Environmental tax competition under firm mobility and leakage

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Abstract

The loss of competitiveness of domestic firms that operate in globalized markets remains a key obstacle to the implementation of effective carbon prices in a world without harmonized climate policies. The relocation of firms and productive activities is the most adverse consequence of unilateral carbon pricing. We analyze countries’ strategic choice of environmental taxes implemented to control the emissions in an imperfectly competitive sector of the economy. Wage effects prevent all firms from locating in the same country when tax levels differ across countries. We demonstrate that environmental taxes are set at an inefficiently low level, compared to a non-strategic reference case where the environmental externalities between countries are neglected. The effect is particularly pronounced when firms are mobile. Hence, the possibility of firm relocation offers a plausible explanation why few countries have implemented effective carbon prices unilaterally until today. In our model, the relation between the strength of the environmental externalities and welfare is non-linear. Under some conditions, countries benefit when externalities become stronger, due to a coordinating effect. In the absence of environmental externalities, tax competition vanishes.

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1 Introduction

Environmental pollution is often not restricted to the region or country where the emissions originate. The most prominent example of transboundary pollution is the emission of greenhouse gases, causing anthropogenic climate change. Transboundary pollution problems are generally harder to address than local pollution problems, due to a lack of a commitment device for sovereign countries to carry out any emissions reductions they have agreed upon. The so-called “free-rider incentive” implies that while each country benefits from other countries’ efforts to reduce their emissions, a country is individually better off neglecting the positive externalities of its own abatement efforts upon the other countries (and, thus, behaves non-cooperatively).\footnote{The literature on international cooperation in climate policy is, thus, mostly pessimistic about the prospects of future cooperation (e.g., Barrett 1994).} As countries’ abatement targets (INDCs) in the recent Paris Agreement are non-binding, this issue remains unresolved until today.

Transboundary pollution is merely one example (albeit a particularly pressing one) where countries’ non-cooperative choice of a policy instrument can lead to a globally inefficient outcome. E.g., it is well-known also from the literature on tax competition that when capital is mobile, but countries need capital income taxes to finance the provision of a (local) public good, then taxes are often set inefficiently low as countries compete for capital. All countries could be made better off if they could jointly commit to set higher capital income taxes, in order to finance a higher provision of the public good.\footnote{E.g. Zodrow&Mieszkowski (1986), Oates&Schwab (1988), Keen&Marchand (1997). Doyle and van Wijnbergen (1994) introduce a sequential bargaining game between a host country and a foreign multinational firm to obtain an outcome where the host country gradually increases the tax rate after the firm has incurred fixed costs.} A closely related strand of literature analyzes competition among countries for the location of firms in an imperfectly competitive industry (e.g., a monopoly). In this case, instead of imposing a tax, countries may subsidize firms in order to affect their location choice. Also in this case, the involved countries could be made better off by jointly lowering (or abandoning) the subsidy.

Conceptually, tax (or subsidy) competition, and the free-rider problem in climate policy, are closely related phenomena. In both cases, the absence of a commitment device and the lack of cooperation in the choice of a policy instrument (e.g., a carbon tax) imply that countries neglect externalities between them (e.g., related to the location of capital / firms across countries, or transboundary pollution). This paper combines different strands of literature, by recasting the problem of countries’ non-cooperative choice of an emissions tax in a framework of international tax competition, where two countries compete for the location of polluting firms.
in an imperfectly competitive industry.³

The contribution of our paper is two-fold. We extend the existing literature on tax competition with endogenous firm locations in an imperfectly competitive industry, by introducing an alternative modeling framework with endogenous wage effects. This framework does not depend on transportation costs to explain why firms locate in different countries when tax (or subsidy) rates differ across countries. Furthermore, we introduce environmental externalities into our tax competition model and, thus, combine strands of literature that have previously been mostly separated.

Most of the existing models of countries competing for the location of firms assume transportation costs to explain why firms have an incentive to choose locations close to the market(s) they serve. This makes the location decision less elastic with respect to changes in countries’ policy variables. We develop a model with international trade in the sector of interest and in a numeraire good sector, without transportation or trade costs in either of the sectors. In our model, wage rates in the two countries are endogenously affected by the location and output decisions of firms. To obtain this effect, we assume that labor is a scarce production factor, and that the marginal product of labor in the numeraire good sector is declining. Therefore, a larger output in the sector of interest implies that the marginal product of labor in the numeraire good sector increases, which positively affects the domestic wage rate. The wage effect balances differences in marginal production costs across countries, in particular due to changes in the countries’ tax rates, and prevents all firms from locating in the same country when policies differ across countries.⁴

As a benchmark, we first analyze countries’ non-cooperative choice of an output subsidy in the absence of environmental externalities. It is shown that countries set their output subsidies optimally and achieve the global welfare optimum. The subsidy, thus, neutralizes welfare losses related to imperfect competition, and induces firms to produce the same output level as they would under conditions of perfect competition. Hence, tax competition effectively vanishes. Most importantly, this result is obtained independently of whether firms’ location choices are exogenously fixed, or determined endogenously. When locations are fixed, the country with a smaller number of firms offers a higher subsidy rate to the firms located in this country. When firms are free to choose their locations, both countries choose identical subsidy rates in

³Martin et al. (2014) analyze compensation rules in the EU Emissions Trading Scheme, considering the risk of firm relocation. They find empirical evidence for overcompensation.

⁴We believe the scarcity of labor supply is a plausible explanation for why firms within sectors are usually distributed across several countries, rather than concentrated within a single country. Even in large countries, the supply of skilled or specialized labor can be scarce. Furthermore, positive relations between FDI and local wages have been observed empirically (e.g. Tomohara&Takii, 2011). This is in line with our model.
equilibrium, and a symmetric distribution of firms across countries arises endogenously.

The situation is quite different when environmental externalities are taken into consideration. In this case, new distortions arise. First of all, countries neglect how their own abatement efforts affect welfare of the other country. This is the well-known free-rider incentive, that prevents a globally efficient outcome when countries do not cooperate in their choice of emissions taxes. In addition to this, the market outcome and, thus, emissions in country B are affected by country A’s emissions tax, and vice versa. E.g., when country A raises its emissions tax, this raises the world price of the good, and induces firms in country B to increase their output (and, thus, emissions). Hence, emissions leakage takes place. This reduces countries’ incentives to tax emissions. The effect is reinforced by tax competition. Environmental tax competition is, thus, detrimental to welfare.

The effect is particularly pronounced when firms are free to choose their location. In this case, the output in country B responds more elastically to unilateral policy changes by country A. As a result of environmental tax competition and leakage, countries may set emissions taxes far below those predicted by the standard free-rider argument, which only captures the idea that countries neglect their direct impact upon the other country’s welfare, via the negative externalities caused by their emissions. Therefore, firm mobility offers a plausible explanation for the widely observed reluctance of countries to introduce effective emissions prices unilaterally, in addition to the well-known free-rider argument.

We finally analyze how the strength of the environmental externalities affects welfare in our model. Surprisingly, we find this relation to be non-monotonic. When the environmental damage parameter is small, countries almost achieve the global welfare optimum, and the direct impact of the damages upon each country implies that welfare decreases in the size of the damage parameter. When the damage parameter is in an intermediate range, the negative

5Markuset al. (1993) analyze endogenous location choices of two polluting firms in a two-country model with transportation costs. In contrast to our results, the authors find that a single policy instrument is in general insufficient to eliminate several market failures. In our model, if appropriately chosen by both countries, a single policy instrument can eliminate all market failures (including environmental externalities). In Markuset al. (1995), the authors endogenize both countries’ tax rates in a model of tax competition, but restrict their attention to a monopolistic industry structure.

6For recent contributions on leakage and related policy issues, see e.g. Bushnell&Mansur (2011), Fischer&Fox (2011), and the references cited therein.

7Hence, emissions taxes are even lower than those chosen by countries that set their emissions taxes non-cooperatively but when the industry is perfectly competitive.

8Bjorvatn&Schjelderup (2002) analyze spillovers in the provision of a public good in a capital income tax competition framework. In contrast to our results, these authors find that in the limiting case with perfect spillovers, international tax competition vanishes because in equilibrium, potential gains from attracting additional capital are offset by a reduction in the provision of the global public good by the other countries.
welfare effects of environmental tax competition distort the outcome, and welfare is much lower than in the global welfare optimum. However, when the damage parameter becomes sufficiently large, countries (non-cooperatively) set emissions taxes that are so high that production of the polluting good is terminated. Therefore, when the environmental damages become severe, the outcome under tax competition gradually approaches the global welfare optimum again that – for severe damages – requires zero production of the polluting good. Stronger externalities can, thus, create a coordinating effect that explains why countries sometimes benefit from an increase in the damage parameter. The relation between the strength of the externalities and welfare is, thus, U-shaped. This holds both when firms’ locations across countries are fixed, and when they are determined endogenously.

