

Carbon tax, emission permits, and carbon leak under price competition

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Abstract

Carbon tax policies in a country are often criticized as leading to production shifting to other unregulated countries ("carbon leak"). We analyze here the different impact on leakages and trade of a carbon tax and of an emission permit policy enacted by one country (the "home" country) in a two country model of price competition with differentiated products.

A lower carbon leak, a reduction in global emissions, and an improvement in traded volumes can be achieved by means of an emission standards, whereas a carbon tax improves the traded values; governments may have to face a trade-off between leakages and trade balance.

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1 Introduction

Efforts by industrialized countries to reduce polluting emissions have been accompanied by concerns over the effectiveness of unilateral measures, in terms of both welfare loss and carbon leakages. It is in fact well established in the literature that measures targeting a subset of manufacturers within a country ([Holland, 2012](#)) or manufacturers in only a subset of countries (incomplete regulation) can induce production and emission leakages to unregulated firms and in other countries ([Paltsev, 2001](#)), or they encourage domestic firms to relocate plants ([Babiker, 2005](#)). Even if recent contributions report a decline in these trends ([Barker et al., 2007](#); [Baylis et al., 2014](#); [Sanna-Randaccio et al., 2014](#)), considerable attention has been devoted to the analysis of these "leakages" mechanisms - several contributions also analyzing countervailing measures, like border adjustments or upstream-downstream subsidies ([Fischer and Fox, 2012](#); [Fischer et al., 2012](#)).

A related question is which is the type of policy that minimizes leakages. For instance, intensity standards, that set limits to carbon emissions per unit of output, have been proved to be inefficient ([Fischer, 2001](#); [Holland et al., 2009](#)), since "they cannot attain the first best, could increase carbon emissions", and entail "much higher abatement costs than an efficient policy" (See [Holland et al., 2009](#), p. 1). Still, according to [Holland \(2012\)](#), intensity standards can be welfare superior to a carbon tax and allow for a

second best outcome, in the presence of incomplete regulation and leakages.

So far, most of the existing literature on carbon leakages arising from local or incomplete regulation focuses on perfectly competitive markets. However, most issues in environmental regulation have been widely analyzed also in the context of oligopolistic industries (([Arora and Gangopadhyay, 1995](#); [Amacher et al., 2004](#); [Moraga-González and Padrón-Fumero, 2002](#)) are concerned with environmental qualities in a duopoly; ([Toshimitsu, 2008](#); [Kurytyka and Mahenc, 2011](#); [Carlsson, 2000](#)) deal with environmental taxation in duopolies; ([Lahiri and Ono, 2007](#)) compare welfare under permits and taxes; ([Requate, 2006](#)) provides a summary view). Furthermore, as argued by [Fowlie \(2009\)](#), "The majority of emissions that are currently subject to regional, market-based regulations come from industries that are often characterized as imperfectly competitive (important examples include restructured electricity markets and cement)" (See [Fowlie, 2009](#), p. 73). Finally, [Ryan \(2012\)](#) and [Fowlie et al. \(2012\)](#) supply evidence that concentrated industries are crucially affected by environmental regulation; using data for the U.S. Portland cement industry, the first provides an assessment of welfare reductions and increase in sunk costs, and the second of the welfare losses and "leakages" from incomplete regulation.

Based on these considerations, in this paper we analyze the implementation of an environmental policy under imperfect competition in prices. In the baseline version of the model we assume that firms cannot price discriminate across countries. This assumption may fit the case where leakages occur within the same country due to incomplete regulation, while also serving as a first approximation for a two country model. In the second version

of the model we allow firms to price discriminate across countries. On top of deriving the carbon leakages, we also consider the effects on the international competitiveness of the regulated country, by assessing the impact on its trade balance. We compare the effects of the two alternative instruments, a carbon tax and an emission permit (or absolute standard) whereby a firm is allowed to a maximum quantity of emissions. We do not consider abatement efforts and focus instead on the effects generated by strategic interaction in price competition. Although we think that abatement would also be affected, the focus on pricing strategies allows to reveal a channel of "transmission" of policies that per se is sufficient to bring forth leakage effects.

Price competition is different according to the policy tool that is chosen. The effect of a carbon tax on the price reaction function of the taxed firm in a model with differentiated products is obvious and there is no surprise that a carbon leak shall arise in that case. It is less obvious, by contrast, what is the effect on the equilibrium outcome in the case of a restriction on the quantity of emissions, and it is not a priori clear whether a leak will arise or not. An emission policy implies a constraint on the price choices by the home firm which must set prices for its product high enough to curtail its own demand and satisfy the emission limit. This implies that the regulated firm must follow a rule and cannot use its best reply function, while the foreign firm becomes a Stackelberg leader who can set its own price "expecting" the rival's response to abide the constraint. In this way it is not a priori clear whether the foreign firm will choose a price strategy to gain market shares in volumes or just in value, or both, with possible different implications for

emissions. In our framework, firms are immobile - as in the short run or due to technological constraints, and carbon leakages following climate policy regulation occurs only through trade flows and not through plant relocation (see instead [Petraakis and Xepapadeas, 2003](#); [Sanna-Randaccio et al., 2014](#)). To enable meaningful comparisons, the policy instruments that the regulator can introduce are tailored so as to guarantee the same level of emissions in the home country. In particular, the tax level is adjusted so as to achieve an "equivalent tax", namely a tax such that the equilibrium outcome entails the same desired level of emissions in the home country as the standard.

First of all, we confirm the existing concerns over unilateral environmental regulation in the case of a carbon tax, which may in fact induce an unwanted increase in global emissions. However in our model an absolute standard is more likely to lead to lower emissions abroad than to leakages, the more general message being that a standard leads to less leakage than a tax. We then observe that the carbon tax is an inferior instrument, not only in terms of leakage but also in terms of trade balance: this policy measure, in fact, leads to a greater emission leakage and also induces losses in the home country trade balance in volumes. A standard instead also leads to possible improvements in the trade balance in volumes. The trade balance in values, instead, deteriorates under either policy; however a carbon tax can lead to a lower deterioration than a standard, but only if goods are very close substitutes. The emission leak effects is however always unchanged and in favor of a standard. Overall, our findings point to the superiority of a standard over a carbon tax.

Our findings depart from [Holland \(2012\)](#), where the inferiority of a stan-

standard stems from the firms changing their input compositions, choosing different emission levels in their cost minimization problem. In our framework instead, the relative superiority of emission permits is intrinsic to the strategic interaction occurring between the firms in the two countries.

This work is structured as follows: Section 2 sets up the general model and analyzes the simplified case of a globally integrated demand with no price discrimination; Section 3 develops the full discrimination case and draws the trade balance conclusions; last, Section 4 draws the main conclusions. In Annex I, we consider an intermediate case, with the domestic firm discriminating between the two countries, and the foreign firm setting a uniform price.

