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Can Cleaner Environment Promote International Trade? Environmental Policies as Export Promoting Mechanisms

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Working Paper Series

18-10

September 2018

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February 2018

Abstract

We develop an international duopoly model where the firms export their output to a world-market. Production uses a depletable resource, and it generates pollution which affects negatively households' welfare. Governments control pollution using (i) an emission tax, the revenue from which finances public pollution abatement, (ii) a revenue-recycling tax, refunded to the emitting firm contingent on reducing the cost of private pollution abatement, and (iii) an environmentally related standard. **We evaluate them as (i) export promoting Non-Tariff Measures (NTMs) measuers,** and (ii) resource conserving/depleting **and welfare enhancing** policy instruments. Our results indicate that, by and large (i) public pollution abatement works as an export-promoting but resource depleting mechanism, which under certain conditions can enhance welfare; (ii) revenue recycling works as an export-contracting but resource preserving mechanism, and (iii) environmental standards relative to public abatement work as an export-contracting but resource preserving mechanism, but relative to revenue recycling work in the opposite direection.

Keywords: Emission taxation, Public Pollution Abatement, Recycling tax revenues, Environmental Related Standards, International Trade.

JEL Classification: F18, H23 and Q58.

1 Introduction

1.1 Contribution and the issue at hand

Traditionally and for a long time, price and quantity related trade policy instruments, such as, trade taxes, i.e., import and export taxes/subsidies, and import quotas, have been adopted not only in the pursuit of trade objectives, but also in meeting other national (non-) economic interests, e.g., enhancement of employment and government tax revenues, protection of "traditional" sectors of economic activity from foreign competition. Nowadays, in an era where $GATT/WTO$ initiatives fiercely promote the liberalization of world trade, countries, to a large extent, have been restricted from using these trade-restricting policies. Subsequently, other non-tariff measures ($NTMs$) have largely emerged as strategic policies to restrict imports and to promote exports, to improve welfare, to protect the natural environment from over-usage and illegal trade of natural resources, and to encourage the usage of environmentally friendlier products and the investment in "greener" production technologies.[1]

We construct a model of an international duopoly, e.g., firm-country 1 and firm-country 2. The two firms have identical production technologies, produce and sell a homogeneous product to the ROW. We assume that this product is not consumed in the two countries, thus, production of each firm tantamounts to the country's exports to the ROW. Production uses a depletable natural resource, e.g., forests, which exists in fixed endowment in each country, and it also genrates local pollution emissions. The extraction of the resource is costly to the firms. Pollution emissions are abated partly by the firms via a costly "private" activity

[1] Copeland and Taylor (2004), and Copeland (2012) provide an excellent survey of using policy instruments such as environmetal taxes and standards, and tradable and non-tradable emission permits in the pursuits of trade-cum-environment policy objectives.

in response either to emissions taxes or to $ERSs$ adopted by their national governments, and partly by the governments themselves which undertake so-called "public sector pollution abatement activity". Households in the two countries derive utility from the "consumption" of clean-environment, and from the "enjoyment" of the undepleted amount of the natural resource.

We assess the effectiveness of specific environmental policies, as potential $NTMs$ in the sense of increasing exports and expanding national share in ROW's market, and as policy measures of conserving the natural resource and improving welfare. The environmental policies we consider here are: (i) an emission tax, whose revenue finances public pollution abatement; (ii) a revenue-recycling tax, refunded to the own emitting firm, contingent on adopting private pollution abatement; and (iii) an environmentally related standard (ERS). In controlling pollution the two countries act non-cooperatively, choosing ex-ante an abatement regime to which they commit. We examine the following three pollution abatement regimes. Regime I: Country 1 implements an emissions tax, with the tax revenue being lump-sum rebated partly to the polluting firm to compensate for its pollution abatement cost, and partly to local households. Country 2 adopts an ERS. Regime II: Both countries impose an emissions tax, and the two governments use the revenue to finance public sector pollution abatement activity. Regime III: Country 1 imposes an emissions tax and uses the revenue to finance public sector pollution abatement, while country 2 implements an ERS.

Our results indicate that, by and large (i) public pollution abatement works as an export-promoting but resource depleting mechanism, which under certain conditions can enhance welfare; (ii) revenue recycling works as an export-contracting but resource preserving mechanism, and (iii) environmental standards relative to public abatement work as an export-contracting but resource preserving mechanism, but relative to revenue recycling work in

the opposite direction.

Refunding or recycling of environmental tax revenues is first instituted in Sweden in 1992. The country introduced an environmental charge on nitrogen oxide (NOx) emissions, whose revenue was refunded to the affected plants in proportion to the amount of energy produced.[2] As a result, there was a 35% reduction in NOx emissions within 20 months after the implementation of the tax. Norway in January 2007, introduces a tax on NOx emissions, in order to meet the NOx emissions standards, as agreed under the Gothenburg protocol. In May 2008, the tax is transformed into a Fund for investment through an agreement between the Norwegian government and business organizations resulting to further decline in NOx emissions. Refunding is tied directly to actual abatement costs at the firm level (expenditure based refunding); while compensations are paid to certain affected industries inter alia freight ships, fishing vessels and aircrafts. Switzerland in 2008, introduces the Carbon Dioxide (CO_2) incentive tax on all hydrocarbon fuels. Part of the tax revenue is redistributed to companies in proportion to the total payroll of their employees, another part is redistributed to the Swiss public via health insurance programs, and the remaining of the revenue is allocated to a 10-year building program for climate-friendly building renovations.

In many countries, particularly developed ones, along with private sectors' initiatives for pollution abatement in response to various government policies, there is substantial evidence of direct public sector involvement in so-called pollution and abatement control policies (PAC), e.g., Linster et al. (2007).[3] Governments apply various earmarked programs which frequently are environmentally motivated. For instance, in the Netherlands

[2] According to *Aidt (2010)* and *Sterner and Fredriksson (2005)*, emission taxation is more politically acceptable if the tax revenues are refunded to the regulated industry. Polluters pay a charge on pollution and the revenues are refunded to them in proportion to their output market share.

[3] The authors report, among other things, that during 1990-2000 for most countries public expenditures accounted for about 40-60% of total PAC expenditures. Public PAC expenditures as a percentage of total PAC expenditures averaged 55 percent in Canada, Finland, France and Korea, 77 percent in Germany, 35 percent in Japan, and 40 percent in the US.

the proceeds from taxes on water pollution fully finance the prevention of the country's surface waters pollution. In Germany revenue from wastewater taxation finances improvements in municipal sewage treatment whereas in France, tax revenues from environmentally related taxes finance environmental projects such as waste treatment, water quality improvements and toxic pollution control.[4]

1.2 Related literature

Recent studies conclude that, particularly in developed economies, (i) the effect of environmental factors is more profound than that of income growth on individual's well-being; and (ii) public spending for the provision of non-consumption public goods, e.g., ensuring environmental protection and improvement, is far more important for the well-being of their citizens, relative to public spending related to economic growth.[5] For example, higher welfare gains occur with increased public expenditures on environmental improvements, e.g., cleaner air and water, increased amount of waste recycling, rather than, e.g., on public education and health see, Rehdanz, K. and Maddison, D. (2005), Welsch, H. (2006), Ng, Y. K. (2008), Ong, Q. and Quah, E. (2014). In conjunction to this literature, our study concludes, as previously reviewed, that public pollution abatement is effective as a NTM, leading to higher exports and welfare, while, as an instrument of environmental policy it proves to be less effective relative to the other two environmental policies considered here.

In the literature on the recycling of environmental tax revenues, two key results which emerge are, first, high emission taxes must accompany a policy of recycling environmental tax revenues, for it to be effective in reducing emissions, and in creating incentives for firms to adopt cleaner ER&D technologies, e.g., Sterner and Hoglund (2006). Second, refunding can speed up

[4] The OECD/EU databases on environmentally related taxes report numerous earmarked levies: 65 different taxes in 18 countries and 109 fees and charges in 23 countries.

[5] The economic rationale of the argument is that as real incomes grow and households can afford consumption of certain public expenditure items such as education, they prefer increased public spending in areas of limited private consumption spending, e.g., environmental quality.

the diffusion of abatement technology if firms do not strategically influence the size of the refund, e.g., Coria and Mohlin (2013). Our study reproduces both results.

