ON THE GOVERNMENTS' ABILITY TO IMPLEMENT OPTIMAL ENVIRONMENTAL POLICIES DURING TRADE LIBERALIZATION

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Abstract

We examine the impact of trade liberalization on environmental policy, in a two-country, *n*-firm model. Initially under high trade costs, governments in autarky implement the environmental tax rates that maximize social welfare. When trade costs decrease and firms can compete non-cooperatively both at home and abroad, a problem arises in the setting of the optimal tax against pollution. We show that there is a range of trade costs such that governments are not able to implement any optimal environmental policy. Furthermore, the extent of the problem depends on the number of firms. The less competitive markets are, the larger the range of trade costs within which there is no equilibrium in the game between governments and firms. We also show that environmental policies are more stringent when the markets are open, nevertheless, at positive trade costs, social welfare is lower.

Keywords: Environmental tax; Bilateral trade; Trade liberalization.

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On the governments' ability to implement optimal environmental policies during trade liberalization

1. Introduction

"Is free trade good for the environment?"[1] A large literature has tried to answer this question by analyzing the links between trade, environmental policies, governments and firms' strategies, most of the time in a two-country model with one or two firms. A part of this literature focuses on the fact that governments may strategically use environmental policies to impact on the pattern of trade, when tariffs are banned and firms' location are exogenous (Barrett, 1994, Walz and Wellisch, 1997, Tanguay, 2001; Duval et al., 2002,).

Another part of the literature analyzes the problem of environmental tax competition among governments with multinational firms (Eerola (2004)) or with endogenous plant locations (Markusen et al. (1993)). All of these papers stress that firm location depends on different variables (fixed costs, transport costs, environmental standards, market size). Some of them show that governments may act strategically in order to drive polluting firms to other countries by setting a too-tough environmental policy. Markusen et al. (1995) describe this as the NIMBY (Not In My Back Yard) case. At the opposite, governments may have an incentive to choose low environmental standards to attract more firms; see for example Motta et al. (1994), Hoel (1997).

Most analyses show that when firms are mobile, there exist critical values of environmental standards leading to large discontinuities in welfare levels; and this lack of continuity constrains most of the authors to proceed by simulations or comparative statics. Moreover, in this literature, governments act as Stackelberg leaders: they fix the environmental standard in a first stage and in a second stage firms compete non – cooperatively in quantity and/or choose their location, taking the governments' decisions as given. Petrakis et al. (2003) have shown, in a two-country, one firm model, that this temporal dimension may lead to time inconsistency issues when the firm location decision is endogenous.

In the present paper, we also aim to introduce a temporal dimension in analyzing the impact of a gradual trade liberalization on environmental policies, with immobile firms. Starting from autarky, we assume that governments want to fix an environmental tax in order to maximize national global welfare[2] and we wonder whether, when trade liberalization occurs, the *ex-post* equilibrium delivers outcomes consistent with the *ex-ante* social choice. We consider a two-country model, but the framework of our model is more general than in the other models in the related literature. First, in each country, *n* firms ($1 \leq n < \infty$) produce a polluting homogenous good. This assumption enables us to highlight the relation between market structure and governments' environmental strategies and we show that our results are robust regardless the firms' number. Second, we assume that firms may sell their output on both markets. This assumption differs from a large part of the trade and environment literature where it is often assumed that firms sell all their output in a third market and governments maximize firms' profits minus environmental damage (See for example, Barrett, 1994, Walz et al, 1997). In our model, welfare implications are different since governments take also into account the national consumers' surplus.

In section 2 we present the general framework of the model. In section 3 we describe the initial situation in which trade costs are so high that countries are in autarky. In that case, governments are able to implement environmental taxes maximizing social welfare (consumers 'surplus, profits, tax revenues minus the disutility of pollution) and maintain consumers' surplus and social welfare at the same level whatever the market structure.