2 The Model

2.1 The general model

We assume that there is only one firm in the home country H and one firm in the foreign country F, both in a polluting industrial sector. Alternatively, we may also think of these two firms as being located in the same country but being subject to two different environmental regulations: one firm may in fact belong to a regulated sector, and the other to an unregulated industry producing a substitute product. In our baseline setting, we rule out price discrimination, whereas in our international 2 country model, firms do price discriminate across countries. The government in country H decides to reduce domestically produced emissions to a given level, s , below the current level achieved under an unrestricted market equilibrium. The

government can use one of two policies: either introduce a carbon tax t , on each unit of pollutant, or target an overall emission level, assumed to be exogenous. Our framework differs from [Holland \(2012\)](#), where firms can instead choose the level of emissions e , a costless input, so as to minimize their cost function.

The quantity of emissions per unit of production by the domestic firm is β , with $0 < \beta < 1$, while that of the foreign firm is set equal to 1, in order to simplify exposition and without loss of generality. Exporting to the other country implies a transport cost equal to τ , per unit. The domestic firm is denoted as firm 1 and the foreign firm as firm 2. Production costs are $C_i(q_i) = c_i q_i$ for $i = 1, 2$.

The firms' products are differentiated and firms compete in prices. Product differentiation is reflected by $\gamma \in (0, 1)$, with $\gamma = 0$ for independent goods. We have normalized to 1 the parameter for the own price in the demand function of good i , therefore we impose the realistic restriction $\gamma < 1$, namely that the own price effect on demand is greater in size than the cross effect of a change in the price of the rival good.¹ The inverse demand functions in country H and F for $i = 1, 2$ with $i \neq j$ are, respectively:

$$D_i^h(p_i^h, p_j^h) = A + \gamma p_j^h - p_i^h \quad (1)$$

$$D_i^f(p_i^f, p_j^f) = B + \gamma p_j^f - p_i^f \quad (2)$$

¹We work with inverse demand functions. A similar interpretation can be obtained starting from direct demand functions where $q_i = a - q_i - \lambda q_j$, for $i = 1, 2$. The parameter λ in $(0, 1)$ reflects the degree of substitutability between goods, with perfect substitutability obtained when λ tends to 1 and independent goods when $\lambda = 0$. Our parameter γ is equivalent to $\lambda/(1 - \lambda)$. Our main results hold if γ is replaced by $\lambda/(1 - \lambda)$.

where p_i^h, p_i^f represent the prices quoted by firm i in country H and F respectively.

A carbon tax is a unit tax on emissions. The only firm paying the tax under a tax policy is the home firm. The carbon tax implies an increase in the marginal cost of production for the home firm from c_1 to $c_1 + \beta t$, given the exogenous emission rate β .

The emission permit, by contrast, sets an implicit limit on production by the home firm:² if the level of allowed emissions is s , that is $q\beta = s$, total production by the home firm cannot exceed the quantity s/β . Emissions above this floor imply a penalty, w , with $w = k + \omega(e - s)$. Hence, to avoid the emission penalty, firm 1 must choose the price pair (p_1^h, p_1^f) that satisfies the following constraint:

$$A + B + \gamma(p_2^h + p_2^f) - p_1^h - p_1^f \leq s/\beta. \quad (3)$$

For the remaining of the analysis we shall assume that the foreign country is not adopting any policy concerning emissions - or that firm 2 is not subject to regulation. It follows that production will increase abroad and decrease at home, after the anti-emission policies, determining a *carbon leak*. Carbon leak is usually defined as the ratio between the changes in emissions, as in [Fischer and Fox \(2012\)](#). In our analysis, we instead compare two alternative policies that generate the same level of emissions by firm 1. In this framework, carbon leak would be the ratio between the changes in emissions by

²Our emission permit policy differs from an intensity standard policy, as the regulation target is the total level of emissions s rather the unitary polluting content β .

the two firms under these two scenarios (indexed by i).

$$\frac{\Delta e_2^i}{|\Delta e_1^i|}.$$

By definition the denominator is the same in either case. As such, our carbon leak measures essentially compares the changes in emissions by firm 2 under the two policy scenario, namely Δe_2^{ct} and Δe_2^{st} .

2.2 A simplified case

In the present sub-section, we shall analyze the case where each firm quotes the same price at home and abroad, although we do not rule out cost asymmetries. Further we eliminate transportation costs. The general model in the next section allows firms to price discriminate across countries so that each firm chooses two prices, although in order to simplify we shall then impose symmetric costs.

Since no price discrimination is possible and no transportation cost exists, the two countries can be viewed as a single market and total demand to firm 1 and 2 can be defined as, respectively,

$$D_i(p_i, p_j) = M + \gamma p_j - p_i, \text{ for } i = 1, 2, i \neq j$$

where we preserve the notation γ for the substitutability parameter, for convenience. The cost functions are $C_i(q_i) = c_i q_i$, for $i = 1, 2$ and with $c_i < M$. The best reply functions in the game where no policies are adopted

by either country are

$$p_i = (1/2)(M + c_i + \gamma p_j) \text{ for } i, j = 1, 2. \quad (4)$$

The Nash equilibrium prices are easily derived as:

$$p_i^* = [M(2 + \gamma) + 2c_i + \gamma c_j] / (4 - \gamma^2), \text{ for } i \neq j, \text{ and } i, j = 1, 2. \quad (5)$$

Total quantities produced in equilibrium are

$$q_i^* = [(M(2 + \gamma) - c_i(2 - \gamma^2) + \gamma c_j)] / (4 - \gamma^2). \quad (6)$$

Total quantity is

$$q^* = [2M - (c_1 + c_2)(1 - \gamma)] / (2 - \gamma).$$

Finally, the equilibrium profits are $\pi_1^* = (q_1^*)^2$ and $\pi_2^* = (q_2^*)^2$.

2.2.1 Emission permits

Suppose now that country H sets an emission permit up to s . The constraint forces firm 1 to set a price high enough so that demand for its product satisfies the constraint $\beta q_1(p_1, p_2) < s$ or $\beta(M + \gamma p_2 - p_1) < s$. This can be rewritten as $p_1 \geq M + \gamma p_2 - \theta$, where $\theta \equiv s/\beta$ is a convenient notation. As part of the policy one can assume that an output exceeding s/β can only be produced with the additional cost of a penalty on emissions. We shall assume this penalty to be high enough to make it worthwhile for

the firm to respect the target at equilibrium - otherwise the policy design would fail. The level of s (or of θ) here must be such that $\theta < q_1^*$ where q_1^* is defined by (6). The penalty w is assumed to be a function of emissions in excess of s , namely $w(e) = k + \omega(e - s)$, where $e = \beta q_1$. Let the function

$$B_1^u(p_2) = (M + c_1 + \gamma p_2)(1/2) \quad (7)$$

denote the unconstrained best reply for firm 1 when no policy is implemented. $B_1^u(p_2)$ is a linear function of p_2 . Further, if s is such that $M - (s/\beta) < (1/2)(M + c_1)$, or $M - c_1 < 2\theta$, then the constraint expressed as the function $p_1 = C(p_2) \equiv M + \gamma p_2 - \theta$ crosses from below the function $B_1^u(p_2)$, at the value $p_2 = (2\theta - M + c_1)/\gamma \equiv p_{20}$. Otherwise, if $M - c_1 > 2\theta$, the constraint lies above the function $B_1^u(p_2)$ for all $p_2 > 0$, but the algebra would not be altered. Therefore, the profit maximization program for firm 1 respecting the emission target is modified as

$$\max_{p_1} (p_1 - c_1) (M + \gamma p_2 - p_1) \text{ s.t. } M + \gamma p_2 - p_1 \leq \theta \quad (8)$$

The maximization program if the firm exceeds the constraint is

$$\max_{p_1} (p_1 - c_1)\theta + (p_1 - c_1 - \omega)q(p_1, p_2, \theta) - k$$

where the function $q(\cdot)$ is defined as $q(\theta, p_2, p_1) = \max[(M + \gamma p_2 - p_1 - \theta), 0]$.

