Pollution effects of free trade areas : a general equilibrium analysis

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Abstract

A 2 factors, 2 goods, 3 countries general equilibrium model is developed so as to assess the particular effects of a Free Trade Area (FTA) on pollution emissions. In this model, countries differ through factor endowment, national income and consumer aversion for pollution. The main contribution of this model is to endogenize three variables : pollution tax; pollution technological abatement, which is chosen by the firm to maximize profit ; and world prices, which influence pollution, through changes in terms of trade. Numerical simulations show that a FTA increases world pollution emissions, as compared to full trade liberalization, even if it may reduce pollution emissions inside the FTA. A second result is that in case of tariff retaliation from the third country, world pollution is further increased. The intuition underlying these results is that protection incites the country with the cleanest technology to leave some production to countries with dirtier techniques. Another explanation, though minor, may be found in the improvement of the partners' terms of trade, which lead countries to increase the production of the polluting good. Finally, a FTA can lead to a decrease in world pollution only if its implementation is followed by an increase in consumer pollution aversion in the partner countries.

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1 Introduction

In the past decade, the relationship between trade and environment has become a major topic for economic research, both theoretically an empirically. In a very complete survey, Huang and Labys (2000) classify the issues linking environment and trade in broad categories, such as the effects of environmental policies on comparative advantage, terms of trade, industrial location, trade effects on environmental quality and welfare, the interaction between trade policies and environmental policies, etc...

Concerning pollution effects of trade liberalization, recent theoretical literature provides mixed results. Indeed, some authors find a negative environmental impact of free trade. For example, Chichilnisky (1994) demonstrates in the case of natural resources that if private property right are not established, trade will increase resource extraction and will thus harm the environment. This work can be extended to non natural resources by introducing pollution permits. Similarly, Daly and Goodland (1994) argue that free trade has detrimental environmental effects because it allows polluting industries to move to countries with weak environmental policies. This is the pollution haven hypothesis, which suggests that low income developing countries will be made dirtier with trade. Similarly, Copeland and Taylor (1994) demonstrate that free trade harms global environment if specialization are driven only by differences in pollution policies. They focus on income effects due to trade liberalization. In the same way, Perroni and Wigle (1994), which distinguish local from global pollution, also find a negative -although limited- relationship.

However, more recent theoretical work does not provide a systematic negative relationship between trade and the environment : for example, assuming that global environmental quality is a public good whose supply responds endogenously to trade-induced changes in relative prices and income, Copeland and Taylor (1995) show that free trade leaves world pollution unaffected if trade equalizes factor prices. In this model, pollution will increase in the country which specializes in the dirty good and decrease in the other country, leaving global pollution levels unchanged. However, if trade does not equalize factor prices, world pollution increases. These authors also show that the pollution impact of free trade depends on the initial world income distribution. If countries have different income levels, then free trade may increase world pollution. This is due to the fact that pollution permit prices are lower in human-capital-scarce countries. This gives rise to pollution havens. However, trade has no adverse effects on the environment if income levels are more similar, because trade equalizes pollution permit prices. A key feature of this model is that pollution is transboundary. Terms of trade effects are also analyzed, but attempts to manipulate them with pollution policy leaves world pollution unaffected.

In a different analytical framework, Copeland and Taylor (1999) evolve a dynamic model in which analyses the role of cross-sectoral externalities on pollution and welfare. They assume that the manufacturing sector generates pollution which lowers the productivity of the agricultural sector. In this model, which includes environmental regeneration, trade is a crucial factor which may geographically separate the clean and the dirty sector. But the effects of free trade on pollution are also mixed and depends on specialization : the country which increases the production of the dirty good experiences some environmental damage, whereas the other country, by specializing in the clean good, improves its environment.

In the same way, Lehr and Maxwell (2000) provide mixed results. These authors focus on the reaction of environmental standards when trade is not driven by differences in environmental regulation, but rather by comparative advantages. In this model, environmental standards are made endogenous. This implies that countries will optimize pollution abatement levels. Moreover, they take into account transboundary pollution, by assuming that a portion of each country's pollution stock negatively affects the utility of the citizens in the other country. The main finding is that international trade increases domestic and global pollution only if nations exhibit increasing marginal disutilities of pollution.