The modeling framework we use is closely related to the one adopted by Haufler and Wooton (2010). These authors also analyze tax/subsidy competition of two countries for a fixed number of Cournot firms, and analyze the impact of economic integration on the strength of tax/subsidy competition and welfare. Economic integration is measured by the size of transportation or trade costs of the good (lower trade costs per unit correspond to higher integration).\(^9\)

The basic modeling setup with imperfect competition and countries taxing/subsidizing firms used by Haufler and Wooton (2010), goes back to Brander and Spencer (1985), and has subsequently been adopted and modified by several authors to analyze a variety of questions. E.g., Haufler and Wooton (1999) analyze tax/subsidy competition between two countries for a monopolistic firm. The authors show that when countries are of equal size, countries offer inefficiently high subsidies in equilibrium.\(^10\) By contrast, Ferrett and Wooton (2010a) show that subsidy competition can vanish when two countries, instead, compete to attract plants in a duopolistic industry. In a model with (involuntary) unemployment, Haaparanta (1996) analyzes competition between countries to attract FDI. While the ownership of plants can in general affect the outcome of a tax/subsidy competition game, Ferrett and Wooton (2010b) show that the equilibrium outcome (plant location and tax/subsidy offers) can, under certain conditions, be independent of the international distribution of a monopolistic firm’s ownership.\(^11\) In our model, we make the simplifying assumption that profits generated within the sector of interest, always accrue in the country where a firm is located (both under exogenous and endogenous location choices). Although some of our results may not carry over to a more general setup, we believe this is a useful benchmark case to study.

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\(^9\)The authors find a U-shaped relation between trade costs and welfare.

\(^{10}\)In Haufler&Wooton (2006), the authors extend their analysis to allow for regional tax/subsidy coordination in a three-country model, where the two countries that can coordinate their policies are part of a union.

\(^{11}\)Warr (1983) shows that under certain conditions, a redistribution of income among consumers does not affect the provision of a public good. Kemp (1984) shows related results for countries that supply international public consumption goods.
Janeba (1998) analyzes subsidy competition in a duopoly model without transportation costs. Each firm operates with a convex cost function, and the shape of the cost function is independent of the country where the firm is located. The author shows that when firms are free to choose their location, subsidy competition vanishes, because firms respond to marginal differences in tax/subsidy rates by relocating to the country with the lower tax (resp. higher subsidy) rate. In contrast to this, we do not assume that firms’ costs are independent of their location choice. Since the wage level in each country is a function of output in that country, the wage rate increases when many firms shift their production to the same country. This counteracts the tendency of firms to agglomerate in one country when tax/subsidy rates differ.

The remainder of this paper is organized as follows. Section 2 introduces our framework for modeling tax/subsidy competition under imperfect competition with local wage effects, and shows that in the absence of environmental externalities, countries achieve the global welfare optimum. Section 3 extends the model to include environmental externalities, and shows that environmental tax competition is detrimental to welfare. Section 4 concludes. All proofs are relegated to the Appendix.

2 Model

In the first stage of our model, two countries (A and B) non-cooperatively set taxes (or subsidize) the output of firms in an imperfectly competitive sector of the economy (our sector of interest). The total number of firms in this sector is denoted by $k$. It is, by assumption, exogenously fixed.\footnote{Each firm may, e.g., possess sector-specific knowledge that allows this firm to produce the good. The knowledge is protected by patents, which creates a barrier to entry. See Haufler and Wooton (2010).} The distribution of the $k$ firms across the two countries is either exogenously fixed, or determined endogenously in the second stage of the game (“firm mobility”). In the final stage, firms compete in quantities (Cournot competition). Apart from a (possibly) skewed distribution of firms across them, countries A and B are identical.

The good produced in this sector of the economy is tradable. Since we do not assume any trade costs, the market price $P$ of the homogeneous good is the same in both countries. In order to derive an upward-sloping labor supply curve, we add a numeraire good sector to the model. The details of our trade model are shown in Appendix A.1, where we provide a rigorous microeconomic foundation for simple relations used to describe demand and costs in our sector of interest. Namely, we derive the following inverse demand curve and linear relation between the marginal costs in the sector of interest in country $l \in \{A, B\}$, and the produced quantity...
$Q_l$ in country $l$ in this sector:

$$P(Q) = \alpha - \beta Q$$

$$c_l(Q_l) = \gamma_l + \delta Q_l,$$

where $Q \equiv Q_A + Q_B$ is the aggregate output quantity produced in the sector, and $c_l$ is the marginal cost in the sector of interest in country $l$. The parameters $\alpha, \beta > 0$ characterize the inverse demand function. $\gamma_l$ is the tax per unit of output charged by country $l$ (resp., a subsidy per unit of output if $\gamma_l < 0$).\(^{13}\) The endogenous wage rate in country $l$ is given by $w_l(Q_l) \equiv \delta Q_l$. As shown in Appendix A.1, it is a linearly increasing function of the output $Q_l$ in country $l$'s sector of interest. The parameter $\delta > 0$ describes the responsiveness of the wage rate in each country to changes in the respective output $Q_l$. If $\delta$ is large, small changes in output have a large effect upon the wage rate in country $l$.

Intuitively, the wage rate in country $l$ is increasing in $Q_l$ because labor is shifted from the numeraire good sector into the sector of interest. Since the marginal productivity of labor in the numeraire good sector is decreasing (e.g., because land is another scarce production factor used in the numeraire good sector), an increase in $Q_l$ that implies a decrease in the amount of labor used to produce the numeraire good, leads to an increase in the wage rate in country $l$. This raises the marginal costs of firms producing the good of interest (see (2)).

In Appendix A.1, we also derive the following expression for country $l$'s welfare:

$$U_l(Q, Q_l) = \delta Q_l + \frac{\delta}{2} (1 - Q_l)^2 + (\alpha - \beta Q - \delta Q_l)Q_l + \frac{\beta}{4} Q^2.$$ \((3)\)

Note, that welfare is expressed here only as a function of the output quantities $Q_A$ and $Q_B$ in the sector of interest. For further details about how the numeraire good sector interacts with these variables, see Appendix A.1.

For later reference, let us also characterize the welfare optimum. It corresponds to the highest feasible joint welfare that both countries can (potentially) achieve when they fully cooperate in setting their tax/subsidy policies. In Appendix A.2, we show that the welfare optimum is reached when each country produces a quantity of $Q^*_l = \alpha/(2\beta + \delta)$, yielding a welfare per country of

$$U^*_l = \frac{\alpha^2 + 2\beta\delta + \delta^2}{2(2\beta + \delta)}.$$ \((4)\)

Note that this result holds independently of the (exogenous or endogenous) distribution of firms in the sector of interest across countries.\(^{14}\)

\(^{13}\)Later, we will interpret $\gamma_l$ as the sum of an output subsidy and an emissions tax.

\(^{14}\)In the absence of environmental externalities between countries (as is assumed here), the welfare optimum can also be reached under autarky, where trade between the two countries is prohibited, when each country regulates its domestic industry optimally to offset welfare losses of imperfect competition.
Before adding environmental externalities to the model, let us first analyze the benchmark case without pollution. This is interesting, because our model differs in a number of ways from other setups used in the literature on international tax competition. E.g., our model highlights the importance of wage effects to explain why the relocation of firms comes to a halt even when tax rates differ persistently across countries: A country that attracts firms by charging lower taxes experiences a shift of labor into this sector of the economy. This drives up wages in this country – an effect that counter-balances the tax incentives. Hence, the country can attract some additional firms in the sector of interest from abroad, but not all firms.

Also in the absence of firm mobility, tax competition can play an important role. This is because we assume that firms’ profits accrue in the country where they are located. Hence, countries may be tempted to charge lower taxes or to subsidize the output of their domestic firms in order to increase their market share in the global market.

We proceed by first analyzing the model without pollution for an exogenously fixed (and possibly skewed) distribution of firms across countries. Then we consider the case with mobile firms. Environmental externalities are added to the model in Section 3.

### 2.1 Non-cooperative taxation of immobile firms

In this subsection, we treat the distribution of the $k$ firms in our sector of interest across the two countries as exogenously fixed. This is a useful benchmark case, that will later help us to identify which effects in our model are related to the mobility of firms. Many of the results derived in this subsection are also valid when the distribution of firms is endogenous, and will, thus, be used also in later sections.

Let the number of firms in the sector of interest located in country A be $k_A$. The number of firms located in B is, thus, $k_B = k - k_A$. Following Haufler and Wooton (2010), we do not require $k_A$ to be an integer.\(^{15}\) The profit of firm $i$ in country $l$ is denoted by $\pi_{il}$.\(^{16}\) It is given by:

$$\pi_{il} = [P(Q) - c_l(Q_i)] q_{il},$$  \hspace{1cm} (5)

where $q_{il}$ is the firm’s output quantity. In order to derive the first-order condition of profit maximization, it is convenient to use the following relations to separate $q_{il}$ from the aggregate

\(^{15}\)Mathematically, it is convenient to ignore integer problems. When $k_A$ is not an integer, our results are admittedly harder to interpret. However, when $k$ becomes sufficiently large, results differ only marginally from those obtained when an integer constraint is added to the model.

