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# Environmental Effects of Capital Income Taxation - A New Double Dividend?

Hendrik Ritter\* • Marco Runkel<sup>†</sup> • Karl Zimmermann<sup>‡</sup>

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## Abstract

We analyze a  $n$ -country, two-period Nash tax competition game to evaluate Sinn's proposal to use capital income taxation as a means to decelerate fossil fuel extraction (Sinn, 2008). The interest and discount rate is determined on a perfectly competitive consumer loan market on which the resource extractor acts as the loan supplier. Our first result is that, with perfectly identical countries, tax rates are inefficiently low in the Nash equilibrium of the tax competition game since the tax distortion and the environmental externality are not taken into account. The second result is that, in an asymmetric setting with resource-exporting and -importing countries, the tax can turn into a subsidy in the exporting country. Moreover, we show that partial cooperation of the importers is always beneficial to them, but can be harmful to the exporter. Finally, we identify cases where full cooperation is self-enforcing.

**Keywords:** Capital taxation • Green paradox • Non-renewable resources

**JEL Classification:** H21 · H23 · Q38 · Q54

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# 1 Introduction

It is by now widely accepted that burning fossil fuels alters the global climate via the greenhouse effect and induces significant changes to living conditions of humans – most of which are expected to be harmful or costly.<sup>1</sup> Overall damages depend primarily on accumulated emissions. Furthermore, the speed of accumulation matters since it determines whether damages begin to occur sooner or later in time. Climate policy could therefore aim at postponing extraction in case it is inevitable that most if not all deposits of fossil fuels will be exploited. In doing so, the policy flattens the time path of emissions and therefore reduces the discounted sum of damages. However, the Green Paradox, identified by Sinn (2008), indicates that the climate policy maker should be careful in designing the policy instrument. For example, a carbon tax that increases over time, an option frequently discussed in policy, might under certain conditions accelerate climate change by giving owners of fossil fuel resources the incentive to increase extraction today and reduce extraction tomorrow in order to escape the higher tax burden in the future.

Because of this problem, alternative policy measures have been discussed. An important example is a source-based tax on capital (Sinn, 2008). The basic idea of such a tax rests on the fact that owners of fossil fuel resources invest their revenues from selling the resource on the world capital markets. If the firms and households that demand this capital have to pay a tax on their interest payments or on the principal, then capital demand and therefore the interest rate on the capital market fall. As a consequence, the resource owner's incentive to supply capital and, thereby, to extract today is weakened. The time path of resource extraction and thereby emissions is flattened, as intended by the tax.

In this paper, we contribute to the discussion on the role of a source-based capital tax as a climate policy instrument. Our main contribution is to show that the usefulness of such a tax depends on whether the tax is set non-cooperatively (decentrally) by national governments or cooperatively (centrally) by at least a subset of national governments. In any case, the capital tax induces the above described positive effect of flattening the time path of emissions and thereby slowing down climate change. Nevertheless, in a fully decentralized setting, where each government only takes into account the welfare in its own country, the capital tax will be inefficient, since each government ignores the effects on welfare in other countries and therefore inflicts policy externalities on the other countries. These externalities are internalized under full cooperation so that the capital tax implements the first-best optimum. Moreover, we show that, compared to the fully decentralized case, welfare improvements may be obtained if only a subset of countries (e.g. resource importing countries) cooperate. Perhaps most interestingly, we identify cases where the threat of cooperation among a subset of countries (resource-importing

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<sup>1</sup>See Stern et al. (2006) for an overview.

countries) gives other countries (resource-exporting countries) the incentive to cooperate as well, so the fully centralized solution may be self-enforcing. In sum, our results show that some degree of coordination is required in using a source-based capital tax as a climate policy instrument. Without coordination such a tax fails to implement the first-best solution.

These results are derived in a two-period multi-country model. Each country hosts a firm that produces an output good with the help of a natural resource in each period. The resource is extracted from a fixed stock by a multinational enterprise, which invests its first-period revenue on the world capital market. In each country and period, the household consumes the output of the firms. It is the owner of the firm in its country as well as of the resource firm and uses the resulting profit income in order to finance consumption. In addition, consumption in the first period is financed by a consumer loan that the household takes out on the world capital market and that is paid back inclusive of interest payments in the second period. We model the source-based capital tax as a tax that the government of a country imposes on its household's debt repayment in the second period.<sup>2</sup> The use of the resource in production causes emissions that lead to global climate change, modeled by a damage function in each country. We concentrate on the damage in the first period in order to highlight the role of capital taxation for flattening the time path of emissions.

We first focus on the symmetric case where all countries are identical. A comparative static analysis shows that the capital tax rate of each country has the conjectured effect of flattening the time path of extraction and emissions. However, if we consider a policy game in which the countries non-cooperatively set their capital tax in order to maximize welfare of their households, the tax rate of each country causes policy externalities on the other countries. We show that in sum there are two externalities. First, the individual government takes into account only the effect of its capital tax on environmental damage in its own country, but ignores that also environmental damage in other countries is reduced (environmental externality). Second, while tax policy distorts the decision by the domestic household (decrease of loan demand) it compensates such distortion in other countries (increase of loan demand), which is also not taken into account by policy makers and to which we refer as the intertemporal fiscal distortion externality. Both externalities are positive implying that, in the symmetric Nash equilibrium of the policy game, the capital tax rates are inefficiently low.

It is obvious that this inefficiency is removed and capital taxation becomes first-best, if all countries set their rates cooperatively, taking into account the effects on the other countries' welfare. Compared to the non-cooperative solution, welfare in all countries then

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<sup>2</sup>An alternative would be to introduce a source based-tax on the capital input of firms. To keep the analysis tractable, however, we ignore capital input of firms and thereby focus on the source-based capital taxation in the household sector.

increases. More importantly, we show that it may also help when only a subset of countries plan to cooperate. To illustrate this, we focus on the (realistic) case with two resource-importing countries (that do not own a part of the resource firm) and one resource-exporting country (that fully owns the resource firm, but has negligible environmental damage). In equilibrium, resource-importing countries impose higher taxes than the resource-exporting country, which might even set a subsidy. This is due to the fact that a tax increase in any country diminishes environmental damage but also decreases the resource rent, which benefits the resource-importing countries and generates a loss for the resource-exporting country. If resource-importing countries cooperate they set higher equilibrium tax rates and yield greater welfare, which happens at the expense of the resource-exporting country, where welfare decreases. However, the resource-exporting country may increase welfare by cooperating with other countries as well. We identify cases where all countries have higher welfare under full cooperation than under partial cooperation. In these cases, the centralized (social optimum) solution is self-enforcing.

The Green Paradox has been an active field of research and debate in environmental economics lately. The very term was introduced by Sinn (2008), but earlier contributions such as Ulph and Ulph (1994) and Sinclair (1992, 1994) already pointed out this possible adverse effect of carbon or resource taxation. Recent surveys on climate change mitigation policy and the Green Paradox have been provided by van der Ploeg and Withagen (2015), Jensen et al. (2015), and van der Meijden et al. (2017), however, without reference to any type of capital or savings taxation as an instrument of climate change mitigation policy.

Among the contributions analyzing capital taxation as a climate policy instrument are van der Meijden et al. (2014) who employ a model with asymmetric countries, i.e. purely resource-exporting and resource-importing countries. They focus on the analysis of comparative static effects of carbon taxation and capital taxation on the speed of extraction. For the capital tax, modeled as a tax on household asset holdings similar to our approach, they find that extraction is slowed in period 1 when only the natural resource enters into production. Adding capital to the production function, they find the effect to be ambiguous owing to more complex mechanisms of adjustment of prices and quantities. In their model, the market discount rate depends on the marginal productivity of capital in period 2 as well as the supply of savings by asymmetric households. Also Habla (2016) studies the comparative static effect of a capital tax on the time path of resource extraction using a model with symmetric countries and where capital and the resource serve as factors of production. In contrast to the present work, the capital tax is modeled as a tax on the input of capital in production in the second period. The findings again indicate an ambiguous effect of the capital tax in period 2 on the extraction path of the resource. Following Habla (2016) this effect depends on the degree of complementarity of the two production factors. Furthermore, Habla (2016) finds that the capital tax performs less well compared to a carbon tax when fiscal policy consists

of a single tax instrument. However, he also suggests that the capital tax might have an advantage when it comes to time consistency when modeled as a household savings tax. We will take up this notion here. Furthermore, in order to conduct welfare analysis with symmetric as well as asymmetric countries, we abstract from capital as a factor of production - a detail which has been extensively studied by van der Meijden et al. (2014) and Habla (2016).

Finally, Franks et al. (2017) present a model with asymmetric countries (resource-importing and resource-exporting) and four factors of production: the natural resource, capital, locally fixed labor and tax-financed infrastructure. Due to the detailed modeling of production, they employ a numerical analysis to study taxation policy equilibria of a Nash game among local governments. The capital tax is modeled as a tax on the input of capital in local production, like in Habla (2016). Further differences in comparison to our model are that public revenues are spent entirely on productive infrastructure and that Franks et al. (2017) abstract from environmental damage. In their analysis, they find that in the Nash equilibrium the capital input tax induces faster extraction over time than the resource input tax. From there they infer that carbon taxation should be preferred to capital taxation when policy consists of a single instrument. The effects on domestic as well as foreign welfare should be quite different from the present model.

These three contributions account for general equilibrium effects, which we also do. This refers not only to considering fossil fuel supply, but also to endogenizing the resource extractor's discount rate, which represents the opportunity cost to leaving fossil resources underground. While the notion of the Green Paradox focused on including the demand side of the global market for fossil resources, most contributions studying carbon taxation and the Green Paradox follow the seminal work of Hotelling (1931) and assume a fixed interest rate. In order to endogenize the interest rate, we follow Eichner and Pethig (2011, 2013) in the general model set up.

This paper is organized as follows. Section 2 presents the structure and main assumptions of the model. Section 3 analyzes the symmetric Nash equilibrium of the non-cooperative policy game between the countries and compares the resulting capital tax rates with the first-best tax rates under full centralization. Section 4 turns to the case of asymmetric countries and partial cooperation between resource-importing countries. Section 5 concludes.

## 2 The Model

Consider a world with  $n \geq 2$  countries and two periods, where there is a non-replenishable natural resource with initial stock  $\bar{e}$ . This resource stock is extracted by a single, representative **resource-extracting firm** that is the global supplier of the resource. The firm must decide whether to extract in the first or second period. For simplicity, extraction

costs are assumed to be negligible.