A limited strand of the international trade-cum-environment literature considers the simultaneous abatement of pollution by the private and public sectors in trade models of perfect competition, e.g., Hatzipanayotou et al. (2005), Hadjiyiannis et al. (2009), Tsakiris et al. (2015). In this line of research, governments finance public pollution abatement activities via lump-sum taxation, or revenues from environmental taxes, or via proceeds from the sales of tradable emissions permits. To the best of our knowledge, the issue of public pollution abatement, is not been raised yet in the framework of imperfectly competitive open-economies models.

Another strand of the literature, relevant to our study, is the one considering the trade and welfare effects of ERSs in imperfectly competitive models of open economies. For example, Barrett (1994) examines the effects of standards as barriers to trade, suggesting that environmental protection standards can enhance innovation and competitiveness of some industries, but this result rests on specific assumptions. Barrett's approach can be considered as a precursor of the idea of using environmental standards as NTMs to promote and enhance trade. Ulph (1996) comparing the cases where both governments use the same policy instrument, either environmental taxes or standards, concludes that environmental standards lead to lower distortions to both environmental policy and R&D investment, and to significantly higher welfare in both countries relative to environmental taxes.

2 Regime I: Revenue Recycling vs ERS

In this section, we examine the case where country 1, imposes a revenue-recycling tax per unit of emissions. Part of the emission tax revenue is refunded to the emitting firm in a manner reducing its cost undertaking pollution abatement, while the remaining is lump-sum distributed to the country's households. Country 2 implements an environmentally related standard (ERS). Hence, pollution emissions by firm 2 cannot exceed the standard set by the government. A lower (higher) ERS refers to a tighter (laxer) environmental constraint.

2.1 The Model

We consider an international duopoly, where one firm is located in country 1 and the other in country 2. Firms have identical production technologies and produce an identical and homogeneous product. Due to the complexity of the analytical solutions, we assume that this commodity is consumed only in the ROW. The inverse demand for the product in ROW is assumed linear of the form $P = B - Q$, where P is the world price, the parameter $B > 0$ captures the size of the world commodity market, and $Q = q_1 + q_2$ is the total output sold, i.e., exported, by the two firms in ROW's market. Without loss of generality, we assume zero production and transportation costs.

Output q_i, $i = 1, 2$, is produced by the use of a depletable natural resource, whose endowment $\overline{R_i}$ is fixed in a country.[6] For tractabilityn of the results, we denote the production function of the i^{th} good by the linear formulation $q_i = AR_i$, where R_i is the amount of the resource used, and A, a positive constant, denotes the marginal product of the resource. The extraction of this resource is costly to the firms, and because of the assumed linearity between q_i and R_i, extraction entails a convex cost function of the form $\frac{1}{2}\gamma q_i^2$, where $\gamma > 0$ is assumed the same for both firms.

Both firms use an "end-of-pipe" pollution abatement technology. Assuming, without loss of generality, that one unit of production generates one unit of pollution emissions, e.g., see Poyago-Theotoky (2007), each firm's total emissions equal production minus private pollution abatement r_i:

$$E_i(q_i, r_i) = (q_i - r_i). \tag{1}$$

The adoption of private pollution abatement is also costly to the firms.

[6] We assume that this endowment is quite high, so that it never reaches complete depletion due tothe firms' production activity.

We assume a convex cost function of the form $\frac{1}{2}kr_i^2$, where larger values of the parameter $k(>0)$ denote a less efficient private pollution abatement technology. The profit functions of the two firms are given by:

$$\begin{aligned}\pi_1(q_1, q_2, r_1; t_1, \delta) = (B - q_1 - q_2)q_1 - t_1(q_1 - r_1) - \\ [\frac{1}{2}k(r_1)^2 - \delta t_1(q_1 - r_1)] - \frac{1}{2}\gamma q_1^2, \\ s.t. \quad R_1 < \overline{R_1}\end{aligned} \tag{2}$$

$$\begin{aligned}\pi_2(q_1, q_2, r_2; s_2) = (B - q_2 - q_1)q_2 - \frac{1}{2}k(r_2)^2 - \frac{1}{2}\gamma q_2^2, \\ s.t.\ q_2 - r_2 \leq s_2 \quad \text{and} \quad R_2 < \overline{R_2}.\end{aligned} \tag{3}$$

where t_1 and δ are respectively the emission tax per unit of emissions and the share of environmental tax revenue refunded to firm 1; s_2 is the ERS set by country 2. When $\delta = 1$, firm 1 gets a full tax refund, equivalent to not paying taxes. Thus, for the rest of the analysis, we consider $\delta \in [0, 1)$, e.g., Gersbach and Requate (2004). Under recycling of tax revenue, firm's 1 profits are defined as **the difference between export revenue minus the amount of emission taxes paid**, i.e., $t_1(q_1 - r_1)$, its net, after tax refund, cost of private pollution abatement, i.e., $[\frac{1}{2}k(r_1)^2 - \delta t_1(q_1 - r_1)]$, and the cost of extracting the depletable natural resource $\frac{1}{2}\gamma q_1^2$. Firm 1 is binded in its production of q_1 by the resource use constraint stating that the demand for the natural resource R_1 cannot exceed its available fixed endowment $\overline{R_1}$. Under the ERS, firm's 2, profits are **the difference between export revenue minus** the incured full cost of private pollution abatement, i.e., $\frac{1}{2}k(r_2)^2$, and the cost of the resource extraction $\frac{1}{2}\gamma q_2^2$. Firm 2 is binded by the ERS s_2 and the resource use constraint $R_2 < \overline{R_2}$.

The two governments choose non-cooperatively the level of environmental regulation by maximizing their own national welfare functions, respectively, given by:

$$SW_1 = \pi_1 + (1-\delta)t_1(q_1 - r_1) - D(E_1) + (\overline{q_1} - q_1)^2, \tag{4}$$

$$SW_2 = \pi_2 - D(E_2) + (\overline{q_2} - q_2)^2, \tag{5}$$

where, $(1-\delta)t_1(q_1 - r_1)$ is tax revenues lump-sum distributed to households in country 1, and $D(E_i) = \frac{1}{2}\theta(q_i - r_i)^2$ denotes the production-generated overall environmental damage inflicted upon the residents of country i. The parameter $\theta(> 0)$, assumed the same for both countries, reflects the marginal damages from unabated emissions. $(\overline{q_i} - q_i)^2$ captures consumers' enjoyment of the undepleted amount of the natural resource, where $\overline{q_i} = A\overline{R_i}$, is the level of output corresponding to the full endowment of the resource R_i. **Since by our assumptions it is the rest of the world that consumes the output of firms** 1 **and** 2**, and it isnot affected by pollution emissions generated by the two firms,** ROW**'s welfare, which only depends on the amount of imports from countries** 1 **and** 2**, is tacitly omitted from the rest of the analysis.**

A two-stage pre-commitment game ensues. In the $1st$ stage, the two governments set non-cooperatively their environmental policy in order to maximimize national welfare. Government 1 chooses t_1 for a given δ, and government 2 sets s_2.[7] In the $2nd$ stage, taking the governments' policy choices as given, the two firms choose non-cooperatively their output quantities q_1, q_2 and the levels of resource use, R_i, and of private pollution abatement, r_i.[8] The sub-game perfect equilibrium of the game is solved by backwards induction.

[7] **Alternatively, for country 1 a policy of endogenously choosing** δ**, the share of environmental tax revenue refunded to its firm, at a given tax rate** t_1**, produces equivalent results.**

[8] We assume that firms act within a framework of complete information. Cooper and Riezman (1989), and Antoniou et al (2012), among others, introduce uncertainty, assuming that when firms maximize their profits, they are more informed about demand and costs conditions than governments are.

