zero tax base, cf. footnote 20. If that happens, it might call for an even weaker thin capitalization rule, and it will reduce the optimal royalty tax, all else being equal. Our general case for positive royalty taxation remains valid, however.

withholding tax on royalties at its efficient level and eliminating transfer pricing.

Against the background of an increasing importance of knowledge-intensive business models and intellectual property rights, we propose a reconsideration of the use of withholding taxes on royalty payments. Such a withholding tax is particularly attractive for combating profit shifting because it is unilaterally effective, i.e., countries do not have to coordinate, but each country benefits from introducing it unilaterally. The latter is especially important if the trend for intensified tax competition for paper profits via the introduction of (aggressive) patent boxes (see, e.g., the U.S. tax reform in 2017) continues.

Our results also relate to the current discussion on thin capitalization rules. For royalty taxes to be efficient, it is necessary to implement weaker thin capitalization rules. While there are good reasons for the OECD's (2015a, Action 4) push for stricter regulation of thin capitalization, our results indicate a risk of overshooting.

Furthermore, using a withholding tax on royalties mitigates the problem of evaluating the arm's-length price of the intellectual property, as discussed in OECD (2015b). The price for this simplification is an investment distortion, see Eq. (13c), because the royalty tax falls on real costs (in our model R_i^b). However, this distortion can be fully neutralized by relaxing the thin capitalization rule and granting a higher deductibility of internal debt. Importantly, the arm's-length component is also not required to determine the optimal thin capitalization rule.

Our findings offer explanations for the variety in royalty tax rates observed in several countries in the EU and OECD (see Table 2). Our main scenario predicts royalty taxes equal or close to the corporate tax. That is also in line with the introduction of royalty taxes in Norway and the Netherlands in 2021. Moreover, we can explain royalty taxes higher than the corporate tax with our findings on taxing quasi-economic rents, and we can justify positive royalty taxes significantly lower than the corporate tax with high agency costs of internal debt and a substantial weight of competition for capital investment. Nevertheless, there are some countries that do not impose a royalty tax at all – many of them tax havens and conduit countries following quite different tax models.

5. Extensions and discussion

We believe that our analysis provides a strong case in favor of royalty taxes (combined with relaxed thin capitalization rules). However, our model rests on a few simplifications to keep it tractable. In the following, we discuss the effect of some important assumptions and their generalization.

5.1. Royalty payments by domestic firms

In our model, domestic firms do not use special technologies and do not make any royalty payments for the use of an intangible asset. In reality, however, domestic firms' production often requires royalty payments for external technologies (and patents). Hence, domestic firms are also affected by a tax on royalty payments if the royalty is paid to a foreign company. That will challenge the case for high royalty taxes because (purely) domestic firms cannot rely on internal debt from a tax haven for tax optimization. Some domestic firms can bypass that problem by relying on services of trustees to enact 'disguised' round-tripping of equity, even without having an official affiliate in a low-tax country. For such domestic firms, our analysis fully applies again. Their royalty payments are taxed, but investment distortions are alleviated by higher internal leverage.[31] However, most domestic firms do not have this option. Similarly, a substantial share of multinationals do not operate debt shifting with an internal bank in a tax haven because the fixed costs of such a setup are too high for them (see Goldbach et al., 2021, for empirical evidence). For these two types of firms, royalty taxation creates investment distortions because they do not benefit from weakened thin capitalization rules.

A promising way to relieve firms without internal banks would be a 'royalty stripping rule' – designed similarly to an earnings stripping rule for interest deductions. Such a rule introduces a ceiling for deductible royalty payments relative to an earnings measure (e.g., Earnings Before Interest, Taxes, Depreciation and Amortization, i.e., EBITDA). If this ceiling is defined as the average (or higher quintiles) royalty payment that domestic firms pay to third parties, the burden on domestic firms is minimized, most of the true arm's-length payments on intangibles should be exempted from royalty taxation, and investment distortions are largely removed.

Importantly, even if not all investment distortions can be alleviated, this does not speak against royalty taxation per se. The optimal tax rate likely will be below the corporate tax rate, but the main mechanisms behind royalty taxation remain in place. It is very unlikely that the optimal royalty tax drops to zero; see our related discussion of the case of nonbinding thin capitalization rules in Section 4.2.

5.2. Endogenous technological progress and R&D investment

Another important assumption is that our model is static and the analysis treats technological progress and its underlying R&D investment as exogenous. In reality, technological progress is a dynamic process that depends on endogenous R&D investment decisions. As in our setting a tax on royalty payments reduces the after-tax returns on R&D investment, R&D incentives

31 We are grateful to one of the referees for highlighting this.

deteriorate and technological progress might slow. If that happens, there are intertemporal investment distortions even if weaker thin capitalization rules mitigate distortions in productive (non-R&D) capital investment. Such negative effects on the quality of the intangible asset constitute an additional cost factor for royalty taxation and work in favor of lower royalty taxes. Unless the distortions in R&D investment are 'infinitely' large, however, the optimal royalty tax should still remain positive – in contrast to the ban on any royalty taxation in the EU Interest and Royalty Directive.