The best reply for firm 1 when it violates the constraint and pays the penalty lies along the best reply of firm 1 under a simple tax on emissions, given by $B_1(p_2, \omega) = B_1^u(p_2) + (\beta\omega)/2$, where the tax rate would be ω . The

constraint crosses this line at the point with horizontal coordinate $p_{2R} \equiv (2\theta - M + c_1 + \beta\omega)/\gamma$. However, firm 1 will adopt this reply function only for a price by firm 2 above p_{2R} as it shall be clarified shortly.

Hence the best reply for firm 1, considering also the constrained part, is

$$CB_1(p_2) = \begin{cases} B_1^u(p_2) = (1/2)(M + c_1) + (\gamma/2)p_2 & \text{for } 0 \leq p_2 \leq p_{20} \\ C(p_2) = M + \gamma p_2 - \theta & \text{for } p_{20} < p_2 < p_{2R} + \eta \\ B_1(p_2, \omega) = (1/2)(M + c_1 + \beta\omega) + (\gamma/2)p_2 & \text{for } p_{2R} + \eta < p_2. \end{cases} \quad (9)$$

The functions $B_1^u(p_2)$, $B_1(p_2, \omega)$ and the constraint $C(p_2)$ are represented in Figure 1 below, for the case where $M - c_1 < 2\theta$, where in the graph, $T = M - \theta$. The constrained best reply $CB_1(p_2)$ is a piecewise linear function represented as the thick line with a kink at the point p_{20} and a discontinuity at the point $p_{2R} + \eta$.³ The admissible values for p_1 satisfying the constraint depend upon the policy measure, θ , and upon p_2 . The idea here is that firm 1, when its unconstrained best reply, $B_1(p_1)$, leads to a penalty for over-emissions, will choose p_1 so as to satisfy the constraint exactly.

We shall assume that the constraint be binding, least the policy would fail its objective in terms of emissions in the home country. In this case, firm 2 acts as a Stackelberg leader, choosing p_2 knowing that p_1 shall be set so as to satisfy the constraint. Hence the maximization problem for firm 2

³Firm 1 does not switch to the best reply $B_1(p_1) + \beta\omega/2$ for a price $p_2 = p_{2R}$ because of the fixed part in the penalty, k . It would do so only if k was equal to zero.

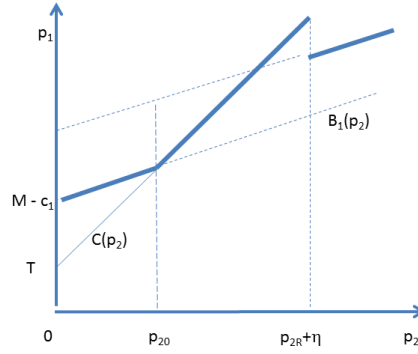


Figure 1: Constrained optimization

is

$$\max_{p_2} (p_2 - c_2) (M + \gamma (M + \gamma p_2 - \theta) - p_2).$$

The profit maximizing price for 2 is

$$\hat{p}_2 = [M(1 + \gamma) - \theta\gamma + c_2(1 - \gamma^2)] / (2 - 2\gamma^2)$$

and p_1 is determined by the constraint as $p_1 = M + \gamma\hat{p}_2 - \theta$ or

$$\hat{p}_1 = \frac{M(2 + \gamma - \gamma^2) - \theta(2 - \gamma^2) + \gamma c_2(1 - \gamma^2)}{2(1 - \gamma^2)}.$$

Under the standard, equilibrium production by firm 2 is given by

$$q_2(s) = (1/2)[M(1 + \gamma) - c_2(1 - \gamma^2) - \gamma\theta]$$

where it is useful to take note that $-dq_2(s)/d\theta = \gamma/2$. Obviously, setting $\theta = 0$ in $q_2(s)$ does not give the unregulated equilibrium quantity as the quantity $q_2(s)$ is computed using a Stackelberg solution. Total production by both firms is:

$$Q(s) = (1/2)[M(1 + \gamma) + \theta(2 - \gamma) - c_2(1 - \gamma^2)].$$

The quantity (and emissions) produced in country F increases by the amount $q_2(s) - q_2^*$, where q_2^* is given by equation (6).

Therefore,

$$\Delta e_2^{st} = \gamma \frac{M(1 - \gamma)}{2(2 - \gamma)} + \gamma \frac{\gamma c_2(3 - \gamma^2) - 2c_1}{2(4 - \gamma^2)} - \frac{\theta\gamma}{2}. \quad (10)$$

For γ tending to zero Δe_2^{st} goes to zero. Further, one can show that for reasonable differences in marginal costs, the change in production and hence in emissions by firm 2 is *negative* for a wide range of values for s and therefore for θ : a negative leakage implies that policy in country H has a positive spillover in terms of global reduction. Neglecting the term in costs, a carbon leak can occur only if θ is lower than $M(1 - \gamma)/(2 - \gamma) \equiv \theta'$, which is a very low production level for firm 1, given that the unconstrained production would be q_1^* as defined above. For instance if costs were zero, $q_1^* = M/(2 - \gamma)$ and θ/q_1^* should be lower than $(1 - \gamma)$, or $s/(\beta q_1^*) < (1 - \gamma)$; a percentage reduction in emissions lower than commonly required by policies unless γ is very low (say less than 0.1). This, however, does not exclude that carbon leakage can occur under a permit policy, though it looks unlikely to happen in our model, under reasonable assumptions. These considerations

shall be summarized after a comparison with a tax policy is completed.

We shall compare the change in emissions under a standard with the carbon leak obtained under the carbon tax - levied only on firm 1 - which provides an emission reduction exactly equal to a given standard policy s .