Then (section 4), we show that as trade costs decrease there is a limit value below which firms are able to export if the autarky tax is held. This is consistent with the reciprocal dumping result identified by Brander and Krugman (1983). But now both governments and firms strategize under open economy conditions. We model this by assuming they both play a non-cooperative game. In the first stage governments choose the optimal tax maximizing national social welfare in open economy. The optimal tax in this case is higher than the tax under autarky. The second stage is a Cournot game in which firms compete non-cooperatively on both markets, taking as given the tax rates in both countries.

We show that the non-cooperative equilibrium is not consistent with the social choice correspondence because the higher tax undermines firms' ability to export at the current level of trade costs. Indeed, we find that there is a range of trade costs such that there is no implementable optimal environmental policy.

In Section 5 we analyze the sub-optimal policy in this range of trade costs. Regulators may set a sub-optimal tax, higher than the optimal autarky tax in order to prevent the firms from exporting; or lower than the optimal open market tax in order to allow exports. In this last case, the exported quantities are very tiny and constant regardless of the level of trade costs as long as governments are not able to implement the optimal environmental taxes. We show that regulators choose to prevent the firms from exporting.

We consider welfare aspects in section 6. The objective of trade liberalization is to increase exchange and welfare by the reduction of costly impediments to trade. That hope has been alternately challenged (e.g., by Brander and Krugman, 1983, Tanguay, 2001) and reinforced (e.g., by Walz et al, 1997). We contribute to that debate by investigating the welfare consequences of trade liberalization when governments behave strategically when setting environmental policies.

As indicated above, environmental policies are more stringent in an open market than in autarky. Nevertheless, we show that social welfare is lower because there is the waste due to trade costs (reciprocal dumping) .

We conclude in section 7 with a summary of the findings.

2. The model

We consider a model of two identical countries (*i,j*), and a polluting industry consisting of *n* firms ($1 \leq n < \infty$)[3] in each country. Pollution is purely local. Assume one unit of polluting emission for each unit of output and let γ denote the marginal damage resulting from one unit of emission[4]. The firms' technology is described by a same constant marginal cost equal to zero. However, firms must pay a tax *t* on emissions[5]. In each country, there is an identical linear demand: $P = a - Q$[6]. Markets are segmented and we assume that firms must pay a linear trade cost, s, if they export.

Firms' profits depend on whether they are able or not to export and whether foreign firms export or not. Since Brander and Krugman (1983), we know that the rivalry of oligopolistic firms in segmented markets may lead to a two-way trade under the condition that the autarky price in each country exceeds the marginal cost of exporting (in our model pollution tax plus trade cost) by the firm in the other country.

It follows that profits are determined by the interaction of one strategic variable (the pollution tax decided by regulators) and two parameters: trade cost, s, and marginal damage, γ. We consider the consequences of a gradual decrease in trade cost (as the result of an international agreement) on the environmental policy, for a given level of γ. Note that, deliberately, we do not explicitly interpret s which, for example, may include tariff and non-tariff barriers, foreign market accessibility, or transport and distribution costs. The result of the agreement is a decrease in trade cost, by removing tariffs between members, but the final level of s depends on the other trade cost's components.

In a first stage, each country's regulator assesses a pollution tax, t, on emissions in order to maximize global welfare which is the sum of consumers' surplus, profits plus tax revenues net of the disutility of pollution. In a second stage, firms compete non-cooperatively on both markets, taking as given the tax rates in both countries.

Assume first, as a benchmark, that trade cost level is so high that firms are not able to export .

3. Autarky

In each country, (i,j), maximizing profits leads to a produced quantity by each firm equal to:

$$q_A = \frac{(a-t)}{n+1} \tag{1}$$

and $(\forall i,j)$, each firm's profit is given by: $$\Pi_A = \left(\frac{(a-t)}{n+1}\right)^2 \tag{2}$$

The autarky equilibrium price is: $$P_A = \frac{(a+nt)}{n+1} \qquad (\forall i,j) \tag{3}$$

The objective function of each government is, $(\forall i,j)$:

$$W = CS + n\Pi + (t - \gamma)Q \tag{4}$$

Where CS, $n\Pi$, tQ are respectively the national consumers surplus, global profit and tax revenues (with $Q = n\, q_A$). $\gamma\ Q$ is the global environmental damage.