The total resource rent is therefore given by the discounted sum of sales. In period  $t = 1, 2$ , the firm extracts  $e_t^s$  of the resource and sells this amount on the world resource market at price  $p_t$ . The revenues from period 1,  $p_1 e_1^s$ , are supplied on the world capital market at rate  $r$ , resulting into earnings of  $r p_1 e_1^s$  in period 2. Profit maximization of the extraction firm can thus be written as

$$\max_{e_1^s, e_2^s} \quad \pi^R = [1 + r] p_1 e_1^s + p_2 e_2^s \quad (1)$$

$$\text{s. t.} \quad \bar{e} = e_1^s + e_2^s, \quad (2)$$

where  $\pi^R$  in (1) is the end value of the resource rent and (2) represents the resource constraint. The resulting first-order condition reads

$$p_1 [1 + r] = p_2. \quad (3)$$

This is the well-known Hotelling rule stating that the time path of discounted resource prices has to be flat. As long as prices  $p_1$  and  $p_2$  are greater than zero, which we assume throughout, the total resource stock  $\bar{e}$  will be fully exploited.

Next to that, there is a representative **production firm** in each country producing a homogeneous consumption good. The natural resource is the only factor of production. In period  $t$ , the firm in country  $i = 1, \dots, n$  uses  $e_{it}$  units of the resource in order to produce output according to the production function  $F(e_{it})$  with  $F' > 0 > F''$ . Normalizing the price of output to one, profit maximization of the firm in country  $i$  in period  $t$  reads

$$\max_{e_{it}} \pi_{it} = F_t(e_{it}) - p_t e_{it}. \quad (4)$$

The resulting first-order condition is given by

$$F'_t(e_{it}) = p_t. \quad (5)$$

It equates the marginal returns of the resource to the resource price.

Each country is populated by a **single, representative household**. It is the owner of the domestic production firm and holds a share  $\mu_i \in [0, 1]$  of the resource-extracting firm. Hence, the household in country  $i$  has a profit income of  $\pi_{i1}$  in period 1 and  $\pi_{i2} + \mu_i \pi^R$  in period 2. In addition, the household in country  $i$  takes out a loan  $b_i$  on the world capital market in period 1, which she has to repay inclusive of interest payments in period 2. Moreover, the household must pay a tax on the loan. The tax rate in country  $i$  is denoted by  $\tau_i$  and the revenues from this tax,  $\tau_i b_i$ , are transferred back to the consumer in a lump-sum way. This tax on consumer loans represents the source-based capital tax in our model.

In period  $t$ , the household in country  $i$  uses its income net of taxes in order to finance private consumption  $c_{it}$ , which yields life-time utility given by the function  $u_i = V(c_{i1}) + c_{i2}$ . The choice of this functional form guarantees that consumption  $c_t$  is a normal good in both periods with positive but decreasing marginal utility in the first period ( $V' > 0 > V''$ ).

Each household maximizes life-time utility. The optimization problem of the household in country  $i$  reads

$$\max_{c_{i1}, c_{i2}, b_i} \quad U_i = V(c_{i1}) + c_{i2} \quad (6)$$

$$\text{s. t.} \quad c_{i1} = \pi_{i1} + b_i, \quad (7)$$

$$c_{i2} = \pi_{i2} + \mu_i \pi^R + T_i - [1 + r + \tau_i] b_i, \quad (8)$$

where equations (7) and (8) represent the budget constraints in period 1 and 2 respectively. Inserting (7) and (8) in (6) and taking the derivative with respect to  $b_i$  gives the first order condition

$$V'(c_{i1}) = 1 + r + \tau_i. \quad (9)$$

This condition equates the intertemporal rate of substitution to the gross interest factor. It determines optimal borrowing of the household as a function of the tax rate. The choice of a quasi-linear utility function rules out income effects on first-period consumption through a change of the gross interest rate, meaning that the substitution effect is dominant in the change of loan demand. This is equivalent to assuming a positive elasticity of savings with respect to the interest rate.

On the world capital market, the supply of the resource extractor meets the demand of the households. Formally, we obtain the market clearing condition

$$\sum_{i=1}^n b_i = p_1 e_1^s. \quad (10)$$

On the market for the resource, the supplier is the resource extractor while the firms demand the resource. In period  $t$ , we obtain the market clearing condition

$$\sum_{i=1}^n e_{it} = e_t^s. \quad (11)$$

Finally, in each period, we have a world product market, where the production firms supply the good and households demand it. Due to Walras' law, however, we can ignore the equilibrium conditions and normalize the prize to unity (see Eichner and Pethig, 2013).



Using the resource in production is assumed to generate emissions in a one-to-one relation. Emissions, in turn, are supposed to produce environmental damages, which is not taken into account by private actors. This damage is represented by the damage function  $D(e_1^s)$ . It represents net damage from “early” emissions (in  $t = 1$ ), and satisfies  $D' > 0$  and  $D'' \geq 0$ , i.e. positive and non-decreasing marginal damage. The focus on damage from first-period emissions can be justified by several arguments: First, the inclination of the emission path determines the pace of atmospheric greenhouse gas (GHG) concentration increase. If the emission path is sufficiently steep, the GHG concentration might rise disproportionately fast due to the saturated capacity of natural sinks, which normally keep a large part of emissions from entering into the atmosphere. This in turn could lead to a temporary overshoot of the new long-term level of atmospheric greenhouse gas concentration, which leads to a higher level of damages. Second, apart of a possible overshooting, a faster emission path leads to a quicker rise in greenhouse gas concentration and to an earlier commence of damages and a higher present value of the social cost of carbon (see Hoel, 2011). Third, as we consider climate change, we concentrate on stock damages. When we explicitly model the environmental damage from the second period, we may define  $D(e_1^s, e_2^s) := D_1(e_1^s) + D_2(e_1^s + e_2^s)$ , with  $D'_1 - D'_2 > 0$  and  $D''_1(\cdot) + D''_2(\cdot) \geq 0$ . Assuming zero extraction costs we have  $\bar{e} = e_1^s + e_2^s$  and therefore the overall damage function only depends on first-period extraction  $D(e_1^s) := D_1(e_1^s) + D_2(\bar{e})$ .

For later purposes we will derive the effects of the policy on the equilibrium allocation in the factor and the savings market (and consequently also in the product market). This equilibrium allocation is determined by equations (3), (5), (9), (10), and (11). In the following we focus on a symmetric situation where each country uses the same tax rate  $\tau_i = \tau$  for all  $i = 1, \dots, n$  and each household has the same share  $\mu_i = \mu$  in the global resource rent given by equation (1). From (5) it follows that  $F'_{it} = F'_t$  and  $F''_{it} = F''_t$  and thus  $e_{it} = e_t$  so that we have  $\pi_{it} = \pi_t$  and  $T_i = T$ . From there and from (9) it follows that  $b_i = b = \frac{1}{n}p_1e_1^s = \mu\pi_1^R$ ,  $c_{it} = c_t$  as well as  $V'(c_{i1}) = V'(c_1)$ .<sup>3</sup>

A change in the tax rate  $\tau_i$ , holding the policy variables of all other countries constant and evaluating at the symmetric situation, has the following effect on equilibrium prices

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<sup>3</sup>This also applies to all second derivatives of the utility functions.

and quantities (see Appendix A for a derivation.):

$$\frac{\partial r}{\partial \tau_i} = -\frac{1}{n} \frac{F'_1 F''_2 + F'_2 F''_1}{F'_1 F''_2 + F'_2 F''_1 + (F'_1)^3 V''} < 0, \quad (12)$$

$$\frac{\partial p_1}{\partial \tau_i} = \frac{1}{n} \frac{F''_1 (F'_1)^2}{F'_1 F''_2 + F'_2 F''_1 + (F'_1)^3 V''} > 0, \quad (13)$$

$$\frac{\partial p_2}{\partial \tau_i} = -\frac{1}{n} \frac{F''_2 (F'_1)^2}{F'_1 F''_2 + F'_2 F''_1 + (F'_1)^3 V''} < 0, \quad (14)$$

$$\frac{\partial e_1^s}{\partial \tau_i} = \frac{(F'_1)^2}{F'_1 F''_2 + F'_2 F''_1 + (F'_1)^3 V''} < 0, \quad (15)$$

$$\frac{\partial b_i}{\partial \tau_i} = \frac{(n-1)(F'_1 F''_2 + F'_2 F''_1 + (F'_1)^3 V'') + V'' (F'_1)^2 [F'_1 + F'_1 e_1]}{n V'' (F'_1 F''_2 + F'_2 F''_1 + (F'_1)^3 V'')} < 0, \quad (16)$$

$$\frac{\partial b_j}{\partial \tau_i} = \frac{e_1 (F'_1)^2 F''_1 V'' - F'_1 F''_2 - F'_2 F''_1}{n V'' (F'_1 F''_2 + F'_2 F''_1 + (F'_1)^3 V'')} > 0, \quad (17)$$

with  $F''_t = F''_t(e_t)$ .

The intuition of these results is as follows: On the capital market, an increased capital tax in country  $i$  reduces demand for capital in country  $i$  ( $b_i$ ), see (16). This leaves the capital market with excess supply and the interest rate adjusts downward according to (12). Households in other countries  $j \neq i$  will therefore demand more capital as can be seen in (17). The fall in the interest rate implies a lower discount rate for the extractor, which gives it the incentive for postponing extraction from the first to the second period, see (15). This postponement, in turn, increases the scarcity of the resource in the first period and makes it more abundant in the second period, with the consequence that the resource price rises in the first and falls in the second period, as can be seen in (13) and (14).

It is worth mentioning that the postponement of resource extraction identified in (15) is exactly what Sinn (2008) had in mind when proposing a source-based capital tax for flattening the time path of resource use and emissions. And for a closed economy, this beneficial effect should imply that the capital tax may be used as a Pigouvian instrument with which the environmental externality can be internalized. However, in a multi-country framework like ours, in which countries may decentrally set their tax, the question arises, whether the capital tax is still efficient in internalizing the pollution externality. We therefore turn to the decentralized choice of the capital tax.

### 3 Symmetric Policy Game

We now turn to the choice of capital tax rates by the local governments and first focus on the fully decentralized case where each government non-cooperatively sets its capital tax rate in order to maximize welfare in its own country while ignoring the effect of welfare on

the other countries. Welfare of a country equals utility of the household in this country less environmental damage. Formally, the government of country  $i$  maximizes

$$W_i = V(c_{i1}) + c_{i2} - D(e_1^s), \quad (18)$$

taking into account the private budget constraints in (7) and (8) as well as the effects of the tax rates determined by the comparative static results (12) - (17). In solving the above problem, country  $i$  takes as given the tax rate  $\tau_j$  of all other countries  $j \neq i$ . Hence, we obtain a non-cooperative (Nash) policy game between the  $n$  countries.