2.2 Output competition, resource use, and pollution abatement

Starting with the $2nd$ stage of the game, firms in the two countries maximize profits given in equations (2) and (3). Differentiating the profit functions with respect to q_1 and q_2, we derive the following first-order conditions ($f.o.c$):

$$\frac{\partial \pi_1}{\partial q_1} = 0 \Leftrightarrow q_1 = \frac{B - q_2 - t_1(1-\delta)}{2+\gamma}, \quad \text{and} \tag{6}$$

$$\frac{\partial \pi_2}{\partial q_2} = 0 \Leftrightarrow q_2 = \frac{B - q_1 + ks_2}{2+k+\gamma}, \tag{7}$$

By the $f.o.c$ (6), $\frac{\partial q_2}{\partial q_1}\ |_{firm1}= -2+\gamma < 0$ is the slope of firm 1's reaction function. Other things equal, a laxer environmental tax (t_1)or a higher share of refunding (δ) shifts firm 1's output reaction function outwards. By the $f.o.c$ (7), $\frac{\partial q_2}{\partial q_1}\ |_{firm2}= -\frac{1}{2+k+\gamma} < 0$ is the slope of firm 2's reaction function. A laxer environmental standard (s_2) increases firm 2's output. Solving simultaneously the first-order conditions, we obtain the profit maximizing levels of output for the two firms as functions of the policy instruments $t_1$and s_2, and the parameters of the model. That is:[9]

$$q_1 = \frac{B(1+k+\gamma) - ks_2 - (2+k+\gamma)(1-\delta)t_1}{k(2+\gamma)+(1+\gamma)(3+\gamma)}, \tag{8}$$

$$q_2 = \frac{B(1+\gamma) + (1-\delta)t_1 + ks_2(2+\gamma)}{k(2+\gamma)+(1+\gamma)(3+\gamma)}. \tag{9}$$

where, $\frac{\partial q_1}{\partial t_1} < 0$, $\frac{\partial q_1}{\partial s_2} < 0$, $\frac{\partial q_2}{\partial s_2} > 0$ and $\frac{\partial q_2}{\partial t_1} > 0$. **The levels of pollution abatement by the two firms are derived from the following $f.o.c$:**

$$\frac{\partial \pi_1}{\partial r_1} = 0 \Leftrightarrow r_1 = \frac{(1-\delta)}{k}t_1, \quad \text{and} \tag{10}$$

[9] In order to ensure that $q_1 > 0$ and $q_2 > 0$, the conditions $t_1 < \frac{B(1+k+\gamma)-ks_2}{(2+k+\gamma)(1-\delta)}$ and $s_2 > \frac{-B(1+\gamma)-t_1(1-\delta)}{2(k+\gamma)}$ must hold. The second-order conditions for the maximazation problems are also satisfied i.e. $\frac{\partial^2\pi_1}{\partial q_1^2} = -(2+\gamma) < 0$ and $\frac{\partial^2\pi_2}{\partial q_2^2} = -(2+k+\gamma) < 0$.

$$r_2 = q_2 - s_2 = \frac{B(1+\gamma) - (1+\gamma)(3+\gamma)s_2 + (1-\delta)t_1}{k(2+\gamma) + (1+\gamma)(3+\gamma)}, \tag{11}$$

where, $\frac{\partial r_i}{\partial t_1} > 0$, $\frac{\partial r_i}{\partial \delta} < 0$, and $\frac{\partial r_2}{\partial s_2} < 0$, $i = 1, 2$.

The following results emerge from conditions (8)-(11). First, a higher t_1 lowers (increases) output, thus exports, of firm 1 (2). It also induces both forms to undertake more private pollution abatement activity. On the one hand, firm 1 is motivated to undertake more r_1, since it is refunded with more emission tax revenue by its own goverenment. On the other hand, firm 2, binded by a fixed ERS s_2, since it is motivated to expand output and exports, it is also induced to undertake more of pollution abatement (r_2) on its own. Second, a higher fraction δ of refunded emission tax revenue to firm 1 raises its output and exports levels, and lowers output and exports of firm 2. However, it induces both firms to lower their own private pollution abatement activity. A laxer ERS by country 2, raises (lowers) output and exports by firm 2 (1). It discourages firm 2 from expandings its own private pollutiona abatement initiative r_2, while it does not affect firm 1's pollution abatement level r_1. Thus, laxer environmental policies in terms of either a lower emission tax by country 1 or/and a looser ERS by country 2, create rent-shifting incentives for both countries via higher production and exports.

Finally, the levels of resource use by the two firms, i.e., $R_i = q_i/A$, are:

$$R_1 = \frac{B(1+k+\gamma) - ks_2 - (2+k+\gamma)(1-\delta)t_1}{A[k(2+\gamma) + (1+\gamma)(3+\gamma)]},$$
$$R_2 = \frac{B(1+\gamma) + (1-\delta)t_1 + ks_2(2+\gamma)}{A[k(2+\gamma) + (1+\gamma)(3+\gamma)]}. \tag{12}$$

In accordance with the results in (8) and (9), a higher emissions tax by country 1 lowers the resource use in that country, but it intensifies the resource use in country 2. A tighter ERS by country 2, lowers resource use in the country but it intensifies it in country 1.

Overall from the above results, we conclude that laxer environmental policies in terms of either a lower emission tax by country 1 (t_1)or/and a looser ERS by country 2 (s_2), entails rent-shifting incentives for both countries via higher production and exports, and lead to "*resource depletion*" locally, but to "*resource savings*" abroad.

2.3 Nash Equilibrium: Welfare and optimal policy levels

Continuing with the $1st$ stage of the game, country 1 chooses non-cooperatively t_1 and country 2 chooses non-cooperatively s_2 so as to maximize national welfare. In its choice of the welfare maximizing policy, each government accounts for the two firms' reaction to these welfare maximizing policy choices. Substituting equations (2) and (3) in equations (4) and (5), the two countries' national welfare functions are as follows:

$$SW_1(q_1, q_2, r_1; t_1, \delta, s_2) = (B - q_1 - q_2)q_1 - \frac{1}{2}k(r_1)^2 - \frac{1}{2}\gamma q_1^2 - \frac{1}{2}\theta(q_1 - r_1)^2 + (\overline{q_1} - q_1)^2, \text{ and} \tag{13}$$

$$SW_2(q_1, q_2, r_2; t_1, \delta, s_2) = (B - q_2 - q_1)q_2 - \frac{1}{2}k(r_2)^2 - \frac{1}{2}\gamma q_2^2 - \frac{1}{2}\theta(q_2 - r_2)^2 + (\overline{q_2} - q_2)^2. \tag{14}$$

Substituting q_1, q_2, r_1 and r_2, from equations (8), (9), (10) and (11), we obtain the two countries' welfare levels as functions of the policy instruments t_1 and s_2, and of the parameters of the model. Setting $\frac{dSW_1}{dt_1} = 0$ and $\frac{dSW_2}{ds_2} = 0$, we obtain the countries' reaction fumctions:

$$t_1 = \frac{\begin{gathered}[k(k(-ks_2(5+2k+2\gamma)+B(1+k+\gamma)(5+2k+2\gamma)- \\ 2\overline{q_1}(2+k+\gamma)(3+2k+(4+k)\gamma+\gamma^2))- \\ (1+k+\gamma)(3+k+\gamma)(-ks_2+B(1+k+\gamma))\theta)]\end{gathered}}{\begin{gathered}[(1-\delta)(k(k^3\gamma+(3+4\gamma+\gamma^2)^2+k^2(2+\gamma(8+3\gamma))+ \\ +k(2+\gamma)(4+\gamma(10+3\gamma)))+(1+k+\gamma)^2(3+k+\gamma)^2\theta)]\end{gathered}} \tag{15}$$

$$s_2 = \frac{\begin{gathered}k(2+\gamma)[B(1+\gamma)(4+k+\gamma)-2\overline{q_2}(3+2k+(4+k)\gamma+\gamma^2)+ \\ t_1(4+k+\gamma)(1-\delta)]\end{gathered}}{\begin{gathered}k[(3+4\gamma+\gamma^2)^2+k(2+\gamma)(-2+\gamma(2+\gamma))]+ \\ [k(2+\gamma)+(1+\gamma)(3+\gamma)]^2\theta\end{gathered}} \tag{16}$$

Solving equations (15) and (16) simultaneously, we obtain the Nash equilibrium emission tax for country 1, and the Nash equilibrium ERS for country 2 as functions of the parameters $B, \delta, k, \gamma, \theta, \overline{q_1}$ and $\overline{q_2}$:[10]

$$t_1^N = f_1(\delta, B, k, \gamma, \theta, \overline{q_1}, \overline{q_2}) \tag{17}$$

$$s_2^N = f_2(B, k, \gamma, \theta, \overline{q_1}, \overline{q_2}) \tag{18}$$

Substituting t_1^N and s_2^N into (8), (9), (10) and (11), we obtain the Nash equilibrium levels of outputs i.e. exports, of private pollution abatement, and of resource use as functions of $B, k, \gamma, \theta, \overline{q_1}\ \overline{q_2}$ and A. [11]

$$\begin{aligned} q_1^N &= g_1(B, k, \gamma, \theta, \overline{q_1}, \overline{q_2}), \qquad q_2^N = g_2(B, k, \gamma, \theta, \overline{q_1}, \overline{q_2}), \\ r_1^N &= h_1(B, k, \gamma, \theta, \overline{q_1}, \overline{q_2}), \qquad r_2^N = h_2(B, k, \gamma, \theta, \overline{q_1}, \overline{q_2}), \\ R_1^N = \frac{q_1^N}{A} &= f_1(B, k, \gamma, \theta, \overline{q_1}, \overline{q_2}, A), \qquad R_2^N = \frac{q_2^N}{A} = f_2(B, k, \gamma, \theta, \overline{q_1}, \overline{q_2}, A). \end{aligned} \tag{19}$$

[10] The reaction functions $\partial SW_1/\partial t_1 = 0$, $\partial SW_1/\partial \delta = 0$ and $\partial SW_2/\partial s_2 = 0$, give a system of three equations which are overdetermnined. Thus, it suffices to solve two of them in order to obtain the optimal values i.e **either t_1 and s_2 for a given δ, or δ and s_2 for a given t_1.** For a given value of δ, there is a unique optimal value of t_1^N and vice-versa. The optimal value of the standard imposed in country 2 s_2^N is always independent of δ.