Governments choose the environmental tax in order to maximize W. Substituting into (4), q_A and Π by their respective values (given by (1) and (2)), we obtain the optimal[7] environmental tax maximizing W in autarky for each country:

$$t_A = -\frac{a}{n} + \gamma \frac{(n+1)}{n} \qquad (5)$$

Note that $t_A < 0$ if $a > \gamma(n+1)$. With a low number of firms, regulators may subsidize the firms if the marginal damage is not too high.

It is not surprising that the optimal tax decreases when the market is less competitive $\left(\frac{dt_A}{dn} > 0\right)$ and tends to its pigouvian value ($t_A = \gamma$) when the firms' number tends to infinity. Because governments have only one instrument, the environmental tax, they use it also to mitigate against market failures arising from non-competitive behavior. **In particular, in the context of underproduction due to imperfect competition, governments set lower tax rates against pollution.** This is how regulators maintain consumers' surplus and welfare at the same level (the perfect competitive market level), regardless of the market structure. Substituting in (4) t by its optimal value t_A (given by (5)), we see that consumers' surplus and global welfare do not depend on the number of firms. When governments are able to implement the optimal autarky tax, consumers' surplus and welfare in each country are given by:

$$CS_A = W_A = \frac{1}{2}(a-\gamma)^2 \qquad (6)$$

Global profit is $n\Pi = \frac{(a-\gamma)^2}{n}$ and $(t \;\; - \gamma)Q = -\frac{(a-\gamma)^2}{n}$

4. Trade liberalization

Assume now that, following an international agreement, trade costs decrease gradually between countries. We know that the timetable for full implementation of an international agreement matters. For example, Walmsley et al. (2001) have shown that the timing of trade liberalization has been an important focal point in China's WTO accession negotiations, particularly in the textile and clothing agreement. Let us show how, in our model, the timetable of trade liberalization matters.

Country *j* firms will be able to export as soon as (Brander and Krugman (1983))

$$t_j + S < P_A^i \tag{7}$$

where P_A^i is country *i* autarky price given by (3). Remember that countries are identical, so in autarky, $P_A^i = P_A^j$ and $t_j = t_i = t_A$ given by (5).

It follows that both countries will export and two-way trade occur if:

$$S < \frac{(a - t_A)}{n+1} \tag{8}$$

Starting from autarky and assuming a decrease in S, the limit value of trade cost at which firms can export under the optimal autarky tax given by (5) is:

$$S_{t_A}^{\lim} = \frac{a-\gamma}{n} \tag{9}$$

For trade costs below this value, firms compete non-cooperatively on both markets. Their best strategy is to export and the result of the game is two-way trade.

In the open market, firms play a non cooperative game and maximize their profit separately on each segmented market. The results of the Cournot-Nash game between firms are : On the country *i* market:

$$q_{open}^i = \frac{a}{2n+1} - \frac{(n+1)t_o^i}{2n+1} + \frac{n(t_o^j + S)}{2n+1} \quad \text{and} \quad q_{open}^j = \frac{a}{2n+1} - \frac{S(n+1)}{2n+1} + \frac{nt_o^i}{2n+1} - \frac{t_o^j(n+1)}{2n+1} \tag{10}$$

and on the country *j* market (noted by *):

$$q*_{open}^i = \frac{a}{2n+1} - \frac{S(n+1)}{2n+1} + \frac{nt_o^j}{2n+1} - \frac{t_o^i(n+1)}{2n+1} \quad \text{and} \quad q*_{open}^j = \frac{a}{2n+1} - \frac{(n+1)t_o^j}{2n+1} + \frac{n(t_o^i + S)}{2n+1} \tag{11}$$

where q^i_{open} and $q*^j_{open}$ are the quantities produced for the national market by each firm respectively in countries i and j while $q*^i_{open}$ and q^j_{open} are the exported quantity by each firm. t^i_o and t^j_o are the emission taxes in open economy.