In this section, we assume all countries to be symmetric ( $\mu_i = \frac{1}{n}$ ) and focus on the symmetric Nash equilibrium of the policy game. This equilibrium is determined by the first-order condition of country  $i$ 's welfare maximization given by

$$\frac{\partial W_i}{\partial \tau_i} = \underbrace{(V' - 1 - r) \frac{\partial b_i}{\partial \tau_i}}_{CE_{ii}(-)} - \underbrace{V' \frac{\partial p_1}{\partial \tau_i} e_{i1}}_{PE_{ii1}(-)} - \underbrace{\frac{\partial p_2}{\partial \tau_i} e_{i2}}_{PE_{ii2}(+)} + \underbrace{\frac{\partial p_2}{\partial \tau_i} \mu_i \bar{e}}_{RE_{ii}(-)} - \underbrace{\frac{\partial r}{\partial \tau_i} b_i}_{IE_{ii}(+)} - \underbrace{D' \frac{\partial e_1^s}{\partial \tau_i}}_{EE_{ii}(+)} = 0, \quad (19)$$

where we have used the first-order condition of the firm, given by (5).

The total impact of country  $i$ 's tax rate on country  $i$ 's welfare in (19) is composed of several effects. Profit income of country  $i$ 's household in period 1 is affected negatively by an increase in country  $i$ 's tax rate ( $PE_{ii1}$ ), since the resource becomes more costly in period 1 due to the comparative static effect in (13). The opposite happens to profit income from production in period 2 ( $PE_{ii2}$ ), since the resource becomes cheaper in period 2, see (14). For the same reason the resource rent declines ( $RE_{ii}$ ). Moreover, interest payments of the household decrease ( $IE_{ii}$ ) due to the fall in the interest rate identified in 12. The decrease in capital demand revealed in (16) implies a fall in period 1 consumption and a rise in period 2 consumption. The associated effect on welfare in country  $i$  ( $CE_{ii}$ ) is negative due to (16) and since marginal utility in period 1 is higher than the interest paid per unit of capital in period 2 ( $V' > 1 + r$ ), see the first-order condition of the private household given by (9).<sup>4</sup> All these effects influence the welfare of country  $i$  via consumption in period 1 and 2. Moreover, welfare in country  $i$  is improved by a decline in environmental damage, since the increase in country  $i$ 's capital tax rate reduces first-period resource extraction and, thus, emissions ( $EE_{ii}$ ).

The first-order condition of the policy maker can be further simplified using the first-order condition of the resource extractor, given by (3), and the first-order condition of

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<sup>4</sup>This requires a positive rate  $\tau_i$ . Since the equilibrium tax rates in the symmetric model are greater than zero, see equation (21), we determine the sign of  $CE_{ii}$  only for  $\tau_i > 0$ .

the household, given by (9), which gives

$$\frac{\partial W_i}{\partial \tau_i} = \underbrace{\tau_i \left( \frac{\partial b_i}{\partial \tau_i} - \frac{\partial p_1}{\partial \tau_i} e_{i1} \right)}_{IFDE_{ii}(-)} \underbrace{- D' \frac{\partial e_1^s}{\partial \tau_i}}_{EE_{ii}(+)} = 0. \quad (20)$$

After consolidation, there remains an effect on utility, to which we refer to as the intertemporal fiscal distortion effect ( $IFDE_{ii}$ ). It is negative, firstly, since  $\tau_i > 0$  distorts the capital market where the intertemporal rate of substitution is greater than the relative intertemporal price for a capital, see equation (9), and, secondly, since the net effect on income means a reduction of first period income.<sup>5</sup> Finally, the environmental effect  $EE_{ii}$  remains also in the consolidated representation of marginal welfare in country  $i$ .

Inserting the comparative static results given by (13), (15) and (16) we can solve the first-order condition (20) for a non-closed-form expression of the capital tax rate in the Nash equilibrium, which reads

$$\tau^\circ = \frac{nD'(F_1')^2V''}{(n-1)(F_1'F_2'' + F_2'F_1'') + n(F_1')^3V''} > 0. \quad (21)$$

In order to assess whether this tax rate is efficient, we compute the policy externality, i.e. the effect of one country's tax rate on the welfare of other countries. If this externality is positive (negative), then the equilibrium capital tax rate is inefficiently low (high).

Computing the cross-country derivative of the welfare function defined in (18) and taking into account the first-order condition of the firm, given by (5), we obtain

$$\frac{\partial W_j}{\partial \tau_i} = \underbrace{(V' - 1 - r) \frac{\partial b_j}{\partial \tau_i}}_{CE_{ij}(+)} \underbrace{- V' \frac{\partial p_1}{\partial \tau_i} e_{j1}}_{PE_{ij1}(-)} \underbrace{- \frac{\partial p_2}{\partial \tau_i} e_{j2}}_{PE_{ij2}(+)} \underbrace{+ \mu_j \bar{e} \frac{\partial p_2}{\partial \tau_i}}_{RE_{ij}(-)} \underbrace{- \frac{\partial r}{\partial \tau_i} b_j}_{IE_{ij}(+)} \underbrace{- D' \frac{\partial e_1^s}{\partial \tau_i}}_{EE_{ij}(+)}. \quad (22)$$

The impact of a change of country  $i$ 's capital tax on welfare in a foreign country is again composed of several effects. Profit income in period 1 in country  $j$  is negatively affected by a rise in country  $i$ 's tax rate ( $PE_{ij1} < 0$ ) due to the rise in the resource price, given by the comparative static effect in (13). On the contrary, profit income in period 2 in country  $j$  is positively affected by a rise in country  $i$ 's tax rate ( $PE_{ij2}$ ) due to the fall of the resource price in period 2, given by (14). Furthermore, utility is also affected by a decreasing resource rent for the same reason ( $RE_{ij}$ ). The interest payments by the household in country  $j$  decline ( $IE_{ij}$ ) due to the fall in the interest rate. These four effects are identical to those for the household in country  $i$ . However, the effect of raising country  $i$ 's tax on credit demand by the household in country  $j$  is positive (see 17), instead of negative as in the case of the household in country  $i$ . Together with an intertemporal marginal rate of substitution higher than the market interest rate this gives a positive

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<sup>5</sup>The net effect comprises decreasing capital demand and profit income in period 1, see (13) and (16).

effect of credit demand on welfare ( $CE_{ij}$ ). Finally, raising the tax in country  $i$  positively affects welfare in country  $j$  via a postponement of extraction and consequently reduced environmental damage ( $EE_{ij}$ ), see comparative static effect given by (12). Again, this effect is identical to the environmental effect in country  $i$  arising from a change in country  $i$ 's tax rate.

Considering the first-order condition of the resource extractor, given by (3), and the household's first order condition (9) in (22) we obtain the consolidated external effects of country  $i$ 's tax policy on country  $j$ 's welfare

$$\frac{\partial W_j}{\partial \tau_i} = \underbrace{\tau_j \left( \frac{\partial b_j}{\partial \tau_i} - \frac{\partial p_1}{\partial \tau_i} e_{j1} \right)}_{IFDE_{ij}} - \underbrace{D' \frac{\partial e_1^s}{\partial \tau_i}}_{EE_{ij}(+)}. \quad (23)$$

Just as could be seen above for welfare in country  $i$ , we find that the net effect on utility depends partly on the credit demand effect  $CE_{ij}$  and partly on the profit income effect in period 1  $PE_{ij1}$ . However, since the household in country  $j$  increases its demand for debt in period 1, the  $IFDE_{ij}$  comprises a positive and a negative partial effect, where the latter goes back to decreasing profit income in period 1. Using (13), (12) as well as (17) in (23) and considering  $\tau_j = \tau^\circ > 0$  from (21) we find

$$\frac{\partial W_j}{\partial \tau_i} = \tau^\circ \frac{-F_1' F_1'' - F_2' F_1''}{n(F_1' F_1'' + F_2' F_1'' + V''(F_1')^3)} - D' \frac{(F_1')^2}{n(F_1' F_1'' + F_2' F_1'' + V''(F_1')^3)} > 0, \quad (24)$$

which states that at the Nash equilibrium this external effect of a marginal change in country  $i$ 's tax rate on country  $j$ 's welfare is positive while the intertemporal fiscal distortion effect is positive as well.

Hence, despite the fact that an increase in the capital tax rate of a country reduces first-period resource extraction and emissions, as conjectured by e.g. Sinn (2008), in a fully decentralized economy where each government chooses its tax rate only to maximize welfare in its own country, the capital tax rate is inefficiently low. The rationale can be explained with the two policy externalities identified in (24). First, each country takes into account that an increase in its capital tax reduces emissions and thus environmental damage suffered by its household. However, it ignores that environmental damage experienced by the households in the other countries declines as well (environmental externality). Second, the same argument holds with respect to the market distortion caused by capital tax policy. Each country takes into account the effects on its own household but ignores that an increase in its capital tax rate attenuates the distortion abroad (intertemporal fiscal distortion externality). As both policy externalities are positive, the equilibrium capital tax rates are inefficiently low.

**Proposition 1.** *In the symmetric Nash equilibrium of the fully decentralized policy game, the capital tax rates  $\tau_i^\circ$  are inefficiently low.*

*Proof.* See Appendix B. ■

Of course, if all countries cooperate, i.e. each country sets the capital tax rate in order to maximize the sum of welfare of all countries, the externalities will be internalized and the capital tax rates become efficient. Formally, this means that the sum of welfare levels in all countries is subject to optimization of each local policy maker. The first-order condition consequently reads

$$\frac{\partial(W_i + \sum_{k=1, k \neq i}^n W_k)}{\partial \tau_i} = \frac{\partial W_i}{\partial \tau_i} + \sum_{k=1, k \neq i}^n \frac{\partial W_k}{\partial \tau_i} = 0. \quad (25)$$

Using (20) and (23) as well as (13), (15), (16), (17), and again the symmetry assumption gives

$$\tau_i^* = \tau^* = \frac{nD'}{F'_1} > 0. \quad (26)$$

In this fully centralized case, the capital tax does not only have the desired effect to flatten the time path of emissions, but is also efficient. However, full cooperation is hardly expected to be achieved in reality and neither is perfect symmetry among countries. We therefore turn to a more realistic setting with resource-exporting and -importing countries where the latter cooperate in setting their capital tax rates.

## 4 Asymmetric Policy Game

There are two resource-importing countries  $A$  and  $B$  and one resource-exporting country  $R$ . The resource-exporter owns the whole resource stock, so that  $\mu_R = 1$  and  $\mu_A = \mu_B = 0$ . Moreover, we assume that the resource exporter faces negligible climate damage, i.e. the damage  $D(e_1^s)$  does not enter welfare of country  $R$ .<sup>6</sup> Analyzing this asymmetric case, we will not only consider full non-cooperation and full cooperation, but also partial cooperation where countries  $A$  and  $B$  set their capital tax rates in order to maximize joint welfare of their households and ignoring welfare of country  $R$ . As an example, one can think of the exporting country to be Saudi Arabia and the two resource-importing countries to be the European Union as a regional block that coordinates its regional policy.