Finally, some authors show that the environmental effects of trade may become positive. For example, Alpay (2000) generates a Ricardian game theory model with a public environmental good and a private good. They first start from the standard assumption that the benefit of pollution abatement might be international, whereas the costs will be borne strictly by the consumers and firms of the country which implements this environmental policy. This might give rise to free riding with very little pollution abatement. However, when the abatement is carried out by diverting resources from the export sector, international trade improves the terms of trade of the country engaged in abatement. When terms of trade effects exceed environmental costs, this provides an incentive to pollution abatement. Thus, under reasonable assumptions, free riding is no longer a non cooperative Nash equilibrium, and thus the global environment might improve, since free trade can provide incentives to transmit and enlarge global environmental protection.

A similar positive conclusion is also found by Antweiler et al. (2001). The main contribution of this paper is to include both factor endowment and income differences as determinants of trade. Thus, unlike the previous approaches, it analyses whether changes in the production of a dirty good induced by trade is motivated by factor endowment or pollution haven motives. This paper also includes some other crucial variables such as pollution abatement and pollution taxes. By explicitly decomposing trade environmental effects into scale, composition and technique effects[1], the authors demonstrate that free trade can improve the global environment. A key determinant of trade pollution effects

[1] This decomposition has been widely used, notably since Grossman and Krueger (1993).

for the country which exports the dirty good is the elasticity of marginal damage with respect to income. If this elasticity is above unity, then free trade lowers pollution emissions.

One particular aspect of trade liberalization is the implementation of preferential trading areas (PTAs). Surprisingly, very little theoretical attention is paid to this particular case. From a theoretical point of view, and to our knowledge, no study specifically deals with environmental impact of PTAs. Haaparanta and Riiponen (2002) focus on the welfare impact of a customs union in the case of transboundary pollution. However, the main question in this study is not the pollution impact of customs unions, but rather what is the appropriate environmental policies among the customs union members, in order to ensure Pareto improvement.

This paper investigates the relationship between preferential trading arrangements and pollution. A 2 factors, 2 goods, 3 countries general equilibrium model is developed to assess the particular effects of a Free Trade Area (FTA) on pollution. We assume that the capital-intensive good is polluting whereas the labour-intensive good is clean. In this model, countries differ through factor endowment, national income and consumer aversion for pollution.

The first contribution of this model is to endogenize three variables : pollution tax, pollution technological abatement, which is chosen by the firms to maximize profit ; and world prices, which will influence trade and pollution, through changes in terms of trade. Secondly, the model allows to compare pollution effects of a FTA to other tariff policies (full trade liberalization, non discriminating protection). Pollution effects due to the third country's tariff retaliation are also taken into account, both inside and outside the FTA. Finally, indirect effects of the FTA, such as changes in consumer aversion for pollution, are also investigated.

The general equilibrium model is presented in the second section. Simulations and results are left to the third section, while the appendix displays the complete system of equations.

2 the model

We assume an open economy that produces two final goods, A and B, with two primary factors, labour L and capital K. Industry A is capital-intensive and generate a pollution stock Z_A, defined as :

$$Z_A = e_A(\theta_A)Q_A \tag{1}$$

where Q_A corresponds to industry A's production, and e_A is the pollution intensity (emissions per unit of A) in this industry. The latter depends on the abatement technology (θ_A), which corresponds to the share in total factors allocated to produce a cleaner technology.

Pollution stock can be decomposed into the technique effect (e_A), the composition effect (φ_A) and the scale effect (S_A) :

$$Z_A = e_A(\theta_A)\varphi_A S \tag{2}$$

with :

$$\varphi_A = \frac{P^0_{WA} Q_A}{P^0_{WA} Q_A + P^0_{WB} Q_B} \tag{3}$$

and :

$$S_A = P^0_{WA} Q_A + P^0_{WB} Q_B \tag{4}$$

P^0_{WA} and P^0_{WB} account for base-year world prices (with $P^0_{WA} = 1$). These three effects are now commonly found in the literature, since Grossman and Krueger (1993).

