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International Emissions Trading
Scheme in an Open Economy with
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Abstract

This paper presents a model of imperfect international competition. Within this framework, the optimal choice of national environmental policy instrument and international emissions trading scheme is discussed. The choice of national instrument is restricted to absolute and relative standards, which form the basis for permit and credit trading respectively. It is shown that relative standards and credit trading lead to higher output than emission ceilings and permit trading. I find that governments want to increase production beyond the level reached with emission ceilings and therefore prefer relative standards. Furthermore, international emissions trading is only optimal when the country imports emission quotas, and in several cases, governments will choose not to allow international emissions trading.

Key words: environmental policy, emissions trading, credit trading, international trade, imperfect competition, strategic behavior.

JEL classifications: F12, L51, Q25, Q28

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1 Introduction

International emissions trading is becoming more of a reality after the Kyoto Protocol allowed such trade and especially after the EU has started implementing a scheme of its own. As the discussion within the EU showed, the design of an emissions trading scheme is not straightforward and countries have different preferences.

One of the most important issues in the design of emissions trading is what its basis should be. The traditional choice is a cap on emissions, which is distributed over the emission sources in the form of permits. The initial distribution can either be done through grandfathering where the permits are given for free, or by auctioning them. There are some theoretical arguments in favor of auctioning, but political reality dictates that permits are grandfathered, with at most a small part auctioned off to facilitate entry to the regulated sector. This is also the outcome in the EU scheme. Another possibility is to base emissions trading on relative standards (see Boom (2001), Gielen et al. (2002) and Boom (2003a)). In this system, firms are allowed to emit a certain amount per unit of output (or an input) and can sell credits if they can stay below the standard. Total emissions are not fixed, but can change with output. In the following, the scheme based on absolute emission ceilings will be denoted by permit trading, while the system based on relative standards will be denoted as credit trading. The two schemes have a different impact on output and marginal abatement costs. These differences stem from the differences in the underlying instruments. So just as relative standards lead to higher output per firm than absolute standards, the same is the case with credit trading versus permit trading. At the same time, credit trading gives higher marginal abatement costs than permit trading. Because of the differences in impacts of the two schemes, firms and governments may have preferences for one system over the other. This issue is the main subject of this paper.

As will be clear from the description of the two emissions trading schemes given here, a preference for one of them is linked to a preference for the underlying instrument. Therefore, when analyzing the preference for international emissions trading scheme, it is instructive to analyze the preference between emission ceilings and relative standards too. Furthermore, when analyzing preferences for both international trading scheme and national instrument, it becomes possible to determine whether engaging in international emissions trading scheme is beneficial for a country.

Boom (2003b) analyzes strategic choice of emissions trading scheme for the case of perfect international competition when countries have market power. His findings are that the preference for emissions trading scheme

depends on whether a country is an importer or an exporter of the good. An exporter wants to lower domestic production, while an importer wants to expand production. Since permit trading leads to a lower production level than credit trading, exporting countries generally prefer permit trading, while importers prefer credit trading. Whether or not a country wants to engage in international emissions trading depends on whether it becomes a seller or buyer of emission quotas. A country that sells quotas will contract domestic production, while a buyer will expand production. Depending on which is compatible with domestic preferences, a country may prefer to allow private international emissions trading. However, it may also be the case that the country prefers *not* to engage in international emissions trading.

With imperfect competition in the goods market, other forces come to play. Now the firms are engaged in a strategic game where market share is an important factor in determining profits. Furthermore, imperfect competition leads to lower output than perfect competition. If the country also consumes the good, it may therefore have an incentive to increase production. These factors make that preferences for both national instrument and international emissions trading scheme may be different with imperfect than with perfect competition.

Other papers have discussed strategic choice of environmental policy and instrument choice in an international setting (see next section for an overview). However, only a few discuss relative standards and almost none credit trading. Furthermore, when these instruments are considered, only the case of perfect competition is discussed.

In this paper I will analyze the optimal choice of national instrument and international emissions trading scheme by governments when there is imperfect and international competition in the market for the output. More precisely, I present a partial equilibrium model of a market with two firms, producing a homogeneous good, each located in a different country. Governments can at the national level choose between emission ceilings and relative standards, while at the international level they can choose between permit and credit trading and no international emissions trading.

The paper is organized as follows. In the next section, an overview of related literature is given. The model is discussed in Section 3. First I will analyze the case without international emissions trading. Here the government can choose between emission ceilings and relative standards. It will be shown that the government always wants to increase production above the level reached with emission ceilings. After that, in subsection 3.2, the choice of international emissions trading scheme is discussed. The choice between schemes is more or less the same as that between national instruments, but with a change in the (shadow) price of emissions. However, it is shown that in

certain cases, especially when the country becomes a seller of emission quotas, countries may prefer not to engage in international emissions trading. Conclusions are given in section 4.

2 Overview of the literature

The literature on strategic environmental policy in models with international trade is mostly based on two seminal articles by Spencer and Brander (1983) Brander and Spencer (1985)) on international R&D rivalry and government export subsidies. In the basic model Spencer and Brander (1983), R&D leads to lower marginal production costs and thereby to higher output. In a duopoly model firms will invest in R&D for strategic purposes. This leads to higher investment in R&D, larger firm and total output and lower industry profit. The reason for this is that firms are caught in a Prisoner's Dilemma where each firm has an incentive to increase R&D to be able to commit to higher output levels, while combined profits would be higher if they would not increase output. If governments provide subsidy for R&D, these effects are even more pronounced (Brander and Spencer (1985)). The government can more credibly commit to a large subsidy on R&D than the firm can commit to a large level of R&D, so that with government subsidies output is larger. If there is domestic consumption, the subsidy can be welfare improving, since output increases and product price decreases. Also here, firm profits are lower if neither of the firms and governments had invested strategically in R&D.