The *ex-ante* tax (t_A), however, is no longer optimal because governments' objective functions have changed since the countries are open to trade. Social welfare is still given by (4) but now consumer surplus must include the imported quantities: $CS^i_o = \frac{1}{2}(nq^i_{open} + nq^j_{open})^2$ and $CS^j_o = \frac{1}{2}(nq*^i_{open} + nq*^j_{open})^2$. Profits must include the exported quantities. Thus, trading countries' welfare are:

$$W^i{}_{open} = \frac{1}{2}\left(nq^i_{open} + nq^j_{open}\right)^2 + n\left(\Pi(q^i_{open})\right) + n\left(\Pi(q*^i_{open})\right) + (t-\gamma)\ n(q^i_{open} + q*^i_{open}) \qquad (12)$$

and $$W^j{}_{open} = \frac{1}{2}\left(nq*^i_{open} + nq*^j_{open}\right)^2 + n\left(\Pi(q^j_{open})\right) + n\left(\Pi(q*^j_{open})\right) + (t-\gamma)\ n(q^j_{open} + q*^j_{open})$$

The non cooperative game between governments maximizing social welfare leads to the reaction functions (using (10) and (11)):

$$t^i_o = \frac{-2a(n+1) - nt^j_o + S(n+1) + 2\gamma(n+1)(2n+1)}{3n+4n^2} \quad \text{and}$$

$$t^j_o = \frac{-2a(n+1) - nt^i_o + S(n+1) + 2\gamma(n+1)(2n+1)}{3n+4n^2} \qquad (13)$$

Finally, the open market optimal taxes are :

$$t^i_o = t^j_o = t_o = -\frac{a}{2n} + \frac{(2n+1)\gamma}{2n} + \frac{S}{4n} \qquad (14)$$

It is straightforward to see that this *ex-post* optimal tax is higher than the optimal autarky tax[8], and that it decreases for a higher number of firms. The optimal environmental tax with trade is higher because the opening of markets leads to more competition which reduces the government's tendency to lighten up on the environmental tax.

It follows that the optimal open market tax on pollution is closer to the pigouvian tax, hence higher, than the autarky one. Environmental policies are more stringent in open market than in autarky[9].

Note also that the higher is the trade cost, the higher the open market emission tax. Trade cost has two opposite effects on the tax level. On the one hand, because trade cost reduces the pro-competitive effect of trade, the regulators have an incentive to lower t_{open} with high values of *S*. On the other hand, since Brander and Krugman (1983) we know that opening the market between two symmetric oligopolistic markets may be welfare[10] decreasing, because of the waste due to trade cost (firms' outputs are perfect substitutes and imports cost more). It follows that governments have an incentive to use environmental policies to reduce trade by setting a higher tax for higher value of trade cost and this second effect over-balances the first one. We know also (see Brander and Krugman (1983)) that the pro-competitive effect of having more firms may counterbalance the negative effect of trade cost and that, with free entry, trade may be welfare improving. It follows that governments increase the open market tax with trade cost but this increase is softened when there are more firms.

Substituting the value of the open market optimal taxes in (10) and (11), we obtain the quantities produced by firms :

$$q^i_{open} = q*^j_{open} = \frac{a-\gamma}{2n} + \frac{S(2n-1)}{4n} \quad \text{and} \quad q*^i_{open} = q^j_{open} = \frac{a-\gamma}{2n} - \frac{S(2n+1)}{4n} \qquad (15)$$

In each country, global production, thus pollution, are lower with trade than in autarky as long as trade cost is positive (see Appendix 1).

Nevertheless, it is straightforward to see using (15) that the limit value of trade cost allowing firms to export $(q*^i_{open} > 0\ ,\ q^j_{open} > 0)$ when governments set the optimal open market tax is:

$$S^{\lim}{}_{t_{open}} = \frac{2}{2n+1}(a-\gamma) \qquad (16)$$

As long as trade cost is higher than (or equal to) this limit value, firms are not able to export .

The principal result is that since $S^{\lim}{}_{t_{open}} < S^{\lim}{}_{t_A}$ (see (9)), the optimal emission tax level t_{open} determined in (14) is not consistent for trade cost values such that $S^{\lim}{}_{t_{open}} < S < S^{\lim}{}_{t_A}$.