On the firm side, pollution generates two additional costs in industry A, related to pollution tax (t_A), and to pollution abatement (θ_A). Thus, the total cost function is :

$$TC_A = wl_A Q_A + rk_A Q_A + Q_A P_A \theta_A + t_A Z_A \tag{5}$$

with :
$l_A = \frac{L_A}{Q_A}$ and $k_A = \frac{K_A}{Q_A}$and w and r corresponding to wages and the interest rate.

The profit function is thus :

$$\Pi_A = P_A Q_A - wl_A Q_A - rk_A Q_A - Q_A P_A \theta_A - t_A e_A(\theta_A) Q_A \tag{6}$$

First order conditions for the choice of Q_A and $\theta_A$are :

$$P_A = \frac{wl_A + rk_A + t_A e(\theta_A)}{1 - \theta_A} \tag{7}$$

$$e^{'}_A(\theta_A) = \frac{P_A}{t_A} \tag{8}$$

Thus, following Antweiler et al. (2001), we derive from equation (8) that

$$\theta_A = \theta_A(\frac{P_A}{t_A}) \tag{9}$$

with $\theta_A^{'} < 0$, and

$$e_A = e_A(\frac{P_A}{t_A}) \tag{10}$$

with $e_A^{'} > 0$

Concerning the clean industry (B), we used standard profit and cost functions which leads to the standard zero profit equation :

$$P_B = wl_B + rk_B \tag{11}$$

Factor demands are then derived from the minimum cost function :

$$k_A = \left[\left(\frac{\alpha_A}{1-\alpha_A}\right)\frac{w}{r}\right]^{1-\alpha_A} \tag{12}$$

$$k_B = \left[\left(\frac{\alpha_B}{1-\alpha_B}\right)\frac{w}{r}\right]^{1-\alpha_B} \tag{13}$$

$$l_A = \left[\left(\frac{1-\alpha_A}{\alpha_A}\right)\frac{r}{w}\right]^{\alpha_A} \tag{14}$$

$$l_B = \left[\left(\frac{1-\alpha_B}{\alpha_B}\right)\frac{r}{w}\right]^{\alpha_B} \tag{15}$$

where α_A and α_B correspond to the standard Cobb-Douglas production function parameter.

On the demand side, consumers are supposed to be adverse to pollution. Pollution is thus represented as a public "bad", which reduces consumer utility. We then maximizea Cobb-Douglass utility function (equation 16) subject to an income constraint in which the pollution revenue is distributed to the consumer (equation 17).

$$U = C_A^{\beta} C_B^{\psi} Z_A^{-m} \tag{16}$$

$$Y + t_A Z_A = P_A C_A + P_B C_B \tag{17}$$

with C_A, C_B and Y denoting respectively the consumption of good A and B and total revenue ; t_A corresponds to the pollution tax, with $0 < \beta, \psi, m < 1$.

First order conditions lead to :

$$C_A = \frac{\beta}{(\beta + \psi - m)} \frac{Y}{P_A} \tag{18}$$

$$C_B = \frac{(\psi)}{(\beta + \psi - m)} \frac{Y}{P_B} \tag{19}$$

$$Z_A = \frac{m}{(\beta + \psi - m)} \frac{Y}{t_A} \tag{20}$$

We thus observe that the optimal pollution is negatively (positively) related with pollution tax (total revenue) .

To sum up, the equations used in the model are those corresponding to pollution (equations 1,20, 9,10)[2], household expenditure (equations 18 and 19), zero profit conditions (equations 7 and 11), factor demands (equations 12-15), as well as standard equations related to factor market and product market clearing equations (see the appendix for a complete description of the model).