\(^{16}\)In Appendix A.1, superscript $y$ is used for variables characterizing the sector of interest. It is omitted in the main text where we always focus on this sector.
quantities $Q$ and $Q_l$:

$$Q_l = Q_{-i,l} + q_{il}, \text{ and } Q = Q_l + Q_m,$$

where $m \neq l$ and $l, m \in \{A, B\}$.

Using (1) and (2), we, thus, obtain the following expression for firm $i$’s profit:

$$\pi_{il} = [\alpha - \gamma_l - (\beta + \delta)(Q_{-i,l} + q_{il}) - \beta Q_m] q_{il}.$$

 Implicit in this decomposition is the following assumption. When firm $i$ chooses its output quantity, it realizes not only its own impact upon the endogenous market price $P$ (as is standard in a Cournot game). It also takes into consideration its impact upon the endogenous wage rate in country $l$, where the firm is located.\(^{17}\)

The maximization of (6) over $q_{il}$ yields the following first-order condition:

$$0 = \alpha - \gamma_l - (\beta + \delta)(Q_{-i,l} - 2q_{il}) - \beta Q_m.$$

Within each country $l$, all firms face the same output price $P$ and the same marginal production cost $c_l(Q_l)$. Therefore, in each country, all firms choose an identical output level, denoted by $q_l$. The relations: $q_{il} = q_l$ and $Q_{-i,l} = (k_l - 1)q_l$, can, therefore, be used to simplify (7):

$$0 = \alpha - \gamma_l - (\beta + \delta)(k_l - 1)q_l - \beta k_m q_m.$$

This condition is generic – it has to be fulfilled for $l, m \in \{A, B\}$ and $m \neq l$. Solving this set of equations, we obtain the following equilibrium quantity in country $l$ (per firm):\(^{18}\)

$$q^*_l = \frac{(\alpha - \gamma_l)(\beta + \delta)(k_m + 1) - (\alpha - \gamma_m)\beta k_m}{(\beta + \delta)^2(k_l + 1)(k_m + 1) - \beta^2 k_l k_m}.$$

The expressions for the equilibrium price $P^*$, total output $Q^*$, and welfare $U^*_A$ under a given distribution of firms across countries $k_A$ and $k_B$ are rather lengthy and not shown here.\(^{19}\)

Let us now introduce our notion of non-cooperative taxation. By assumption, countries can impose a tax or pay a subsidy per unit of output in the sector of interest. Let $\gamma_l$ be country $l$’s tax resp. subsidy instrument (see (2)). It is, by assumption, chosen before the market outcome is determined. Hence, each government can credibly commit to its policy (we rule out possible issues of time-inconsistency), but governments do not coordinate or cooperate in their choices.

\(^{17}\)An alternative approach would be to assume price-taking behavior in the labor market. However, it seems implausible to assume that the Cournot firms realize the impact they have on the market price of the good they produce, but not on the wage rate that is equally affected by their output decision.

\(^{18}\)Note, that $q^*_A$ and $q^*_B$ have the same denominator – a property that simplifies subsequent calculations.

\(^{19}\)In this paper, we derive closed-form solutions. In order to handle algebraically complicated expressions, it is helpful to use a computer. Some intermediate results are not shown, but can be obtained from the authors upon request.
of $\gamma_l$. It is well-known from the literature on tax competition that this can lead to distortions or inefficiencies in the governments’ policy choices.

The following result compares welfare under non-cooperative taxation (for an exogenously fixed distribution of firms) with the global welfare optimum in which countries cooperatively determine output and consumption decisions (see Appendix A.2).

**Proposition 1** When the distribution of firms across countries is exogenously fixed, and countries set their tax/subsidy instruments non-cooperatively, the global welfare optimum is reached. This holds independently of the given distribution of firms across countries.

As shown in Appendix A.2, the quantity produced in country $l$ in the sector of interest is in the global welfare optimum independent of the given distribution of firms across countries (see (26)). Since the outcome under tax competition coincides with this welfare optimum, it follows immediately that:

**Corollary 1** Under non-cooperative tax policies with fixed firm locations, total output $Q_l$ of the sector of interest in each country is independent of the given distribution of firms $(k_A, k_B)$.

Hence, if the distribution of firms across countries is skewed, fewer firms in one country produce the same total output as a larger number of firms in the other country. Note, that (by (27)), the country with the smaller number of firms, thus, pays a larger subsidy per unit of output. This counteracts the tendency of these firms to strategically reduce their output in order to push down the wage rate in this country.

The finding that the distribution of firms becomes irrelevant for the market outcome when countries set their tax/subsidy instruments $\gamma_l$ non-cooperatively, is intriguing. Intuitively, countries have two reasons to subsidize the output of domestic firms. On the one hand, a subsidy helps to reduce the welfare losses related to imperfect competition. On the other hand, since (due to imperfect competition) firms can earn positive profits, each country has an incentive to subsidize the domestic firms in order to increase their market share in the global market, which implies that some of the surplus generated in the foreign country is shifted to the home country. The reason why a single policy instrument is sufficient to eliminate both distortions at the same time, is that the second distortion (subsidizing the home industry in order to shift surplus from the foreign to the home country) vanishes once the first distortion has been eliminated. When (given the subsidy) firms behave as if the sector were perfectly competitive (which eliminates the first distortion), then from a social point of view (taking into account profits, consumer surplus, and transfers), it is as if firms in this sector were earning
zero profit. From this point, it cannot be in country l’s interest to increase the subsidy rate further.

2.2 Non-cooperative taxation of mobile firms

In the following, we derive countries’ choices of their tax/subsidy instrument \( \gamma_l \), when the distribution of firms across countries is not fixed, but determined endogenously. Recall that the timing of the game is as follows. In stage 1, regulators in A and B announce (and credibly commit to) their choice of the policy parameter \( \gamma_l \). In stage 2, firms choose their location (A or B), and in stage 3, they compete in quantities.

Let us first characterize the market outcome, including the endogenous location of firms \((k^*_A, k^*_B)\), for any given choice of the policy parameters \((\gamma_A, \gamma_B)\). The results of stage 3 are identical to those derived in the previous subsection. Since firms are free to choose their location in stage 2, they shift from A to B or vice versa, until the profits per firm are equalized across countries. Hence, the following condition is used to compute \( k^*_A \) (given \((\gamma_A, \gamma_B)\)):

\[
\pi_{iA}(k^*_A, k^*_B) = \pi_{iB}(k^*_A, k^*_B),
\]

where \( k^*_B = k - k^*_A \). Our next result simplifies the derivation of \( k^*_A \):

**Lemma 1** When countries are symmetric (except for the choice of their policy parameters \( \gamma_l \)), and firms are mobile, equilibrium output per firm is the same in both countries: \( q^*_A = q^*_B \equiv q^* \).

Intuitively, if mobile firms face an identical output price, they choose to locate in the country with the lower marginal costs. Via the endogenous wage effects in our model, firm relocation, thus, equalizes marginal costs across countries (but not necessarily the wage rates, as labor is immobile). But equal marginal costs and prices imply equal output quantities.

Using the equilibrium condition \( q^*_A = q^*_B = q^* \) in (8), and solving for \( k_A \) (using \( k_B = k - k_A \)), we obtain the following endogenous distribution of firms across countries:

\[
k^*_A = \frac{(\alpha - \gamma_A)k\delta - (\gamma_A - \gamma_B)(\beta(k + 1) + \delta)}{(2\alpha - \gamma_A - \gamma_B)\delta}.
\]

Using our findings from Section 2.1, the remaining results for the equilibrium outcome under firm mobility are now easily obtained:

\[
q^* = \frac{2\alpha - \gamma_A - \gamma_B}{2\beta(k + 1) + \delta(k + 2)}, \text{ and } \pi^*_{il} = (\beta + \delta)(q^*)^2.
\]

The following result highlights an interesting feature of our model.
Proposition 2 When countries are symmetric (except for the choice of their policy parameters $\gamma_l$), aggregated output $Q^*$ under firm mobility is the same as under fixed locations with $k_A = k/2$.

According to Proposition 2, the endogenous relocation of Cournot firms among symmetric countries (except for $(\gamma_A, \gamma_B)$) does not affect total output $Q$, relative to a case where the location of firms is fixed and $k_A = k/2$ is used as reference point. When the policy parameters $\gamma_A$ and $\gamma_B$ are altered, then this usually affects total output (unless they are changed in reverse directions and their sum remains constant). However, the effects on $Q^*$ are identical when location choices are exogenous and when they are determined endogenously. In order to provide some intuition, here is a brief summary of the effects underlying this result.