The analysis of this asymmetric setting is quite complicated and we will therefore later on focus on specific functional forms and on numerical simulations. In order to get an intuition of what is going on in the asymmetric case, however, it is useful to have a look at the welfare effects of the capital tax rate in the general case. Let us start with the

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<sup>6</sup>This assumption may either be motivated by really small damages in resource-rich countries or by the fact that the governments of such countries often ignore the implications of climate damage.

resource-importing countries. Taking into account  $\mu_A = \mu_B = 0$  and computing the derivative of country  $i$ 's welfare function (18) with respect to  $\tau_i$  for  $i = A, B$ , we obtain

$$\frac{\partial W_i}{\partial \tau_i} = \underbrace{(V' - 1 + r) \frac{\partial b_i}{\partial \tau_i}}_{CE_{ii}} - \underbrace{V' \frac{\partial p_1}{\partial \tau_i} e_{i1}}_{PE_{ii1}} - \underbrace{e_{i2} \frac{\partial p_2}{\partial \tau_i}}_{PE_{ii2}} - \underbrace{\frac{\partial r}{\partial \tau_i} b_i}_{IE_{ii}} - \underbrace{D'_i \frac{\partial e_1^s}{\partial \tau_i}}_{EE_{ii}}, \quad i = A, B. \quad (27)$$

There are two differences to the corresponding expression (19) in the symmetric case. First, the comparative static effects of the tax rate on price, capital and the resource are no longer given by (12) - (17), but are much more complicated due to the country asymmetry. Second, an increase in the capital tax rate of the pure resource-importing country does not have a negative effect on the household's income via a change in profit from the resource extracting firm, since the household in the resource-importing country is not an owner of this firm. Formally, the term  $RE_{ii}$  is missing in (27). Intuitively, the tax burden of a resource importer's capital tax is now fully (instead of partially) exported to the resource exporting country. Even without partial cooperation, this effect gives the resource importer the incentive to increase the tax rate compared to the fully symmetric case (but keep in mind, that a rigorous comparison with the symmetric case is not possible since the comparative static effects are different under symmetry).

The welfare effect of the capital tax rate in the resource-exporting country is obtained from differentiating the welfare function (18) for  $i = R$  with respect to  $\tau_R$ , taking into account  $\mu_R = 1$  as well as ignoring the environmental damage. We obtain

$$\frac{\partial W_R}{\partial \tau_R} = \underbrace{(V'_R - 1 + r) \frac{\partial b_R}{\partial \tau_R}}_{CE_{RR}} - \underbrace{V'_R \frac{\partial p_1}{\partial \tau_R} e_{R1}}_{PE_{RR1}} - \underbrace{\frac{\partial p_2}{\partial \tau_R} e_{R2}}_{PE_{RR2}} + \underbrace{\frac{\partial p_2}{\partial \tau_R} \bar{e}}_{RE_{RR}} - \underbrace{\frac{\partial r}{\partial \tau_R} b_R}_{IE_{RR}}. \quad (28)$$

Compared to the symmetric case, we have three differences. First, the comparative static effects of the tax rates are again more complicated than in the symmetric case. Second, there is no longer a positive effect of the capital tax rate of a resource-exporting country on this country's environment since the environmental damage does not enter the welfare function. Third, the effects in (28) capture the full fall of profit income from the resource-extracting firm since the household in country  $R$  is now the sole owner of this firm. The second and third differences ceteris paribus give the resource-exporting country the incentive to lower its tax rate, compared to the symmetric case. In fact, in our numerical analysis we identify cases where the resource-exporting country subsidizes capital demand of its household.

However, an analysis with general functional forms is not tractable in the asymmetric case. We therefore confine ourselves to an example. Utility is supposed to be quadratic in period-1 consumption and linear in period-2 consumption. Production is linear in period 1 and quadratic in period 2. The former assumption leads to profits being zero in period

1. Environmental damage is linear in period-1 extraction. Formally, we have

$$U(c_{i1}, c_{i2}) = \gamma c_{i1} - \frac{\eta}{2} [c_{i1}]^2 + c_{i2}, \quad (29)$$

$$F_1(e_{i1}) = \alpha e_{i1}, \quad (30)$$

$$F_2(e_{i2}) = \alpha [1 + \rho] e_{i2} - \frac{\beta}{2} e_{i2}^2, \quad (31)$$

$$D_i = \delta e_1^s, \quad (32)$$

where  $\alpha, \beta, \gamma, \delta, \eta, \rho > 0$ . Note that  $F_t$  denotes the production function in period  $t = 1, 2$  and  $D_i$  the environmental damage in country  $i = A, B$ . Damage in country  $R$  is zero by assumption.

With these specifications, the first-order conditions (9) and (5) of the household and the firm can be written as

$$0 = \alpha - p_1, \quad (33)$$

$$0 = \alpha[1 + \rho] - \beta e_{i2} - p_2, \quad (34)$$

$$0 = \gamma - \eta b_i - 1 - r - \tau_i, \quad (35)$$

for  $i = A, B, R$ . These conditions together with the market clearing conditions (10) and (11) determine the resource allocation  $(e_{i1}, e_{i2})$ , capital demand  $b_i$ , resource prices  $p_1$  and  $p_2$  and the interest rate  $r$  as function of the tax rates  $\tau_i$  for  $i = A, B, R$ . Solving gives the explicit solutions, which read

$$r = \frac{3\alpha^2\rho\eta - \beta(3 - 3\gamma + \alpha\bar{e}\eta + \tau_A + \tau_B + \tau_R)}{3(\beta + \alpha^2\eta)}, \quad (36)$$

$$p_1 = \alpha, \quad (37)$$

$$p_2 = \frac{\alpha(3\alpha^2(1 + \rho)\eta + \beta(3\gamma - \alpha\eta\bar{e} - \tau_A - \tau_B - \tau_R))}{3(\beta + \alpha^2\eta)}, \quad (38)$$

$$e_1^s = \frac{\beta\bar{e} - \alpha(3 + 3\rho - 3\gamma + \tau_A + \tau_B + \tau_R)}{\beta + \alpha^2\eta}, \quad (39)$$

$$e_{i1} = \frac{\beta\bar{e} - \alpha(3 + 3\rho - 3\gamma + \tau_A + \tau_B + \tau_R)}{3(\beta + \alpha^2\eta)}, \quad (40)$$

$$e_{i2} = \frac{\alpha(3 + 3\rho - 3\gamma + \alpha\bar{e}\eta + \tau_A + \tau_B + \tau_R)}{3(\beta + \alpha^2\eta)}, \quad (41)$$

$$b_i = \frac{\alpha\beta\bar{e}\eta + 3\alpha^2\eta(\gamma - 1 - \rho - \tau_i) + \beta(-2\tau_i + \sum_{j \neq i} \tau_j)}{3(\beta + \alpha^2\eta)}. \quad (42)$$

In accordance with the general case, a tax rate increase in country  $i = A$  increases the fossil fuel consumption in period 2 ( $e_{i2}$ ) as well as loans of foreign households (for  $i = A$  that is  $b_B, b_R$ ). At the same time an increase in  $\tau_i$  decreases loans of the domestic household ( $b_A$ ) as well as the interest rate  $r$ , the resource price in period 2, and resource



consumption and supply in period 1 ( $e_{i1}, e_1^s$ ).

Inserting the equilibrium values into the welfare function, we obtain

$$W_i = \gamma b_i - \frac{\eta}{2}[b_i]^2 + \alpha[1 + \rho]e_{i2} - \frac{\beta}{2}[e_{i2}]^2 - p_2 e_{i2} + \tau_i b_i - (1 + r + \tau_i)b_i - \delta e_1^s \quad i = A, B \quad (43)$$

$$W_R = \gamma b_R - \frac{\eta}{2}[b_R]^2 + \alpha[1 + \rho]e_{R2} - \frac{\beta}{2}[e_{R2}]^2 - p_2 e_{R2} + p_2 \bar{e}^s + \tau_R b_R - (1 + r + \tau_R)b_R \quad (44)$$

where  $e_{i1}, e_{i2}, b_i$  for  $i = A, B$  and  $e_1^s$  and  $p_2$  depend on  $\tau_i$  for  $i = A, B, R$  according to our results derived above.

## 4.1 Efficient (Cooperative) Solution

As a benchmark, we first consider the efficient solution, chosen by a social planner that sets the tax rates in order to maximize the sum of welfare  $W_A + W_B + W_R$ . In Appendix C we show that the solution to this welfare maximization is

$$\tau_A^* = \tau_B^* = \tau_R^* = \frac{2\delta}{\alpha} =: \tau^*. \quad (45)$$

Equation (45) represents the Pigouvian solution. The efficient tax rates reflect the marginal environmental damage in country  $A$  and  $B$  in terms of first-period output, i.e.  $\frac{2\delta}{\alpha}$ . This interpretation is confirmed by the fact that in the absence of environmental damage, the optimal tax rates in (45) are equal to zero (since then  $\delta = 0$ ). Asymmetries in rent ownership do not come into play here since only the sum of national welfare levels is maximized and second-period consumption enters welfare linearly.

## 4.2 Nash Equilibrium Among Non-cooperating Countries

Next, we consider the fully non-cooperative case where each country sets its capital tax rate in order to maximize just its own welfare, taking as given the capital tax rate of the other countries. In the equilibrium of this Nash policy game the countries set the tax rates (see Appendix D)

$$\tau_A^\circ = \tau_B^\circ = \frac{\alpha\eta [\beta\bar{e}(2\beta + 3\alpha^2\eta) + 3\delta(8\beta + 9\alpha^2\eta)]}{9(\beta + \alpha^2\eta)(2\beta + 3\alpha^2\eta)} > 0, \quad (46)$$

$$\tau_R^\circ = -\frac{2\alpha\beta\eta(2\beta\bar{e} + 3\alpha^2\bar{e}\eta - 3\delta)}{9(\beta + \alpha^2\eta)(2\beta + 3\alpha^2\eta)} \leq 0. \quad (47)$$

In order to understand these results, it is useful to distinguish between the cases with and without environmental damages in order to disentangle the effects from strategic

taxation in the presence of resource rents and the effect of the climate externality.