The first use of these models in the field of international environmental problems was to analyze the strategic choice of level of environmental policy. Some examples are Barrett (1994), Ulph (1994, 1996a,b, 1997) and Rauscher (1997). The main conclusion is that governments have an incentive to set a lower than optimal level of environmental policy when the domestic producer of a good operates on an oligopolistic market. However, as Barrett (1994), Ulph (1996a) and Rauscher (1997) have pointed out, the reaction of the government is dependent on market conduct. The above mentioned conclusion only holds when firms compete with quantities (Cournot competition). When firms engage in price, or Bertrand, competition governments will want to impose overly strict environmental policies.

A second use of the models by Brander and Spencer is in the modelling of instrument choice when there is international trade. Ulph (1992) uses a duopoly model where the two firms are located in different countries and the commodity is not consumed in the two countries. Production costs are dependent on two inputs: one denoted as energy is an input that causes

pollution, the other is a non-polluting production factor which is referred to as capital. Ulph then considers three cases: a single stage Cournot model, a two stage Stackelberg model and a two stage Cournot model. In the one stage Cournot model, the firms, knowing which instrument the governments have chosen, set their capital level and output simultaneously. It is shown that the reaction function is steeper when a tax is imposed than when a ceiling is imposed on the firm. This implies that a firm will react with a smaller change in output on a given change in foreign output under ceilings than under taxes. The conclusion from this model is that in a one shot Cournot model, countries are indifferent between ceilings and taxes. The reason for this is that in a one-shot game there is no strategic interaction and all instruments discussed give the same output. The choice of instrument is then a purely domestic decision.

In the two other cases, can invest strategically in capital, thereby changing their production capacity. The driving force behind the results that follow is that firms will invest more in capital when they are regulated through taxes than when they are facing emission ceilings. The second case discussed by Ulph (1992) is a Stackelberg model. The outcome is that in the optimum, the Stackelberg follower will prefer ceilings, while the leader is indifferent between taxes and ceilings. This outcome ensures the lowest total output and thereby the highest industry profits. The most interesting model for our purposes is the two-stage Cournot model. In this model, the firms first simultaneously choose their level of capital, and thereafter simultaneously choose their level of output and energy. In this case, the use of ceilings by both countries is a Nash equilibrium in the choice of instruments. The reason for this is that under taxes the firms over-invest in capital and thereby increase production. Each country then has an incentive to shift to ceilings, which lowers the incentive to over invest and raises profits. The model used by Ulph does not contain any specification for consumers' surplus, but in general the conclusions will hold as long as the consumption of the good in the two countries only represents a small share of world consumption.

In a more recent paper (Ulph (1996b)), Ulph generalizes the Cournot model described above. Instead of using only two inputs, energy and capital, a more general specification of the cost function is given. Furthermore, the 1996 paper allows for both production and consumption in the two countries. The more general model of technology makes that the use of emission ceilings is no longer always the dominant strategy.

Also in Ulph (1996a) the use of ceilings induces less strategic behaviour by the firms than does the use of taxes. However, it is now not always optimal to use ceilings. The choice of instruments is dependent on the relative sizes of the producer and the consumer surplus. With a relatively large producer

surplus government prefers ceilings, while with a relative large consumer surplus it prefers taxes.

Feenstra et al. (1996) and Feenstra (1998c) have extended the model of Ulph (1992) to a fully dynamic analysis. In doing this they use a differential game approach where firms use open-loop investment strategies and feedback strategies for the choice of the polluting input. Their model confirms the conclusions of Ulph (1992) that investment is lower when both countries use ceilings. Furthermore, the situation in which both countries choose ceilings is also with Feenstra et al. (1996) a Nash equilibrium.

A further development is given in Feenstra (1998b) where both investments and level of the polluting input are determined by feedback strategies. Now it is not always true that investment is larger under taxes than under ceilings. In the feedback model the substitutability of production factors is important: if the substitution effects are large enough, investment is larger under ceilings than under taxes, and hence governments will prefer taxes.

Both Feenstra et al. (1996) and Feenstra (1998b) assume that the product is not consumed in the countries where it is produced. As with Ulph (1992), the results of both models will hold as long as consumption in the two countries only represents a small part of world consumption. However, if consumption is large, governments might reverse their preferences.

None of the papers described above include relative standards or credit trading in their analysis. Relative standards are analyzed by Helfand (1991) and Ebert (1998), who show that they lead to higher output levels than emission ceilings. Dijkstra (1999) analyzes preference for instrument of environmental policy at the national level and includes relative standards. He assumes perfect competition in the goods market and shows that consumers should prefer relative standards because of the higher output level, but that firms will prefer permit trading because they lead to higher profits.

Dijkstra (1998) analyzes a model with perfect competition between firms and explicitly includes the consumer surplus. He studies four cases: autarky, international trade without pollution, international trade and domestic pollution and international trade and global pollution. The model is a one shot game of instrument choice between governments, where the first two cases are used as benchmarks. Dijkstra finds that production is too low with emission taxes when a country imports the polluting good. This result comes about irrespective whether pollution is local or transboundary. A second case occurs only with transboundary pollution. Dijkstra assumes that the foreign country does not reduce emissions. If the domestic country reduces emissions, domestic output becomes lower and foreign output increases. The latter effect is unwanted because foreign output is more polluting than domestic output. Therefore, it would be better to have both low domestic emissions

and high domestic output. This can be achieved with relative standards.