[11] Sustituting (17) into (8), (9), (10) and (11) δ is eliminated from all the optimal values. Thus the equilibrium results hold for any value of δ. **See also footnote (9). ????**

At Nash equilibrium, the emission levels are:

$$E_1^N = q_1^N - r_1^N = z_1(B, k, \gamma, \theta, \overline{q_1}, \overline{q_2}), \tag{20}$$
$$E_2^N = q_2^N - r_2^N = z_2(B, k, \gamma, \theta, \overline{q_1}, \overline{q_2}).$$

After substituting the equilibrium values q_1^N, q_2^N, r_1^N, and r_2^N into equations (13) and (14), the Nash equilibrium welfare levels for countries 1 and 2 are given respectively as follows:

$$\begin{aligned} SW_1^N &= w_1(B, k, \gamma, \theta, \overline{q_1}, \overline{q_2}), \\ SW_2^N &= w_2(B, k, \gamma, \theta, \overline{q_1}, \overline{q_2}). \end{aligned} \tag{21}$$

Due to the complexity of the analytical equilibrium solutions , we proceed to obtain numerical results. In particular we obtain numerically the optimal values of t_1^N,δ and s_2^N and for a wide set of values for the parameters of the model. The Nash equilibrium tax t_1^N and the Nash equilibrium share of recycled emission tax revenue δ are chosen simultaneously by the government in 1. Hence, t_1^N is always a function of δ. We also obtain the equlibrium values of q_1^N, q_2^N, r_1^N, r_2^N, R_1^N, R_2^N, E_2^N, E_2^N, SW_1^N and SW_2^N. These results are discussed in the following section.

2.4 Main results and numerical simulations {Would like to discuss further...}

This section presents and discusses, the relevant to *Regime I* **results of the numerical simulations as reported in Colums** (A) **in** *Tables* 1 **and** 2 **of** *Appendix A***, and by the diagrammatic illustrations in** *Appendix B***.** *Table* 1 (2) **reports results for relatively low (high) values of efficiency of the public sector in abating pollution. Colums** (A) **report the Nash equilibirum values of the variables relevant to** *Regime I* **for specific values of the parameteres of the model, given at the bottom of each table. Since the latter activity is non-pertinent to** *Regime* 1**, Colums** (A) **in** *Tables* 1 **and** 2 **are identical. Based on these findings, we state the following Result.**

Result 1 *At Nash equilibrium, exports, social welfare are always higher under the environmental standard, whereas private pollution abatement is higher and the levels of net emissions and resource use are lower under a revenue-recycling tax, independently of the parameter values of the model.*

Discussion: According to the results of column A in $Tables$ 1 **or(?)** 2, the ERS works as an export promoting mechanism, i.e., an effective NTM mechanism as country 2's production, and consequently, exports to the ROW **increase**. **In the downswing, however, the ERS results to a more extensive depletion of the resource used, relative to revenue recycling (??). A higher emissions tax accompanied by revenue recycling (?)** fosters the undertaking of pollution abatement activity by firms, independently of the parameter values of the model. This result is in line with Coria and Mohlin (2013) who conclude that emission tax refunding can accelerate the diffusion of abatement technology if firms cannot strategically influence the size of the refund.[12,13] Thus, the undertaking of pollution abatement, induced by revenue reclycling to the polluting firm, reduces emissions more than the ERS does. Therefore, the ERS works successfully as a NTM in the sense of enhancing trade flows, whereas revenue recycling can be considered as an effective environmental policy measure in terms of both reducing emissions and protecting the depletion and conserving the endowment of the natural resource. **Welfare-wise the ERS is superior to revenue recycling (??).**

In order to assess the robustness of the above results, we perform a number of sensitivity experiments of the numerical findings to the chosen parameter values. These numerical experiments are graphically illustrated

[12]Note that in our model, the share of the refund is set by the government and not by the firm, and that the government is pre-committed to this choice. After setting the share of the refund, the governement chooses the optimal emission tax so as to maximize the country's social welfare. Therefore, there is a unique optimal tax, for every given value of δ.

[13]For the recycling policy to be effective in terms of firms' pollution abatement activity and emission reduction, it must be accompanied by a high tax. Sterner and Hoglund (2006) demonstrate that significant abatement effects can be achieved if only a sufficiently high tax is charged. A real-world example along these lines is the Swedish charge on nitrogen oxides and its successful **implementation** underpins this result.

in *Appendix B*.[14] Relevant to *Regime I*, *Figures* 1 and 2 verify the aforementioned results. All other things equal, *Figure* 1 refers to varying the parameter (k), and *Figure* 2 depicts the results when varying the cost of extraction of the resource (γ).

Figure 1 shows that when varying, e.g., increasing k, firms' pollution abatement becomes more expensive, their abatement activity falls, and thus they pollute more. Production, resource use, and export levels decline for both firms. However, the "positive" effect from the lower net emissions and households' enjoyment of "consumong" the undepleted resource endowment outweigh the "negative" effect from the decrease in production and exports, thus national welfare increases in both countries. Relative to country 1 in country 2 the Nash equilibrium levels of exports, of resource use, and of national welfare are higher, while in country 1 private pollution abatement is higher and net emissions are lower.

Figure 2 shows that when varying, e.g., increasing γ, the cost of the resource extraction, production, exports and the use of the depletable resource decrease in both countries. Pollution abatement activity falls in both countries and net emission decline. However, the effect of an increase in γ on national welfare is ambiguous. Based on the simulations, we observe that while for lower values of γ national welfare levels fall, for higher values of the parameter national welfare levels increase.

3 Regime II: Public Pollution Abatement vs Revenue Recycling

3.1 The Model

Now we let the two countries control production-generatd pollution emissions by imposing an emissions tax, t_1 and t_2, respectively. However, the **emerging** emission tax revenue is dispersed differently **by each gov-**

[14] Although a wide range of such experiments has been performed, here, for brevity and space consideration we only report those related to varying the firms; cost of abatement (k), the cost of resource extraction (γ), and the governments' efficiency in abating pollution emissions (c). All other numerical experiments are readily available upon request.

ernment. In country 1 the government retains this revenue in order to purchase, at a constant world price, an internationally traded good, in quantity g, which then it uses for pollution abatement, e.g., see, Hadjiyiannis et al. (2009). Asuming that the government maintains an active, balanced, budget constraint, we have:[15]

$$g = t_1(q_1 - r_1). \tag{22}$$

In country 2 the government follows a scheme of revenue-recycling of the emission tax revenue, at rates δ and $(1-\delta)$, respectively, to its pollution emitting firm 2 and to domestic households. All other analytical features being the same as in the previous regime, the profit functions of the two firms are given as follows:

$$\begin{aligned} \pi_1(q_1, q_2; r_1, t_1) = (B - q_1 - q_2)q_1 - t_1(q_1 - r_1) - \\ \frac{1}{2}k(r_1)^2 - \frac{1}{2}\gamma q_1^2, \quad s.t. \quad R_1 < \overline{R_1} \end{aligned} \tag{23}$$

$$\begin{aligned} \pi_2(q_1, q_2, r_2; t_2) = (B - q_2 - q_1)q_2 - t_2(q_2 - r_2) - \\ [\frac{1}{2}k(r_2)^2 - \delta t_2(q_2 - r_2)] - \frac{1}{2}\gamma q_2^2, \quad s.t. \quad R_2 < \overline{R_2}. \end{aligned} \tag{24}$$

Governments in the two countries choose **non-cooperatively the optimal rates of emission taxes,** i.e., t_1 and t_2 by maximizing their national welfare levels:

$$SW_1 = \pi_1 - D(E_1) + (\overline{q_1} - q_1)^2, \qquad \text{and} \tag{25}$$

$$SW_2 = \pi_2 + (1-\delta)t_2(q_2 - r_2) - D(E_2) + (\overline{q_2} - q_2)^2, \tag{26}$$

where environmental damage due to emissions, $D(E_i)$ $i = 1, 2$, in the two

[15] This specification implies a constant unit cost of pubic pollution abatement which is normalized to unity. Alternatively one may consider non-linear abatement technologies which may differ between the two regions, e.g., $f(g)$ and $f^*(g^*)$. In such a case $f_g > 0$ and $f^*_{g^*} > 0$ denote the effectiveness of public pollution abatement activity in each region. In our model, we assume that $f_g = f^*_{g^*} = 1$.

countries is of the form:

$$D(E_1) = \frac{1}{2}\theta[(q_1 - r_1) - cg]^2, \qquad \text{and} \qquad D(E_2) = \frac{1}{2}\theta(q_2 - r_2)^2. \quad (27)$$

The parameter $0 < c \leq 1$ captures country 1's government efficiency per unit of public pollution abatement.