The last set of equations corresponds to composite import nest. Following the Armington specification, imports are differentiated by place of origin, and importers choose between different market sources according to market prices (equation 21).

$$Pm_{is}^{r} = Pw_i * chge_s * (1 + tm_{is}) * (1 + tm_{is}^{r}) \tag{21}$$

$$\exp_{is}^{r} = \mu_{is}^{r} \left(\frac{Pm_{is}}{Pms_{is}^{r}} \right)^{\sigma_i} imp_{is} \tag{22}$$

with :

$$Pm_{is} = \sum_{r} MS_{is}^{r} * Pms_{is}^{r} \tag{23}$$

and :

$$MS_{is}^{r} = \frac{Pms_{is}^{r} * \exp_{is}^{r}}{\sum_{r} Pms_{is}^{r} * \exp_{is}^{r}} \tag{24}$$

where :

[2] The functional form used for equations 9 and 10 are :

$$\theta_a = \left(\frac{P_A}{t_A} \right)^{\gamma}$$

and

$$e_a = \left(\frac{P_A}{t_A} \right)^{\eta}$$

with $\gamma < 0$ and $\eta > 0$

Pms_{is}^{r} : market price by source of commodity i imported from source r to destination s (i=A,B)

Pw_i : product i's world price

$chge_s$: country s' exchange rate

tm_{is} : tariff applied to product i by country s' imports whatever the import source (in case of multilateral tariffs)

tm_{is}^{r}: tariff applied to product i by country s' imports from country r (in case of bilateral tariffs)

$\exp_{is}^{r}$: good i's exports from r to s

imp_{is} : country s' imports of good i.

Pm_{is} : market price of product i in country s

MS_{is}^{r} : market share of source k in aggregate imports of product i in country s.

σ_i : CES of imports by origin

μ_{is}^{r} : country r's initial market share in country s ' imports.

Thus, a decrease in the bilateral tariff applied to source r lowers the market price differentiated by source (Pms_{is}^{r}). This gives rise to an import substitution effect, with an increase in imports from source r (equation 22). It also implies a fall in the composite market price of good i (Pm_{is}).

3 simulations and results

Simulations have been performed with the above model applied to 3 countries which differ in three aspect. The first is factor endowment. Country 1 is capital-abundant, country 3 is labour-abundant, and country 2 is the intermediate country, i.e. labour-abundant vis-a-vis country 1 and capital abundant vis-a-vis country 3.

$$\frac{K_{A1}}{L_{A1}} > \frac{K_{A2}}{L_{A2}} > \frac{K_{A3}}{L_{A3}} \tag{25}$$

The second difference is abatement technology : country 1 (North) has a cleaner technology that country 2 (intermediate), which in turn has a cleaner technology than country 3 (South) :

$$\theta_{1A} > \theta_{2A} > \theta_{3A} \tag{26}$$

This means that country 1 has the lowest pollution intensity for good one, and the highest pollution tax for a given price P_A (according to equations 9 and 10).

Finally, it is assumed that consumers are more pollution-averse in country 1 than in country 2, and they are more consumer adverse in country 2 than in country 3 :

$$m_{1A} > m_{2A} > m_{3A} \tag{27}$$

Everything being equal, this difference in pollution aversion implies an higher pollution tax in country A than in country B and C.

The other parameters are assumed to be identical in all countries.

3.1 Direct effects of a free trade area and comparison with other tariff policies

3.1.1 Full trade liberalization (simulation 1)

We start from full trade liberalization (simulation 1, figure 1)[3]. In this situation, country 1 exports good A and imports good B, whereas country 3 exports good B and imports good A. Country 2 may export good A (to country 3) or good B (to country 1), and import good A (from 1) or good B (from 2).

In this situation, the highest pollution emissions are found in country 1, which is specialized in the dirty good. In this country, pollution is essentially due to the scale and composition effect, whereas the technique effect is pollution-reducing. On the opposite, country 2 has the lowest pollution concentration, because it is specialized in the clean good (low composition and scale effects) and pollution intensity is under control, since the technology is not too dirt. Country 3 is in an intermediate position, since the low composition and scale effects are compensated by a high pollution intensity due to highly polluting production technology.