The model presented in the following section has much in common with the model by Brander and Spencer (1985). However, in my model, there is no possibility for firms to invest strategically in capital. The competition between firms is modelled as a one-shot game. Results in my model are driven by the differences in impact on the industry between the instruments. This is also the major difference between my analysis and those by Ulph discussed above. Whereas Ulph (1992) finds that governments prefer the instrument that gives rise to least strategic investment in capital and thereby to least increase in production, I find the opposite. The reason for this difference is that what matters in the models by Ulph is that governments want domestic firms to react as little as possible to foreign changes in output, while I find that governments prefer an increase in domestic output, no matter how the foreign firm and government react.

3 The Model

In the model, there are two producers of a homogeneous good each located in a different country. These producers are the sole producers of the good in the world. Revenues for each producer are represented by $R^i(q_i, q_j)$, where q_i is the output of firm i . The revenue function has the following properties: $R_{q_i}^i > 0$, $R_{q_j}^i < 0$, $R_{q_i q_i}^i < 0$, $R_{q_i q_j}^i < 0$. Costs for each producer are represented by $C^i(q_i, E_i)$, where E_i is emissions of a pollutant, which is a variable input. It is assumed that $C_{q_i}^i > 0$, $C_{E_i}^i < 0$ and $C_{q_i q_i}^i > 0$, $C_{E_i E_i}^i > 0$, and $C_{q_i E_i}^i < 0$.

The governments of both countries have committed themselves to a certain emission level that is lower than the business as usual level. This assumption makes it possible to focus on the choice of policy instrument without interference from a possible strategic choice of emission level. The choice of instruments at the national level is limited to relative standards and emission ceilings because these two instruments can form the basis for emissions trading. However, as Dijkstra (1999) shows, taxes and tradable permits lead to the same production level as emission ceilings and the analysis for the latter is basically the same as for these other instruments. In the model, it is assumed that the firms and countries have no market power in the emissions quota market. The rationale for this is that the international emission quota market is likely to be large and firms from several industries will be engaged in emissions trading. Therefore, it is less likely for a firm, or industry, to have market power in the emission quota market than in the product market.

The government essentially has two decisions to make. First, it has to choose the domestic instrument, and secondly, it has to choose whether to

allow international emissions trading or not. However, international emissions trading may influence the choice of national instrument.

In the following, we will first analyze instrument choice by the government when international emissions trading is not allowed. After that, we discuss the case where international emissions trading is possible. In both cases, the analysis takes the form of a two stage model where firm behavior is analyzed first and government behavior last.

3.1 No International Emissions Trading

We begin by analyzing the case where the two countries do not allow their firms to trade emissions internationally. This means that only domestic instruments are relevant for the model. Since the ultimate goal of this paper is to analyze the preference for international emissions trading scheme, only emission ceilings and relative standards are discussed, since these can form the basis for emissions trading. In the following, we will first analyze the second stage in which the firms set their production level. After that, the choice of instrument by the government is discussed.

3.1.1 Stage Two: Firm Behavior

The government can choose between two instruments of environmental policy: emission ceilings and relative standards. With emission ceilings, a cap equal to \bar{E}_i is placed on the emissions of the firm. Under relative standards, a standard equal to \bar{e}_i is placed on emissions per unit of output. Total allowed emissions with this instrument are then given by $\bar{e}_i q_i$, i.e., the relative standard times output.

In the following, each firm takes the output of the other firm as given when deciding on its own output level. That is, the firms are engaged in Cournot competition.

Emission ceilings. Given the ceiling \bar{E}_i set by the government, the firm's objective function becomes:

$$\begin{aligned} \max_{q_i, E_i} \quad & \Pi_i = R^i(q_i, q_j) - C^i(q_i, E_i) \\ \text{s.t.} \quad & E_i \leq \bar{E}_i \end{aligned} \tag{1}$$

The first order conditions are

$$\begin{aligned} R_{q_i}^i &= C_{q_i}^i \\ -C_{E_i}^i &= \lambda_i \end{aligned} \tag{2}$$

Here, λ_i is the shadow price of emissions. The first order conditions are the usual ones, showing that the firms sets marginal revenue equal to marginal production costs and equates marginal abatement costs with the shadow price of emissions. The second order condition for profit maximization with respect to output is

$$\frac{\partial^2 \Pi_i}{\partial q_i^2} = R_{q_i q_i}^i - C_{q_i q_i}^i < 0$$

Equation (2) is a function of both q_i and q_j . In other words, it gives the optimal production level for firm i for every level of production of firm j . Hence, equation (2) can be seen as the reaction function of firm i . The slope of the reaction function is given by implicitly differentiating equation (2) to q_j

$$\frac{dq_i}{dq_j} = \frac{-R_{q_i q_j}^i}{R_{q_i q_i}^i - C_{q_i q_i}^i} \quad (3)$$

The assumptions made about the revenue and costs curve show that:

$$-1 < \frac{dq_i}{dq_j} < 0$$

Hence, the Nash equilibrium will be stable. To determine the effects of changes in emissions on the reaction function, we differentiate equation (2) with respect to the emission ceiling, assuming that the ceiling is binding:

$$\frac{dq_i}{d\bar{E}_i} = \frac{C_{q_i E_i}^i}{R_{q_i q_i}^i - C_{q_i q_i}^i}$$

Hence, an increase in the emission ceiling will lead to an outward shift of the firm's reaction function.