Suppose, that starting from a situation where $\gamma_A = \gamma_B = 0$, the parameter $\gamma_A$ is unilaterally raised. When locations are fixed, the taxation of output in country A depresses the output of firms located in A. This reduction in output pushes the market price $P$ upwards, which gives firms located in B an incentive to raise their output. This reduces the effect of country A’s unilateral tax policy upon the total quantity $Q$, but does not neutralize it. Now consider the case where locations are endogenous. A unilateral increase in $\gamma_A$ makes firms located in A less competitive, and induces a shift of firms towards B. The endogenous relocation of firms comes to a halt when the competitive disadvantage is offset ($c_A(Q_A) = c_B(Q_B)$), as wages in B increase, while wages in A decrease. The overall effect of the raise in $\gamma_A$ upon the total quantity $Q^*$ is negative. However, it turns out to be the same both under exogenous and endogenous location choices.

Let us now analyze how countries set their tax/subsidy instruments. The following result shows that the main finding obtained under fixed locations (Proposition 1), continues to hold also when firms’ locations are endogenous:

Proposition 3 When firms are mobile, and countries set their tax/subsidy instruments non-cooperatively, the global welfare optimum is reached.

The finding that the first-best outcome is obtained under non-cooperative tax policies, both under exogenous and endogenous location choices of firms across countries, is not trivial, because the effects of a policy change on local wages $w_l$ and output $Q_l$ are different in both cases. To see this, suppose that starting from a situation where $\gamma_A = \gamma_B$ holds, country A raises $\gamma_A$. The resulting decline in output $Q_A$ is more pronounced when locations are endogenous, relative to the outcome obtained under an endogenous distribution of firms across countries, when the policy parameters of both countries are equal ($\gamma_A = \gamma_B$).

Note, that $k_A = k/2$ is the outcome obtained under an endogenous distribution of firms across countries, when the policy parameters of both countries are equal ($\gamma_A = \gamma_B$).

In the presence of environmental externalities, this causes emissions leakage.
to the case where locations are fixed. Hence, starting from a situation where $\gamma_A = \gamma_B$, welfare of country A is always higher after a raise in $\gamma_A$ when locations are fixed, relative to the case where they are endogenous (not shown).

However, despite these differences, the *equilibrium* choices of $\gamma_A$ and $\gamma_B$ are the same in both cases. Underlying this result is the same basic finding, that holds both when locations are exogenous or endogenous. Namely, when countries subsidize output in an imperfectly competitive industry to eliminate welfare losses due to imperfect competition, then also the incentives to induce firms to obtain a higher market share in the world market, or to prevent their relocation to the other country, vanish. Hence, in the absence of further market failures (such as an environmental externality – see Section 3, below), a single policy instrument allows countries to eliminate welfare losses due to imperfect competition, *despite* countries’ non-cooperative choice of this policy instrument.

### 3 Taxes and welfare under environmental externalities

Let us now introduce environmental externalities into the model. The case we are interested in is where the emissions intensity in the sector of interest is higher than in the numeraire good sector. For simplicity, we assume that the production of the numeraire good causes no emissions, while the production of one unit of output in the sector of interest causes one unit of emissions.\(^{22}\) Welfare of each country is affected by the total emissions of both countries, given by the total output $Q = Q_A + Q_B$. We assume a linear damage function, with a slope of $\varphi$. Hence, to compute country $l$’s welfare as a function of the output quantities $Q$ and $Q_l$, the term $-\varphi Q$ must be added to the expression in (3). Furthermore, whenever the distribution of firms across countries is fixed, we will restrict our attention to the symmetric case where $k_A = k/2$. Therefore, both under exogenous and endogenous location choices, outcomes will be symmetric, and the *equilibrium* policy parameter for each country will be denoted by $\gamma$.\(^{23}\)

Most of the analysis from Section 2 remains unchanged. Firms and consumers (by assumption) neglect the environmental externalities in their production and consumption decisions. Therefore, environmental externalities will affect the outcome only indirectly, through changes in the policy parameter $\gamma$. Countries face the following trade-off. On the one hand, they have an incentive to subsidize the output of firms in order to reduce the efficiency losses due to imperfect competition. On the other hand, they should tax production because it causes en-

\(^{22}\)See also Markusen et al. (1995).

\(^{23}\)The more general case where the exogenous distribution of firms can be skewed is algebraically less convenient, and adds little to the understanding of our main results in this section.
vonic damages. Because of the externalities between countries, country 𝑙’s incentives to tax production in the sector of interest do not reflect the full global benefit of emissions reduction. Furthermore, as countries are engaged in tax competition, results will depend on whether firms’ location choices are endogenous or exogenously fixed. We will show below that when firms are free to choose their location, tax competition becomes more intense. This is detrimental to welfare.

3.1 Global and autarky welfare optimum

Under environmental externalities, there are two different benchmark cases to consider. On the one hand, there is again the global welfare optimum, that delivers the highest feasible welfare that countries can (potentially) reach when they fully cooperate. Environmental externalities within and between countries are, then, fully internalized, and the adverse welfare effects of imperfect competition are neutralized by appropriate policy intervention. On the other hand, a useful benchmark to consider is the case where each country acts on its own, but strategic behavior of countries is ruled out. This delivers the same maximum welfare as in a situation where trade between countries is prohibited, and environmental externalities between countries are neglected. The policy maker in each country, thus, only takes into consideration domestic environmental damages, and tries to offset the adverse effects of imperfect competition within its country. This autarky case is the more relevant benchmark for our analysis, because we do not allow for the possibility that countries set their tax instruments cooperatively. Hence, under decentralized policy-making in the two countries, the highest feasible welfare that could potentially be reached is the autarky welfare optimum.

To compute the welfare maximum in the autarky case, define \( \hat{\alpha} \equiv \alpha - \varphi \). Given this definition, the welfare analysis in Appendix A.2 remains unchanged when the parameter \( \alpha \) is replaced by \( \hat{\alpha} \) everywhere. Hence, the welfare maximum under autarky is given by (26) and (4), when \( \alpha \) is replaced by \( \hat{\alpha} = \alpha - \varphi \).

To obtain the global welfare optimum where environmental externalities between countries are also internalized, replace \( \alpha \) by \( \tilde{\alpha} \equiv \alpha - 2\varphi \). Results are otherwise the same.

Let us now analyze how a regulator in country 𝑙 can implement the autarky welfare op-

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24 Given a technology that converts one unit of labor into one unit of output, a tax per unit of emissions is equivalent to a tax per unit of output.

25 Recall that we simply have to subtract \( \varphi Q_l \) from the expression for welfare to take into account environmental damages.

26 Note, that in the absence of environmental externalities between countries, the global welfare optimum coincides with the autarky welfare optimum. Therefore, a distinction between global and autarky welfare optimum was not necessary in Section 2.
timum under market conditions with the help of taxes or subsidies (assuming that regulators do not interact strategically). As mentioned above, countries face a trade-off between subsidizing production in order to alleviate the welfare losses related to imperfect competition, and taxing production in the sector of interest in order to induce firms to internalize the domestic environmental damages caused by their production. In order to disentangle these two motives, it is useful to express the policy parameter $\gamma$ as the sum of two (hypothetically) independent policy instruments: an output subsidy $\sigma$ to correct for the market failure due to imperfect competition, and an emissions tax $\tau$. Furthermore, we assume that the presence of environmental externalities does not affect countries’ choice of the output subsidy. This is motivated by our earlier finding that in the absence of environmental externalities, the welfare optimum is reached even under decentralized policy-making (see Propositions 1 and 3). Therefore, from now on we assume that the output subsidy is always fixed and given by (see (28)):

$$\sigma \equiv \frac{2\alpha(\beta + \delta)}{k(2\beta + \delta)}.$$  

(11)

The policy instrument $\gamma$ will from now on be expressed as: $\gamma = \tau - \sigma$.

Under conditions of perfect competition, the output subsidy $\sigma$ is clearly zero because the welfare losses of imperfect competition then vanish. As the Cournot outcome converges to the perfectly competitive one for $k \to \infty$, $\sigma$ converges to zero when $k \to \infty$. The optimal emissions tax under perfect competition and autarky is, therefore, $\tau = \varphi$. Given this tax rate, firms internalize the domestic external damages caused by their productive activities. For simplicity, we refer to this tax rate as the Pigouvian tax.

Under imperfect competition, however, the Pigouvian tax rate $\tau = \varphi$ is insufficient to implement the welfare maximum. Cournot competition distorts the outcome, and as a result of this, regulators have to create additional incentives for firms to lower their emissions. This result is summarized in the next lemma:

**Lemma 2** Under imperfect competition, regulators must set the emissions tax $\tau$ above the Pigouvian tax level $\varphi$ to achieve the autarky welfare maximum under market conditions.

Intuitively, imperfectly competitive firms are less responsive to an emissions tax because they have a positive margin for each unit they sell. Therefore, they are less willing to lower their output in order to reduce their emissions as compared to competitive firms. To account for this, regulators have to implement emissions taxes above the Pigouvian level to reach the autarky welfare optimum under market conditions.
3.2 Environmental tax competition with immobile firms

Let us now analyze how the presence of environmental externalities affects the outcome under tax competition. We first consider the case where the number of firms per country is exogenously fixed (and \(k_A = k/2\)). The expression shown in (8) for the equilibrium quantity per firm, for a given set of policy instruments \((\gamma_A, \gamma_B)\), remains valid. In order to endogenize these instruments, follow the same steps as shown in the proof of Proposition 1, adding the expression \(-\varphi Q\) to the welfare function in (3). The results are summarized in the following Lemma:

**Lemma 3** Under tax competition and exogenous locations, the equilibrium choice of the policy instrument \(\gamma^*\) is linearly increasing, and total output \(Q^*\) is linearly decreasing in the damage parameter \(\varphi\). Welfare per country is a linear-quadratic function of \(\varphi\).