We consider a pre-commitment game played in two stages. In the $1st$ stage, both governments choose non-cooperatively emission taxes t_1, and t_2 to maximize national welfare. In the $2nd$ stage, taking the governments' policy choices as given, firms 1 and 2 decide on output quantities q_1 and q_2, and levels of resource use R_i and of pollution abatement r_i. The sub-game perfect equilibrium of the game is solved by backward induction.

3.2 Output competition, resource use, and private pollution abatement

In the $2nd$ stage the two firms chose outputs to maximize profits given the non-cooperative choice of $t_1$and t_2 by their governmentsn. Maximizing the profit functions (23) and (24) with respect to q_1 and q_2, i.e., setting $\frac{\partial \pi_i}{\partial q_i} = 0$, we obtain the reaction functions of firms 1 and 2, respectively as follows:[16]

$$B - q_2 - t_1 = q_1(2 + \gamma) \qquad \text{and} \qquad B - q_1 - t_2(1 - \delta) = q_2(2 + \gamma). \quad (28)$$

Solving the above system, yields the Cournot-Nash equilibrium values of outputs as functions of t_1, t_2:

$$q_1 = \frac{B(1+\gamma) + t_2(1-\delta) - t_1(1+\gamma)}{3 + 4\gamma + \gamma^2}, \qquad q_2 = \frac{B(1+\gamma) + t_1 - t_2(1-\delta)(2+\gamma)}{3 + 4\gamma + \gamma^2}. \quad (29)$$

[16]Note that both the second-order conditions ($\frac{\partial^2 \pi_i}{\partial q_i^2} = -2 < 0$) and the stability condition ($\Delta = 3 > 0$) hold throughout the section. Furthermore, in order to ensure that $q_i > 0$ the conditions $t_1 < \frac{1}{2}[B + t_2(1-\delta)]$ and $t_2 < \frac{B + t_1}{2(1-\delta)}$ must also be satisfied. **We assume this to be the case, else the two firms have no incentives to produce.**

Simple comparative statics show the following effects of changes in environmental taxes on outputs and exports of the two firms:

$$\frac{\partial q_i}{\partial t_i} < 0,\ i = 1,2 \qquad \text{and} \qquad \frac{\partial q_i}{\partial t_j} > 0,\ i = 1,2, \quad j = 2,1, \tag{30}$$

$$\frac{\partial q_1}{\partial \delta} < 0, \qquad \text{and} \qquad \frac{\partial q_2}{\partial \delta} > 0. \tag{31}$$

The interpretation of the above comparative statics results is as follows. **Equations (30) indicate that a higher emission tax by one country reduces output and exports of its own firm, and increases output and exports of the rival firm. This result attests** to a strategic substitutability between $t_1$and t_2. Equations (31) indicate that when country 2 refunds a larger share of the emission tax revenue to its polluting firm, production and exports increase in country 2, whilst they decline in country 1.

Firms' levels of pollutionn abatement are given by the first-order-conditions $\frac{\partial \pi_i}{\partial r_i} = 0$. Thus, we obtain:[17,18]

$$r_1 = \frac{t_1}{k} \qquad \text{and} \qquad r_2 = \frac{t_2(1-\delta)}{k}, \tag{32}$$

where, $\frac{\partial r_1}{\partial t_1} = \frac{1}{k} > 0$ and $\frac{\partial r_2}{\partial t_2} = \frac{1-\delta}{k} > 0$. Pollution abatement by the both firms rises the higher is the emission tax rate, and the lower is the cost of undertaking this activity (k). Moreover, firm 2 undertakes more pollution abatement with a higher share of emission tax revenue (δ) refunded to it by the government.

[17] The second-order conditions $\partial^2 \pi_i / \partial r_i^2 = -k < 0, i = 1,2$ since $k > 0$, hold throughout the paper, so the conditions for interior solutions are satisfied.

[18] **Applying into equations (32) the conditions which ensure positive outputs (exports) for the two firms, i.e., see footnote 16 (?), yields the additional conditions** $r_1 < \frac{1}{(2+\gamma)k}[B(1+\gamma) + t_2(1-\delta)]$ and $r_2 < \frac{B(1+\gamma)+t_1}{k(2+\gamma)}$.

Finally, the optimal levels of resource use are given by:

$$R_1 = \frac{q_1}{A} = \frac{B(1+\gamma) + t_2(1-\delta) - t_1(1+\gamma)}{A[3+4\gamma+\gamma^2]},$$
$$R_2 = \frac{q_2}{A} = \frac{B(1+\gamma) + t_1 - t_2(1-\delta)(2+\gamma)}{A[3+4\gamma+\gamma^2]}. \tag{33}$$

In this case, optimal resource use in each country declines with the own emission tax and it increases with a higher emission tax by the other country.

Overall from the above results, we conclude that laxer environmental policies in the sense of a lower emission tax by either country, entails rent-shifting incentives for both countries via higher production and exports, and lead to "*resource depletion*" locally, but to "*resource savings*" abroad, irrespectively of the manner governments dispose of the emission tax revenue, i.e., financing the provision of public pollution abatement or refunding it locally, partly to the emitting firm and partly to local households.

3.3 Nash equilibrium: Welfare and optimal emission taxes

In the $1st$ stage, each government chooses non-cooperatively the emission tax that maximizes its national welfare, accounting for firms' reaction to its environmental policy.

Country 1's welfare function is defined as the sum of the firm's profits minus the environmental damages plus consumers' enjoyment of the undepleted amount of the natural resource. That is:

$$\begin{aligned} SW_1(q_1, q_2, r_1; t_1, t_2) = \pi_1 - D(E_1) + (\overline{q_1} - q_1)^2 = \\ (B - q_1 - q_2)q_1 - t_1(q_1 - r_1) - \frac{1}{2}k(r_1)^2 - \\ \frac{1}{2}\gamma q_1^2 - \frac{1}{2}\theta[(q_1 - r_1) - cg]^2 + (\overline{q_1} - q_1)^2, \end{aligned} \tag{34}$$

with the government satisfying its budget constraint in equation (22).

Country 2's welfare function is defined as the sum of the firm's profits plus lump-sum distributed to households emission tax revenue, plus households' enjoyment of the undepleted amount of the natural resource, minus the incurred environmental damage:

$$\begin{gathered}SW_2(q_1, q_2, r_2; t_1, t_2) = \pi_2 + (1-\delta)t_2(q_2 - r_2) + (\overline{q_2} - q_2)^2 - D(E_2) = \\ (B - q_2 - q_1)q_2 - t_2(q_2 - r_2) - [\frac{1}{2}k(r_2)^2 - \delta t_2(q_2 - r_2)] - \frac{1}{2}\gamma q_2^2 + \\ (1-\delta)t_2(q_2 - r_2) + (\overline{q_2} - q_2)^2 - \frac{1}{2}\theta(q_2 - r_2)^2.\end{gathered} \tag{35}$$

Substituting q_1, q_2, r_1 and r_2, from the equations (29) and (32), we obtain the levels of total welfare in countries 1 and 2 as functions of the environmental taxes t_1 and t_2. However, the associated first-order conditions ($\partial SW_1/\partial t_1 = 0$ and $\partial SW_2/\partial t_2 = 0$) cannot be solved analytically. We therefore proceed to obtain numerical results, in particular to obtain numerically the optimal values of t_1 and t_2 for a wide set of values for the parameters of the model. These results are discussed in the following section.