Relative Standards. Under a relative standard, the government sets an emission ceiling \bar{e}_i per unit of production. The firm is then allowed to emit $\bar{e}_i q_i$ in total. Since the government is perfectly informed, it sets the relative standard equal to $\frac{\bar{E}_i}{q_i}$. The optimization problem of the firm becomes

$$\begin{aligned} \max_{q_i, E_i} \quad & \Pi_i = R^i(q_i, q_j) - C^i(q_i, E_i) \\ \text{s.t.} \quad & E_i \leq \bar{e}_i q_i \end{aligned} \quad (5)$$

The first order conditions are

$$\begin{aligned} R_{q_i}^i &= C_{q_i}^i - \lambda_i \bar{e}_i \\ -C_{E_i}^i &= \lambda_i \end{aligned}$$

where λ_i is the shadow price of emissions. Combining the first order conditions gives

$$R_{q_i}^i = C_{q_i}^i + C_{E_i}^i \bar{e}_i \quad (6)$$

Comparing (2) with (6), it is clear that (6) contains the additional term $C_{E_i}^i \bar{e}_i$. This term is negative, implying that under relative standards $P < C_{q_i}^i$ and that production is larger under relative standards than under emission ceilings (see also Helfand (1991), Ebert (1998) and Dijkstra (1999)). The additional term can be seen as an output subsidy. With relative standards, firms are rewarded for additional output by additional allowed emissions. Although marginal production costs are lower under relative standards, marginal abatement costs are higher. Another interpretation of the difference between relative standards and emission ceilings is then that under relative standards the firm is deprived of an efficient method to reduce emissions, namely by reducing output. Under relative standards, the firm must reduce emissions per unit of output and not emissions per se. Although reducing output may lead to some reduction of emissions per unit of output, marginal abatement costs and output will be higher as a result of the reduction in abatement possibilities.

The second order condition for profit maximization is given by

$$\frac{\partial^2 \Pi_i}{\partial q_i^2} = R_{q_i q_i}^i - C_{q_i q_i}^i - C_{E_i q_i}^i \bar{e}_i < 0$$

Again, by implicit differentiation of first order condition (6) the slope of the reaction function, can be found

$$\frac{dq_i}{dq_j} = \frac{-R_{q_i q_j}^i}{R_{q_i q_i}^i - C_{q_i q_i}^i - C_{q_i E_i}^i \bar{e}_i} \quad (7)$$

From the second order condition, it is clear that

$$-1 < \frac{dq_i}{dq_j} < 0$$

Which shows that the Nash equilibrium will be stable. A comparison of (3) and (7) shows that

$$\left| \frac{dq_i}{dq_j} \right|^{rs} > \left| \frac{dq_i}{dq_j} \right|^{ec}$$

where the superscripts *rs* and *ec* stand for relative standards and emission ceilings respectively. This result arises because $C_{q_i E_i}^i \bar{e}_i < 0$. Hence, a firm regulated through relative standards is more responsive to a change in output by the foreign firm than a firm regulated through emission ceilings.

To determine the effects of changes in emissions on the reaction function, we differentiate equation (6) with respect to the relative standard, \bar{e}_i :

$$\frac{dq_i}{d\bar{e}_i} = \frac{C_{q_i E_i}^i \frac{\partial E_i}{\partial \bar{e}_i} + \bar{e}_i C_{E_i E_i}^i \frac{\partial E_i}{\partial \bar{e}_i} + C_{E_i}^i}{R_{q_i q_i}^i - C_{q_i q_i}^i - C_{q_i E_i}^i \bar{e}_i}$$

The sign of this equation is not immediately clear. The denominator is negative from the second order condition, as are the first and third term in the nominator. However, the second term in the nominator is positive. Suppose that the nominator is positive, giving $dq_i/d\bar{e}_i < 0$. This implies that a stricter relative standard leads to larger output. This may be conceivable for some ranges of output where production is inefficient. However, this cannot hold at all production levels, since when \bar{e}_i goes to zero, production must go to zero too. Hence, in the following we assume that $dq_i/d\bar{e}_i > 0$ for all relevant levels of production. This implies that $-C_{q_i E_i}^i \frac{\partial E_i}{\partial \bar{e}_i} - C_{E_i}^i \frac{\partial E_i}{\partial \bar{e}_i} > \bar{e}_i C_{E_i E_i}^i \frac{\partial E_i}{\partial \bar{e}_i}$, so that production increases as the relative standard is set higher.

3.1.2 Stage One: Government Choice of Instrument

The objective of the government is to maximize domestic welfare. We will analyze government behavior in two steps. First we assume that the country under analysis does not consume the good, but exports total production. Later on we will relax this assumption and allow for domestic consumption of the good. In both cases, it is assumed that both countries have committed to reducing emissions by a certain amount.

Without domestic consumption, welfare of the home country is given by

$$W^h(q_h, q_f) = R^h(q_h, q_f) - C^h(q_h, E_h)$$

where h stands for home country and f for the foreign country. The government realizes that as it changes the output of the domestic firm through its environmental policy, the foreign firm will react by an opposite change in production. This implies that $q_f = q_f(q_h)$, with dq_f/dq_h given by (3) when the foreign country uses emission ceilings or

$$\frac{dq_i}{dq_j} = \frac{R_{q_i q_j}^i}{R_{q_i q_i}^i - C_{q_i q_i}^i - \frac{\bar{E}_i}{q_i} C_{q_i E_i}^i + \frac{\bar{E}_i}{q_i^2} C_{E_i}^i}$$

when the foreign country uses relative standards. The latter is different from the reaction function of the firm since the government knows that the relative standard will change as q_i changes, while the firm assumes that \bar{e}_i is

constant. For firms, we assumed that $|dq_i/dq_j|^{rs} > |dq_i/dq_j|^{ec}$. For this to hold for countries too, it has to hold that

$$-E_i C_{q_i E_i}^i + \frac{E_i}{q_i} C_{E_i}^i > 0$$

which we assume is the case in the remainder of the paper. Using this, the first order condition for welfare maximization becomes

$$\frac{\partial W^h}{\partial q_h} = R_{q_h}^h + R_{q_f}^h \frac{dq_f}{dq_h} - C_{q_h}^h = 0 \quad (9)$$

The first term gives the direct effect of a change in domestic output on domestic revenue, which is positive. The second term gives the change in revenue as a result of the change in foreign output, which is positive and the third term gives the change in costs resulting from the change in output, which again is positive.