To compute the emissions tax, use \(\tau = \gamma + \sigma\) and (11) in (31) (see the proof of Lemma 3). This yields:

\[
\tau^*_{\text{exog}} = \frac{4(1 + k) \beta^2 + 2(2 + k)^2 \beta \delta + (2 + k)^2 \delta^2}{k(2 + k)(2 \beta^2 + 3 \beta \delta + \delta^2)} \varphi. \tag{12}
\]

Let us compare the emissions tax rate \(\tau^*_{\text{exog}}\) under environmental tax competition (with exogenous firm locations) with the Pigouvian tax rate \(\tau = \varphi\) that induces firms to internalize external damages under perfect competition, and with the optimal tax \(\tau^o\) that implements the autarky welfare maximum under imperfect competition.

**Proposition 4** Tax competition with exogenous locations is detrimental to welfare in the presence of environmental externalities. The emissions tax rate can be smaller or greater than the Pigouvian tax. It is above (below) the Pigouvian tax if the number of firms \(k\) is sufficiently small (large). However, it is always lower than the optimal tax that implements the autarky welfare maximum under imperfect competition. Hence, environmental tax competition induces countries to set inefficiently low emissions taxes.

In other words, the detrimental effects of environmental tax competition do not vanish even when the number of firms converges to infinity, so that the sector of interest becomes perfectly competitive. Intuitively, when the total number of firms \(k\) is large, then distortions related to imperfect competition vanish. The Cournot outcome converges to the competitive outcome, and the output subsidy converges to zero. However, an imperfection remains that distorts the choice of the emissions tax away from the autarky optimum: emissions leakage.\(^27\)

\(^{27}\)Related to carbon dioxide emissions, this phenomenon is more commonly known as carbon leakage.
Although we obtain a symmetric outcome in equilibrium, to compute this equilibrium we must evaluate changes in the welfare of each country following a deviation from the equilibrium strategy. E.g., suppose country A unilaterally chooses a higher emissions tax $\tau_A$. This leads to reduced emissions in A, but raises the world price $P$, which induces firms located in country B to produce a higher output $Q_B$, and hence, higher emissions. Leakage implies that country A’s incentives to raise $\tau_A$ in order to reduce global emissions are lower than in a comparable situation where the emissions in B remain fixed. This logic applies to both countries, which leads to an inefficiently low choice of the emissions tax rate $\tau$ in both countries.

To demonstrate that the inefficiently low choice of the emissions taxes is indeed related with the problem of leakage, subtract $\varphi Q_A$ ($\varphi Q_B$) from country A’s (B’s) welfare in (3), instead of $\varphi Q$. This modification corresponds to a problem of local pollution, instead of global pollution where each country’s welfare depends only on aggregated emissions $Q$. Solving for the endogenous emissions tax rate under local pollution, one obtains the optimal tax rate $\tau^*$ (see (30)) that implements the autarky welfare maximum under market conditions. Hence, the welfare optimality result of Section 2 (see Propositions 1 and 3) is restored when environmental damages occur only locally.

### 3.3 Environmental tax competition with mobile firms

Now consider the case with endogenous location choices. To derive the outcome under tax competition, add $-\varphi Q$ to the welfare function in (3), and follow the same steps as outlined in the proof of Proposition 3. We obtain the following result that extends the findings of Lemma 3 to the case with mobile firms:

**Lemma 4** Under tax competition and endogenous locations, the equilibrium choice of the policy instrument $\gamma^*$ is linearly increasing, and total output $Q^*$ is linearly decreasing in the damage parameter $\varphi$. Welfare per country is a linear-quadratic function of $\varphi$.

To compute the emissions tax, use $\tau = \gamma + \sigma$ and (11) in (33) (see the proof of Lemma 4). This yields:

$$\tau^*_{\text{endog}} = \frac{\delta(2\beta(k+1) + \delta(k+2))}{(\beta + \delta)(2\beta + \delta)(k+1)} \varphi. \quad (13)$$

Let us compare the outcome under tax competition when locations are endogenous with our earlier results for fixed locations.

**Proposition 5** The welfare-reducing effect of tax competition under environmental externalities is more pronounced when firms are free to choose their location, relative to the case where
locations are fixed (and \( k_A = k/2 \)). When locations are endogenous, total output \( Q^* \) is higher, while the emissions tax \( \tau^* \) is lower than under exogenous locations.

Proposition 5 tells us that – unlike in the case without environmental externalities (see Section 2) – results are no longer the same when firms are free to choose their location, relative to the case where locations are fixed. The reason for this is that when firms can relocate, output in country \( l \) reacts more elastically to unilateral changes in the policy parameter \( \gamma_l \). Under tax competition, this induces countries to choose lower values of \( \gamma \) in equilibrium, implying lower taxes resp. higher subsidies paid per unit of output (tax competition is more intense). As a result, total output \( Q \) in this sector is higher when locations are endogenous.

As under exogenous locations, the welfare-reducing effect of tax competition under environmental externalities is related to the problem of emissions leakage. When firms are able to relocate to country B in response to a raise in the emissions tax in A, the leakage rate (i.e. the raise in emissions in B divided by the reduction in emissions in A) is higher than under fixed locations.

Interestingly, by Proposition 2, for any given choice of the policy instruments \((\gamma_A, \gamma_B)\) and, hence, \((\tau_A, \tau_B)\), a unilateral increase in \( \tau_A \) has precisely the same effect upon global emissions (that are equal to \( Q \)) under exogenous as under endogenous locations. However, under endogenous locations, the decline in domestic output \( Q_A \) is more pronounced, which implies that country A’s market share in the world market for the polluting good is reduced more substantially. This leads to more intense tax competition and additional welfare losses under endogenous locations. Hence, leakage alone is an insufficient explanation for the effects that we identify in this paper. It is the interaction of leakage and environmental tax competition that drives our results.

It is important to highlight that the welfare-reducing effects of international tax competition under environmental externalities identified above, arise in addition to the well-known free-rider problem in the choice of countries’ climate policies when countries do not internalize the negative environmental externalities they inflict upon each other. The free-rider problem is embedded in our model as well. However, in the presence of imperfect competition and emissions leakage, countries’ reluctance to set (globally) efficient emissions taxes (in the absence of cooperation) is even more severe, especially when firms are able to relocate to another country in response to a unilateral policy change. This is illustrated in Figure 1, that shows (schematically) the relative size of the emissions tax \( \tau \) for the different cases analyzed above.

To correctly interpret Figure 1, recall that an emissions tax of \( 2\varphi \) implements the global welfare optimum (full cooperation) under market conditions when \( k \to \infty \) (perfect competition), whereas \( \tau = \varphi \) implements the autarky welfare optimum under the same conditions. Under
imperfect competition \((k < \infty)\), the optimal tax rate \(\tau^o\) that implements the autarky welfare optimum under market conditions is larger than the Pigouvian tax rate \(\varphi\) because oligopolistic firms are less responsive to environmental tax incentives. When countries set their emissions taxes non-cooperatively and firms are immobile, an emissions tax of \(\tau^*_{\text{exog}}\) is implemented that lies strictly below \(\tau^o\) (so environmental tax competition is detrimental to welfare). When firms are mobile, the situation gets worse: the equilibrium tax rate in this case, \(\tau^*_{\text{endog}}\), is even lower, as a result of intensified environmental tax competition.

Let us briefly analyze when the firms’ option to relocate is particularly detrimental to welfare (relative to the case where locations are fixed). To this end, we compute the ratio of the endogenous emissions taxes under the two cases. Using (12) and (13), we obtain:

\[
\frac{\tau^*_{\text{exog}}}{\tau^*_{\text{endog}}} = \frac{(k + 1)(2\beta + \delta(k + 2))}{\delta k(k + 2)}.
\]

This ratio is linearly increasing in the parameter \(\beta\), and can become arbitrarily large (e.g. for small \(\delta\)). Furthermore, computing the first derivative of \(\frac{\tau^*_{\text{exog}}}{\tau^*_{\text{endog}}}\) w.r.t. the parameter \(k\), we find that the ratio is declining in \(k\). This indicates that the distorting effect of free location choices upon the endogenous choice of the emissions tax in both countries is particularly severe when the number of firms in the polluting sector \((k)\) is small. This is intuitive, as a smaller \(k\) implies higher profits, and already a minor increase in the number of domestic firms then leads to a significant rise of domestic firms’ global market share. Countries are, thus, ready to compete more vigorously for the location of firms by setting low emissions taxes.