2.2.2 Competition under a carbon tax

We shall now assume that on each unit of emission produced by firm 1 the government in country H levies a tax equal to t , so that the marginal cost of firm 1 raises to βt . No other restriction is imposed. The profit maximization program for firm 1 results in the best reply function given in (9), where c_1 must be replaced by $c_{1t} \equiv c_1 + \beta t$. The equilibrium prices and quantities can be easily derived by appropriately rewriting the solutions in (5) and the following equations. The equilibrium quantity by firm 1 in particular is given as a function of t , $q_1^*(t) = [M(2 + \gamma) - c_{1t}(2 - \gamma^2) + \gamma c_2] (4 - \gamma^2)^{-1}$. It is sufficient to set this quantity equal to s/β in order to find $t(s)$, the tax that brings forth an equilibrium quantity of emissions equal to s . The solution is

$$\hat{t} = t\beta = \frac{M(2 + \gamma)}{(2 - \gamma^2)} + \frac{(\gamma c_2 - \theta(4 - \gamma^2))}{(2 - \gamma^2)} - c_1$$

It is immediate to see that \hat{t} is positive as far as the limit on emissions is binding, namely as far as $\beta q_1^* > s$ (or equivalently $q_1^* > \theta$). It is therefore straightforward to compute the Nash price equilibrium and the equilibrium

quantities. Since $dq_2(t)/dc_{1t} = \gamma/(4 - \gamma^2)$ one has that

$$-\frac{dq_2(t)}{d\theta} = -\frac{dq_2(t)}{dc_{1t}} \frac{d\hat{t}}{d\theta} = \frac{\gamma}{2 - \gamma^2}.$$

An increase in the reduction $q_1^* - \theta$ (a reduction in θ) brings forth an increase in production abroad. Hence there is a leakage of emissions abroad whenever a reduction in emission is obtained through a carbon tax.

2.2.3 Comparison of policies

By comparing the increase in production in the foreign country under the two regimes we can state that the carbon leak under a carbon tax is larger than under an emission permit.

Proposition 1 *If price discrimination is not allowed (or firms sell in the same country), (i) a standard policy that reduces emissions by the regulated firm to a target level s entails a lower carbon leak than an equivalent carbon tax t . (ii) Furthermore, it is possible that a standard leads to lower emissions by the foreign competitor, depending also on cost parameters, for relevant ranges of carbon reduction objectives.*

That a tax induces a higher leak is intuitively explained by noting that in absolute terms one has $\left| \frac{dq_2(t)}{d\theta} \right| > \left| \frac{dq_2(s)}{d\theta} \right|$. The intuition is that a quantity restriction under price competition allows the unregulated firm (the foreign firm) to exploit the regulation by choosing the point on the constrained price reaction function of the rival as in a Stackelberg game. This price manipulation favors the profit extraction by the unregulated firm with respect to

the carbon tax that leads to equivalent equilibrium emissions in the home country. In a sense the unregulated firm gains more in value and less in volumes when it exploits the restriction imposed on firm 1.

Remark 1 *A unilateral carbon tax may lead to an increase in global emissions.*

If price discrimination is impossible, the reduction in emissions at home is equal to $q^* - \theta$, while the increase abroad under a tax is $[\gamma/(1 + \gamma)] \hat{t}$. Simple computations show that this sum is positive as far as $q^* - \theta$ is positive, e.g. as far as the restriction on emissions is binding for the regulated firm.

3 The two country model

In this section, we assume again that there are two firms located in two different countries, the home and the foreign one respectively, and each firm can supply its product in both countries.⁴ Firms can now price discriminate across countries. Demand functions in the two countries are given by (1) and (2). Production and transport costs are assumed to be equal to zero, to simplify.⁵

When there are no emission restrictions in country H , the two firms engage

⁴Production only takes place in country H for firm 1 and in country F for firm 2.

⁵This framework could be also extended to analyze a 3-firm setting, with two symmetric firms located in the regulated country and one firm located in the unregulated country. The demand functions individually faced by each firm in the domestic country H are

$$D_1^h = A + \gamma p_3 + \beta p_2 - p_1 \quad D_2^h = A + \gamma p_3 + \beta p_1 - p_2 \quad D_1^f = A + \gamma(p_1 + p_2) - p_3$$

Since firms 1 and 2, in the home country, are perfectly symmetric, they will be allowed to produce up to 50% of total emissions each. Since there is no trade in emission permits, the two firms will be charging exactly the same price, and the conclusions in terms of leakage and trade balance will be similar to those of the 2-by-2 setting.

in price competition and the resulting equilibrium is symmetric. Prices are $p_i^{bh} = A/(2 - \gamma)$ and $p_i^{bf} = B/(2 - \gamma)$ and equilibrium demands are $D_i^{bh} = A/(2 - \gamma)$ and $D_i^{bf} = B/(2 - \gamma)$ for $i = 1, 2$, where the superscript b refers to the baseline setting.

3.1 Emission permits vs. carbon tax

We now assume that an emission permit is introduced in country H : as a consequence, total emissions by firm 1 in the regulated country cannot exceed the emission permit $\theta = s/\beta$. Here, given the solution to the unconstrained competition game, for the restriction on emissions s to lead to lower emissions, it must be true that $\beta(A + B)/(2 - \gamma) > s$, or $\bar{\theta} \equiv (A + B)/(2 - \gamma) > \theta$. In a general form, the binding constraint for firm 1 is $D_1^{sh} + D_1^{sf} < \theta$, where superscript s distinguishes the permits setting. The constraint can be written as $A + B - \theta + \gamma(p_2^h + p_2^f) - p_1^h - p_1^f = \theta$ if it binds, so that it is apparent that it does not define the two prices set by firm 1 even if the prices by the foreign firm, p_2^f and p_2^h are given. This implies that Stackelberg leadership by firm 2 determines the position of the constraint but that firm 1 has some leeway in adjusting the prices domestically and abroad so as to maximize its profits along the constraint (The "Maquilladora" example provided in the Annex I clarifies the mechanics of the price setting procedure when the constraint is in three dimensions). The Lagrangian for firm 1 is

$$L(p_1^h, p_2^f, \lambda) = (A - p_1^h + \gamma p_2^h) p_1^h + (B - p_1^f + \gamma p_2^f) p_1^f + \lambda (A + B - \theta + \gamma(p_2^h + p_2^f) - p_1^h - p_1^f) \quad (11)$$

The "Stackelberg follower" prices for firm 1 are

$$\begin{aligned} p_1^{sh} &= \frac{3A + B - 2\theta}{4} + \frac{1}{4}\gamma p_2^f + \frac{3}{4}\gamma p_2^h \\ p_1^{sf} &= \frac{3B + A - 2\theta}{4} + \frac{3}{4}\gamma p_2^f + \frac{1}{4}\gamma p_2^h \end{aligned} \quad (12)$$

Firm 2 acts as Stackelberg leader, and maximizes

$$\max_{p_2^h, p_2^f} \left(A + \gamma p_1^{sh} - p_2^h \right) p_2^h + \left(B + \gamma p_1^{sf} - p_2^f \right) p_2^f \quad (13)$$

where p_1^{sh} and p_1^{sf} are as in (12). As a result,⁶ in equilibrium total emissions, which are equal to total quantities, are given by:

$$\beta D_1^s = \beta\theta \text{ and } D_2^s = (1/2) [(A + B)(1 + \gamma) - \theta\gamma].$$

In accordance with the analysis in the baseline model, we need to determine the carbon leak when firm 1 is subject to either an emission permit or a carbon tax. After the introduction of a carbon tax t on firm 1, we solve for the Nash equilibrium prices,⁷ and find total equilibrium emissions:

$$\beta D_1^t = \beta \frac{(A + B)(2 + \gamma) - 2t(2 - \gamma^2)}{4 - \gamma^2} \text{ and } D_2^t(t) = \frac{(A + B)(2 + \gamma) + 2t\gamma}{4 - \gamma^2}.$$

We assume that the government in country H introduces a tax t such

⁶See Annex II for the formal derivation.