Whether and to what extent endogenous R&D investment affects our results strongly depends on the setting and potential additional instruments. A royalty tax in only one, small country should not affect R&D investment by (large) multinationals. Such a tax would only have a negligible effect on R&D returns for multinationals that are active in many countries. Hence, investment in innovation is rather unlikely to react to a royalty tax in a small country. In contrast, when several countries or large economic blocks such as the EU introduce royalty taxes where the arm's-length remuneration for R&D investment is no longer tax deductible, incentives to innovate will be negatively affected. Over time, the welfare costs from adverse effects on R&D activities in multinationals and innovation in general may substantially reduce the benefits of curbing profit shifting.

One straightforward way to reduce and eliminate distortions in R&D investment would be to rely on direct, front-end subsidies on R&D expenditures, e.g., R&D tax credits. Analyzing so-called 'patent boxes', Haufler and Schindler (2021) note that such subsidies are the marginal instrument to foster R&D investment and to internalize spillover effects from R&D, both under policy coordination and in a setting with unilateral tax competition. Implicit ex post subsidies via a reduced income tax rate on royalty income only serve as an instrument for competition for paper profits. These findings coincide with empirical evidence that indeed preferential tax treatments for royalty income foster competition for paper profits rather than innovation and patents (e.g., Köthenbürger et al., 2018). Equivalent insights should basically carry over to the implicit subsidy in our model, i.e., to the absence of royalty (withholding) taxes and profit shifting. In that sense, ex ante subsidies are likely to be a more efficient way to foster innovation.

There is, however, one important difference between our setting and the choice between ex ante R&D subsidies and ex post subsidies via a patent box. In our setting, the revenue from the royalty tax accrues in the country that levies the withholding tax, whereas the direct R&D subsidy is born by the country that hosts the R&D unit of the multinational. Due to the withholding taxes in the other countries, the subsidizing country has to share revenues from global R&D income paid to the R&D unit so that there is a common public goods problem. The country hosting the R&D unit sets the direct R&D suboptimally low, and investment distortions from introducing royalty taxes remain. However, if many countries, e.g., the EU as a whole, were to coordinate the introduction of royalty taxation, they should also be able to coordinate the introduction of direct R&D subsidies, which mitigates the public goods problem.

In addition to direct R&D subsidies, there is a unilateral instrument that does not require any coordination among countries: A royalty stripping rule allows for curbing abusive royalty payments without interfering (substantially) with R&D incentives. A ceiling for the tax deductibility of royalties, relative to profit measures, ensures that productive and innovative firms can deduct an average remuneration from R&D investment. That mitigates negative effects on innovation. Furthermore, the stripping rule prevents excessive profit shifting.[32] Modeling the details of such a royalty stripping rule, in particular the impact on R&D investment and innovation (i.e., technological change), is beyond the scope of this paper but constitutes an interesting avenue for future research.

5.3. Transfer pricing via the interest rate

Our model focuses on transfer pricing in intangibles, which have been seen as the most relevant shifting channel and the greatest challenge for controlling profit shifting for the last decade; see, e.g., OECD (2013). In reality, of course, multinationals can also engage in transfer pricing in (more) tangible goods. An obvious extension in our setup would be to additionally allow for transfer pricing via the interest rate on internal debt. By having the possibility to deviate from the arm's-length rate, the multinationals gain an additional margin to play with.

Whether transfer pricing via interest rates affects the results in our model depends on the exact specification of the concealment costs (i.e., mainly on which OECD transfer pricing method applies). In a framework à la Schindler and Schjelderup (2016) where the transactional net margin method applies, interest rate manipulation and the level of debt shifting are independent of each other. Then, there should be no effect on our royalty tax results because a weaker thin capitalization rule will not foster transfer pricing via the interest rate.[33] In contrast, if a larger level of debt shifting facilitates transfer pricing in interest rates, because it reduces its concealment costs, an increase in debt shifting will foster transfer pricing via the interest rate. The markup on the arm's-length rate remains constant, but the level of shifted profits increases (see, e.g., Gresik et al., 2017).

32 Of course, multinationals will use transfer pricing on other margins instead. For transfer pricing in tangible goods, however, there are comparable goods and parallel market transactions. Furthermore, tax authorities have decades of experience with such forms of transfer pricing.

33 In Schindler and Schjelderup (2016), multinationals have an optimal amount of profits that they want to shift via interest rate manipulation. If the stock of internal debt increases, they will reduce the internal interest rate to maintain their optimal level of shifted profits.