In the absence of environmental damage ( $\delta = 0$ ), the importing countries  $A$  and  $B$  choose a capital tax rate greater than zero ( $\tau_A^\circ = \tau_B^\circ > 0$ ) and the resource-exporting country  $R$  a capital tax rate of less than zero ( $\tau_R^\circ < 0$ ). In the asymmetric setting, the importing countries do not suffer from losses in the resource rent, but benefit from lower resource prices and, thus, higher firm profits in  $t = 2$  as well as from lower interest rates ( $PE_{ii2}$  and  $IE_{ii}$  in equation (27); remember that first-period profits and, thus,  $PE_{ii1}$  is zero). This effect overcompensates the negative effect from the capital demand effect  $CE_{ii}$ , so that countries  $A$  and  $B$  choose positive tax rates. The picture is different for the resource-supplying country. We here observe the same effects of the marginal tax rate on second-period firm profit and interest payments as for countries  $A$  and  $B$  ( $PE_{RR2}, IE_{RR}$ ). But at the same time a tax increase in country  $R$  lowers the resource rents ( $RE_{RR}$ ). As country  $R$  receives the entire global resource rent the latter effect is stronger than the former giving country  $R$  the incentive to subsidize capital demand of its household. However, lowering the tax also stimulates capital demand in country  $R$  which, together with  $\tau_R < 0$ , is a negative effect on domestic utility, just like in the resource-import-countries.

Introducing climate damages in the resource-importing countries ( $\delta > 0$ ) leads to a rise in the equilibrium capital tax rates in all countries. The reason is that each resource-importing country now takes into account the environmental damage in its country ( $EE_{ii}$ ) and, thus, chooses a higher tax rate. The resource-exporting country follows since the capital tax rates of the countries are strategic complements. To formally see this note that from the welfare functions in (43) and (43) we obtain

$$\frac{\partial^2 W_i}{\partial \tau_i \partial \tau_R} = \frac{\partial^2 W_R}{\partial \tau_R \partial \tau_i} = \frac{\beta}{9\eta(\beta + \alpha^2\eta)} > 0 \quad i = A, B. \quad (48)$$

That tax rates are strategic complements is owed to the specific functional forms of our example as well as to the assumption of fix total extraction. Thus it need not generally be the case that higher tax rates in importer countries motivate higher taxes in exporter countries.<sup>7</sup>

Given our choice of specific functional forms, strategic complementarity implies that the sign of  $\tau_R$  is indeterminate. Hence, what was a subsidy in the absence of environmental damage ( $\delta = 0$ ) may turn into a tax on capital demand if damages are considered ( $\delta > 0$ ). In order to assess efficiency of the non-cooperative policy equilibrium with asymmetric

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<sup>7</sup>Absolute values of variables, given by (36) – (42), depend on all tax rates whereas their partial derivatives are invariant to the level of tax rates. Thus,  $IE_{ii}, PE_{ii2}$  become stronger when tax rates rise anywhere, while  $RE_{ii}$  and  $CE_{ii}$  stay constant. So, when higher damage motivates the resource importers to set higher tax rates, the resource-exporting country experiences a constant marginal burden through  $RE_{iR}$  and  $CE_{iR}$  while the marginal benefit via  $IE_{iR}, PE_{iR2}$  increases. So it reduces its subsidy.

countries, we ask: What is the relation of the equilibrium tax rates  $\tau_i^\odot$  for  $i = A, B, R$  to the efficient tax rate  $\tau_i^* = \frac{2\delta}{\alpha}$  and what are the consequences for welfare? These questions are answered in the following proposition.

**Proposition 2.** *In the asymmetric setting with two resource-importing countries  $A$  and  $B$  and one resource-exporting country  $R$  and the functional forms specified in (29) - (32), the relation of the equilibrium tax rates  $\tau_i^\odot$  and the welfare levels  $W_i^\odot$  to the efficient tax rates  $\tau_i^*$  and welfare levels  $W_i^*$  for  $i = A, B, R$  is represented in the following table.*

country	$\delta > 0$	$\delta = 0$
$i = A, B$	$\tau_i^\odot > 0$	$\tau_i^\odot > 0$
	$\tau_i^\odot \leq \tau_i^*$	$\tau_i^\odot > \tau_i^*$
	$W_i^\odot < W_i^*$	$W_i^\odot < W_i^*$
$i = R$	$\tau_R^\odot \leq 0$	$\tau_R^\odot < 0$
	$\tau_R^\odot < \tau_R^*$	$\tau_R^\odot < \tau_R^*$
	$W_R^\odot \leq W_R^*$	$W_R^\odot < W_R^*$

*Proof.* See Appendix E ■

Let us start with the case where environmental damage is absent ( $\delta = 0$ ). In this case, the equilibrium tax rates of the resource-importing countries are positive and inefficiently high, while the tax rate of the resource-exporting country is negative and inefficiently low. Welfare is inefficiently low in all countries. The driving force behind these results is the asymmetric distribution of resource ownership. Because the resource-importing countries do not own the resource firm, they do not take into account the negative effects of their capital tax rates on the resource rent. Thus, they can export the tax burden to the resource-exporting country and choose inefficiently high tax rates. This argument is reversed for the resource-exporting country since it owns the resource firm to 100%. In order to increase the resource rent, country  $R$  therefore sets the capital tax rate negative and, thus, inefficiently low.

When we introduce the environmental damage ( $\delta > 0$ ), all countries raise the equilibrium tax rates due to reasons explained above. However, also the efficient tax rate increases. Consequently, each resource-importing country may now set the capital tax rate inefficiently low, since it ignores the positive effect of its tax rate on the other resource-importing country's welfare via a decline in environmental damage. Welfare in the resource-importing countries is still inefficiently low. In the resource-exporting country, the capital tax rate increases compared to the case without damages as well, but it stays below the efficient rate. Interestingly, welfare of country  $R$  may now be higher than in the efficient solution, since it may obtain a larger resource rent. Hence, full decentralization may be beneficial for the resource-exporting country.

### 4.3 Partial Cooperation: Coordinated Policy in Importing Countries

What happens if the resource-importing countries cooperate? In order to address this question, assume that country  $A$  and  $B$  set their capital tax rates  $\tau_A$  and  $\tau_B$  in order to maximize joint welfare  $W_A + W_B$ , while country  $R$  chooses its capital tax rate  $\tau_R$  such that only its own welfare is maximized. In Appendix F we show that the tax rates in the resulting Nash equilibrium are given by

$$\tau_i^\otimes = \frac{2\alpha\eta \left[ \beta\bar{e} (2\beta + 3\alpha^2\eta) + 3\delta (8\beta + 9\alpha^2\eta) \right]}{3(\alpha^2\eta + \beta)(9\alpha^2\eta + 4\beta)} > 0 \quad i = A, B \quad (49)$$

$$\tau_R^\otimes = -\frac{2\alpha\beta\eta (3\alpha^2e\eta + \beta\bar{e} - 6\delta)}{3(\alpha^2\eta + \beta)(9\alpha^2\eta + 4\beta)} \leq 0 \quad (50)$$

Inserting these expressions in the welfare functions (43) and (44) gives the welfare levels  $W_i^\otimes$  for  $i = A, B, R$  under partial cooperation.

The following proposition compares the equilibrium under partial cooperation with the equilibrium under full decentralization and the efficient solution.

**Proposition 3.** *In the asymmetric setting with two resource-importing countries  $A$  and  $B$  and one resource-exporting country  $R$  and the functional forms specified in (29) - (32), the relation of the equilibrium tax rates  $\tau_i^\otimes$  and welfare levels  $W_i^\otimes$  under joint welfare-maximization among countries  $A$  and  $B$  to the efficient equilibrium tax rates  $\tau_i^*$  and welfare levels  $W_i^*$  as well as to the equilibrium tax rates of non-cooperation  $\tau_i^\odot$  and welfare levels  $W_i^\odot$  for  $i = A, B, R$  is represented in the following table.*

$i$	$\delta > 0$	$\delta = 0$
$i = A, B$	$\tau_i^\otimes > \tau_i^\odot$	$\tau_i^\otimes > \tau_i^\odot > \tau_i^*$
	$\tau_i^\otimes \leq \tau_i^*$	
	$W_i^\otimes \leq W_i^*$	$W_i^\otimes > W_i^* > W_i^\odot$
	$W_i^\otimes > W_i^\odot$	
$i = R$	$\tau_R^* > \tau_R^\otimes > \tau_R^\odot$	$\tau_R^* > \tau_R^\otimes > \tau_R^\odot$
	$W_R^\otimes \leq W_R^*$	$W_R^* > W_R^\odot > W_R^\otimes$
	$W_R^\otimes \leq W_R^\odot$	

*Proof.* See Appendix G. ■

There are three important insights from Proposition 3. First, in comparison to full decentralization, under partial coordination all countries choose a higher capital tax rate ( $\tau_i^\otimes > \tau_i^\odot$  for  $A, B, R$ ). The reason is that the resource-importing countries  $A$  and  $B$  now internalize their mutual policy externalities, i.e. environmental and intertemporal fiscal distortion externalities. Since in sum these externalities are positive, equilibrium tax rates of countries  $A$  and  $B$  are higher than under full decentralization. Country  $R$

follows since tax rates are strategic complements. Note that the increase in tax rates flattens the extraction path and thereby reduces environmental damage compared to full decentralization. Second, compared to full decentralization, under partial cooperation welfare is higher in the resource-importing countries  $A$  and  $B$  ( $W_i^\otimes > W_i^\circ$  for  $A, B$ ) and may higher or be lower for the resource-exporting country  $R$  ( $W_R^\otimes \leq W_R^\circ$ ). This may be explained by the fact that higher taxes by countries  $A$  and  $B$  reduce the profit of the resource-extracting firm. But on the other hand, strategic complementarity leads to an increase of  $\tau_R$  and helps to attenuate the domestic intertemporal fiscal distortion effect in country  $R$ . Third, the welfare comparison between partial cooperation and full centralization (social planner) is ambiguous ( $W_i^\otimes \leq W_i^\circ$  for  $A, B, R$ ), provided we assume the presence of environmental damage ( $\delta > 0$ ). On the one hand partial cooperation may be so beneficial for the resource-importing countries  $A$  and  $B$ , that their welfare is higher and the welfare of the resource-exporting country  $R$  is lower in the fully centralized solution. On the other hand, the benefits of partial cooperation may be relatively small so that welfare of countries  $A$  and  $B$  indeed improves, compared to the full decentralization, but stays below welfare under full centralization, whereas the welfare of the resource-exporting country  $R$  may exceed welfare in the social planner solution. Finally, welfare under partial cooperation may fall short of welfare under full centralization for all countries.

This ambiguity of the welfare comparison opens the door for an interesting constellation. It may be that the threat of the resource-importing countries  $A$  and  $B$  to partially cooperate induces the resource-exporting country to voluntarily cooperate as well, so the fully centralized (social planner) solution is self-enforcing. In order to illustrate this possibility, we present a numerical example. We specify the parameters of the functions (29) - (32) as

$$\alpha = 1, \quad \rho = 1, \quad \beta = 0.25, \quad \gamma = 2, \quad \bar{e} = 20, \quad \eta = 0.125$$

and analyze the effects of variations in the marginal environmental damage  $\delta$  on equilibrium tax rates and welfare. The results are displayed in Figures 1 - 4.