⁷With firm 1 problem defined by:

$$\max_{p_1^h, p_1^f} = (p_1^h - t)D_1^h(p_1^h, p_2^h) + (p_1^f - t)D_1^f(p_1^f, p_2^f).$$

that total emissions by firm 1 reach the desired level, that is $D_1^t = \theta^8$ - this desired tax level, \tilde{t} , is the solution to $2(2 - \gamma^2)\tilde{t} = (2 + \gamma)(A + B - \theta(2 - \gamma))$.

Hence, total emissions are

$$\beta D_1^t + D_2^t(\tilde{t}) = \beta\theta + ((A + B)(1 + \gamma) - \theta\gamma)/(2 - \gamma^2),$$

where subscript t denotes the carbon tax scenario.

3.2 Carbon leak and global emissions

It is now possible to compare the levels of carbon leak, as previously defined, to assess the change in emissions in firm 2 under the two alternative scenarios.⁹ The differences in production by firm 2 under a tax and under a standard are

$$\Delta q_2(s) = \gamma \frac{(A + B)(1 - \gamma) - \theta(2 - \gamma)}{2(2 - \gamma)} \quad (14)$$

and

$$\Delta q_2(t) = \gamma \frac{(A + B - \theta(2 - \gamma))}{(2 - \gamma)(2 - \gamma^2)}. \quad (15)$$

and

$$D_2^t - D_2^s = (\gamma/2) ((A + B)(1 + \gamma) - \theta\gamma) / (4 - 2\gamma^2). \quad (16)$$

⁸Letting $g^{-1} = (2 - \gamma)(2 - \gamma^2)$, the corresponding prices are given by the equations

$$\begin{aligned} p_1^{th} &= g(A(3 - \gamma^2) + B - \theta(2 - \gamma)), & p_1^{tf} &= g(B(3 - \gamma^2) + A - \theta(2 - \gamma)) \\ p_2^{th} &= \frac{g}{2}A(4 - 2\gamma^2 + \gamma) + \gamma(B + (\gamma - 2)\theta), & p_2^{tf} &= \frac{g}{2}(\gamma(A + (\gamma - 2)\theta) + B(-2\gamma^2 + \gamma + 4)) \end{aligned}$$

⁹By definition, the change in emission by firm 1 is 0.

Considering that a carbon leak under a standard can be positive only for very large reductions in emissions and since the expression in (16) is positive as far as $\gamma > 0$ and increasing in γ , we can state the following result.

Proposition 2 *When international price discrimination is allowed, the carbon leak under a tax policy is larger than under an emission standard; a standard only leads to leakage if the target reduction in emissions is more than 50%. The difference between the two policies increases with the degree of substitution between the foreign and domestic goods.*

This result confirms the comparison obtained when price discrimination is not allowed. As a remark, the change in global emissions under a standard policy is negative if $\Delta q_2(s) + \beta \Delta q_1 < 0$, where $\Delta q_2(s)$ is given by (14) and where Δq_1 is the same under the two policies, namely equal to $\beta(\theta - (A + B)/(2 - \gamma))$. Since after some manipulations this inequality can be written as

$$(A + B)(2\beta - \gamma + \gamma^2) > \theta(4\beta - 2\gamma + \gamma^2 - 2\beta\gamma),$$

one only has to check whether this inequality could be violated for $\theta = \bar{\theta}$ or $\theta = (A + B)/(2 - \gamma)$. The inequality then is reduced to $\gamma^2(2 - \gamma) > 0$, which holds true as far as $\gamma > 0$.

As for a tax policy by contrast one has that the global change in emissions is negative if $\Delta q_2(t) + \beta \Delta q_1 < 0$ where $\Delta q_2(t)$ is given by (15). The

expression for the global change in emissions then becomes

$$\Delta q(t) = \gamma \frac{A + B - \theta(2 - \gamma)}{(2 - \gamma)(2 - \gamma^2)} + \beta \left(\theta - \frac{A + B}{2 - \gamma} \right),$$

or, letting $\sigma^{-1} = (2 - \gamma)(2 - \gamma^2)$, one has

$$\Delta q(t) = \sigma [A + B - \theta(2 - \gamma)] (\beta\gamma^2 + \gamma - 2\beta)$$

Since σ is positive and since the term $(A + B) - \theta(2 - \gamma)$ is positive for the admissible levels of θ , one has that a global reduction can be obtained only if $\gamma < \beta(2 - \gamma^2)$. This last inequality can be violated for low values of β and high values of γ . Hence increases in global emissions obtained out under a carbon tax, the larger the difference (here, $1 - \beta$) in emission rate between foreign and home firm and the higher the substitutability between goods, γ .

Remark 2 *If international price discrimination is allowed, an emission permit policy never leads to higher global emissions. An equivalent carbon tax leads to an increase in global emissions if the degree of product substitutability is high and the emission rate of the home firm is low enough, with the exact region given by the pairs (γ, β) lying below the curve $\beta = \gamma/(1 - \gamma^2)$.*

This qualifies the validity of the result obtained in Section 2. The results for carbon leak and for global emissions hinge upon the underlying price adjustments: under either policy, both the domestic and the foreign firm prices increase; however, the price increase under a standard is higher than under a tax, with the corresponding decrease in the quantities produced and in particular by firm 2, reducing the leakage.

3.3 Trade balance

In this section, we quantify the trade gains/losses following the unilateral implementation of the environmental policy in country H . We define trade balance as either the difference in imported and exported quantities or the net balance in terms of values. For simplicity, we assume that the two markets have equal size, that is $A = B = M$; here the maximum value for θ is $\bar{\theta} = 2M/(2 - \gamma)$. The trade balance of the baseline setting is exactly equal to 0.

As for traded volumes, the trade balance under a tax or an emission permit are, respectively, given by

$$\begin{aligned}
 TBQ^t &= \frac{(1 + \gamma)((2 - \gamma)\theta - 2M)}{2(2 - \gamma^2)} \\
 TBQ^s &= (1/4)((2 + \gamma)\theta - 2(1 + \gamma)M)
 \end{aligned} \tag{17}$$

In the case of a carbon tax, the implementation of a unilateral environmental policy worsens, relatively to the baseline setting, the trade balance of the regulated country which becomes a net-importer for any value of γ . In the case of a standard policy instead, the regulated country can become a net exporter, according to the value taken by θ : if this is close enough to the maximum, $2M/(2 - \gamma)$, the country becomes a net exporter. The exact range of values for θ for which this is the case is $2M(1 + \gamma)/(2 + \gamma) < \theta < \bar{\theta}$ or θ in $(\tilde{\theta}(\gamma), \bar{\theta}(\gamma))$, where both the lower and upper bounds of the interval are increasing functions of γ . The gap $\bar{\theta}(\gamma) - \tilde{\theta}(\gamma)$ widens as γ increases,

namely as substitutability increases. In practical terms, even an important percentage reduction in emissions can be achieved while leading to an improvement in the trade balance in volumes by using a standard, provided γ is high enough - think of industries like cement, or steel. For instance, a simulation shows that γ equal to 0.5 allows a percentage reduction of slightly more than 10% in emissions while guaranteeing an improvement in trade volumes.