3.4 Main results and numerical simulations {Would like to discuss further...}

We presents and discuss, the relevant to *Regime II* **results of the numerical simulations as reported in Colums** (B) **in** *Tables* 1 **and** 2 **of** *Appendix A*, **and by the diagrammatic illustrations in** *Appendix B*. **As previously noted,** *Tables* 1 and 2, **respectively, report the results for relatively low (high) values of efficiency of the public sector in abating pollution, i.e., low (high) values of the parameter** c. **Colums** (B) **report the Nash equilibirum values of the variables relevant to** *Regime II* **for specific values of the parameteres of the model, given at the bottom of each table. Based on the results of the numerical simulations we state the following Results**:

Result 2 ***Regardless of whether emission tax revenue finances public pollution abatement or is refunded to the own emitting firm and households, then, independentlyof the parameters of the model,***

production, exports, and resource use fall with a higher own emission tax, and increase with a higher emission tax by the other country.

Result 3 ***When emission tax revenue finances public pollution abatement as opposed to beign refunded to the own emitting firm and households, then:***

(i) Production, exports and resource use are higher, independently of the values of the parameters of the model.

(ii) Emissions are lower and welfare is higher when the government pursuing public pollution abatement is efficient in undertaking this activity, i.e., the values of c ***are high.***

(iii) Emissions are higher and welfare is lower when the government pursuing public pollution abatement is relatively inefficient in this activity, i.e., the values of c ***arer low, and firms are relatively inefficient in abating pollution, i.e., the values of*** k ***are also low.***

Result 4 ***Let emission tax revenue finance public pollution abatement as opposed to beign refunded to the local emitting firm and households. Then, for high values of*** c***, exports and resource use are higher, but welfare is lower. For low values of*** c***, exports and resource use are higher, and welfare is lower, for low values of*** γ ***of the firms' cost of extracting the resource.***

Result 5 For high values of k, countries 1 and 2 face a trade-off between choosing a welfare-enhancing policy or an exports-promoting one, when the country pursuing public pollution abatement is relatively inefficient in this activity.

Discussion: ....

....

The discussion above indicates that it is not the choice of an emission tax, per-ce, as the policy instrument to control pollution

that characgterizes the results, but to a large extent, the manner of disposing of the tax revenue generated from it.

According to the results, on the one hand, public pollution abatement is always an export promoting mechanism, i.e., an effective NTM mechanism, even if the government is relatively inefficient in abating pollution. On the other hand, revenue recycling always fosters the undertaking of pollution abatement activity by firms, independently of the parameter values of the model. This result can be considered as partly in line with Coria and Mohlin (2013) who conclude that emission tax refunding can speed up the diffusion of abatement technology if firms cannot strategically influence the size of the refund.[19] However, when the government is relatively efficient in abating pollution i.e. for large values of c, then, firm 1, is discouraged from this undertaking since the government can "step-in" and reduce emissions successfully. When the government is relatively inefficient in doing so, i.e. for low values of c, then revenue recycling serves this purpose, i.e., undertaking pollution abatement by firms reduces the polluting emissions more than public pollution abatement does.

When government in 1, is relatively inefficient in abating pollution and the private cost of abatement k is low, then, countries 1 and 2 face a trade-off between choosing a welfare-enhancing policy or an exports-promoting one. In other words, public pollution abatement promotes the country's exports to the ROW whereas emission tax revenue recycling enhances social welfare. As the government in 1 becomes more efficient in abating pollution, i.e. as c increases, public pollution abatement is considered also high-yield in terms of promoting exports, enhancing welfare and reducing polluting emissions Therefore, public pollution abatement can be used as both an effective environmental policy and as a NTM. In conjunction to other studies (see for instance Rehdanz, K. and Maddison, D. (2005), Welsch, H. (2006), Ng, Y. K. (2008), Ong, Q. and Quah, E. (2014)) which claim that higher welfare gains occur with increased public expenditures on environmental

[19] Note that in our model, optimal taxes are endogenously determined by the governments in the first stage of the game and not by the firms. They also set the share of the refund and are pre-committed to all these choices.

improvements, our results provide evidence that public pollution abatement works always successfully as a NTM i.e. an exports promoting mechanism, but works as an effective environmental policy instrument only under certain conditions, i.e. for large values of c. Finally, public pollution abatement results in higher levels of resource use which on the one hand fosters its exports to the ROW but on the other uses more the depletable resource that is being used in the production process.

Furthermore, in order for the recycling policy to be effective in terms of firms' pollution abatement activity and emission reduction, it must be accompanied by a high tax. This finding is in line with Sterner and Hoglund (2006) who demonstrate that significant abatement effects could be achieved if only a sufficiently high tax is charged. A real-world example along these lines is the Swedish charge on nitrogen oxides and its successful effects underpin this result.

In order to assess the robustness of the above results, we perform a number of sensitivity experiments of the numerical findings to the chosen parameter values. These numerical experiments are graphically illustrated in *Appendix B*. Relevant to *Regime II*, *Figures* $3-8$ verify the aforementioned results. All other things equal, *Figure* 3 refers to varying the parameter (k), and *Figure* 3 depicts the results when varying the cost of extraction of the resource (γ).

The main numerical findings are summarized in Tables 1 and 2. Table 1 shows the comparison of the different schemes for a low value of c whereas table 2 shows the comparison for large values of c. Column (A) reports the results for the case of no policy intervention, while the remaing columns present results where the governments intervene to mitigate the effects of emissions on social welfare. Column (C) in both tables presents the results for the case where the first country engages in public pollution abatement while the second one uses revenue recycling. We also compare these results with two benchmark cases. First, when both governments engage in public pollution abatement (col. E), and second, when both governments engage in tax-revenue recycling (col. F). According to the results, when both countries "recycle", they achieve a higher level of welfare compared to when they both engage in public pollution abatement independently of whether the governments are relatively efficient in this activity or not.When both countries engage in public pollution abatement, then the sum of their exports to ROW is larger compared to when they both recycle, independently of the governments' efficiency in abating pollution. In addition when both countries engage in public pollution abatement, they manage to attain a significantly lower level of polluting emissions, independently of the governments' efficiency in abating pollution, meaning that the governments "step-in" and manage to reduce emissions more than revenue-recycling does.

In order to assess the robustness of the results, we perform a number of experiments which allow us to explore the sensitivity of the numerical findings to the parameter values we have chosen. Figures 3, 4, 5, 6 and 7 verify the aforementioned results. In particular, Figure 3 presents the results when the only parameter that changes is the first government's efficiency to abate pollution (c). Figure 4 refers to the case in which the only parameter that varies is the cost of firms' pollution abatement activity (k) designed for a low value of c, whereas figure 5 refers to the case in which the only parameter that varies is the cost of firms' pollution abatement activity (k) designed for a high value of c. In case where the only parameter that changes is the cost of extraction (γ), we design two figures; figure 6 depicts those results for a low value of c, whereas figure 7 presents graphically the results for a high value of c.

The numerical results of varying parameter c, i.e., country 1's government efficiency in pursuing pollution abatement are reported in Figure 3. Clearly, when the government in country 1 becomes more efficient in providing public pollution abatement, its own firm's production and exports increase, but net emissions decline, thus, social welfare rises. However, production, exports, and welfare of country 2 decrease as government's 1, efficiency in abating pollution (c), increases. Based on the simulations, we can observe that the level of the tax imposed in country 2 is constant as it is independent from the varying parameter c. However, independently of c, the tax in 2 is always higher than in 1. For every share of the tax revenues which is refunded to the emitting firm, firm 2 has always more abatement expenditures than firm 1. Nevertheless, as the government in country 1 becomes more and more efficient in abating pollution, it successfully manages to reduce total polluting emissions. In other words, the government in 1 "steps-in" and reduces emissions successfully and thus the firm in 1 is discouraged from undertaking private abatement. That's why emissions in country 2 are significantly higher than emissions in country 1 as c increases. In other words, the government in 1, substitutes the pollution abatement activity of the firm and achieves to reduce polluting emissions successfully.

In figure 4, which is designed for low values of c, there is a clear crossover of the welfare results indicating that the effect of the environmental policy on social welfare, is ambiguous and depends on the value of the parameter k of our model. Country 1 is better off in terms of production and exports, making a more extensive use of the depletable resource, while country 2 gains in terms of social welfare. For high values of k, however, public pollution abatement leads to both higher exports and welfare. Nevertheless, public pollution abatement leads to lower net emissions for low values of k, but this is not the case for high values of k. Figure 5 presents graphically the numerical results of our basic model in the case where we vary the pollution abatement cost parameter, k for a high value of c. Country 1 that engages in public pollution abatement is still better off in terms of exports to the ROW but also has a higher level of welfare and resource use.