In the latter scenario, using weaker thin capitalization rules to compensate multinationals for taxes on the arm's-length royalty payment becomes more expensive, as profit shifting increases all else being equal. Such an effect should reduce the level of compensation, might trigger some investment distortions, and eventually reduce the optimal royalty tax because there are additional costs. That would only be a level effect, however, while our qualitative results should remain unchanged. Some (significant) royalty taxation remains optimal. Notably, the (potentially) adverse effect of interest manipulation might be even less relevant if a country applies an earnings stripping rule instead of the traditional safe harbor rules to limit thin capitalization. See the next subsection for a brief discussion of these alternative rules.

5.4. Earnings stripping rules

Our analysis focuses on traditional safe harbor rules to limit the level of (internal) debt on which tax-deductible interest expenses can be claimed. A recent trend in developed countries is the implementation of so-called earnings stripping rules.[34] For example, the EU Anti-Tax-Avoidance Directive (ATAD) requires all EU member states to implement earnings stripping rules until 2024. Earnings stripping rules restrict interest payments relative to an earnings measure (usually EBITDA).

Such rules cannot be easily incorporated into the standard model of tax competition, and our analysis does not directly apply to this set of rules. Nevertheless, the main effects of earnings stripping rules should be relatively straightforward. In our context, the main role of a (weak) thin capitalization rule is to attract capital investment and compensate for royalty tax payments that fall on the arm's-length remuneration for intellectual property. These aims can be achieved by weakening either a safe harbor rule or an earnings stripping rule. Indeed, an earnings stripping rule implements a cost tradeoff between debt shifting and transfer pricing. Relaxing an existing rule leads to both more debt shifting and more transfer pricing (see Gresik et al., 2017). Adding a royalty tax to such a model should tilt the tradeoff in favor of debt shifting as the returns on transfer pricing in royalties decrease. Consequently, we should see the same effects as in our analysis that more debt shifting mitigates investment distortions while transfer pricing is curbed. Because, for high-tax countries, transfer pricing usually is much more welfare deteriorating than debt shifting (Gresik et al., 2015, 2017), our results and intuition should carry over to a setting with earnings stripping rules and royalty taxation.

In an extended setting, an advantage of earnings stripping rules over safe harbor rules would even be that the former rules limit transfer pricing via the

34 Based on data from Ernst & Young (2018), 23 countries, mostly from the OECD, with a pure earnings stripping rule face 42 countries with a pure safe harbor rule and 95 countries that do not restrict thin capitalization at all, i.e., apply a safe harbor rule with $\lambda = 1$.

interest rate. Gresik et al. (2017) show that earnings stripping rules effectively reduce interest rate manipulation because they increase the costs of transfer pricing. It thus follows that using royalty taxes in a setting with additional interest rate manipulation (see the previous Subsection 5.3) is more beneficial (or less expensive) when earnings stripping rules rather than safe harbor rules apply.

6. Conclusion

Recent trends in international business show an increasing relevance of multinational firms and the growing importance of intellectual property. The latter also facilitates international corporate tax avoidance. We capture both trends in a model that combines profit shifting via royalty payments on intellectual property with international competition for capital investment. We ask how a country should strategically position its tax policy in a challenging environment with large countries competing for capital investment and intensified shifting of paper profits to tax havens.

We find that under tax competition, both statutory capital tax rates and thin capitalization rules are always set inefficiently low. In contrast, unilaterally optimized royalty taxes are chosen at their Pareto-efficient level and set equal to the capital tax rate if agency costs of internal debt are sufficiently low. In this case, all competition for capital investment by positive discrimination of multinationals, relative to domestic firms, takes place via thin capitalization rules. Royalty taxation only focuses on profit shifting in intellectual property and eliminates any incentive for transfer pricing. As the royalty tax also falls on the arm's-length payment for the intellectual property, however, it causes a negative investment effect. This effect is fully neutralized by an additional weakening of the thin capitalization rule so that the country remains competitive and royalty taxation effectively does not distort investment. Importantly, a positive royalty tax is still optimal even in cases where the thin capitalization rule is unavailable or cannot be used to mitigate distortions.

These results are surprising because, in general, one may expect that optimal withholding taxes on royalties also face the traditional 'race to the bottom' under tax competition and distort factor allocation. Indeed, our findings question the standard view that withholding taxes are always inefficient. In particular, our results question the ban on royalty taxes in double tax treaties and the EU Interest and Royalty Directive. Neither under coordinated nor under unilateral decision making is a complete ban on withholding taxes on royalties optimal.