Then, we take it that the effect of a tax on the trade balance is negative and that of a standard is positive - and, as it can be easily seen, in the extreme range of policies for which it is negative, less detrimental than that of a tax. Therefore the results can be summarized as follows.

Proposition 3 *For any level of γ in $(0,1)$, the trade balance in volumes of the regulated country worsens if a carbon tax is implemented. The trade balance under a carbon tax is always worse than under a standard. By contrast a standard can improve or deteriorate the trade balance: an improvement is more easily achieved the higher is γ and the lower the target reduction in emissions.*

The second comparison considers instead the trade balance in values as resulting from the two policies. The balances are given by

$$TBV^t = -\frac{(4 - \gamma^2) \theta^2 + 4(1 + \gamma)^2 M^2 - 8(1 + \gamma)\theta M + 2\gamma^3 \theta M}{4(2 - \gamma^2)^2}$$

$$TBV^s = -\frac{(4 - \gamma^2) \theta^2 + 4(1 + \gamma)^2 M^2 - 8(1 + \gamma)\theta M}{16(1 - \gamma^2)}.$$

The numerator in the trade balance for a standard, $TBV^{s,h}$, is decreasing in θ as far as $\theta < \bar{\theta} = M/(2 - \gamma)$, therefore one has a sufficient condition for trade balance in value under a standard to be negative by verifying that for $\theta = M/(2 - \gamma)$ the numerator is positive, which turns out to be true for all values of γ . Similarly, for $TBV^{t,h}$, the same properties apply.

Accordingly, *in either case* the regulated country experiences a trade deficit in terms of values, resulting in a worsening with respect to the unregulated situation. To understand which of the two policies is less detrimental to the trade balance in values, one can take the different between the absolute values of $TBV^{t,h}$ and $TBV^{s,h}$.

$$|TB^t| - |TB^s| = \frac{\gamma^3 (\gamma (\gamma^2 - 4) \theta^2 - 4(\gamma^2 + \gamma)^2 M^2 + 8(\gamma + 1)\theta M)}{-16(2 - \gamma^2)^2 (1 - \gamma^2)} \quad (18)$$

The numerator in (18) is increasing and concave in θ . However, for $\gamma = 0$ the expression is zero and there is obviously no difference between the two policies; for $\gamma > 0$ the numerator is positive for all values of θ in the interval $(\rho_1(\gamma), \bar{\theta}(\gamma))$, where $\rho_1(\gamma) = \frac{\gamma}{4 - \gamma^2} 2M(1 + \gamma)$ and negative for $0 < \theta < \rho_1$. Hence for $\rho_1(\gamma) < \theta < \bar{\theta}$, the deficit under a tax exceeds that under a standard, while the reverse holds for θ below $\rho_1(\gamma)$, namely for desired percentage reductions larger than $(\bar{\theta} - \rho_1) / \bar{\theta}$. We can then summarize the result for trade deficits in values as follows.

Proposition 4 *When firms can price discriminate across countries, for a reasonable range of desired reductions in emissions, losses from trade in values are higher under a carbon tax than under an emission permit, if the*

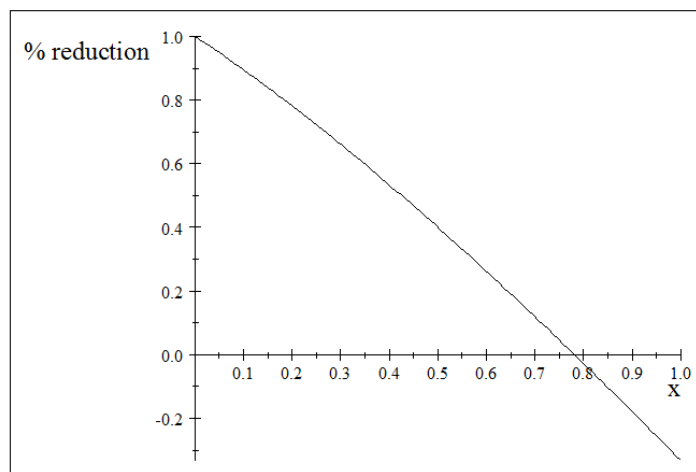


Figure - 2

Figure 2: Percentage reduction

degree of substitution is low; if instead the degree of substitution is higher than 0.78 the tax results in lower trade deficits than a standard for any desired emission reduction.

A more precise statement is that, for a given desired percentage reduction, the difference is in favor of a standard as γ is decreased below 0.78. Above about $\gamma = 0.78$ the difference is always in favor of a tax. The allowed percentage reduction that makes a standard better than a tax in terms of trade balance in values is provided by the graph below, where x on the horizontal axis represents γ . Clearly, for γ higher than 0.78 the trade balance reduction is lower with a tax for any desired percentage reduction in emissions. A reduction of 10% leads to lower trade deficit under a standard provided γ is below about 0.7, as displayed in Figure 2.

4 Conclusions

This paper contributes to the existing literature on anti-pollution policies by comparing the effects, in terms of carbon leakages and trade flows, of two alternative policy instruments that can be unilaterally implemented by an industrialized country, namely a carbon tax and an emission permit policy. Carbon leakages (and job leakages) are an argument against environmental policies in the U.S. and other industrialized countries where some sectors are heavily exposed to competition from less developed countries. In general, leakages are a serious issue in evaluating the real effectiveness of anti-pollution policies at a global scale (e.g. [Morgenstern, 2009](#)). They are also relevant at a national level when regulation is incomplete.

We analyze an international duopoly with price competition and differentiated products. We do not consider relocation of plants (which are medium or long-term decisions), but only production changes and the implied emissions. A carbon tax leads to the expected results in terms of carbon leak, with a carbon leak that may even worsen, at the global level, the result of a unilateral policy. A standard policy provokes a leak only under extreme conditions, namely for unlikely large targeted reductions, otherwise it causes a reduction of emissions abroad as well as at home. Interestingly, the home country then functions as a global regulator in this case. Of course we do not want to stress this particular result as it may be due to the specificity of our model, while the more general argument we propose is that standards are more efficient than taxes in the presence of incomplete regulation and of oligopolistic price competition. The different effects of the two policies arise

because, under a standard, the firm in the unregulated country can expect the regulated firm to have to abide to the regulation and therefore to abandon its best reply function in order to raise prices and curtail production (and therefore emissions). This amounts to let the unregulated firm act as a Stackelberg leader in a two stage game. Under a tax, instead, firms behave as Bertrand competitors in the usual sense; the regulated firm, then, is only penalized as having a higher cost than without a tax.

We have considered two different scenarios: in the baseline one, firms are not discriminating between the two countries, and they charge the same price in the home and foreign country. In a more generalized version, we let instead both firms discriminate by charging two different prices. We measure the carbon leakage by the increase in production abroad - which brings along an increase in emissions abroad hampering the global effectiveness of the antipollution policy. In either case, we observe that a greater carbon leakage occurs under a carbon tax. An increase in global emissions after a carbon tax ([Feddersen, 2012](#)) cannot be ruled out in the full fledged two-country model, while it never occurs under a standard policy. In this sense, perverse results of environmental policies seem to be by far less likely under a standard than under a tax.