To determine which instrument will lead to the highest level of welfare, we compare the first order condition for welfare maximization with the first order conditions for profit maximization for the firm under the two instruments. Comparing (2) with (9) shows that for welfare maximization, output should be higher than the output level attained with an emission ceiling. More precisely, the government is trying to move the domestic firm to the Stackelberg leader position. This can be confirmed by assuming that the domestic firm is the Stackelberg leader and then finding the first order condition for profit maximization, which is identical to (9). It is clear that (9) determines a point of highest welfare for country h given the instrument choice and the behavior of the foreign country. Lower and higher domestic production levels will give lower welfare.

The question now is, whether a switch to relative standards will lead to higher welfare. This clearly depends on how large an increase in production this change of instrument will give. It also depends on the instrument choice of the foreign country, as can be seen from (9), since dq_f/dq_h is larger in absolute terms under relative standards than under emission ceilings for the same level of q_i . This implies that when the foreign country chooses relative standards, the home country will want to increase production more than when the foreign country chooses emission ceilings. The intuition for this is that profits for the firm and thereby welfare is higher with lower total levels of output. Hence, when the foreign country uses emission ceilings, it will not reduce its output as much as with relative standards when the home country increases production. With a certain increase in domestic production, world production will increase more when the foreign country uses emission ceilings

than relative standards. However, this needs not hold in general because q_i will be different for different foreign instrument.

The main result so far is that the country would like to increase production relative to the level realized with emission ceilings, preferably to the level where the domestic firm is the Stackelberg leader. Relative standards do give a higher production level, but it is uncertain whether they lead to a too high production level. Hence, the country will most likely prefer to use relative standards in this case, unless they increase production by too much.

It is important to note that no matter what instrument the foreign country uses, the domestic country prefers a production level that is higher than the one reached through an emission ceiling. Note also that the strategies of the countries actually leads them away from the joint welfare maximizing point. Joint welfare is given by $W = W^i + W^j$, and maximizing with respect to q_i gives

$$\frac{\partial W}{\partial q_i} = R_{q_i}^i + R_{q_i}^j - C_{q_i}^i = 0$$

Comparing this result to the first order conditions for profit maximization with the two instruments shows that the joint optimum production levels in each country are reached at a lower level than the one reached with Cournot competition and emission ceilings. It is clear that the countries are caught in a classical Prisoner's dilemma; both countries want to increase the production of their own firm to capture market share from the foreign firm. By doing so, they increase total world production. However, both countries would be better off if they could agree on a lower production level.

We now turn to the more general case where the country both produces and consumes the product. The welfare function becomes

$$W^h(q_h, q_f) = \mu_h \int_0^y P(y) dy - P(y)\mu_h y + R^h(q_h, q_f) - C(q_h, E_h)$$

where μ_h is the proportion of identical consumers living in country h . The first two terms in the welfare equation give the consumers' surplus, while the last two terms give the producer's surplus. The first order condition for welfare maximization is

$$\frac{\partial W^h}{\partial q_h} = R_{q_h}^h + R_{q_f}^h \frac{dq_f}{dq_h} - C_{q_h}^h - \mu_h y P'(y) \left(1 + \frac{dq_f}{dq_h} \right) = 0$$

The last term gives the total effect of an increase in domestic production on the consumers' surplus. This term is negative, and hence indicates that production should be higher when there is domestic consumption than when

there is no domestic consumption. In other words, with domestic consumption, the country wants to increase production beyond the point of the Stackelberg leader level. But by how much does the country want to increase production?

To find an answer, rewrite revenue for a firm as $R^i(q_h, q_f) = P(q_h, q_f)q_i$. Using this, the first order condition for welfare maximization can be written as

$$\frac{\partial W^h}{\partial q_h} = (P - C_{q_h}^h) + P'(y) \left(1 + \frac{dq_f}{dq_h} \right) (q_h - \mu_h y) = 0 \quad (10)$$

The first term is the first order condition for welfare optimization if the firm and the country have no influence on the product price ($P'(y) = 0$) or in the case of autarky ($q_h = \mu_h y$). In those cases, the country will prefer the output level reached by perfect competition in the market. The second term gives the effect of a change in production on revenue times the trade balance in the product. Hence, to determine the optimal production level, it is important to know whether the country imports or exports the product.

When the country imports the product, $q_h < \mu_h y$, and the last term in (10) becomes positive. To optimize welfare, the country should increase production beyond the perfect competitive level. When the country exports the product, $q_h > \mu_h y$, and the country should have a lower production level than the one realized with perfect competition. Hence, when the country consumes the good, the optimum production level is higher than the Stackelberg leader production level. Depending on whether the country imports or exports the good, optimum production is higher or lower than the full competitive output level respectively. With domestic consumption it is then even more likely that the country will prefer relative standards over emission ceilings and more so when it imports the good than when it exports the good.

3.2 Private International Emissions Trading

We now turn to the case where the domestic firm is allowed to trade emissions on the international emission quota market. Again, we will first analyze firm behavior and thereafter government choice of instrument. We will also determine whether allowing international emissions trading leads to higher or lower welfare for the country.

3.2.1 Stage Two: Firm Behavior

In this part, the behavior of the firms is analyzed when international emissions trading is allowed. There are basically two forms of emissions trading, each based on one of the instruments discussed above. Emissions trading

based on emissions ceilings will be denoted as permit trading, while emissions trading based on relative standards will be denoted as credit trading. In the following, it is assumed that there is an international emissions trading market on which neither the firms, nor their governments have market power. This implies that firms and governments take the emission quota price as given.