In this range of trade costs, firms export at autarky taxes but stay in autarky at the open market taxes. Let us underline that the difference $(S_{t_A} - S_{t_{open}})$ decreases with a larger firms' number :

$$S_{t_A} - S_{t_{open}} = \frac{(a-\gamma)}{n(2n+1)}$$

Proposition 1 summarizes the results.

PROPOSITION 1: There exists a range of trade costs such that an optimal environmental policy cannot be implemented when oligopolistic markets are open between two symmetric countries .

The less competitive are the markets the larger the range of trade costs leading to this problem.

5. Sub-optimal environmental policy

In this section, we analyze the governments' sub-optimal policy for the range of trade cost's values between $S^{\lim}{}_{t_{open}}$ and $S^{\lim}{}_{t_A}$. In this range of trade costs, the autarky tax is not optimal, because, at this level of tax, the firms' best strategy is to export and the open market tax is not optimal because, at this higher level of tax, firms cannot export and countries stay in autarky.

When trade cost reaches the value $S^{\lim}_{t_A} = \frac{a-\gamma}{n}$ then decreases until $S^{\lim}_{t_{open}}$, governments have two options.

- The first option is to set an emission tax higher than the autarky optimal tax in order to prevent firms from exporting. Remember that firms cannot export when $S \geq \frac{(a-t)}{n+1}$, governments may fix an emission tax $t \geq a-(n+1)S$. Because the autarky social welfare decreases when the emission tax moves away from the autarky optimal tax, governments will set the minimum tax allowing countries to stay in autarky. It follows that, if governments choose to stay in autarky, the tax fixed for trade cost's values between $S^{\lim}_{t_A}$ and $S^{\lim}_{t_o}$ will be:

$$t_A^{subopt} = a-(n+1)S \quad (17)$$

Note that, for $S^{\lim} = \frac{a-\gamma}{n}$, t_A^{subopt} is equal to t_A (given by 5). Afterwards, t_A^{subopt} increases proportionally to the decrease in trade cost.

- The second option is to set an emission tax lower than the open market optimal tax in order to allow firms' exports. With a tax $t < a-(n+1)S$, firms are able to export. Because social welfare decreases when the emission tax moves away from the open market optimal tax, governments will set the maximum tax allowing firms to export, hence:

$$t_o^{subopt} = a-(n+1)S-\varepsilon \quad (18)$$

If this sub-optimal tax is applied for each trade cost's values between $S^{\lim}_{t_A}$ and $S^{\lim}_{t_{open}}$, the exported quantities are very slight and constant in this range of trade costs.

Propositions 2 summarizes the results.

Proposition 2 : ***In the range of trade costs between*** $S^{\lim}_{t_A}$ ***and*** $S^{\lim}_{t_{open}}$***, the non cooperative game between governments leads to set in each country a sub-optimal tax in order to stay in autarky .***

In both countries global welfare decreases with lower trade cost between $S^{\lim}{}_{t_A}$ and $S^{\lim}{}_{t_o}$.

Proof of these propositions are provided in appendix 2.

6. Welfare considerations

We have underlined in section 3, that in an oligopolistic market, international trade may be welfare decreasing. If this result is verified in our model, it is interesting to wonder whether governments have an incentive to stay in autarky by keeping the sub-optimal tax (given by(17)), even when trade costs decrease below $S^{\lim}{}_{t_o}$.

Compare first the levels of welfare in autarky and in open market when the corresponding optimal environmental taxes (t_A and t_{open}) are set.

Substituting in (12) t_o^i and t_o^j by their optimal value t_{open} given by (14), and rearranging, we obtain the open market welfare level, $\forall i,j$:

$$W_{open} = \frac{1}{2}(a-\gamma)^2 - \frac{(a-\gamma)S}{2} + \frac{(4n+1)S^2}{8} \qquad (19)$$

Let us first stress that, when $S=0$, the open market welfare is the same than in autarky. This value is given by (6) and does not depend on the firms' number.