As to the effects on trade balance, in the 2 country framework, the carbon tax worsens the trade balance in volumes of the regulated country while the standard policy leads to an improvement if the degree of substitution between the two goods is high enough, otherwise it leads to a worsening. However a tax policy is always leading to worse trade balance in volumes for the home country than an equivalent standard. The results for trade

in values are slightly but interestingly different. First, the trade balance in values deteriorates under either policy. Second, taxes are better than a standard if the two goods are close substitutes. Therefore there can be a trade-off in the choice of a policy, but only if goods are close substitutes: in that case if the Government in the home country is willing to avoid deficits in values it should prefer a tax over a standard, if it aims at avoiding leakages in volumes and in emissions it should prefer a standard.

Annexes

I Carbon leak: the Maquilladoras example

In order to illustrate the effects of a permit policy on the mechanics of inter-firm competition in gradually increasing complexity, we also consider an intermediate case, with only firm 1 selling in both markets and price discriminating across countries. Firm 2, located in country F, instead, only produces for export and only sells in country H - for reference, it is like a Mexican "Maquilladora" exporting to the U.S. Price competition results in a triplet of prices (p_1^h, p_1^f, p_2^h) . The demand functions are given by equations (1) and (2). The equilibrium demand levels in the home country denoted d_i^h for $i = 1, 2$ when neither emission permits nor carbon taxes are in place, are easily computed as $d_i^h = A/(2 - \gamma)$. Production for export to the foreign country by firm 1 is simply $d_1^f = B/2$. Hence the total output by firm 1, denoted by q_1^m , is $q_1^m = (2(A + B) - \gamma B)/(4 - 2\gamma)$.

As in the simplified example discussed in Section 2.2, we shall consider the case where only country H sets limits to emissions, namely total output

by firm 1 cannot exceed s/β , and we shall assume that s is chosen in such a way as to be binding, namely we assume that the desired level of emissions, s , be such that or $s < \beta q_1^m$ or $\theta < [2(A + B) - \gamma B]/(4 - 2\gamma) \equiv \bar{\theta}$, where $\theta \equiv s/\beta$. Now a policy shall have an effect on the composition of output by firm H taken to be the sum of production to be sold at home and for export to F. The constraint to firm 1 when total emission permits are equal to s is given by the equation

$$(A + B) + \gamma p_2^h - p_1^h - p_1^f \leq \theta \quad (19)$$

This constraint, plus the non-negativity constraints on the three prices, describes a region of (x, y, z) triplets in \mathfrak{R}^3 with $(x, y, z) = (p_1^h, p_1^f, p_2^h)$, as displayed in Figure 3. The region of admissible triplets is then defined as the set of points satisfying the non-negativity constraints and above the ("upward sloping") plane parametrized by the equation

$$z = (s/\beta - (A + B))/\gamma + x/\gamma + y\gamma. \quad (20)$$

This plane intersects the vertical axis at the point $(0, 0, -w)$ where $w = (1/\gamma)(A + B - s/\beta)$. It intersects the x -axis at the point $\mathbf{x}_0 = (\gamma w, 0, 0)$ and the y -axis at the point $\mathbf{y}_0 = (0, \gamma w, 0)$. The relevant region must satisfy the non-negativity constraints for prices and therefore coincides with the portion of the plane lying in \mathfrak{R}_+^3 and delimited by the two upward sloping rays originating from the point $(0, 0, -w)$ and crossing through \mathbf{x}_0 and \mathbf{y}_0 respectively, as depicted in Figure 2 below.

It is apparent that the price set by firm 2, p_2^h , implies a restriction on the possible choices of firm 1, given s . Hence the final constraint on firm 1 depends (also) upon p_2^h , as it was the case under the simplified model analyzed above. In this more general set up, the final constraint is expressed as a set defined by the intersection of two planes: the upward sloping plane described by (20) and the horizontal plane of points with coordinates (x, y, p_2^h) . By choosing p_2^h firm 2 sets the "height" of the horizontal plane that intersects with the plane with positive slope. The intersection determines a projection on the (x, y) -plane where $(x, y) = (p_1^h, p_1^f)$; the projection is a portion of a line with slope -1. The maximization problem for firm 1 is then:

$$\begin{aligned} \max_{p_1^h, p_1^f} & (B - p_1^f)(p_1^f - c_1) + (A + \gamma p_2^h - p_1^h)(p_1^h - c_1) \\ \text{s.t.} & \quad (A + B) + \gamma p_2^h - s/\beta = p_1^h + p_1^f \end{aligned}$$

where the constraint is assumed to be binding (if it were not the case then the policy would be ineffective).

Assuming $c_1 = 0$ and no transport costs, the reaction function determining the two prices for firm 1 are:

$$p_1^h = (1/4)(3A + B - 2\theta + 3\gamma p_2^h) \text{ and } p_1^f = (1/4)(A + 3B - 2\theta + \gamma p_2^h) \quad (21)$$

Interestingly, at the solution, the price that firm 1 sets in country F depends upon the price that firm 2 sets in country H. Then, firm 2 acts as a Stackelberg leader and maximizes the profit function $(p_2^h - c_2)(A - p_2^h + \gamma p_1^h)$, where

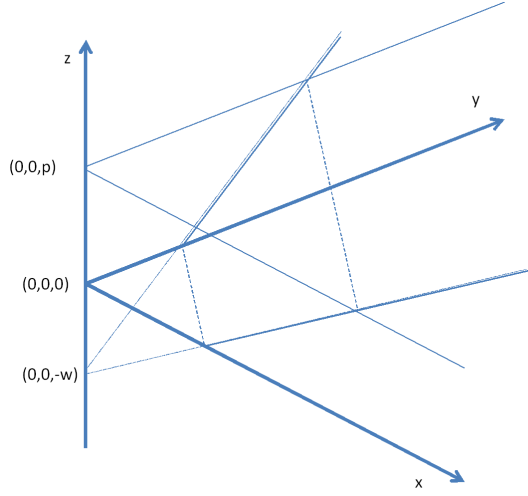


Figure 3: The Maquilladoras pricing

p_1^h is given by equation (21). This equilibrium price for 2 is

$$p_2^{sh} = A(4 + 3\gamma) + \gamma(B - 2\theta)/(8 - 6\gamma^2) \quad (22)$$

One can then retrieve the equilibrium prices of firm 1 by substituting the value so obtained for p_2^h into (21):

$$p_1^{sh} = (1/4)(u + 3A + B - 2\theta) \text{ and } p_1^{sf} = (1/4)(u + A + 3B - 2\theta), \quad (23)$$

where $u = [(3\gamma(A(3\gamma + 4) + \gamma(B - 2\theta)))]/(8 - 6\gamma^2)$.