These figures basically confirm the results from Propositions 2 and 3. For example, partial cooperation benefits the resource importing countries  $A$  and  $B$  compared to full decentralization ( $W_i^\otimes > W_i^\circ$  for  $i = A, B$ ), see Figure 3. Moreover, in the range of a marginal environmental damage of  $\delta = [0.02, 0.15]$  welfare under the social planner solution is higher for all countries than under partial coordination,  $W_i^\otimes > W_i^\circ$  for  $i = A, B, R$ . Taken together these two observations, we can argue as follows: If the countries start from the fully decentralized case, the resource-importing countries  $A$  and  $B$  have an incentive to cooperate independent of country  $R$ 's decision on whether to cooperate as well. By cooperating these countries would gain while the resource-exporting country

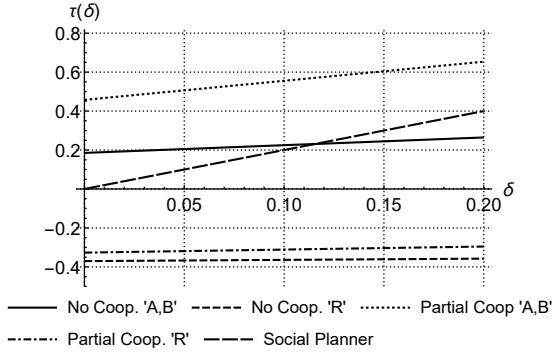


Figure 1: Equilibrium tax rates depending on  $\delta$

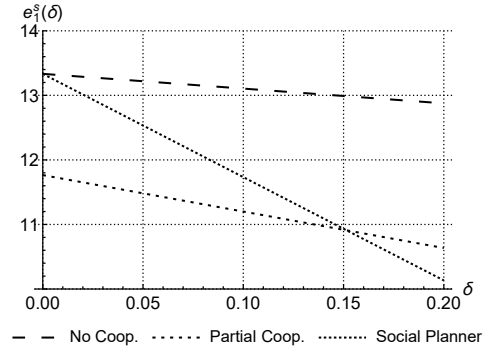


Figure 2: Equilibrium Resource Extraction in Period 1 on  $\delta$

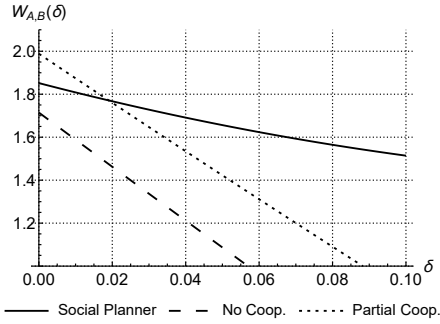


Figure 3: Equilibrium welfare of country  $i$  depending on  $\delta$  ( $\eta = .125$ )

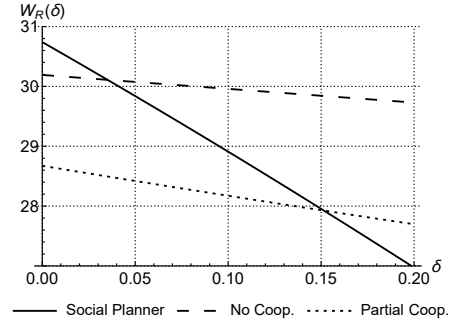


Figure 4: Equilibrium welfare of country  $R$  depending on  $\delta$

$R$  could potentially loose if it did not join the cooperation among countries  $A$  and  $B$ , which is the case in the parameter range of  $\delta = [0.02, 0.15]$ . However, if country  $R$  did also join the cooperation it would gain compared to partial cooperation. Since countries  $A$  and  $B$  would gain compared to both full decentralization and partial decentralization, they have an incentive to accept country  $R$ 's offer to cooperate if marginal environmental damage is in this range. None of the countries has an incentive to deviate from the social planner solution, which therefore is self-enforcing.

The intuition behind this finding is as follows. The resource-exporting country prefers full cooperation to partial cooperation if marginal damage is below a certain threshold (here  $\delta^R = 0.15$ ). This is so since with full cooperation, environmental damages are the only policy motive (not tax exporting!), so importer countries' tax rates are more moderate than under partial cooperation. Yet, resource-importing countries prefer full cooperation if marginal environmental damage is above a certain threshold (here  $\delta^{AB} = 0.02$ ). The higher the damage parameter the less they are capable of compensating inefficiency costs of their policy. Given that  $\delta^{AB} < \delta < \delta^R$ , full cooperation materializes, yet with the downside of lower environmental quality compared to the equilibrium under partial cooperation. This can be seen in Figure 2, which shows that extraction is lower for partial cooperation than for full cooperation if  $\delta < 0.15$ , which directly translates

into lower damages. Of course, whether the marginal environmental damage falls into the range where full cooperation is self-enforcing is an empirical question that is beyond the scope of our theoretical analysis.

## 5 Concluding Remarks

In the present paper, we ask whether a capital tax could serve as an instrument for mitigating climate change as suggested by Sinn (2008). We employ a two-period tax competition model with multiple countries. Each of them implements a local tax on household borrowing - a simple form of source-based capital tax. We abstract from capital in production and model an intertemporal savings market where in the first period earnings of resource extraction are supplied to households, who repay their debt in the second period. This way we incorporate the notion of resource owners, who decide whether to extract in the first period and invest the earnings or to leave stocks in the ground and benefit from an increase in resource prices over time, which alludes to the standard Hotelling framework of resource extraction.

We find that such a capital tax effectively flattens the extraction path of the (polluting) natural resource and thus lowers environmental damage. Thereby the assumption of quasi-linear utility is critical, since it induces that household demand for capital decreases when the local tax rate is increased. The excess supply of savings in turn motivates the resource-extracting firm to postpone extraction to the future. There is empirical evidence of a positive elasticity of savings with respect to interest rate, equivalent to a negative elasticity of household debt here, which justifies this choice, see Boskin (1978), Gylfason (1993), and Bernheim (2002). However, empirical findings vary substantially between values close to zero and above unity and it might be worthwhile to employ a more general functional form for household consumption utility.

The main takeaway from the symmetric model, where the resource rent enters into household income in all countries, is that a lack of cooperation among policy makers yields inefficiently low tax rates. Thereby we complement the findings of Eichner and Runkel (2012). They assess a tax on the input of capital in production and assume that emissions are proportional to capital input. Their findings indicate that in dynamic context, where capital supply is elastic, the decentral policy choice is inefficient. Yet, also the classic market-based climate policy instruments, such as carbon taxes or emission caps, may suffer from an inefficient policy choice in the absence of cooperation, see for example Eichner and Pethig (2015).

Turning to the asymmetric model, we find that the resource-exporting country's policy choice - a lower, maybe even negative tax rate - stands in stark contrast to the policy choice of resource-importing countries. Anecdotal evidence may not match our model perfectly, due to our simplifying assumptions. Nevertheless, there are resource-rich coun-

tries, which rely strongly on the export of natural resources and which implement very low tax rates. For example, public revenues in Kuwait between 2005 and 2008 consisted to 60-70% of oil revenues in and to just 2% of tax revenues, while citizens are broadly exempted from paying taxes at all, see Chemingui and Hajeih (2011). The crucial question is, if such a fiscal policy is motivated by strategic motives such as presented in this paper.

Our assessment of partial and full policy cooperation focuses on the policy choice and the resulting equilibrium allocation and welfare levels. Thereby, we abstain from a rigorous assessment of whether policy makers actually cooperate or not, since this would go beyond the scope of this paper. Therefore, it may very well be that “cooperation” is not a dominant strategy and, consequently, that cooperation could be flawed by a prisoner’s dilemma. Nevertheless, our paper contributes to the literature by determining the policy choice of different countries employing a richer modeling of international fossil fuel markets and extraction dynamics than is common in the literature on climate policy coalitions.<sup>8</sup>

Coming to an end, we may conclude, that the capital tax should be considered an option in climate policy, though with some shortcomings. However, if a Green Paradox may be ruled cannot be answered by our contribution, due to our model set-up with two periods and the choice of a single tax rate by each policy maker. This would probably require the introduction of more periods and therefore one might have to employ numerical methods due to the increased complexity. Other drawbacks are the assumption of fix total extraction of the natural resource and abstracting from (perfect) substitutes in production, such as capital or a green backstop. While endogenous total extraction would tremendously complicate the analysis, it could be useful to deliver a more complete picture concerning the effects of the capital tax on the emission trajectory and thus on climate damage. Considering substitutes like capital or a green energy would introduce inter-linkages of the policy with the associated factor markets as well as feedback effects on the fossil fuel market.

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<sup>8</sup>See for example Nordhaus (2015).



# Appendices

## A Proof of Equations (15) - (17)

The market equilibrium is determined by equations (3), (5), (9), (10) and (11). Furthermore, we need (7) to derive the comparative statics, since  $c_{i1}$  appears in (9). We slightly reformulate (7) by use of (4) and (5), which gives

$$c_{i1} = F_1(e_{i1}) - F'_1(e_{i1})e_{i1} + b_i. \quad (51)$$

Then we totally differentiate (3), (5), (9), (10), (11) and (51), and subsequently apply the symmetry assumption and  $\mu_i = \frac{1}{n}$  as stated in the text. Then, we make use of (3) to replace  $1 + r$ , of (5) to substitute for  $p_1$  and  $p_2$ , and finally of the differentiated resource constraint (2) to replace  $de_2^s$ , and obtain

$$dr + d\tau_i = V'' dc_{i1}, \quad (52)$$

$$dc_{i1} = -e_1 F''_1 de_{i1} + db_i, \quad (53)$$

$$dc_{i2} = -e_2 F''_2 de_{i2} + \frac{1}{n} \bar{e} dp_2 - b dr - \frac{F'_2}{F'_1} db_i, \quad (54)$$

$$F''_1 de_{i1} = dp_1, \quad (55)$$

$$F''_2 de_{i2} = dp_2, \quad (56)$$

$$dp_2 = F'_1 dr + \frac{F'_2}{F'_1} dp_1, \quad (57)$$

$$\sum_{k=1}^n db_k = dp_1 e_1^s + F'_1 de_1^s, \quad (58)$$

$$\sum_{k=1}^n de_{k1} = de_1^s, \quad (59)$$

$$\sum_{k=1}^n de_{k2} = -de_1^s. \quad (60)$$

Next, we use (55) in (53) and, sum up over  $k = [1, \dots, n]$  and substitute  $\sum_{k=1}^n db_k$  by (58). Then we simplify by use  $b = \frac{p_1 e_1^s}{n}$  and  $n \cdot e_t = e_t^s$  for  $t = [1, 2]$ , which we obtain from the symmetry assumption and from (10) and (11), so that we get

$$\sum_{k=1}^n dc_{k1} = F'_1 de_1^s, \quad (61)$$

Then, we also sum up (52), where  $d\tau_i \neq 0$  and  $d\tau_j = 0$  for countries  $j \neq i$ , and use (61), which gives

$$n \cdot dr + d\tau_i = V'' F_1' de_1^s. \quad (62)$$

We now sum up (55) and (56) over  $k = 1, \dots, n$  and substitute  $dp_2$  by (57) to get

$$de_1^s = \frac{n dp_1}{F_1''}, \quad (63)$$

$$de_2^s = \frac{n((F_1')^2 dr + F_2' dp_1)}{F_1' F_2''}. \quad (64)$$

Now, (64) is inserted into (63) with the help of the differentiated resource constraint (2). Then we solve for  $dp_1$  to obtain

$$dp_1 = \frac{-(F_1')^2 F_1''}{F_1' F_2'' + F_2' F_1''} dr. \quad (65)$$

Next, we insert (65) into (63) and receive

$$de_1^s = n \frac{-(F_1')^2}{F_1' F_2'' + F_2' F_1''} dr, \quad (66)$$

which we use in (62), slightly rearrange and obtain

$$\frac{dr}{d\tau_i} = -\frac{1}{n} \frac{F_1' F_2'' + F_2' F_1''}{F_1' F_2'' + F_2' F_1'' + (F_1')^3 V''} < 0. \quad (67)$$