### 3.4 Welfare and the strength of the externality

Let us finally shift our attention to the following question: how does the intensity of the environmental externality – as measured by the damage parameter \(\varphi\) – affect welfare in equilibrium? In the social optimum (both under autarky, and in the global welfare optimum), the answer to this question is trivial: a higher damage parameter unambiguously reduces welfare. However, under tax competition, the answer to this question is not so obvious. To see this, consider...
the following two extreme cases. When \( \varphi = 0 \), we know (by Propositions 1 and 3) that tax competition vanishes and the welfare optimum is reached. Conversely, since total output \( Q \) in the polluting sector (both under exogenous and endogenous locations – see Lemma 3 and 4) is declining linearly in \( \varphi \), there is a critical value of the damage parameter where output in this sector goes to zero. At this point (and beyond), the outcome under tax competition once more coincides with the welfare optimum, which (by Propositions 4 and 5) requires an output \( Q \) that is not greater than that under tax competition for any given \( \varphi \). In between these two extreme cases, welfare losses arise due to tax competition, and it is not obvious whether the relation between \( U^*_l \) and \( \varphi \) is monotonic.

By Lemma 3 and 4, the relation between \( U^*_l \) and \( \varphi \) is linear-quadratic, and it is straightforward to verify that \( U^*_l \) is convex in \( \varphi \) and, thus, has a minimum. However, the non-negativity constraint for \( Q \) has not yet been incorporated. Beyond the critical value of \( \varphi \) where \( Q^* \) goes to zero, welfare becomes independent of \( \varphi \) and is, therefore, just a constant.\(^{28}\) The question about the monotonicity of \( U^*_l \), therefore, translates into a question about the location of the welfare minimum (welfare being minimized over \( \varphi \)), relative to the location of the critical value of \( \varphi \) where \( Q^* \) becomes zero.

**Proposition 6** The relation between welfare under tax competition and the damage parameter \( \varphi \) is non-monotonic both under exogenous and endogenous location choices. When \( \varphi \) is sufficiently large, welfare is increasing in \( \varphi \), due to a coordinating effect of the environmental damages.

Here is an intuitive explanation for the non-monotonicity result of Proposition 6. When the damage parameter \( \varphi \) is small, tax competition does not distort the outcome significantly. In this case, welfare is close to the welfare optimum, and the direct negative effect of a rise in \( \varphi \) upon welfare implies that welfare decreases in \( \varphi \). When \( \varphi \) becomes larger, then in addition to this direct effect, tax competition distorts the outcome, so that welfare is further reduced (relative to the welfare optimum). However, when \( \varphi \) becomes sufficiently large, the environmental damages are so significant that each country individually has a strong incentive to reduce its own output \( Q_l \) of the polluting good. As a positive side effect, this softens the environmental tax competition. This “coordinating effect” amplifies the reduction in countries’ emissions, which explains why the raise in \( \varphi \) can overall lead to an increase in welfare. The outcome again

\[^{28}\text{This holds under exogenous and endogenous locations, and in the welfare optimum. The constant is equal to welfare when the market for good } y \text{ is shut-down. To compute it, simply set } L^*_l = 1, \text{ and insert this into the production function (17) for good } x \text{ to obtain: } x_l = \delta/2. \text{ Using } U_l(x_l) = x_l \text{ (see (15)), this yields: } U_l = \delta/2. \text{ Since } Q = 0, \text{ there are no environmental damages in this case.}\]
approaches the autarky welfare optimum when \( \varphi \) becomes sufficiently large.\(^{29}\) Countries then behave as if they were cooperating in the choice of their emissions taxes.

4 Conclusion

The literature on international environmental cooperation, with climate policy as its most important application, is mostly pessimistic about the prospects of cooperation. The lack of a commitment device and the well-known free-rider problem, make cooperation hard to sustain on a scale needed to tackle the global public good problem of climate protection.

By introducing environmental externalities into a tax/subsidy competition model with imperfect competition, this paper shows that when countries do not cooperate, the outcome can be even worse than predicted by the standard free-rider argument: Countries that compete for the location of firms may set emissions taxes far below the level they would choose if they only ignored negative environmental externalities between them, but otherwise acted non-strategically. Environmental tax competition is, thus, detrimental to welfare, and offers another plausible explanation for why many countries are reluctant to implement effective emissions prices, in addition to the well-known free-rider argument.

This problem is related to (but not restricted to) the issue of emissions leakage. If a country unilaterally raises its emissions tax, this increases the world price of the good, which leads to a higher output (and higher emissions) in the other country. Leakage reduces countries’ incentives to implement emissions prices. The problem is particularly severe when firms can relocate (without costs) to the other country. In this case, domestic output responds more elastically to unilateral policy changes than under fixed locations, and as a result, environmental tax competition intensifies.

Nevertheless, our model predicts globally efficient outcomes for two extreme cases: in the absence of environmental externalities, and when environmental externalities are so strong that production of the polluting good is terminated even without cooperation. In between these extreme cases, the relation between the strength of the externalities and welfare is nonlinear. When damages are already sufficiently severe, welfare increases in the size of the damage parameter.

\(^{29}\)In the autarky welfare optimum, the critical point where output in the polluting sector becomes zero is (by (29)) given by: \( \varphi_{\text{crit}} = \alpha \).
A Appendix

A.1 Trade model

Here we lay out our basic trade model that is used to derive (1) and (2) from more fundamental assumptions. In doing so, we also derive an expression for country $l$’s welfare, that is later used to endogenize countries’ policy instruments $\gamma_A$ and $\gamma_B$.

Demand for our good of interest (produced in the imperfectly competitive sector of the economy) – in the following referred to as good $y$ – is derived by maximizing the utility of a representative consumer in country $l$:

\[ U_l(x_l, y_l) = x_l + \alpha y_l - \beta y_l^2, \]

where $y_l$ is the quantity consumed of good $y$ in country $l$, and $x_l$ is the quantity consumed of the numeraire good $x$. Both goods are tradable, and there are no transportation or other trade costs (e.g. tariffs). Therefore, prices of both goods are equalized across countries. The price of the numeraire good $x$ is normalized to 1. Note, that utility in both countries is quasi-linear.

The representative consumer in each country supplies 1 unit of labor, and labor markets are competitive. Hence, in country $l$, firms from both sectors ($x$ and $y$) face the same wage rate $w_l$. However, labor is an immobile production factor. Therefore, wage rates are not generally equal across countries. The budget constraint of the representative consumer in country $l$ reads:

\[ x_l + Py_l = w_l + \pi^x_l + \pi^y_l + \gamma_l Q_l, \]

where $\pi^x_l$ resp. $\pi^y_l$ are the aggregated profits of firms producing good $x$ resp. $y$ in country $l$. $\gamma_l Q_l$ are the tax revenues (resp. subsidy payments) from sector $y$ in country $l$, that are redistributed to (resp. levied from) consumers in a lump-sum fashion. Note, that due to international trade, the quantity of good $y$ produced in country $l$, $Q_l$, is not generally equal to the quantity of the same good consumed in country $l$ ($y_l$).

The numeraire good $x$ is supplied by competitive firms. The total supply is captured by the following (aggregated) production function in country $l$:

\[ x^s_l = F_l(L^x_l) = \delta \left( L^x_l - \frac{1}{2} (L^x_l)^2 \right), \]

where $x^s_l$ is the quantity of good $x$ supplied by firms located in country $l$, and $L^x_l$ is the amount of labor employed in the production of good $x$. Other input factors (besides labor) are not explicitly modeled. Our specification of the model is consistent with the assumption that the total supply of these other factors (e.g. land) is fixed. This explains the declining marginal productivity of labor in sector $x$. 

\[ 22 \]
Because the labor market in country \( l \) is assumed to be competitive, the wage rate \( w_l \) equals the marginal value of labor in the production of good \( x \):

\[
w_l = \frac{dF_l(L^x_l)}{dL^x_l} = \delta (1 - L^x_l).
\]

Labor supply is inelastic, and aggregate labor supply in each country is equal to 1. Hence:

\[
1 - L^x_l = L^y_l.
\]

Using this relation, we can express the endogenous wage rate in country \( l \) as a function of the amount of labor employed in the production of our good of interest (good \( y \)): \( w_l(L^y_l) = \delta L^y_l \). Furthermore, we assume that 1 unit of labor is needed to produce 1 unit of good \( y \), hence: \( L^y_l = Q_l \). Therefore, the wage rate in country \( l \) is simply a linear function of the quantity of good \( y \) produced in country \( l \) (\( Q_l \)):

\[
w_l(Q_l) = \delta Q_l. \tag{18}
\]

This yields (2). Note, that the wage rate in country \( l \) is zero if country \( l \)’s output in sector \( y \) is zero. This property simplifies the algebraic expressions, but has no qualitative effects upon the results of our model.\(^{30}\)

In order to solve the representative consumer’s problem, insert the budget constraint (16) into the utility function (15) to obtain:

\[
U_l = w_l + \pi^x_l + \pi^y_l + \gamma_l Q_l - P y_l + \alpha y_l - \beta y_l^2.
\]

Maximizing over \( y_l \), we obtain the following demand function for country \( l \):

\[
y_l(P) = \frac{\alpha - P}{2\beta}. \tag{20}
\]

Note, that the right-hand side is independent of the index \( l \) of the country. The aggregate demand of both countries is, thus, given by: \( Y = 2y_l(P) = \frac{\alpha - P}{\beta} \). Solving for \( P \), and using the aggregate market clearing condition for good \( y \): \( Y = Q \), we obtain the inverse demand function \( P(Q) = \alpha - \beta Q \) as shown in (1).