Permit Trading Taking the initial distribution of permits, \bar{E}_i and the price of permits, T as given, the firm's objective becomes:

$$\max_{q_i, E_i} \Pi_i = R^i(q_i, q_j) - C^i(q_i, E_i) - T(E_i - \bar{E}_i) \quad (11)$$

The first order conditions are:

$$\begin{aligned} R_{q_i}^i &= C_{q_i}^i \\ -C_{E_i}^i &= T \end{aligned}$$

The first order conditions are basically the same as those for an emission ceiling, with T replacing λ_i . As a result, slope of the reaction function for permit trading is given by (3). The effect of a change in the price of permits on the reaction function of the firm is given by

$$\frac{dq_i}{dT} = \frac{C_{q_i E_i}^i \frac{dE_i}{dT}}{R_{q_i q_i}^i - C_{q_i q_i}^i}$$

This says that production will go down as the price of permits goes up. An increase in the permit price then leads to an inward shift of the reaction function. An increase in the permit price works as a tightening of environmental policy, which is why we arrive at the result above.

Credit Trading. With credit trading, firms are regulated through relative standards, and are then allowed to sell credits if they can stay below the standard. The objective function of the firm regulated in this way becomes

$$\max_{q_i, E_i} \Pi_i = R^i(q_i, q_j) - C^i(q_i, E_i) - T(E_i - \bar{e}_i q_i)$$

The first order conditions are

$$\begin{aligned} R_{q_i}^i + T\bar{e}_i &= C_{q_i}^i \\ -C_{E_i}^i &= T \end{aligned}$$

Combining the two first order conditions gives

$$R_{q_i}^i = C_{q_i}^i + C_{E_i}^i \bar{e}_i \quad (13)$$

This is identical to (6), the same condition for relative standards. This implies that the slope of the reaction function is given by (7). The effect of a change in the credit price on the reaction function of the firm is now given by

$$\frac{dq_i}{dT} = \frac{C_{q_i E_i}^i \frac{\partial E_i}{\partial T} + \bar{e}_i C_{E_i E_i}^i \frac{\partial E_i}{\partial T} + C_{E_i}^i \frac{d\bar{e}}{dT}}{R_{q_i q_i}^i - C_{q_i q_i}^i - C_{q_i E_i}^i \bar{e}_i} \quad (14)$$

An increase in the price of permits is equivalent to a tightening of environmental policy. Therefore, (14) must be negative. To ensure this, we assume $C_{q_i E_i}^i \frac{\partial E_i}{\partial T} + \bar{e}_i C_{E_i E_i}^i \frac{\partial E_i}{\partial T} + C_{E_i}^i \frac{d\bar{e}}{dT} < 0$.

3.2.2 Stage One: Government Policy

With international emissions trading, the government has two choices to make. First of all, which domestic instrument to choose and secondly, whether or not to allow international emissions trading. In this section, these issues are dealt with.

We start by analyzing the effect of a shift to international emissions trading on profits of the firm. This effect is different for the two instruments. For a shift from emission ceilings to permit trading, it can be found by differentiating equation (1) with respect to the shadow price of emissions

$$\frac{\partial \Pi^i}{\partial \lambda_i} = \frac{dq_i}{d\lambda_i} (R_{q_i}^i - C_{q_i}^i) + R_{q_j}^i \frac{\partial q_j}{\partial q_i} \frac{\partial q_i}{\partial \lambda_i} - \frac{dE_i}{d\lambda_i} (C_{E_i}^i + \lambda_i) - (E_i - \bar{E}_i)$$

Using the first order conditions we can see that the first and third term vanish, giving

$$\frac{\partial \Pi}{\partial \lambda_i} = R_{q_j}^i \frac{\partial q_j}{\partial q_i} \frac{\partial q_i}{\partial \lambda_i} - (E_i - \bar{E}_i) \quad (15)$$

The first term gives the change in revenue because of a change in foreign production. This change is caused by the change in domestic production from a shift to international emissions trading. So this effect only reflects the shift to international emissions trading by the home country, while the foreign country is assumed not to change its policy, with foreign policy either being domestic regulation or international emissions trading. This first term has a negative sign. The second term reflects the proceeds from emissions trading.

Assume at first that the world price of permits is higher than the domestic shadow price of abatement, $T > \lambda_i$, and the domestic firm becomes a seller

of permits. Then from (15), the first term is negative and the second term is negative. Profits decrease because domestic production is lower and foreign production is higher. On the other hand, the firm receives a profit from emissions trading. The overall effect is uncertain and depends on the size of the two effects.

In the next case, the world price of permits is lower than the domestic shadow price, $T < \lambda_i$, which makes the domestic firm a buyer of permits. The first term in (15) is negative and the second term now is positive because $E_i > \bar{E}_i$. Both effects point to higher profits. The domestic firm increases production, while the foreign firm decreases production. At the same time, profits increase because the cost of using emissions has decreased.

The above shows that a shift from emission ceilings to international emissions trading always leads to an increase in profits when the country becomes a buyer of emission quotas. Domestic production is increased and foreign production decreased leading to higher domestic revenues, while at the same time there is a profit from the trade in emission quotas. If the country becomes a seller of permits, the shift to international emissions trading only leads to higher profits if the proceeds from emissions trading outweigh the reduction in revenue because of a reduction in production.