Appendix

Throughout the Appendix (and the paper) we make use of the following elasticity definitions:

1. Elasticity of external leverage w.r.t. the capital tax: $\varepsilon_{\alpha t}{\equiv}\frac{\partial\alpha_i^*}{\partial t_i}\frac{t_i}{1-\alpha_i^*}$
2. Elasticity of internal leverage w.r.t. the capital tax: $\varepsilon_{\gamma t}{\equiv}\frac{\partial\gamma_i^*}{\partial t_i}\frac{t_i}{1-\gamma_i^*}$
3. Elasticity of capital w.r.t. the capital tax (positively defined): $\varepsilon_{kt}{\equiv}-\frac{\partial k_i^m}{\partial t_i}\frac{t_i}{k_i^m}$
4. Elasticity of royalty payments w.r.t. capital investment: $\varepsilon_{Rk}{\equiv}\frac{\partial R_i^b}{\partial k_i^m}\frac{k_i^m}{R_i^*}$
5. Elasticity of capital demand w.r.t. total leverage $d_i{=}\alpha_i^*{+}\gamma_i^*$: $\varepsilon_{kd}{\equiv}\frac{\partial k_i^m}{\partial\lambda_i}\frac{\alpha_i^*+\gamma_i^*}{k_i^m}$
6. Elasticity of capital demand w.r.t. tax deductibility of royalties: $\varepsilon_{k\mu}{\equiv}\frac{\partial k_i^m}{\partial\mu_i}\frac{\mu_i}{k_i^m}$
7. Elasticity of royalty payments w.r.t. their deductibility rate: $\varepsilon_{R\mu}{\equiv}\frac{\partial R_i^{a*}}{\partial\mu_i}\frac{\mu_i}{R_i^*}$

In addition, we use the following weights:

1. Royalty-adjusted measure for the underprovision: $\xi_n{\equiv}\frac{(1-\alpha_i^*)n}{(1-\alpha_i^*)n-(R_i^*-\frac{\partial R_i^b}{\partial k_i^m}k_i^m)}{\ge}1$
2. Underprovision-enforcing effect of royalties: $\xi_R{\equiv}\frac{R_i^*}{(1-\alpha_i^*)n-(R_i^*-\frac{\partial R_i^b}{\partial k_i^m}k_i^m)}{\ge}1$
3. Share of domestic firms' tax base in total capital tax base: $\omega_n{\equiv}\frac{(1-\alpha_i^*)n}{(1-\alpha_i^*)n+(1-\alpha_i^*-\lambda_i^*)k_i^m-R_i^*}{>}0$
4. Share of royalties in total capital tax base: $\omega_R{\equiv}\frac{R_i^*}{(1-\alpha_i^*)n+(1-\alpha_i^*-\lambda_i^*)k_i^m-R_i^*}{\ge}0$
5. Share of quasi-economic royalty rents in total capital tax base: $\omega_{RR}{\equiv}-\frac{R_i^*-\frac{\partial R_i^b}{\partial k_i^m}k_i^m}{(1-\alpha_i^*)n+(1-\alpha_i^*-\lambda_i^*)k_i^m-R_i^*}{\le}0$
6. After-external-leverage share in the economy's total equity: $\omega_\alpha{\equiv}\frac{(1-\alpha_i^*)(n+k_i^m)}{(1-\alpha_i^*)n+(1-\alpha_i^*-\gamma_i^*)k_i^m}{>}0$
7. After-internal-leverage share in the economy's total equity: $\omega_\gamma{\equiv}\frac{(1-\gamma_i^*)k_i^m}{(1-\alpha_i^*)n+(1-\alpha_i^*-\gamma_i^*)k_i^m}{>}0$

Appendix A1: Derivation of Eqs. (13a)-(13c)

Using Eq. (12) to substitute for k_j^m in Eq. (11) and then differentiating the arbitrage condition with respect to k_i^m and t_i yields

$$\left(\kappa f''(k_i^m)+\mu_i\frac{\partial^2 R_i^b}{\partial(k_i^m)^2}\right)dk_i^m-(1-\alpha_i^*-\gamma_i^*)dt_i=-\left(\kappa f''(k_j^m)+\mu_j\frac{\partial^2 R_j^b}{\partial(k_j^m)^2}\right)dk_i^m. \tag{A1}$$

Applying symmetry, i.e., $\alpha_j^* = \alpha_i^*$, $\gamma_j^* = \gamma_i^*$, $k_j^m = k_i^m$, $t_j = t_i$ and $\mu_j = \mu_i$, we can rewrite

$$\frac{dk_i^m}{dt_i} = -\frac{dk_j^m}{dt_i} = \frac{1-\alpha_i^*-\gamma_i^*}{2\left(\kappa f''(k_i^m)+\mu_i \frac{\partial^2 R_i^b}{\partial (k_i^m)^2}\right)} < 0 \tag{A2}$$

which is Eq. (13a)

Analogously, differentiating the arbitrage condition with respect to k_i^m and λ_i yields

$$\left(\kappa f''(k_i^m)+\mu_i \frac{\partial^2 R_i^b}{\partial (k_i^m)^2}\right) dk_i^m + (t_i - C_\gamma')d\lambda_i = -\left(\kappa f''(k_j^m)+\mu_j \frac{\partial^2 R_j^b}{\partial (k_j^m)^2}\right) dk_i^m \tag{A3}$$

and therefore Eq. (13b).