In the following, we derive an expression for welfare in country \( l \), that depends only on parameters and on the output quantities \( Q_A \) and \( Q_B \) in our sector of interest. These output

\(^{30}\)In order to obtain a positive wage rate \( w_l \) when \( Q_l = 0 \), the production function \( F_l(L^x_l) \) must be modified. Under our specification, the marginal product of labor declines to zero when \( L^x_l \) approaches 1. This is what drives wages to zero in this case. A decline in the output of sector \( y \), thus, induces downward pressure on wages, which leads to a shift from labor income (\( w_l \)) towards profits (\( \pi^x_l \)). In our model, this shift has no direct welfare impact, because profits accrue within the country.
quantities will later be endogenized, depending (among other things) on the distribution of firms across countries. However, the following welfare analysis is valid for any $Q_A$ and $Q_B$. Therefore, we can use the expression derived below also to compute welfare in the benchmark case where the distribution of firms across countries is not flexible but exogenously fixed. In order to derive this expression, we use (19), and replace $\pi^x_l$, $\pi^y_l$, as well as $y_l$ by expressions that depend only on the parameters of the model: $\alpha$, $\beta$, $\gamma_l$, $\delta$ ($l \in \{A, B\}$).

The profit of sector $x$ in country $l$ is given by: $\pi^x_l = x^*_l - w_l L^x_l$. Using (17) to replace $x^*_l$, this becomes: $\pi^x_l = (\delta - w_l) L^x_l - \delta (L^x_l)^2 / 2$. Using $L^x_l = 1 - L^y_l = 1 - Q_l$ and $w_l = \delta Q_l$ (from (18)), this simplifies to:

$$\pi^x_l = \delta \left(1 - Q_l\right)^2 / 2.$$  \(21\)

Country $l$’s aggregated profit in sector $y$ is given by: $\pi^y_l = (P - c_l(Q_l))Q_l$. Using (2), this becomes:

$$\pi^y_l = (P - \gamma_l - \delta Q_l)Q_l.$$ \(22\)

Using (21), (22), (20), (18), and (1) in (19), and after rearranging, we obtain expression (3) for country $l$’s welfare (shown in the main text). Before this welfare expression can be used to endogenize $\gamma_A$ and $\gamma_B$ under non-cooperative taxation, the output quantities $Q_A$ and $Q_B$ need to be determined. See the main text.

### A.2 Welfare optimum

Since firms in sector $y$ operate with a constant returns-to-scale technology (converting 1 unit of labor into 1 unit of output), the distribution of firms across countries has no effect upon the global welfare optimum, as long as a positive number of firms produces in each country, what we assume.\(^{32}\)

Since countries are – apart from the number of firms in this sector of the economy – symmetric, the global welfare optimum leads to a symmetric allocation across countries, inducing an identical welfare in each country. Hence, by (15):

$$W = U_A + U_B = 2 U_l = 2(x + \alpha y - \beta y^2),$$ \(23\)

where $x$ and $y$ are the consumed quantities of the two goods per country. Re-scaling the global welfare function, we obtain the same expression as in (15). This is intuitive. Since countries are

\(^{31}\)At this stage, $\gamma_l$ is treated as a parameter. Later, it will be endogenized.

\(^{32}\)Any single firm in country $l$ can produce a given output quantity $Q_l$ as efficiently as a larger number of firms can.
effectively symmetric, the global welfare optimum does not involve any trade, and the outcome for an individual country is the same as in a situation where trade is prohibitively costly.

The problem is to maximize global welfare under the following constraints:

\[ x = F(L^x_l) = \delta \left( L^x_l - \frac{1}{2}(L^x_l)^2 \right), \quad y = L^y_l, \quad L^x_l + L^y_l = 1. \] (24)

Combining these conditions, we obtain the following relation:

\[ x = \delta \left( 1 - y - \frac{1}{2}(1 - y)^2 \right). \]

Plugging this into our target function, we obtain for welfare per country:

\[ U_l = \delta \left( 1 - y - \frac{1}{2}(1 - y)^2 \right) + \alpha y - \beta y^2. \] (25)

The maximization over \( y \) yields the following result that holds under optimality:

\[ Q^*_l = y^* = \frac{\alpha}{2\beta + \delta}. \] (26)

Plugging this into (25), we obtain country \( l \)'s welfare in the global welfare optimum, as shown in (4) (see the main text).

A.3 Proofs for Section 2

Proof of Proposition 1:

It must be shown that under international tax competition (given some fixed distribution of firms across countries), the welfare optimal result derived in Section A.2 is obtained (independently of \((k_A, k_B)\)). To this end, insert \( k_l q^*_l \) (using (8)) into (3) to derive country \( l \)'s welfare \( U_l \) as a function of the governments' choice variables \((\gamma_A, \gamma_B)\), and the parameters of the model. This expression is lengthy and, therefore, not shown here. Algebraically, it is a linear-quadratic function of \( \gamma_A \) and \( \gamma_B \). To derive the outcome under non-cooperative taxation, maximize \( U_l \) over \( \gamma_l \), taking the strategy of the other country as given. Solve the linear system of first-order conditions for \((\gamma_A, \gamma_B)\) to obtain the following result:

\[ \gamma^*_l = -\frac{\alpha(\beta + \delta)}{k_l(2\beta + \delta)}. \] (27)

Plugging this result back into (8), it is straight-forward to verify that the aggregate quantity produced of good \( y \) per country: \( Q^*_l = k_l q^*_l \) under non-cooperative taxation coincides with the corresponding quantity in the global welfare optimum, shown in (26). Inserting this quantity back into (3), it is easy to verify that under non-cooperative taxation, each country achieves...
the same welfare as in the global welfare optimum (see (4)). Q.E.D.

Proof of Lemma 1:
When locations are endogenous, marginal production costs are equalized across countries: $c_A = c_B = c$. For otherwise, firms located in the country with the higher marginal production cost, could achieve a higher profit by relocating to the other country (recall that all firms face the same output price $P$, so locations can differ only in marginal costs). Now suppose, $c_A = c_B = c$ holds, but $q_A \neq q_B$. This implies that firms located in A do not earn the same profit as firms located in B, because $\pi_{il} = (P - c)q_{il}$ (see (5)). This is a contradiction to the condition $\pi_{A}(k^*_A, k^*_B) = \pi_{B}(k^*_A, k^*_B)$, which requires that – in an equilibrium with free location choices – firms are indifferent between both locations. Q.E.D.

Proof of Proposition 2:
The aggregated quantity when locations are endogenous is $Q^* = kq^*$, where $q^*$ is given by (10). When locations are exogenously fixed, and $k_A = k/2$, $Q^*$ can be derived using (8) (setting $k_l = k_m = k/2$). In both cases, the same total output $Q^*$ is obtained. Q.E.D.

Proof of Proposition 3:
The welfare optimum derived in Section A.2 is our reference point also when the distribution of firms is endogenous, because it is independent of this distribution. Hence, we need to show that the outcome under non-cooperative taxation when location choices are endogenous, coincides with this outcome. To this end, use (9) and (10) to obtain expressions for $Q^*_l$ and $Q^*$. Use these in (3) to derive welfare as a function of the policy parameters $(\gamma_A, \gamma_B)$. As under fixed locations, one obtains a linear-quadratic function of $\gamma_A$ and $\gamma_B$. Take the derivative of $U_l$ w.r.t. $\gamma_l$ ($l = A, B$), and solve the resulting linear system of equations for $(\gamma_A, \gamma_B)$ to find:

$$\gamma^*_l = -\frac{2\alpha(\beta + \delta)}{k(2\beta + \delta)}.$$  \hspace{1cm} (28)

This is the same result as in (27), when $k_l$ is replaced by $k/2$. Note, that the outcome under non-cooperative taxation with endogenous locations is symmetric, hence, $k_l = k/2$ is fulfilled in equilibrium. To complete the proof, note that by Proposition 1, for any given distribution of firms across countries, the welfare optimum is always obtained under non-cooperative taxation. Therefore, it is also obtained under the symmetric distribution with $k_A = k/2$. Given this symmetric distribution, the subsidy rates $\gamma_l$ are identical when the distribution of firms is exogenous or endogenous (as shown above). It follows that also under an endogenous distribution of firms, the welfare optimum is achieved under non-cooperative taxation. Q.E.D.
A.4 Proofs for Section 3