Nevertheless, with a positive trade cost, governments have a supplementary problem: bounding the waste due to trade cost. We show in appendix 3 that, when $S>0$, the open market welfare is always lower than the autarky one. With only one instrument, the environmental tax, the governments do not achieve, in open market, to counterbalance the waste due to trade cost and mitigate against market failures.

Consequently, we must verify if the regulators have an incentive to stay in autarky by setting the sub-optimal tax given by (17) even when S reaches the value $S^{\lim}{}_{t_o}$. We show in appendix 4 that (W_{open} - W_A^{subopt}) is positive if S< $\frac{2}{2n+1}(a-\gamma)$ which is the limit level of trade cost allowing exports when the open market optimal tax is set .

Proposition 4*: *With positive trade cost, the open market global welfare is lower than in autarky. Nevertheless, regulators have no incentives to maintain the sub-optimal taxes in order to stay in autarky as soon as they are able to implement the open market optimal taxes.

Fig.1 illustrates the evolution of global welfare ($\forall i,j$), according to the decrease in trade costs and the pollution taxes chosen by countries. As long as trade cost is above $S_{t_A}^{\lim} = \frac{a-\gamma}{n}$, countries are in autarky. Between $S_{t_A}^{\lim}$ and $S^{\lim}{}_{t_{open}} = \frac{2(a-\gamma)}{2n+1}$, governments set the sub-optimal tax t_A^{subopt} and welfare decreases. At $S^{\lim}{}_{t_{open}}$ governments set the open market optimal tax and firms export . Welfare first decreases until $S = \frac{2(a-\gamma)}{4n+1}$ then increases with lower trade costs and reaches the autarky level at zero trade cost.

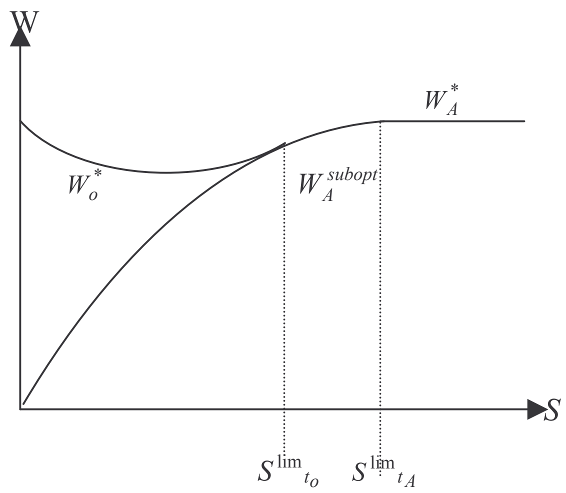

Fig.1 Evolution of global welfare

7. Summary and conclusions

We develop a two-country model with a polluting industry and governments setting environmental taxes to maximize social welfare. We consider the consequences of a decrease in trade cost on the environmental policy. The model differs significantly from the related literature by assuming that there are n firms in each country and that firms sell their output on both markets. In autarky, governments are able to set the socially optimal environmental tax and limit markets' failures: they keep the social welfare at the same level regardless the firms' number. When trade cost decreases, there is a range of trade costs such that the non-cooperative game between firms leads to results not consistent with the governments' social choice. The lower is the firms' number, the larger the range of trade costs leading to the problem. In this range of trade costs, a sub-optimal tax may be set but this sub-optimal policy prevents firms from exporting and global welfare decreases in both countries with lower trade costs.

With further trade liberalization, governments may set the optimal open market taxes.

We show that the environmental policy is more stringent with trade than in autarky. Nevertheless, opening the market decreases social welfare relatively to autarky. Now the open market social welfare increases with lower trade costs and reaches the autarky level at zero trade cost.

In our model we have assumed symmetric countries for simplicity. Adding some asymmetries across countries (for example different market structures by assuming $n_i \neq n_j$) or/and among firms (for example different production costs) should be a fruitfull direction for future research. Unfortunately, it will be difficult to solve analytically this more general model. Another area for future research is to consider a transboundary pollution which favours cooperative environmental policies and wonder if such effect mitigate or worsen the sub-optimal problems described.