Differentiating the arbitrage condition with respect to k_i^m and μ_i finally yields

$$\left(\kappa f''(k_i^m)+\mu_i \frac{\partial^2 R_i^b}{\partial (k_i^m)^2}\right) dk_i^m + \left(\frac{\partial R_i^b}{\partial k_i^m}\right) d\mu_i = -\left(\kappa f''(k_j^m)+\mu_j \frac{\partial^2 R_j^b}{\partial (k_j^m)^2}\right) dk_i^m \tag{A4}$$

and therefore Eq. (13c).

Appendix A2: Proof of Proposition 1

Aggregate welfare is $W^c = u(x_i, g_i) + u(x_j, g_j)$. The first-order condition with respect to the statutory capital tax then reads as $\frac{\partial W^c}{\partial t_i} = u_x\left(\frac{\partial x_i}{\partial t_i}+\frac{\partial x_j}{\partial t_i}\right) + u_g\left(\frac{\partial g_i}{\partial t_i}+\frac{\partial g_j}{\partial t_i}\right) = 0$, which yields, using Eqs. (17a), (18a), (20a) and $\frac{\partial x_j}{\partial t_i} = 0$,

$$\frac{u_g}{u_x} = \frac{(1-\alpha_i^*)n + (1-\alpha_i^*-\gamma_i^*)k_i^m}{(1-\alpha_i^*)n + (1-\alpha_i^*-\gamma_i^*)k_i^m - t_i^*(n+k_i^m)\frac{\partial \alpha_i^*}{\partial t_i} - t_i^* k_i^m \frac{\partial \gamma_i^*}{\partial t_i}} > 1. \tag{A5}$$

The effect of a change in the thin capitalization rule on welfare is

$$\frac{\partial W^c}{\partial \lambda_i} = u_x\left(\frac{\partial x_i}{\partial \lambda_i}+\frac{\partial x_j}{\partial \lambda_i}\right) + u_g\left(\frac{\partial g_i}{\partial \lambda_i}+\frac{\partial g_j}{\partial \lambda_i}\right) = (u_x - u_g)t_i k_i^m \frac{\partial \gamma_i^*}{\partial \lambda_i} - u_x C_\gamma' k_i^m \frac{\partial \gamma_i^*}{\partial \lambda_i} \leq 0,$$

where we have used Eqs. (17b), (18b), (20b), $\frac{\partial x_j}{\partial \lambda_i} = 0$ and $u_x < u_g$ according to Eq. (A5). If the thin capitalization rule is not binding, a change in the rule has no effect on welfare. If the thin capitalization rule is binding, it is optimally set to zero because an increase in λ_i reduces welfare. The effect of a change in the deductibility rate for royalties on welfare is

$$\frac{\partial W^c}{\partial \mu_i} = u_x \left(\frac{\partial x_i}{\partial \mu_i} + \frac{\partial x_j}{\partial \mu_i} \right) + u_g \left(\frac{\partial g_i}{\partial \mu_i} + \frac{\partial g_j}{\partial \mu_i} \right) = (u_x - u_g) R_i^* - u_g \mu_i \frac{\partial R_i^{a*}}{\partial \mu_i} < 0,$$

where we have used Eqs. (17c), (18c), (20c), $\frac{\partial x_j}{\partial \mu_i} = 0$ and again $u_x < u_g$ according to Eq. (A5). The deductibility rate for royalties is optimally set to zero, that is, the withholding tax on royalties is optimally set to its maximum, i.e., $\tau_i^c = t_i^c$. Using $\lambda_i^c = 0$ and $\mu_i^c = 0$, we can rewrite Eq. (A5) as $\frac{u_g}{u_x} = \frac{1}{1 - \frac{\partial \alpha_i^*}{\partial t_i} \frac{t_i^*}{1-\alpha_i^*}} > 1$.

Appendix A3: Derivation of Eq. (29)

If a change in the statutory capital tax leads to an identical change in the deductibility rate for royalties, the first-order condition for the statutory tax rate reads as

$$\frac{du(x_i, g_i)}{dt_i} = u_x \left(\frac{\partial x_i}{\partial t_i} + \frac{\partial x_i}{\partial \mu_i} \frac{d\mu_i}{dt_i} \right) + u_g \left(\frac{\partial g_i}{\partial t_i} + \frac{\partial g_i}{\partial \mu_i} \frac{d\mu_i}{dt_i} \right).$$