Proof of Lemma 2:
To compute the tax level that implements the welfare maximum under autarky, let us first determine which choice of the policy instrument $\gamma$ corresponds to the optimal quantity $Q^o$. Using (26), we find for the optimal quantity (recall, that we must replace $\alpha$ by $\alpha - \varphi$):

$$Q^o = \frac{2(\alpha - \varphi)}{2\beta + \delta}.$$  \hfill (29)

The total output quantity under market conditions is given by $kq^*$, where $q^*$ is given by (8). Using $\gamma_l = \gamma_m \equiv \gamma$ and $k_l = k_m = k/2$ due to symmetry, we obtain for the total quantity:

$$Q^* = \frac{2k(\alpha - \gamma)}{2\beta(k + 1) + \delta(k + 2)}.$$  

Equalizing $Q^o$ and $Q^*$, and solving for $\gamma$, we obtain the following policy parameter that implements the welfare maximum under market conditions:

$$\gamma^o \equiv \frac{-2\alpha(\beta + \delta) + (2(1 + k)\beta + (2 + k)\delta)\varphi}{(2\beta + \delta)k}.$$  

Using $\tau = \gamma + \sigma$ and (11), we, thus, obtain for the emissions tax:

$$\tau^o = \frac{2\beta(k + 1) + \delta(k + 2)}{(2\beta + \delta)k} \varphi.$$  \hfill (30)

Subtracting the denominator from the numerator (neglecting $\varphi$), we find the expression: $2(\beta + \delta)$, which is greater than zero. It follows that $\tau^o > \varphi$, which completes the proof. Q.E.D.

Proof of Lemma 3:
Following the steps outlined in the main text, we obtain the following expressions (the subscript $\text{exog}$ indicates the case with exogenous locations):

$$\gamma^*_\text{exog} = \frac{-2(2 + k)\alpha(\beta + \delta)^2 + (4(1 + k)\beta^2 + 2(2 + k)^2\beta\delta + (2 + k)^2\delta^2)\varphi}{k(2 + k)(2\beta^2 + 3\beta\delta + \delta^2)} \hfill (31)$$

$$Q^*_\text{exog} = \frac{2((2 + k)\alpha(\beta + \delta) - (2\beta + (2 + k)\delta)\varphi)}{(2 + k)(\beta + \delta)(2\beta + \delta)}.$$  \hfill (32)

The expression for $U_l$ is rather lengthy and, therefore, not shown here. However, it is straightforward to verify that the numerator is linear-quadratic in $\varphi$, while the denominator is independent of $\varphi$. Q.E.D.

Proof of Proposition 4:
The endogenous emissions tax rate under tax competition when locations are fixed is given
by (12). Subtracting the denominator from the numerator (omitting \( \varphi \)), we find the following expression:

\[
2(2 - k^2)\beta^2 + (8 + 2k - k^2)\beta\delta + 2(2 + k)\delta^2.
\]

This is greater than zero when \( k \) is sufficiently small.\(^{33}\) Hence, the emissions tax is greater than the Pigouvian tax when \( k \) is small. To show that \( \tau \) is below the Pigouvian tax when \( k \) is sufficiently large, compute the limit of (12) for \( k \to \infty \) to find:

\[
\lim_{k \to \infty} \tau^*_\text{exog} = \frac{\delta\varphi}{\beta + \delta} < \varphi.
\]

To show that the emissions tax rate under tax competition is lower than the optimal tax that implements the autarky welfare maximum under imperfect competition, subtract \( \tau^*_\text{exog} \) (using (12)) from \( \tau^o \) (using (30)) to obtain an expression that is strictly greater than zero (for \( \varphi > 0 \)) (not shown). For the difference between welfare (per country) in the global welfare optimum, and welfare under tax competition with exogenous locations, we find:

\[
U^o_l - U^\text{exog}_l = \frac{(2(1 + k)\beta + (2 + k)\delta)^2\varphi^2}{2(2 + k)^2(\beta + \delta)^2(2\beta + \delta)} > 0, \text{ for } \varphi > 0.
\]

Therefore, environmental tax competition is detrimental to welfare under exogenous firm locations.\(^{34}\) Q.E.D.

**Proof of Lemma 4:**

When locations are endogenous, we obtain the following expressions under tax competition:

\[
\gamma^*_\text{endog} = \frac{-2\alpha(1 + k)(\beta + \delta)^2 + k\delta(2\beta(1 + k) + \delta(2 + k))\varphi}{k(1 + k)(2\beta^2 + 3\beta\delta + \delta^2)} \quad (33)
\]

\[
Q^*_\text{endog} = \frac{2\alpha((1 + k)(\beta + \delta) - k\delta\varphi)}{(1 + k)(2\beta^2 + 3\beta\delta + \delta^2)}. \quad (34)
\]

The expression for \( U_l \) is not shown, but it is of the same basic algebraic form (linear-quadratic in \( \varphi \)) as under exogenous locations. Q.E.D.

**Proof of Proposition 5:**

To show that the equilibrium value of \( \tau \) is lower when locations are endogenous, subtract (13) from (12) to obtain:

\[
\tau^*_\text{exog} - \tau^*_\text{endog} = \frac{(2(1 + k)\beta + (2 + k)\delta)^2\varphi}{k(2 + 3k + k^2)(2\beta^2 + 3\beta\delta + \delta^2)} > 0, \text{ for } \varphi > 0.
\]

\(^{33}\)For \( k \to 0 \), \( \tau^\text{exog} \) converges to infinity.

\(^{34}\)Using the global welfare optimum as reference point, which delivers the same welfare as under autarky in the absence of environmental externalities. The difference between \( U^o_l \) and \( U^\text{exog}_l \) is smaller when the autarky welfare optimum is used as reference point. However, \( U^o_l \geq U^\text{exog}_l \) is always fulfilled. This follows immediately from the inefficient choice of \( \gamma \).
For the difference in output quantities, we find:

\[ Q_{\text{endog}}^* - Q_{\text{exog}}^* = \frac{2(2(1 + k)\beta + (2 + k)\delta)\varphi}{(2 + 3k + k^2)(\beta + \delta)(2\beta + \delta)} > 0 \text{, for } \varphi > 0. \] (35)

To show that tax competition is more detrimental to welfare when locations are endogenous, compared to the case with exogenous locations, compute:

\[ U_{l\text{exog}}^* - U_{l\text{endog}}^* = \frac{(3 + 2k)(2(1 + k)\beta + (2 + k)\delta)^2\varphi^2}{2(2 + 3k + k^2)^2(\beta + \delta)^2(2\beta + \delta)} > 0 \text{, for } \varphi > 0. \]

Q.E.D.

Proof of Proposition 6:

The relation between welfare and \( \varphi \) is non-monotonic if the welfare minimum (over \( \varphi \)) is located at a lower value of \( \varphi \) than the critical value of \( \varphi \) where \( Q^* \) becomes zero. To see that this is the case both under exogenous and under endogenous location choices, we first compute the critical values of \( \varphi \) (denoted by \( \varphi_{\text{crit}} \)) for both cases. To this end, use (32) and (34), and set the numerator of each expression equal to zero. Solving for \( \varphi \), this yields:

\[ \varphi_{\text{crit}}^{\text{exog}} = \frac{(k + 2)\alpha(\beta + \delta)}{2\beta + (k + 2)\delta} \] (36)

\[ \varphi_{\text{crit}}^{\text{endog}} = \frac{(k + 1)\alpha(\beta + \delta)}{\delta k}. \] (37)

To derive the location of the minimum of the welfare function (denoted by \( \varphi_{\text{min}} \)), compute the first derivative of \( U_l \) (computed by following the steps outlined in the proof of Lemma 3 for exogenous locations, resp. Lemma 4 for endogenous locations) w.r.t. \( \varphi \), and set the result equal to zero. Solving for \( \varphi \), one obtains the location of the minimum (not shown). To complete the proof, compute the ratio: \( \varphi_{\text{crit}}^{\text{exog}} / \varphi_{\text{min}}^{\text{exog}} \). E.g., in case of fixed locations, we find:

\[ \frac{\varphi_{\text{crit}}^{\text{exog}}}{\varphi_{\text{min}}^{\text{exog}}} = \frac{4(k + 1)\beta + (4 + 3k)\delta}{2(k + 1)(\beta + \delta)}. \]

To show that the ratio \( \varphi_{\text{crit}}^{\text{endog}} / \varphi_{\text{min}}^{\text{endog}} \) is greater than 1 (so \( \varphi_{\text{crit}}^{\text{endog}} > \varphi_{\text{min}}^{\text{endog}} \)), subtract in each case (exog, endog) the denominator from the numerator. Interestingly, both for exogenous and endogenous locations, this difference is given by the same expression: \( 2\beta(k + 1) + \delta(k + 2) > 0 \). Therefore, when \( \varphi \) is increased (in a comparative statics’ sense), then the welfare function of each country reaches a minimum before the output quantity in sector \( y \) (\( Q \)) goes down to zero. This completes the proof. Q.E.D.
References


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