Appendix 1

In autarky the global production is equal to $Q_A = (a-\gamma)$ and in open market $Q_{open} = (a-\gamma) - \frac{S}{2}$. Then, with positive trade costs, global production and damage are lower with trade than in autarky, then increases with the decrease in trade cost and reaches the autarky level at zero trade cost.

Appendix 2

Assume that trade cost has reached some value between $S^{\lim}{}_{t_A}$ and $S^{\lim}{}_{t_o}$, and that both governments have chosen to set the sub-optimal tax in order to stay in autarky.

Countries' welfare is given by :

$$W_A = \frac{1}{2}\left(n\left(\frac{a-t}{n+1}\right)\right)^2 + n\left(\frac{a-t}{n+1}\right)^2 + (t-\gamma)n\left(\frac{a-t}{n+1}\right) \quad (\forall i,j) \qquad (20)$$

Substituting into (20) *t* by its sub-optimal value given by (17), we obtain:

$$W_A^{subopt} = -\frac{1}{2}(nS)^2 + (a-\gamma)(nS) \qquad (21)$$

Note that W_A^{subopt} decreases with lower values of trade costs: $\frac{dW_A^{subopt}}{dS} = (a-\gamma)n - n^2 S$ is positive if $S < \frac{a-\gamma}{n}$, which is the limit value $S^{\lim}_{t_A}$ defined in (9).

Assume now that both governments have chosen to set the sub-optimal tax allowing firms' exports, in each country the quantities exported by each firm are $q*^{i}_{open}$ and q^{j}_{open} given by (10) and (11). Substituting in (10) and (11) *t* by its sub-optimal value given by (18), we see that the quantities exported are very slight and constant whatever the decrease in trade costs in the range [$S^{\lim}{}_{t_A}$, $S^{\lim}{}_{t_o}$]: $q^*_{open} = \left(\frac{\varepsilon}{2n+1}\right)$

Open market country welfares are given by (12). Using (10), (11) and (18), we have, ($\forall i,j$):

$$W_{open}^{subopt} = \frac{1}{2}\left(nS + \frac{2n\varepsilon}{2n+1}\right)^2 + n\left(S + \frac{\varepsilon}{2n+1}\right)^2 + n\left(\frac{\varepsilon}{2n+1}\right)^2 + (a - \gamma - (n+1)S - \varepsilon)\left(nS + \frac{2n\varepsilon}{2n+1}\right) \quad (22)$$

We obtain that $W_{open}^{subopt} - W_{A}^{subopt} = \frac{n\varepsilon}{2n+1}\left(\frac{-2n\varepsilon}{2n+1} - S(2n+1) + 2(a-\gamma)\right)$ is negative if $S > \frac{2}{2n+1}(a-\gamma)$ which is the limit value defined in (16). It follows that, in the range of trade cost $\frac{(a-\gamma)}{n} > S \geq \frac{2(a-\gamma)}{2n+1}$ governments will prefer to stay in autarky by setting the sub-optimal tax t_A^{subopt}.

It remains to show that one country has no incentive to export when the other country chooses to stay in autarky.

Using (13), we obtain that the best response of country i when country j sets $t^j = t_A^{subopt} = a - (n+1)S$ is to set a tax equal to: $t^i = \frac{-a(3n+2) + S(n+1)^2 + 2\gamma(n+1)(2n+1)}{n(3+4n)}$.

Nevertheless, at this tax value, country i firms cannot export since when country j sets $t^j = a - (n+1)S$, the other country firms are able to export only if the domestic tax is lower than this value. Now, $\frac{-a(3n+2) + S(n+1)^2 + 2\gamma(n+1)(2n+1)}{n(3+4n)} < a - (n+1)S$ only when $S < \frac{2(a-\gamma)}{2n+1}$ and this condition does not hold. It follows that country i (respectively j) cannot set an open market optimal tax in response to the autarky sub-optimal tax set by country j (respectively i).