With $d\mu_i/dt_i = 1$ and using Eqs. (17a), (17c), (18a) and (18c), the underprovision of public goods can be measured as

$$\frac{u_g - u_x}{u_g} = \frac{t_i(n + k_i^m)\frac{\partial \alpha_i^*}{\partial t_i} + t_i k_i^m \frac{\partial \gamma_i^*}{\partial t_i} + \mu_i \frac{\partial R_i^{a*}}{\partial \mu_i} - \Delta_k \left(\frac{\partial k_i^m}{\partial t_i} + \frac{\partial k_i^m}{\partial \mu_i} \right)}{(1 - \alpha_i^*)n + (1 - \alpha_i^* - \gamma_i^*)k_i^m - R_i^*}. \quad \text{(A6)}$$

At $\lambda_i = 0$ the thin capitalization rule is binding and, therefore, $\frac{\partial \gamma_i^*}{\partial \lambda_i} = 1$ and $\frac{\partial \gamma_i^*}{\partial t_i} = 0$. Moreover, $\mu_i = t_i$. We rearrange $\left.\frac{\partial u(x_i, g_i)}{\partial \lambda_i}\right|_{\lambda_i = 0, \mu_i = t_i} > 0$ as

$$-\frac{u_g - u_x}{u_g} t_i k_i^m - \frac{u_x}{u_g} C'_\gamma(0) k_i^m + \Delta_k \frac{\partial k_i^m}{\partial \lambda_i} > 0.$$

Using Eq. (A6), $C'_\gamma(0) = 0$, $\frac{\partial k_i^m}{\partial \mu_i} = -\frac{\frac{\partial R_i^b}{\partial k_i^m}}{1-\alpha_i^*} \frac{\partial k_i^m}{\partial t_i}$ and $\frac{\partial k_i^m}{\partial \lambda_i} = -\frac{t_i}{1-\alpha_i^*} \frac{\partial k_i^m}{\partial t_i}$, further rearrangements yield

$$-t_i(n+k_i^m)\frac{\partial \alpha_i^*}{\partial t_i} - \mu_i \frac{\partial R_i^{a*}}{\partial \mu_i} + \Delta_k \left(\frac{1 - \alpha_i^* - \frac{\partial R_i^b}{\partial k_i^m}}{1 - \alpha_i^*} \right) \frac{\partial k_i^m}{\partial t_i} - \Delta_k \frac{(1 - \alpha_i^*)(n + k_i^m) - R_i^*}{1 - \alpha_i^*} \frac{\partial k_i^m}{\partial t_i} \frac{1}{k_i^m} > 0.$$

With $\Delta_k = t_i \left(1 - \alpha_i^* - \frac{\partial R_i^b}{\partial k_i^m} \right)$ and substituting for the elasticity expressions it is

$$-(1-\alpha_i^*)^2(n+k_i^m)\varepsilon_{\alpha t} - (1-\alpha_i^*)R_i^*\varepsilon_{R\mu} + \left(1 - \alpha_i^* - \frac{\partial R_i^b}{\partial k_i^m}\right)\left[(1 - \alpha_i^*)n - R_i^* + \frac{\partial R_i^b}{\partial k_i^m} k_i^m\right]\varepsilon_{kt} > 0.$$

Solving for ε_{kt}, we obtain

$$\varepsilon_{kt} > \frac{1-\alpha_i^*}{1-\alpha_i^* - \frac{\partial R_i^b}{\partial k_i^m}} \cdot \frac{(1-\alpha_i)(n+k_i^m)\varepsilon_{\alpha t} + R_i^* \varepsilon_{R\mu}}{(1-\alpha_i^*)n - \left(R_i^* - \frac{\partial R_i^b}{\partial k_i^m} k_i^m\right)}$$

which is, using $\xi_n \equiv \frac{(1-\alpha_i^*)n}{(1-\alpha_i^*)n - \left(R_i^* - \frac{\partial R_i^b}{\partial k_i^m} k_i^m\right)}$ and $\xi_R \equiv \frac{R_i^*}{(1-\alpha_i^*)n - \left(R_i^* - \frac{\partial R_i^b}{\partial k_i^m} k_i^m\right)}$, Eq. (29).

Appendix A4: Derivation of Eq. (30)

As $\frac{\partial \gamma_i^*}{\partial \lambda_i} = \frac{\partial k_i^m}{\partial \lambda_i} = 0$ for a nonbinding thin capitalization rule, it is obvious that the first-order condition (27) will always be fulfilled. Thus, if the thin capitalization rule has slack, it can be chosen arbitrarily with $\lambda_i \geq \hat{\gamma}_i$ without any effect on welfare.

The more interesting and relevant part is the case where the thin capitalization rule is binding (i.e., $\gamma_i^* = \lambda_i^*$). Analogously to Appendix A3, we rewrite $\frac{\partial u(x_i,g_i)}{\partial \lambda_i}\Big|_{\lambda_i>0,\mu_i=t_i} = 0$ as $\frac{u_g - u_x}{u_g}(t_i - C'_\gamma) = \frac{\Delta_k}{k_i^m}\frac{\partial k_i^m}{\partial \lambda_i} - C'_\gamma$.