Then, we divide (66) and (65) by  $d\tau_i$  and use (67) to derive

$$\frac{de_1^s}{d\tau_i} = \frac{(F_1')^2}{F_1' F_2'' + F_2' F_1'' + (F_1')^3 V''} < 0, \quad (68)$$

$$\frac{dp_1}{d\tau_i} = \frac{1}{n} \frac{F_1'' (F_1')^2}{F_1' F_2'' + F_2' F_1'' + (F_1')^3 V''} > 0. \quad (69)$$

We continue by taking (57), dividing it by  $d\tau_i$  and using (67) and (69) to obtain

$$\frac{dp_2}{d\tau_i} = -\frac{1}{n} \frac{F_2'' (F_1')^2}{F_1' F_2'' + F_2' F_1'' + (F_1')^3 V''} < 0. \quad (70)$$

Now, we take (52) and insert (53) together with (55), divide by  $d\tau_i$  and receive

$$\frac{dr}{d\tau_i} + 1 = V'' \left( -e_1 \frac{dp_1}{d\tau_i} + \frac{db_i}{d\tau_i} \right). \quad (71)$$

Using (67) and (69) and rearranging yields

$$\frac{\partial b_i}{\partial \tau_i} = \frac{(n-1)(F'_1 F''_2 + F'_2 F''_1 + (F'_1)^3 V'') + V''(F'_1)^2 \overbrace{[F'_1 + F''_1 e_1]}^{(>0) \text{ see below}}}{nV''(F'_1 F''_2 + F'_2 F''_1 + (F'_1)^3 V'')} < 0. \quad (72)$$

Note that  $F(e)' + F(e)'' \cdot e > 0$  holds in case  $F(e)' > 0, F(e)'' < 0, F(e)''' > 0$ , which we assume to hold for  $F(e)$ . And finally, we take (52) for country  $j \neq i$  with  $d\tau_j = 0$ , divide by  $d\tau_i$  and insert (67) and (69), which gives

$$\frac{\partial b_j}{\partial \tau_i} = \frac{e_1(F'_1)^2 F''_1 V'' - F'_1 F''_2 - F'_2 F''_1}{nV''(F'_1 F''_2 + F'_2 F''_1 + (F'_1)^3 V'')} > 0. \quad (73)$$

## B Proof of Proposition 1

*Proof.* Take the first-order condition of the centralized policy problem, given by (25), and evaluate it at equilibrium tax rate of the decentralized policy game  $\tau_i = \tau^\circ$ , given by (21). This gives  $\frac{\partial w_i}{\partial \tau_i} = 0$ , since  $\tau_i^\circ$  satisfies (19), as well as  $\sum_{k=1, k \neq i}^n \frac{\partial w_k}{\partial \tau_i} > 0$  due to (24), which holds for all countries  $j \neq i$ . Therefore

$$\left. \frac{\partial(w_i + \sum_{k=1, k \neq i}^n w_j)}{\partial \tau_i} \right|_{\tau_i = \tau^\circ} > 0, \quad (74)$$

which implies  $\tau^\circ < \tau^*$ , where  $\tau^*$  is the efficient capital tax rate which satisfies (25). ■

## C Derivation of (45)

Take the economy's variables as explicit function of the tax rates, see (36) - (42). We use these in the welfare function of each country, given by equations (43) and (44), to write welfare as a function of tax rates, which gives

$$\begin{aligned} W_i = & \frac{1}{18\eta(\beta + a^2\eta)} \left( \alpha^2\eta [9\rho^2 + \beta\eta\bar{e}^2 - 9\tau_i^2 - 18\gamma(1 + \rho) + 9(1 + \rho)^2] \right. \\ & + \beta [-8\tau_i^2 + 2\tau_i(\tau_j + \tau_R) + (\tau_j + \tau_R)^2 - 18\bar{e}\eta\delta] \\ & \left. + 2\alpha\eta[\beta\bar{e}(\tau_i + \tau_j + \tau_R) + 9(3 + 3\rho - 3\gamma + \tau_i + \tau_j + \tau_R)\delta] \right) \end{aligned} \quad (75)$$

for  $i, j = A, B$ ,

$$\begin{aligned} W_R = & \frac{1}{18\eta(\beta + a^2\eta)} \left( 18\alpha^3(1 + \rho)\bar{e}\eta^2 + \beta(\tau_i + \tau_j - 2\tau_R)(\tau_i + \tau_j + 4\tau_R) \right. \\ & + \alpha^2\eta [9\rho^2 - 5\beta\bar{e}^2\eta - 9\tau_R^2 - 18\gamma(1 + \rho) + 9(1 + \rho)^2] \\ & \left. + 2\alpha\beta\bar{e}\eta(9\gamma - 2(\tau_i + \tau_j + \tau_R)) \right) \end{aligned} \quad (76)$$

The optimal set of tax rates  $(\tau_A, \tau_B, \tau_R)$  must satisfy three first order conditions simultaneously. For each country the marginal impact of its tax rate on its own welfare and that of the other countries must be equal to zero. For the welfare functions above, this system of equations writes

$$\frac{\partial W_i}{\partial \tau_i} + \sum_{j \neq i} \frac{\partial W_j}{\partial \tau_i} = \frac{\beta(-2\tau_i + \sum_{k \neq i} \tau_k) - 3\alpha\eta(\alpha\tau_i - 2\delta)}{3\eta(\beta + \alpha^2\eta)} = 0 \quad \text{for } i, j = A, B, R. \quad (77)$$

Solving this system of 3 equations for the three unknowns  $\tau_A, \tau_B, \tau_R$  gives

$$\tau_A^* = \tau_B^* = \tau_R^* = \frac{2\delta}{\alpha}. \quad (78)$$

## D Derivation of (46) and (47)

In the non-cooperative game, the policy maker of each country equates marginal welfare of the household in its country to zero. This is the first-order condition to her optimization problem. Thus we differentiate (75) and (76), this time only with respect to the domestic tax rate, which gives

$$\frac{\partial W_i}{\partial \tau_i} = \frac{-9\alpha^2\eta\tau_i + \beta(-8\tau_i + \tau_j + \tau_R) + \alpha\eta(\beta\bar{e} + 9\delta)}{9\eta(\beta + \alpha^2\eta)} = 0 \quad \text{for } i, j = A, B, \quad (79)$$

$$\frac{\partial W_R}{\partial \tau_R} = \frac{-9\alpha^2\eta\tau_R + \beta(-8\tau_R + \tau_A + \tau_B) - 2\alpha\beta\eta\bar{e}}{9\eta(\beta + \alpha^2\eta)} = 0. \quad (80)$$

Considering the whole policy game, the equilibrium set of tax rates has to satisfy the first-order conditions of all policy makers at the same time. Therefore, we take the first-order conditions (79) and (80) as a system of equations and solve for  $\tau_A^\circ, \tau_B^\circ$ , and  $\tau_R^\circ$ , by which we obtain the equilibrium set tax rates

$$\tau_A^\circ = \tau_B^\circ = \frac{\alpha\eta [\beta\bar{e}(2\beta + 3\alpha^2\eta) + 3\delta(8\beta + 9\alpha^2\eta)]}{9(\beta + \alpha^2\eta)(2\beta + 3\alpha^2\eta)} > 0, \quad (81)$$

$$\tau_R^\circ = -\frac{2\alpha\beta\eta(2\beta\bar{e} + 3\alpha^2\bar{e}\eta - 3\delta)}{9(\beta + \alpha^2\eta)(2\beta + 3\alpha^2\eta)} \leq 0. \quad (82)$$

## E Proof of Proposition 2

Countries  $i = A, B$ :

Take equation (46) and recall the assumption  $\alpha, \beta, \gamma, \eta, \rho > 0$ . Then

$$\delta = 0 : \quad \tau_i^\odot = \frac{\alpha\eta\beta\bar{e}}{9(\beta + \alpha^2\eta)} > 0, \quad (83)$$

$$\delta > 0 : \quad \tau_i^\odot = \frac{\alpha\eta [\beta\bar{e}(2\beta + 3\alpha^2\eta) + 3\delta(8\beta + 9\alpha^2\eta)]}{9(\beta + \alpha^2\eta)(2\beta + 3\alpha^2\eta)} > 0, \quad (84)$$

and using (46) and (45) we obtain

$$\delta = 0 : \quad \tau_i^\odot - \tau_i^* = \tau_i^\odot = \frac{\alpha\eta\beta\bar{e}}{9(\beta + \alpha^2\eta)} > 0, \quad (85)$$

$$\delta > 0 : \quad \tau_i^\odot - \tau_i^* = \frac{2\alpha^2\beta^2\bar{e}\eta + 3\alpha^4\beta\bar{e}\eta^2 - (36\beta^2 + 66\alpha^2\beta\eta + 27\alpha^4\eta^2)\delta}{9\alpha(2\beta^2 + 5\alpha^2\beta\eta + 3\alpha^4\eta^2)} \leq 0. \quad (86)$$