When the country uses relative standards, the effect of allowing international emissions trading can be found by differentiation of equation (5) with respect to the the shadow price of emissions λ_i

$$\begin{aligned} \frac{\partial \Pi}{\partial \lambda_i} = & \frac{dq_i}{d\lambda_i} (R_{q_i}^i - C_{q_i}^i + \lambda_i \bar{e}) + R_{q_j}^i \frac{\partial q_j}{\partial q_i} \frac{\partial q_i}{\partial \lambda_i} - \frac{dE}{d\lambda_i} (C_{E_i}^i + \lambda_i) \\ & - (E_i - \bar{e}q_i) + \lambda_i q_i \frac{d\bar{e}_i}{d\lambda_i} \end{aligned}$$

Using the first order conditions, we can see that the first and third term vanish. Hence, we have

$$\frac{\partial \Pi}{\partial \lambda_i} = R_{q_j}^i \frac{\partial q_j}{\partial q_i} \frac{\partial q_i}{\partial \lambda_i} - (E_i - \bar{e}_i q) + \lambda_i q_i \frac{d\bar{e}_i}{d\lambda_i} \quad (16)$$

The first term gives the change in domestic revenue because of the change in foreign production which is negative. The second term gives the emissions trade volume, the sign of which depends on whether the country becomes a seller or buyer of credits. The third term gives the value of the change in the relative standard. This last term arises because the government will react to a change in production with a change in the relative standard since the latter is defined as allowed total emissions divided by total production. If production rises because of a lower world price of credits, then the relative standard

must be set lower and reverse for the case where production decreases. This implies that $d\bar{e}/d\lambda_i > 0$ and hence that the third term is positive.

First consider the case where the world price of emission quotas is higher than the domestic shadow price, $T > \lambda_i$. In this case, the domestic firm becomes a seller of credits. As mentioned above, the first term has a negative sign, while the third term has a positive sign. Profits decrease because domestic production is lower and foreign production is higher, while profits increase because allowed emissions per unit of production increase. Since the firm becomes a seller, $E_i < \bar{e}_i q_i$ and the second term is negative. So, profits increase because the firm makes a profit on the sale of credits. This leaves us with two positive effects on profit and one negative. Hence, the total effect of allowing international emissions trading on profits is uncertain and depends on the size of the three effects.

In the second case, the world price of emission quotas is lower than the domestic shadow price of emissions, $T < \lambda_i$, and the domestic firm becomes a buyer of emission quotas. The first term in (16) is negative, while the third term is positive. Now the domestic firm increases production while the foreign firm decreases production which leads to an increase in profits for the domestic firm. At the same time, the relative standard is tightened, so that allowed emission per unit of production decrease, which lowers profits. At the same time, the domestic firm now becomes a buyer of permits, $E_i > \bar{e}_i q_i$ and the second term becomes positive. This means that profits increase because the firm can save on abatement costs. We are again left with two factors that have a positive effect on profits, while there is one factor with a negative effect on profits. The overall result depends on the size of the three effects. However, it is unlikely that the change in relative standards outweighs the direct gains from emissions trading. Hence, the shift to international emissions trading will lead to an increase in profits in this case.

Welfare of the country, with domestic consumption and international emissions trading is given by

$$W = \mu_h \int_o^y P(y)dy - P(y)\mu_h y + R^h(q_h, q_f) - C(q_h, E_h) - T(E_h - \bar{E}_h) \quad (17)$$

Differentiating with respect to q_h yields

$$\frac{\partial W^h}{\partial q_h} = R_{q_h}^h + R_{q_f}^h \frac{dq_f}{dq_h} - C_{q_h}^h - \mu_h P'(y) \left(1 + \frac{dq_f}{dq_h} \right) = 0$$

This is identical to the first order condition for welfare maximization without international emissions trading. The implication is that the optimization problem of the government is basically the same in the two cases. However,

there is a difference in that international emissions trading changes the price of emissions and thereby the actual emission level of the country. This in turn will affect welfare, and the effect may be different for different instruments.

To analyze the change in welfare as a result from the shift to international emissions trading, differentiate (17) with respect to the shadow price λ_h

$$\begin{aligned} \frac{\partial W^h}{\partial \lambda_h} = & \frac{dq_h}{d\lambda_h} (R_{q_h}^h - C_{q_h}^h) + R_{q_f}^h \frac{dq_f}{dq_h} \frac{dq_h}{d\lambda_h} - (E_h - \bar{E}_h) \\ & - \mu_h y P'(y) \frac{dq_h}{d\lambda_h} \left(1 + \frac{dq_f}{dq_h}\right) \end{aligned} \quad (18)$$

The first term gives the difference between marginal revenue and marginal cost. The sign of this term depends on whether the country uses credit or permit trading. In the first case $R_{q_h}^h < C_{q_h}^h$ and the term becomes positive, while with permit trading the term vanishes as can be seen from the first order conditions for profit maximization. The second term reflects the reaction by the foreign country to a domestic change in production. This term is negative. The third term reflects the volume of trade and is negative when the country exports emission quotas and positive when it imports them. The fourth term gives the overall change in price times the amount consumed in the home country and is thereby an indicator of consumer welfare.

In the following we will analyze for both instruments separately whether a shift to international emissions trading leads to an increase in welfare or not. With both instruments, there are two cases to consider since the country can become an importer or an exporter of emission quotas.

Permit Trading. With permit trading, the first term in (18) vanishes since $R_{q_h}^h = C_{q_h}^h$ from the first order conditions for profit maximization. This leaves three factors that affect welfare when the country allows international emissions trading. Suppose at first that the world price of emission quotas is higher than the domestic shadow price, i.e., $T > \lambda_h$. This leads to decrease in domestic production, an increase in foreign production and a decrease in world production and consequently to a higher world price of the product. The second term in (18) becomes negative because foreign production is higher. Also the fourth term points to a decrease in welfare because the higher world price of the product decreases consumers' welfare. The third term however shows that there is a welfare increase from emissions trading. As we saw above, permit trading leads to a too low production level. If $T > \lambda_h$, then production will decrease even more if international emissions trading is allowed. Hence, only when the gain from emissions trading is substantial enough will the shift to emissions trading lead to an increase in welfare in this case.