II Derivation of demands in the 2x2 model

Letting $\mu = 4(2 - \gamma^2)(1 - \gamma^2)$ and letting $z_1 = \frac{(4+2\gamma-3\gamma^2+\gamma^4)}{2\mu}$, $z_2 = \frac{\gamma^2(1+\gamma)}{2\mu}$, $z_3 = \frac{2(2-\gamma^2)}{2\mu}$; letting also $k_1 = \frac{(4+3\gamma-3\gamma^2-2\gamma^3)}{\mu}$ and $k_2 = \frac{(\gamma(1+\gamma))}{\mu}$

and $k_3 = \frac{\gamma(2-\gamma^2)}{\mu}$, the equilibrium prices for firm 1 and 2 can be written as:

$$p_1^{sh} = (B + 3A)z_1 - Az_2 - \theta z_3 \quad (24)$$

$$p_1^{sf} = (A + 3B)z_1 - Bz_2 - \theta z_3$$

$$p_2^{sh} = Ak_1 + Bk_2 - \theta k_3$$

$$p_2^{sf} = Bk_1 + Ak_2 - \theta k_3$$

References

Amacher, G. S., Koskela, E., Ollikainen, M., 2004. Environmental quality competition and eco-labeling. *Journal of Environmental Economics and Management* 47 (2), 284 – 306.

URL <http://www.sciencedirect.com/science/article/pii/S0095069603000780>

Arora, S., Gangopadhyay, S., 1995. Toward a theoretical model of voluntary overcompliance. *Journal of Economic Behavior & Organization* 28 (3), 289 – 309.

URL <http://www.sciencedirect.com/science/article/pii/0167268195000372>

Babiker, M. H., March 2005. Climate change policy, market structure, and carbon leakage. *Journal of International Economics* 65 (2), 421–445.

URL <http://ideas.repec.org/a/eee/inecon/v65y2005i2p421-445.html>

Barker, T., Junankar, S., Pollitt, H., Summerton, P., December 2007. Carbon leakage from unilateral Environmental Tax Reforms in Europe, 1995-2005. *Energy Policy* 35 (12), 6281–6292.

URL <http://ideas.repec.org/a/eee/enepol/v35y2007i12p6281-6292.html>

Baylis, K., Fullerton, D., Karney, D. H., 2014. Negative leakage. *Journal of the Association of Environmental and Resource Economists* 1 (1), 51 – 73.

URL <http://ideas.repec.org/a/ucp/jaerec/doi10.1086-676449.html>

Carlsson, F., March 2000. Environmental Taxation and Strategic Commitment in Duopoly Models. *Environmental & Resource Economics* 15 (3), 243–256.

URL <https://ideas.repec.org/a/kap/enreec/v15y2000i3p243-256.html>

Feddersen, J., Jun. 2012. Why we can't confirm the pollution haven hypothesis: A model of carbon leakage with agglomeration. *Economics Series Working Papers* 613, University of Oxford, Department of Economics.

URL <http://ideas.repec.org/p/oxf/wpaper/613.html>

Fischer, C., Jul. 2001. Rebating Environmental Policy Revenues: Output-Based Allocations and Tradable Performance Standards. *Discussion Papers* dp-01-22, Resources For the Future.

URL <https://ideas.repec.org/p/rff/dpaper/dp-01-22.html>

Fischer, C., Fox, A. K., 2012. Comparing policies to combat emissions leakage: Border carbon adjustments versus rebates. *Journal of Environmental Economics and Management* 64 (2), 199–216.

URL <http://ideas.repec.org/a/eee/jeeman/v64y2012i2p199-216.html>

Fischer, C., Greaker, M., Rosendahl, K. E., Oct. 2012. Emissions leakage and subsidies for pollution abatement. pay the polluter or the supplier of the remedy? *Discussion Papers* 708, Research Department of Statistics

Norway.

URL <http://ideas.repec.org/p/ssb/dispap/708.html>

Fowle, M., Reguant, M., Ryan, S. P., Dec. 2012. Market-based emissions regulation and industry dynamics. NBER Working Paper (18645).

URL <https://ideas.repec.org/p/nbr/nberwo/18645.html>

Fowle, M. L., 2009. Incomplete environmental regulation, imperfect competition, and emissions leakage. *American Economic Journal: Economic Policy* 1 (2), 72–112.

URL <http://EconPapers.repec.org/RePEc:aea:aejpol:v:1:y:2009:i:2:p:72-112>

Holland, S. P., 2012. Emissions taxes versus intensity standards: Second-best environmental policies with incomplete regulation. *Journal of Environmental Economics and Management* 63 (3), 375–387.

URL <https://ideas.repec.org/a/eee/jeeman/v63y2012i3p375-387.html>

Holland, S. P., Hughes, J. E., Knittel, C. R., February 2009. Greenhouse gas reductions under low carbon fuel standards? *American Economic Journal: Economic Policy* 1 (1), 106–46.

URL <https://ideas.repec.org/a/aea/aejpol/v1y2009i1p106-46.html>

Kurtyka, O., Mahenc, P., 2011. The switching effect of environmental taxation within Bertrand differentiated duopoly. *Journal of Environmental Economics and Management* 62 (2), 267 – 277.

URL <http://www.sciencedirect.com/science/article/pii/S0095069611000581>

Lahiri, S., Ono, Y., 2007. Relative emission standard versus tax under oligopoly: The role of free entry. *Journal of Economics* 91 (2), 107–128.

URL <http://dx.doi.org/10.1007/s00712-006-0243-1>

Moraga-González, J. L., Padrón-Fumero, N., 2002. Environmental policy in a green market. *Environmental and Resource Economics* 22 (3), 419–447.

URL <http://dx.doi.org/10.1023/A:1016060928997>

Morgenstern, R. D., 2009. Competitiveness and climate policy: Avoiding leakage of jobs and emissions. In: Congressional Testimony prepared for the Committee on Energy and Commerce - U.S. House of Representatives.

Paltsev, S. V., 2001. The Kyoto Protocol: Regional and Sectoral Contributions to the Carbon Leakage. *The Energy Journal* 0 (Number 4), 53–80.

URL <http://ideas.repec.org/a/aen/journal/2001v22-04-a03.html>

Petrakis, E., Xepapadeas, A., 2003. Location decisions of a polluting firm and the time consistency of environmental policy. *Resource and Energy Economics* 25 (2), 197 – 214.

URL <http://www.sciencedirect.com/science/article/pii/S092876550200026X>

Requate, T., 2006. Environmental policy under imperfect competition. In: Tietenberg T. and H. Folmer: *The International Yearbook of Environmental and Resource Economics 2006/2007: A Survey of Current Issues*. Edward Elgar.

Ryan, S. P., 2012. The costs of environmental regulation in a concentrated industry. *Econometrica* 80 (3), 1019–1061.

URL <http://dx.doi.org/10.3982/ECTA6750>

Sanna-Randaccio, F., Sestini, R., Tarola, O., 2014. Unilateral climate policy and foreign direct investment with firm and country heterogeneity. *Nota di Lavoro, Fondazione ENI Enrico Mattei* 55.

Toshimitsu, T., 2008. On the effects of emission standards as a non-tariff barrier to trade in the case of a foreign bertrand duopoly: A note. *Resource and Energy Economics* 30 (4), 578 – 584.

URL <http://www.sciencedirect.com/science/article/pii/S0928765508000262>