If country i sets the sub-optimal tax $t^i = t_o^{subopt} = a - (n+1)S - \varepsilon$ in response to the autarky sub-optimal tax fixed by country j, country i firms are alone to export. If we compare the resulting global welfare ($Wi\, {t^j}_A^{subopt} / {t^i}_o^{subopt}$) to the welfare obtained when both countries stay in autarky (given by (21)), we find that $Wi\, t^{j\,subopt}_{A} \big/ t^{i\,subopt}_{o}$ is higher than Wi^{subopt}_{A} only if $S < \frac{(a-\gamma)(3n+2)}{(2n+1)n+(n+1(n+1)^2)}$ and this value is lower than $S = \frac{2(a-\gamma)}{2n+1}$. It follows that one country will never prefer to export in the range $\frac{a-\gamma}{n} \geq S \geq \frac{2(a-\gamma)}{2n+1}$ and that the non cooperative sub-optimal game leads both countries to set the sub-optimal tax $t^{subopt}_{A} = a-(n+1)S$.

Appendix 3

-At zero trade cost, the open market production (then the pollution) in each country is the autarky one (see Appendix 1). Global welfare is also at the same level than in autarky. Using (19) we obtain ($\forall i,j$) : $W_{open} = \frac{1}{2}(a-\gamma)^2$

-With positive trade cost , the difference between open market and autarky welfares using (19) and (6) is:

$$W_{open} - W_{A} = \frac{S^2(4n+1)}{8} - \frac{(a-\gamma)S}{2}$$

It follows that global welfare is higher with trade at the condition that $S > \frac{4(a-\gamma)}{4n+1}$.

Now this condition does not hold since exports occur only if $S < \frac{2(a-\gamma)}{2n+1}$. Consequently, in open market, welfare is always lower than in autarky but it increases when trade costs decreases and reaches the level of autarky welfare at zero trade costs.

Appendix 4

We have to compare the autarky welfare value when governments assess the sub-optimal tax $t^{subopt}_{A} = a-(n+1)S$ (given by 17) and the open market welfare when the optimal tax

t_{open} (given by 14) is fixed. First, let us note that t_A^{subopt} is equal to t_{open} for $S=\frac{2(a-\gamma)}{2n+1}$.

Then, at this trade cost value, $W_{open} = W_A^{subopt} = \frac{2n(a-\gamma)(n+1)}{(2n+1)^2}$.

When trade cost decreases below this value, W_A^{subopt} continues to decrease (see Appendix 2) and reaches zero for S=0. Moreover the second-order derivative is: $\frac{d^2 W_A^{subopt}}{dS^2} = -n^2$

From (19), we have: $\frac{dW_{open}}{dS} = -\frac{(a-\gamma)}{2} + \frac{(4n+1)S}{4}$ <0 when $S < \frac{2(a-\gamma)}{4n+1}$ and

$\frac{d^2 W_{open}}{dS^2} = \frac{(4n+1)}{4}$.

It follows that the regulators prefer to assess the optimal open market tax allowing trade as soon as $S=\frac{2(a-\gamma)}{2n+1}$. Note that, from this time, the level of the open market welfare first decreases until $S = \frac{2(a-\gamma)}{4n+1}$ then increases with lower trade costs and reaches the value $W_A = \frac{1}{2}(a-\gamma)^2$ when S=0.

Notes

[1] This question is asked by Antweiler et al. (2001).
[2] Governments are only able to implement this environmental tax (they cannot use other instrument in order to control trade).
[3] We exclude the case of perfect competition ($n=\infty$) which cannot lead to trade because countries are exactly identical.
[4]We assume, for simplicity, a linear damage function. Using a quadratic function does not change the results.
[5]The environmental tax is equivalent to a tax on production.
[6] With $a > \gamma$.
[7] More precisely, this tax is not "optimal" from an environmental point of view but is socially optimal from the global welfare point of view.
[8] This is true for all values of $1 \leq n < \infty$. The difference ($t_{open} - t_A = \frac{a-\gamma}{2n} + \frac{S}{4n}$) is positive and tends to zero when the firms' number tends to infinite.
[9] Burguet et al. (2003) obtain the same result in a two –country, two firms model.
[10] We explore the open market impact on welfare in section 5.

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