Using Eq. (A6), $\frac{\partial k_i^m}{\partial \mu_i} = -\frac{\frac{\partial R_i^b}{\partial k_i^m}}{1-\alpha_i^*-\lambda_i^*}\frac{\partial k_i^m}{\partial t_i}$, $\frac{\partial k_i^m}{\partial t_i} = -\frac{1-\alpha_i^*-\lambda_i^*}{t_i - C'_\gamma}\frac{\partial k_i^m}{\partial \lambda_i}$, substituting for the elasticity expressions, and collecting terms leads to

$$\frac{\left[(1-\alpha_i^*)(n+k_i^m)\varepsilon_{\alpha t} + R_i^* \varepsilon_{R\mu}\right](t_i - C'_\gamma)}{(1-\alpha_i^*)n + (1-\alpha_i^*-\lambda_i^*)k_i^m - R_i^*} + C'_\gamma = \frac{(1-\alpha_i^*)n + \left(\frac{\partial R_i^b}{\partial k_I^m}k_i^m - R_i^*\right)}{(1-\alpha_i^*)n + (1-\alpha_i^*-\lambda_i^*)k_i^m - R_i^*} \cdot \frac{\Delta_k}{\alpha_i^*+\lambda_i^*} \cdot \varepsilon_{kd}$$

Applying $\Delta_k = t_i\left(1-\alpha_i^*-\lambda_i^* - \frac{\mu_i}{t_i}\frac{\partial R_i^b}{\partial k_i^m}\right)$ and $\mu_i = t_i$, the optimal share of debt financing $d_i = \alpha_i^* + \lambda_i^*$, relative to taxable profit per unit of capital – and implicitly the optimal level of deductible internal debt λ_i^* – results from the elasticity rule

$$\frac{\alpha_i^*+\lambda_i^*}{1-\alpha_i^*-\lambda_i^*-\frac{\partial R_i^b}{\partial k_i^m}} = \frac{n}{n+k_i^m}\cdot\frac{t_i}{t_i - C'_\gamma}\cdot\frac{(\omega_n+\omega_{RR})\varepsilon_{kd}}{\omega_n\varepsilon_{\alpha t} + \frac{n}{n+k_i^m}\omega_R\varepsilon_{R\mu} + \frac{n}{n+k_i^m}\frac{C'_\gamma}{t_i-C'_\gamma}}. \quad \text{(A7)}$$

If the solution of (A7) implies $\hat{\gamma}_i > \lambda_i^*$, Eq. (A7) defines the unique optimal thin capitalization rule. Otherwise, any nonbinding thin capitalization rule, i.e., any $\lambda_i^* \geq \hat{\gamma}_i$, could be implemented.

Appendix A5: Derivation of Eq. (31)

Assume that agency costs of internal debt are sufficiently low that the thin capitalization rule is binding. We use $\frac{\partial k_i^m}{\partial \lambda_i} = \left(t_i - C'_\gamma\right)\left(\frac{\partial R_i^b}{\partial k_i^m}\right)^{-1}\frac{\partial k_i^m}{\partial \mu_i}$ to rewrite the first-order condition of the thin capitalization rule (27) as

$\frac{u_x-u_g}{u_g}(t_i - C'_\gamma) - C'_\gamma + \Delta_k \frac{\partial k_i^m}{\partial \mu_i} \frac{t_i - C'_\gamma}{\frac{\partial R_i^b}{\partial k_i^m}} = 0$, which yields $\frac{u_x-u_g}{u_g} = \frac{C'_\gamma}{t_i-C'_\gamma} - \Delta_k \frac{\partial k_i^m}{\partial \mu_i} \frac{1}{\frac{\partial R_i^b}{\partial k_i^m}}$.

Using this expression, we rewrite the first-order condition for the royalty tax (28) as $\frac{C'_\gamma R_i^*}{t_i-C'_\gamma} - \Delta_k \frac{\partial k_i^m}{\partial \mu_i} \frac{R_i^*}{\frac{\partial R_i^b}{\partial k_i^m}} - \mu_i^* \frac{\partial R_i^{a*}}{\partial \mu_i} + \Delta_k \frac{\partial k_i^m}{\partial \mu_i} = 0$. Dividing by R_i^* and using the elasticity expressions yields $\frac{C'_\gamma}{t_i-C'_\gamma} - \frac{\Delta_k}{R_i^*} \varepsilon_{k\mu} \frac{k_i^m}{\mu_i^*} \left(\frac{1}{\varepsilon_{Rk}} - 1\right) - \varepsilon_{R\mu} = 0$, which, solving for μ_i^*, can be rewritten as $\mu_i^* = -\frac{\frac{\Delta_k k_i^m}{R_i^*}\left(\frac{1}{\varepsilon_{Rk}}-1\right)\varepsilon_{k\mu}}{\varepsilon_{R\mu} - \frac{C'_\gamma}{t_i - C'_\gamma}}$.