In order to obtain  $W_i^\odot$  and  $W_i^*$  of countries  $i = A, B$ , we use (45) and (46) in (75), from which we can compute

$$\delta = 0 : \quad W_i^\odot - W_i^* = -\frac{\alpha^2\beta^2\bar{e}^2\eta}{162(\alpha^2\eta + \beta)^2} < 0, \quad (87)$$

$$\begin{aligned} \delta > 0 : \quad W_i^\odot - W_i^* = & \frac{-1}{162(\alpha^2\eta + \beta)^2(3\alpha^2\eta + 2\beta)^2} \left[ \alpha^2\beta^2\bar{e}^2\eta(3\alpha^2\eta + 2\beta)^2 \right. \\ & + 6\beta\bar{e}\delta(45\alpha^4\eta^2 + 80\alpha^2\beta\eta + 36\beta^2)(3\alpha^2\eta + 2\beta) \\ & \left. + 9\delta^2(9\alpha^2\eta + 8\beta)(45\alpha^4\eta^2 + 80\alpha^2\beta\eta + 36\beta^2) \right] < 0. \end{aligned} \quad (88)$$

### Country R:

Take (47). By definition we have

$$\delta = 0 : \quad \tau_R^\odot = -\frac{2\alpha\beta\eta\bar{e}}{9(\beta + \alpha^2\eta)} < 0, \quad (89)$$

$$\delta > 0 : \quad \tau_R^\odot = -\frac{2\alpha\beta\eta(2\beta\bar{e} + 3\alpha^2\bar{e}\eta - 3\delta)}{9(\beta + \alpha^2\eta)(2\beta + 3\alpha^2\eta)} \leq 0, \quad (90)$$

and using (47) and (45) we can compute

$$\delta = 0 : \quad \tau_R^\odot - \tau_R^* = \frac{-4\alpha\beta^2\bar{e}\eta - 2\alpha^3\beta\bar{e}\eta^2}{9(\alpha^2\eta + \beta)(3\alpha^2\eta + 2\beta)} < 0, \quad (91)$$

$$\delta > 0 : \quad \tau_R^\odot - \tau_R^* = \frac{-4\alpha\beta^2\bar{e}\eta - 2\alpha^3\beta\bar{e}\eta^2 - 2\delta(9\alpha^4\eta^2 + 14\alpha^2\beta\eta + 6\beta^2)}{9(\alpha^2\eta + \beta)(3\alpha^2\eta + 2\beta)} < 0. \quad (92)$$

In order to obtain  $W_R^\odot$  and  $W_R^\otimes$ , we use (45) and (47) in (76), from which we can compute

$$\delta = 0 : W_R^\odot - W_R^\otimes = -\frac{2\alpha^2\beta^2\bar{e}^2\eta}{81(\alpha^2\eta + \beta)^2} < 0, \quad (93)$$

$$\begin{aligned} \delta > 0 : W_R^\odot - W_R^\otimes = & \frac{1}{81(\alpha^2\eta + \beta)^2(3\alpha^2\eta + 2\beta)^2} \left[ -2\alpha^2\beta^2\bar{e}^2\eta(3\alpha^2\eta + 2\beta)^2 \right. \\ & + 12\beta\bar{e}\delta(18\alpha^4\eta^2 + 37\alpha^2\beta\eta + 18\beta^2)(3\alpha^2\eta + 2\beta) \\ & \left. + 18\delta^2(36\beta^3 + 152\alpha^2\beta^2\eta + 198\alpha^4\beta\eta^2 + 81\alpha^6\eta^3) \right] \leq 0. \end{aligned} \quad (94)$$

## F Proof of (49) and (50)

Take the welfare functions of countries  $i = A, B$ , given by (75), and likewise for country  $R$ , given by (76). The first-order condition of the local policy maker in country  $i = A, B$  writes as follows

$$\frac{\partial W_i}{\partial \tau_i} + \frac{\partial W_j}{\partial \tau_i} = \frac{-9\alpha^2\eta\tau_i + 2\alpha\eta(\beta\bar{e} + 9\delta) + \beta(2(\tau_j + \tau_R) - 7\tau_i)}{9\eta(\alpha^2\eta + \beta)} = 0 \quad (95)$$

for  $i, j = A, B$  and  $i \neq j$ ,

while the first-order condition of the policy maker in country  $R$  is given by (80). Again we solve the system of equations given by all welfare-maximizing policy makers' first-order conditions, which comprises (95) and (80). This gives

$$\tau_A^\otimes = \tau_B^\otimes = \frac{2\alpha\eta \left[ \beta\bar{e}(3\alpha^2\eta + 2\beta) + 3\delta(9\alpha^2\eta + 8\beta) \right]}{3(\alpha^2\eta + \beta)(9\alpha^2\eta + 4\beta)} > 0, \quad (96)$$

$$\tau_R^\otimes = -\frac{2\alpha\beta\eta(3\alpha^2\bar{e}\eta + \beta\bar{e} - 6\delta)}{3(\alpha^2\eta + \beta)(9\alpha^2\eta + 4\beta)} \leq 0. \quad (97)$$

## G Proof of Proposition 3

**Countries i = A, B:**

We take  $\tau_i^\odot$  and  $\tau_i^\otimes$ , given by (46) and (49), and obtain

$$\tau_i^\otimes - \tau_i^\odot = \frac{\alpha\eta(8\beta + 9\alpha^2\eta) [\beta\bar{e}(2\beta + 3\alpha^2\eta) + 3\delta(8\beta + 9\alpha^2\eta)]}{9(\beta + \alpha^2\eta)(4\beta + 9\alpha^2\eta)(2\beta + 3\alpha^2\eta)} > 0, \quad (98)$$

with  $\alpha, \beta, \gamma, \eta, \rho > 0$  and  $\delta \geq 0$ . Since  $\tau_i^\odot > \tau^*$  for  $\delta = 0$ , see Proposition 2, we can infer  $\tau_i^\otimes > \tau_i^\odot > \tau^*$  for  $\delta = 0$ . Then we take  $\tau_i^\otimes$  and  $\tau_i^*$ , given by (45) and (49), and obtain

$$\tau_i^\otimes - \tau^* = \frac{2\beta(3\alpha^4\bar{e}\eta^2 + \alpha^2\eta(2\beta\bar{e} - 15\delta) - 12\beta\delta)}{3\alpha(\alpha^2\eta + \beta)(9\alpha^2\eta + 4\beta)} \leq 0 \text{ for } i = A, B, \quad (99)$$

with  $\alpha, \beta, \gamma, \eta, \rho, \delta > 0$ .

Finally, for a comparison of welfare levels between the partial and the non-cooperation scenario take (75) and insert either (46) or (49) or (45) to receive  $W_i^\odot$ ,  $W_i^\otimes$ , and  $W_i^*$  respectively. Then we obtain

$$W_i^\otimes - W_i^\odot = \frac{\eta (81\alpha^4\eta^2 + 144\alpha^2\beta\eta + 52\beta^2)}{162(\alpha^2\eta + \beta)^2(3\alpha^2\eta + 2\beta)^2(9\alpha^2\eta + 4\beta)^2} \cdot (3\alpha^3\eta(\beta\bar{e} + 9\delta) + 2\alpha\beta(\beta\bar{e} + 12\delta))^2 > 0, \quad (100)$$

$$W_i^\otimes - W_i^* = \frac{2}{9(\alpha^2\eta + \beta)^2(9\alpha^2\eta + 4\beta)^2} \left( \alpha^2\beta^3\bar{e}^2\eta(2\alpha^2\eta + \beta) - 6\beta\bar{e}\delta(3\alpha^2\eta + 2\beta)^3 - 9\delta^2(3\alpha^2\eta + 2\beta)^2(9\alpha^2\eta + 8\beta) \right) \leq 0, \quad (101)$$

with  $\alpha, \beta, \gamma, \eta, \rho, \delta > 0$ . Given  $\delta = 0$ , we obtain  $W_i^\otimes - W_i^\odot > 0$  and  $W_i^\otimes - W_i^* > 0$ . Hence, from the above results and from Proposition 2 we can infer  $W_i^\otimes > W_i^* > W_i^\odot$  for  $\delta = 0$ .

#### Country R:

We take  $\tau_R^\otimes, \tau_R^\odot$  and  $\tau_R^*$ , given by (45), (47), and (50) and obtain

$$\tau_R^\otimes - \tau_R^\odot = \frac{2\alpha\beta\eta \left( \beta\bar{e}(3\alpha^2\eta + 2\beta) + 3\delta(9\alpha^2\eta + 8\beta) \right)}{9(\alpha^2\eta + \beta)(3\alpha^2\eta + 2\beta)(9\alpha^2\eta + 4\beta)} > 0, \quad (102)$$

$$\tau_R^\otimes - \tau_R^* = -\frac{2(3\alpha^4\eta^2(\beta\bar{e} + 9\delta) + \alpha^2\beta\eta(\beta\bar{e} + 33\delta) + 12\beta^2\delta)}{3\alpha(\alpha^2\eta + \beta)(9\alpha^2\eta + 4\beta)} < 0, \quad (103)$$

with  $\alpha, \beta, \gamma, \eta, \rho$  and  $\delta \geq 0$ . Since  $\tau_R^\odot < \tau_R^*$  for  $\delta \geq 0$ , see Proposition 2, we can infer from the above results that  $\tau_R^* > \tau_R^\otimes > \tau_R^\odot$  for  $\delta \geq 0$ . Finally, for a comparison of welfare levels between the partial and the non-cooperation scenario take (76) and insert either (47) or (50) or (45) to receive  $W_R^\odot$ ,  $W_R^\otimes$ , and  $W_R^*$  respectively. Then we obtain

$$W_R^\otimes - W_R^\odot = -\frac{2\alpha^2\beta\eta(9\alpha^2\eta + 8\beta) \left( \beta\bar{e}(3\alpha^2\eta + 2\beta) + 3\delta(9\alpha^2\eta + 8\beta) \right)}{81(\alpha^2\eta + \beta)^2(3\alpha^2\eta + 2\beta)^2(9\alpha^2\eta + 4\beta)^2} \cdot (54\alpha^4\bar{e}\eta^2 + 57\alpha^2\beta\bar{e}\eta - 81\alpha^2\eta\delta + 14\beta^2\bar{e} - 48\beta\delta) \leq 0, \quad (104)$$

$$W_R^\otimes - W_R^* = -\frac{2(\alpha^2\eta(\beta\bar{e} - 9\delta) - 12\beta\delta)}{9(\alpha^2\eta + \beta)^2(9\alpha^2\eta + 4\beta)^2} \cdot (81\alpha^4\eta^2\delta + \beta^2(31\alpha^2\bar{e}\eta + 12\delta) + 27\alpha^2\beta\eta(\alpha^2\bar{e}\eta + 3\delta) + 8\beta^3\bar{e}) \leq 0, \quad (105)$$

with  $\alpha, \beta, \gamma, \eta, \rho, \delta > 0$ . Setting  $\delta = 0$ , we obtain  $W_R^\otimes - W_R^\odot < 0$  and  $W_R^\otimes - W_R^* < 0$ . Hence, from the above results and from Proposition 2 we can infer that  $W_R^* > W_R^\odot > W_R^\otimes$  for  $\delta = 0$ .

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