As this parameter becomes larger, since government 2 engages in recycling of emission tax revenues, it imposes a higher emissions tax and refunds a larger fraction of the revenues to the emitting firm, thus, providing it with an incentive to undertake pollution abatement. Consequently pollution abatement activities undertaken by firm 2 reduce the country's net total emissions. Public pollution abatement increases country 1's production and exports, but it leads to higher aggregate net emissions. As it is expected, when the cost of firms' pollution abatement (k) increases, their pollution abatement activity falls, production and market share for firm 1 increase whereas production and export levels for firm 2 decrease. Nevertheless, total exports to the rest of the world increase. Moreover, aggregate net emissions also increase.

Figures 6 and 7 report the results when the varying parameter is (γ) which captures the cost of the extraction of the resource for a low and a high value of c respectively. It is evident that when the cost of extraction increases, the Nash equilibrium taxes, firms' level of pollution abatement activity, production and total exports, aggregate net emissions, and levels of welfare levels, increase. Again, country 1 is better off in terms of production and exports, making a more extensive use of the depletable resource, while country 2 gains in terms of social welfare. The country that engages in revenue recycling is also better off in terms of higher level pollution abatement activity by its own firm. However, public pollution abatement leads always to lower net emissions.independently of whether the government in 1 is relatively efficient in this activity. When the cost of extraction increases, social welfare levels are higher for the country that uses the revenue-recycling scheme. On the contrary, for low values of γ, the reverse is true. Nevertheless, independently of the extraction cost, public pollution abatement results always in higher levels of resource use fostering production and exports to the ROW.

4 Regime III: Public Pollution Abatement vs Environmental Related Standard

In this setting we continue to assume that, in order to control production-generated pollution, country 1 **imposes an emissions tax whose revenue finances public pollution abatement. Country** 2**, however, adopts an** ERS. Again, we consider a two-stage precommitment game. In the $1st$ stage, the government in country 1 chooses non-cooperatively the emission tax (t_1) that maximizes its total welfare, while government 2 sets non-cooperatively the ERS (s_2). In the $2nd$ stage, the two firms, taking the governments' policy choices as given, choose their profit maximizing output quantities q_1, q_2, and their levels of resource use and of pollution abatement. The sub-game perfect equilibrium of the game is solved by backward induction.

4.1 Output competition, resource use, and private pollution abatement

Firm 's 1 **profit maximization problem is given by eq.(23), described analytically in Section** 3. **Differentiating (23) with respect to** q_1 **gives the reaction function of firm** 1 **for** q_1 **as given by eq.(28-1st part). Similarly, firm 's** 2 **profit maximization problem is given by eq. (3) as presented in Section** 2 **which yields to the reaction function of firm** 2 **for** q_2 **as given by eq. (7).**[20]

Solving simultaneously, we obtain equilibrium outputs for both firms as functions of the environmental tax (t_1) **adopted in country** 1 **and the emissions standard** (s_2) **imposed in country** 2**:**[21]

$$q_1 = \frac{B(1+k+\gamma) - ks_2 - (2+k+\gamma)t_1}{k(2+\gamma)+(1+\gamma)(3+\gamma)}, \qquad q_2 = \frac{B(1+\gamma)+(2+\gamma)ks_2+t_1}{k(2+\gamma)+(1+\gamma)(3+\gamma)}, \tag{36}$$

where $\frac{\partial q_1}{\partial t_1} < 0$**,** $\frac{\partial q_1}{\partial s_2} < 0$**,** $\frac{\partial q_2}{\partial s_2} > 0$**, and** $\frac{\partial q_2}{\partial t_1} > 0$**. By equations (23) and (3), the profit mazimizing levels of firms' pollution abatement activities are**:

$$r_1 = \frac{t_1}{k} \quad \text{and} \quad r_2 = \frac{B(1+\gamma)-(1+\gamma)(3+\gamma)s_2+t_1}{k(2+\gamma)+(1+\gamma)(3+\gamma)}, \tag{37}$$

where $\frac{\partial r_i}{\partial t_1} > 0, \quad i = 1, 2$ **and** $\frac{\partial r_2}{\partial s_2} < 0$**. Finally, firms choose the optimal levels of resource use** $R_i = q_i/A$**, thus:**

$$R_1 = \frac{B(1+k+\gamma) - ks_2 - (2+k+\gamma)t_1}{A[k(2+\gamma)+(1+\gamma)(3+\gamma)]},$$
$$R_2 = \frac{B(1+\gamma)+(2+\gamma)ks_2+t_1}{A[k(2+\gamma)+(1+\gamma)(3+\gamma)]}. \tag{38}$$

Equations (36)-(38) indicate that a country's laxer environmen-

[20] For the analytical solution of q_2 see footnote 8.

[21] In order to ensure that $q_1 > 0$ and $q_2 > 0$, the conditions $t_1 < \frac{B(1+k+\gamma)-ks_2}{2+k+\gamma}$ and $s_2 > \frac{-B(1+\gamma)-t_1}{2(k+\gamma)}$ must hold. The second-order conditions for the maximazation problems are also satisfied i.e. $\frac{\partial^2 \pi_1}{\partial q_1^2} = -(2+\gamma) < 0$ and $\frac{\partial^2 \pi_2}{\partial q_2^2} = -(2+k+\gamma) < 0$.

tal policy, either in terms of a lower emissios tax (t_1) or of a higher ERS (s_2) result to increase own firm's production, exports and resource use, and to a reduction of the corresponding magnitudes for the rival firm. A lower (t_1) reduces pollution abatement undertaken by both firms, while a laxer ERS in country 2 encourages the own fir to expand its pollution abatement activity.

4.2 Nash Equilibrium: Emission tax and ERS

In the $1st$ stage of this pre-commitment game, each government chooses non-coopertively its welfare maximizing environmental policy instrument, accounting for firms' reaction to their policy choice. Thus, the government in country 1 chooses its Nash equilibrium emission tax, whereas government 2 chooses its Nash equilibrium level of the ERS (s_2). Welfare levels in the two countries 'are respectively defined as the sum of own firm's profits minus the environmental damage to domestic households plus consumers' enjoyment of the undepleted amount of the natural resource i.e. $SW_i = \pi_i - D(E_i) + (\overline{q_i} - q_i)^2$, $i = 1, 2$. Country's 1 welfare function is given by equation (34) with the government satisfying its budget constraint in equation (22). Similarly, country's 2 welfare function is given by equation (14).

Substituting q_1, q_2, r_1 and r_2, from the equations (**??**), (**??**) and (37), we obtain the Nash equilibrium levels of welfare for both countries as functions of the environmental tax t_1 and the environmental standard s_2. However, the associated first-order conditions ($\partial SW_1/\partial t_1$ and $\partial SW_2/\partial s_2$) cannot be solved analytically simultaneously. Therefore, once again, we resort to numerical simulation results, particularly for the Nash equilibrium values of t_1 and s_2, given plausible values for the parameters of the model. These numerical results are discussed in the following section.

4.3 Main results and numerical simulations {discuss further ....}

4.3.1 Main results

Recalling that in order to contol pollution, country 1 sets non-cooperatively an emission tax and pursues public pollution abatement, and country 2 chooses non-cooperatively an ERS, the main results of the numerical analysis are the following:

Result 6 *Environmental standards relative to public pollution abatement result to higher welfare independently of the parameter values of the model.*

Result 7 *Public pollution abatement, independently of the values of c, relative to ERS, leads to higher exports and resource use for low values of γ. For higher values of γ, ERS lead to higher exports, resource use and welfare relative to public abatement.*

Result 8 *Public pollution abatement always leads to lower polluting emissions relatively to an ERS, even if the government is relatively inefficient in this activity.*

According to the results, on the one hand, public pollution abatement, by and large, works as an export promoting mechanism and thus an effective NTM, even if the government is relatively inefficient in abating pollution. Moreover, independently of whether the government in country 1, is efficient or not in abating pollution, public pollution abatement is also an effective environmental policy instrument, since it always leads to lower levels of pollution emissions. On the other hand, an ERS, by and large, encourages firms' pollution abatement, independently of the parameter values of the model.

Consequently, in the present framework, comparing public pollution abatement to an ERS, we conclude that the former always is an effective environmental policy and, by and large, an effective instrument in terms of promoting exports as a NTM mechanism, but it leads to higher use of the depletable resource.