Appendix A6: Derivation of Eq. (32)

Assume that the agency costs of internal debt are so high that condition (32) implies no deduction for royalties, i.e., $\mu_i^* = 0$. Evaluating the first-order condition for the thin capitalization rule, i.e., Eq. (27), at $\lambda_i^* = 0$, we can rewrite

$$\frac{\partial u(x_i, g_i)}{\partial \lambda_i}\Big|_{\lambda_i=0,\mu_i=0} > 0 \quad \Leftrightarrow \quad -\frac{u_g - u_x}{u_g} t_i k_i^m + \Delta_k \frac{\partial k_i^m}{\partial \lambda_i} > 0$$

where we have used $C'_\gamma(0) = 0$. Replacing the measure of underprovision and the tax wedge with the respective terms from Eqs. (19) and (26), we obtain

$$-\frac{t_i(n+k_i^m)\frac{\partial \alpha_i^*}{\partial t_i} - (1-\alpha_i^*)t_i \frac{\partial k_i^m}{\partial t_i}}{(1-\alpha_i^*)(n+k_i^m)} t_i k_i^m + (1-\alpha_i^*)t_i \frac{\partial k_i^m}{\partial \lambda_i} > 0$$

and finally, by replacing $\frac{\partial k_i^m}{\partial \lambda_i} = -\frac{t_i}{1-\alpha_i^*}\frac{\partial k_i^m}{\partial t_i}$, using elasticity expressions and collecting terms, $\varepsilon_{kt} > \frac{n+k_i^m}{n}\varepsilon_{\alpha t}$.

Appendix A7: Derivation of Eq. (34)

We assume that $R_i^b > 0$ since otherwise the government has no incentive to use the royalty tax. Using the elasticity definitions, the first-order condition for the royalty tax, i.e., Eq. (28), can be rewritten as

$$\frac{u_x - u_g}{u_g} = \varepsilon_{R\mu} - \frac{\Delta_k k_i^m}{\mu_i^* R_i^*}\varepsilon_{k\mu}. \tag{A8}$$

Moreover, we can use the relationship $\frac{\partial k_i^m}{\partial t_i} = -(1-\alpha_i^* - \gamma_i^*)\left(\frac{\partial k_i^m}{\partial R_i^b}\right)^{-1}\frac{\partial k_i^m}{\partial \mu_i} = -(1-\alpha_i^*-\gamma_i^*)\frac{\varepsilon_{k\mu}}{\mu_i^* R_i^* \varepsilon_{Rk}}$ and the elasticity definitions to rewrite the measure of the underprovision of public goods, i.e., Eq. (26), as

$$\frac{u_g - u_x}{u_g} = \frac{(n + k_i^m)(1 - \alpha_i^*)\varepsilon_{\alpha t} + k_i^m(1 - \gamma_i^*)\varepsilon_{\gamma t} + \Delta_k(1 - \alpha_i^* - \gamma_i^*)\frac{\varepsilon_{k\mu}}{\mu_i^* R_i^* \varepsilon_{Rk}}}{(1 - \alpha_i^*)n + (1 - \alpha_i^* - \gamma_i^*)k_i^m}.$$

Applying Eq. (A7) and using $\frac{(1-\alpha_i^*-\gamma_i^*)k_i^m}{(1-\alpha_i^*)n+(1-\alpha_i^*-\gamma_i^*)k_i^m} = 1-\omega_n$, the first-order condition for the royalty tax , as given in Eq. (A8), can be rewritten as

$$-\frac{(n + k_i^m)(1 - \alpha_i^*)\varepsilon_{\alpha t} + k_i^m(1 - \gamma_i^*)\varepsilon_{\gamma t}}{(1 - \alpha_i^*)n + (1 - \alpha_i^* - \gamma_i^*)k_i^m} = \varepsilon_{R\mu} - \frac{\Delta_k k_i^m}{\mu_i^* R_i^*}\left(1 - \frac{1 - \omega_n}{\varepsilon_{Rk}}\right)\varepsilon_{k\mu}.$$

Solving for μ_i^*, finally, yields $\mu_i^* = -\frac{\frac{\Delta_k k_i^m}{R_i^*}\left(\left[\frac{1}{\varepsilon_{Rk}}-1\right]-\frac{\omega_n}{\varepsilon_{Rk}}\right)\varepsilon_{k\mu}}{\varepsilon_{R\mu}+\frac{(n+k_i^m)(1-\alpha_i^*)\varepsilon_{\alpha t}+k_i^m(1-\gamma_i^*)\varepsilon_{\gamma t}}{(1-\alpha_i^*)n+(1-\alpha_i^*-\gamma_i^*)k_i^m}}$.

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