In the second case, $T < \lambda_h$ and the country becomes an importer of emission quotas. This leads to an increase in domestic production, a decrease in foreign production and an increase in overall production and consequently to a decrease in the world price of the product. In this case, all three remaining terms in (18) point to an increase in welfare. The second term is negative, showing that domestic welfare increases because the domestic firm gains market share and increases revenue. Also in this case, the country gains from emissions trading, now from a lower price of emissions. Finally, total production increases which gives a lower world price of the good, increasing consumers' welfare. This outcome is not very surprising since it has been shown above that output is too small with permit trading. Opening up for international emissions trading when the world permit price is lower than the domestic shadow price then leads to more production. Additionally, the country gains from emissions trading.

Credit Trading. With credit trading, the first term in (18) becomes positive, showing that there is a production distortion compared to the case with permit trading. We start the analysis with the case where, $T > \lambda_h$ and the country becomes an exporter of credits. That is, real emissions will be lower than the emission ceiling set by the government. The result is that domestic production decreases, foreign production increases, while total production decreases and the world price of the product increases. It follows from (18) that the total effect on welfare from a shift to international emissions trading is uncertain. The first term shows an increase in welfare since the production distortion becomes less important because of lower domestic production. However, the second term points to lower welfare since the foreign firm wins market share over the domestic firm. The third term gives the proceeds from emissions trading and shows that the country gains from trading. However, the last term again points to a decrease in welfare since consumers are confronted with higher overall prices. The overall effect depends on the relative size of the four factors here. For example if domestic consumption is very small or nonexistent, the main issue is whether the profits from emissions trading are higher than the losses because of the lower market share of the domestic firm.

When $T < \lambda_h$, the country becomes an importer of emission quotas and domestic emissions will be higher than the emission ceiling set by the government. This results in an increase in domestic production and a decrease in foreign production, however, total world production will increase and the world price of the product will decrease. Three factors now point to an increase in welfare, while one points to a decrease. The decrease in welfare comes from a larger distortion of production compared to the optimal as

shown by the first term in (18). However, foreign production is decreased, the country has lower costs from emissions and consumers gain from lower world prices. Hence, as long as the effect of the production distortion is not too large, allowing international emissions trading leads to an increase in welfare in this case.

The main effects from a shift to international emissions trading are that the country makes a profit on emissions trading and that production is affected. The first effect is always positive. Either the country makes a profit on the sale of emission quotas, or the country gains from lower costs of emissions. The second term can be both positive or negative. When the world price of emission quotas is higher than the domestic shadow price of emissions, production will decrease when the firm engages in emissions trading. As we saw in the part on domestic instruments, emission ceilings, and thereby permit trading, leads to too low production in the first place. A further reduction in production then leads to lower welfare. For credit trading, the effect is more complicated. Relative standards lead to a higher level of production than emission ceilings. However, production may also become too high. If production is lower than optimal with relative standards, allowing international emissions trading may lead to lower welfare when the country becomes a seller of credits. However, if relative standards lead to too much production, emissions trading with a higher world price than the domestic shadow price of emissions may lead to higher welfare.

With the world price of emission quotas lower than the domestic shadow price of emissions, production is increased. This leads to an increase in welfare, unless it leads to too much production. When the country uses relative standards, domestic production may be too high beforehand. The shift to emissions trading then gives even higher production and leads to lower welfare. An important determinant for how high domestic production should be is the proportion of world consumers in the home country. The higher this proportion, the higher domestic production must be.

The result is that allowing international emissions trading will not always lead to an increase in welfare. This is especially the case when the shift to international emissions trading leads to a decrease in domestic production. This leads both to lower domestic profits and lower welfare for consumers. Only if the direct gain from emissions trading is large enough can there be an increase in welfare. When international emissions trading leads to an increase in production, welfare is very likely to increase, both with permit and credit trading.

For government preference of instrument we then find the following. When $T > \lambda_h$, the country will presumably prefer domestic relative standards or

credit trading. These instruments lead to higher production than emission ceilings and permit trading. Credit trading will only be preferred to relative standards in this case when the gain from emissions trading is large enough to offset the loss from lower domestic production, or when relative standards lead to too much output. When $T < \lambda_h$ the country will prefer international emissions trading. Whether permit or credit trading leads to highest welfare depends on how large production is under relative standards and how much the shift to international emissions trading leads to an increase in production. If both effects are not large, then the government will prefer credit trading in this case.

4 Conclusions

In this paper I have presented a model of duopolistic international trade with the two competitors situated in different countries. Within this setting, I have analyzed government preferences for instrument of environmental policy and for international emissions trading scheme.

The analysis leads to two main conclusions. With imperfect competition, governments have an incentive to increase production, which is even strengthened when there is domestic consumption. This leads to a preference for relative standards or credit trading since these instruments lead to a higher output level of the domestic firm than other instruments do. Firms engaged in oligopolistic competition can increase profits if they could commit to a higher output level. Such a commitment is however not credible if it is made by the firm, but it is credible if made by the domestic government. Since the two countries are in the same situation, both will use relative standards to increase output. This leads to higher world output and lower firm profits. Welfare may increase though if there is domestic consumption.

The second main result is that international emissions trading is not always welfare improving. This is especially the case when the country becomes a seller of emission quotas. In this case, domestic and world output will decrease and the world price of the product will increase. This leads to lower firm profits and lower consumers' surplus. Although emissions trading per se leads to an increase in profits for the firm, the other effects can be so large as to outweigh this direct profit from emissions trading.

A possible extension of the model would be to introduce capital as an additional input in which firms can invest strategically. That would combine the current model with those developed by Ulph as discussed in Section 2. Since his results run counter to mine, a combination might be able to determine which effect is stronger.

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