4.3.2 Numerical simulations

The main numerical findings are summarized in Tables 1 and 2. Table 1 shows the comparison of the different schemes for a low value of c whereas Table 2 shows the comparison for large values of c. Column (D) in both tables presents the results for the case where there is public pollution abatement in country 1, whereas in country 2 an ERS is used to control for production generated pollution. We can also compare these results with two benchmark cases. In the first case, both governments engage in public pollution abatement (col. E), while in the second one, both governments impose ERSs (col. G). This comparison indicates that when both countries engage in public pollution abatement, then the sum of their exports to ROWis larger compared to when they both impose ERSs, independently of the governments' efficiency in abating pollution. The levels of net emissions are significantly lower under the public pollution abatement scheme, even if the governments are relatively inefficient in abating pollution. Meanwhile, ERSs lead always to higher levels of welfare than public abatement.and create stronger incentives to invest in private pollution abatement.

In order to assess the robustness of the results we have discussed in the previous subsection, we perform a number of experiments which allow us to explore the sensitivity of our numerical findings to the parameter values we have chosen. Figure 8 depicts graphically the numerical results when varying the parameter c i.e. the efficiency of the government in country 1 in abating pollution. Figures 9 and 10 show the numerical results of the basic model in the case where we vary the cost of abatement parameter (k) for a low and a high value of c respectively. Lastly, figures 11 and 12 present the numerical results of the basic model when the cost of extraction γ varies for a low and a high value of c respectively.

When the varying parameter is c, the country that engages in standards is always better off in terms of welfare whereas public pollution abatement leads to higher production and thus exports. It also makes a more extensive use of the depletable resource than in the environmental standards' case. As the government in country 1 becomes more and more efficient in abating pollution, it successfully manages to reduce total polluting emissions. In other words, the government in 1 "steps-in" and reduces emissions successfully and thus the firm in 1 is discouraged from undertaking private abatement. That's why emissions in country 2 are significantly higher than emissions in country 1 as c increases. In other words, the government in 1, substitutes the pollution abatement activity of the firm and achieves to reduce polluting emissions successfully.

Figures 9 and 10 present the results for a low and a high value of c respectively. In both cases, we can observe that governments face a trade-off between choosing a welfare-enhancing policy i.e. standards vs. an exports promoting one i.e. public pollution abatement. Resource use is more extensive in the case of public pollution abatement whereas private abatement levels of the firm is higher under an environmental standard. However, net emissions are lower under public pollution abatement, even if the government is relatively inefficient in this activity.

Figures 11 and 12 are designed for low and high values of c when the varying parameter is the cost of extraction (γ). In both figures, there is a clear crossover of the exports results indicating that the effectiveness of the environmental policy in terms of higher exports depends on the values of the varying parameter. The same holds for the resource use result as well. For a relatively low cost of extraction, a government must decide whether to impose an ERS that enchances welfare but leads to lower exports, or to engage in public pollution abatement that promotes exports but at the cost of lower welfare. In every case, the governement that engages in public pollution abatement manages to reduce polluting emissions more than an environmental standard does, meaning that the goverment is more effective than private firms in doing so. The same results are true independently of whether the goverment is relatively efficient in abating pollution or not.

5 Concluding Remarks

Although there is a vast literature on trade and the environment that has already examined the effects of free trade on pollution, the opposite question has not been adequately addresed. The present study aims to answer whether "clean environment can promote international trade". To this end, we compare different environmental policies and we evaluate how do they affect trade flows, resource use, welfare levels, and pollution emissions. Our approach provides interesting new insights about the impacts that Non-tariff instruments (NTMs) can have on international trade and resource use, via exports competition among countries in world markets.

Our results indicate that in most cases, public pollution abatement works as an export-promoting but resource depleting mechanism, and is largerly an efficient environmental policy instrument whereas under certain conditions it can be welfare-enchancing. Revenue recycling, on the other hand, largerly works as an export-contracting but resource preserving mechanism. It always encourages private pollution abatement, but its effect on emissions reduction is ambiguous. Environmental standards relative to public abatement largerly works as an an export-contracting but resource preserving mechanism, but relative to revenue recycling works in the opposite way.

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Appendix B - Tables

Table 1: **Main Results — Comparing Different Models**

Variable	No Regulation (A)	Recycl. vs ERS (B)	Abatem. vs Recycl. (C)	Abatem. vs ERS (D)	Both Abatem. (E)	Both Recycl. (F)	Both ERS (G)
t_1	-	8.413	2.522	2.685	2.615	8.163	
t_2	-		8.163		2.615	8.163	
s_2	-	3.236		4.429			3.082
r_1	0	2.944	1.261	1.342	1.307	2.857	2.945
r_2	0	2.857	2.857	1.946	1.307	2.857	2.945
q_1	7.5	6.006	7.268	6.979	6.846	6.071	6.027
q_2	7.5	6.014	5.672	6.376	6.846	6.071	6.027
q_1+q_2	15	12.099	12.941	13.355	13.692	12.142	12.054
$q_1/(q_1+q_2)$	0.5	0.496	0.561	0.522	0.5	0.5	0.5
$R1$	7.5	6.006	7.268	6.979	6.846	6.071	6.027
R_2	7.5	6.014	5.672	6.376	6.846	6.071	6.027
SW_1	62.5	92.072	83.866	80.592	78.472	92.092	92.356
SW_2	62.5	92.374	87.280	105.658	78.472	92.092	92.356
E_1	7.5	3.061	2.976	2.609	2.642	3.214	3.082
E_2	7.5	3.236	2.815	4.429	2.642	3.214	3.082

Notes for Table 1: In all numerical experiments we assume that the share of refunding $\delta = 0.3$, the demand parameter $B = 30$, the cost of private abatement $k = 2$, the inefficiency of the government engaging in abetment takes the value $c = 0.2$, the cost of extraction $\gamma = 1$, the marginal product of extraction A and the damage parameter in the social welfare function θ take the value 1. Column (A) reports the results when no government intervenes to correct the pollution externality. Column (B) reports our results country 1 follows a revenue recycling policy while country 2 imposes an ERS (case 1). Column (C) show the results when the first government engages in public pollution abatement, while country 2 employs revenue recycling (case 2). Column (D) shows the results when the first government uses public pollution abatement whilst the second one uses an ERS (case 3). Column (E) shows results when both governments engage in public pollution abatement, column (F) reports results when when both governments use tax revenue recycling as their instrument while column (G) shows results when both governments impose ERSs.

Table 2: **Main Results — Comparing Different Models (ii)**

Variable	No Regulation (A)	Recycl. vs ERS (B)	Abatem. vs Recycl. (C)	Abatem. vs ERS (D)	Both Abatem. (E)	Both Recycl. (F)	Both ERS (G)
t_1	-	8.413	1.059	1.069	1.062	8.163	
t_2	-		8.163		1.062	8.163	
s_2	-	3.236		4.171		-	3.082
r_1	0	2.944	0.529	0.534	0.531	2.857	2.945
r_2	0	2.857	2.857	1.978	0.531	2.857	2.945
q_1	7.5	6.006	7.817	7.593	7.234	6.071	6.027
q_2	7.5	6.014	5.489	6.149	7.234	6.071	6.027
q_1+q_2	15	12.099	13.306	13.743	14.469	12.142	12.054
$q_1/(q_1+q_2)$	0.5	0.496	0.587	0.552	0.5	0.5	0.5
$R1$	7.5	6.006	7.817	7.593	7.234	6.071	6.027
R_2	7.5	6.014	5.489	6.149	7.234	6.071	6.027
SW_1	62.5	92.072	96.087	92.051	85.929	92.092	92.356
SW_2	62.5	92.374	85.288	102.185	85.929	92.092	92.356
E_1	7.5	3.061	1.111	1.019	1.007	3.214	3.082
E_2	7.5	3.236	2.632	4.171	1.007	3.214	3.082

Notes for Table 2: In all numerical experiments we assume that the share of refunding $\delta = 0.3$, the demand parameter $B = 30$, the cost of private abatement $k = 2$, the inefficiency of the government engaging in abetment takes the value $c = 0.8$, the cost of extraction $\gamma = 1$, the marginal product of extraction A and the damage parameter in the social welfare function θ take the value 1. Column (A) reports the results when no government intervenes to correct the pollution externality. Column (B) reports our results country 1 follows a revenue recycling policy while country 2 imposes an ERS (case 1). Column (C) show the results when the first government engages in public pollution abatement, while country 2 employs revenue recycling (case 2). Column (D) shows the results when the first government uses public pollution abatement whilst the second one uses an ERS (case 3). Column (E) shows results when both governments engage in public pollution abatement, column (F) reports results when both governments use tax revenue recycling as their instrument while column (G) shows results when both governments impose ERSs.