3.1.2 FTA with country 3's tariff retaliation (simulation 2a and 2b)

We now suppose that country 1 and 2 implement a free trade area and impose a tariff on good B's imports from country 3. We will not discuss here directly the trade and income effects of the FTA (notable trade creation and trade

[3]Given that the full model includes 122 variables, of which more than 30 exogenous, simulations are not presented for all of them. Full simulations are available upon request.

diversion)[4]. We will rather focus on pollution effects, since the latter are also linked to trade effects.

Pollution changes depend on the behavior of country 3. The most probable assumption is that this country also charges a tariff on its imports (retaliation). Consequently, as expected by the standard trade theory, country 1 reduces the production and exports of good A (dirty) and increases the production of good B (clean). Conversely, country 3 reduces the production and the exports of good B[5], and increases the production of the dirty good. This gives rise to a fall in the composition effect in country 1 and a rise in this effect in country 3.

The outcome for country 2 depends on its external tariff as compared to country 1. If the former imposes a higher tariff than the latter, then country 3 may continue to export to country 1, and country 2 reduces the production of good B while increasing good A (simulation 2a)[6]. In this case, the composition effect is detrimental to country 2. However, if this country charges a smaller tariff than its partner, then country 3's initial exports to country 1 are completely replaced by those of country 2, which thus increases (reduces) good B (A)'s production(simulation 2b)[7]. Thus, the composition effect is decreasing.

Concerning scale effects, country 1 enjoys a reduction of the scale effect, because the fall in the production of good A overcompensates the rise in the production of good B. Country 3 faces the same situation, given the sharp reduction of the overall economic activity . The issue for country 2 is a decrease (increase) in the scale effect if he produces less (more) good A.

Finally, the technique effect decreases for country 1, which is incited to improve its technology through increased taxes as a proportion of production prices[8]. The opposite argument prevails for country 3. Again, the issue for country 2 depends on its external tariff as compared to its partner. The technique effect decreases if he produces less good A.

Overall, country 1 reduces its pollution emissions through a decrease in the three effects ; on the opposite, pollution increases in country 3. Finally, country 2 reduces (increases) its pollution emissions if he produces less (more) good A.

In each case however, as compared to full trade liberalization, the pollution emissions slightly decrease inside the FTA (whatever the external tariff of the

[4] We also notice that the FTA improves its terms of trade, as the relative world price of good B falls.

[5] Country 1's import demand of good B is now completely supplied by the partner country (trade diversion).

[6] For this simulation, we assume that $tm^3_{B1} = 0.05\%$, $tm^3_{B2} = 0.1\%$, and $tm^1_{A3} = tm^2_{A3} = 0,1\%$.

[7] We assume here that $tm^3_{B1} = 0.1\%$, $tm^3_{B2} = 0.05\%$, and $tm^1_{A3} = tm^2_{A3} = 0,1\%$.

[8] In fact, as Y is reduced in country 1, the absolute tax decreases. However, as a proportion of good A's price, the tax is increasing.

two partners), while the world pollution sharply increases. The very simple intuition underlying this result is that the FTA modifies initial comparative advantages. Thus, by reducing the production of the dirty good inside the FTA, the two partner countries can reduce pollution. However, by increasing the production of the dirty good, country 3 strongly deteriorates its environment. Finally, the world pollution is worsened since the country with the cleanest technology leaves some production to the country with the dirtiest technology. This results points out the crucial role of the technique effect. Indeed, simulations with constant technical effects indicate that the implementation of the FTA would not increase as much world pollution.

It must also be noticed that in simulation 2, the FTA improves its terms of trade, since good B's relative world price decreases. Everything being equal, this is another factor (though minor) which may explains the sharp rise in world pollution, since this encourages countries to produce more good A.

3.1.3 FTA without retaliation (simulation 3)

The above results hold provided that country 3 also increases its external tariff. However, if we consider that the FTA only increases its external protection, whereas country 3 does not charge any tariff (or leaves constant its external tariffs), then pollution is increased inside the FTA, but decreases outside (simulation 3)[9]. This is due to the fact that country 3 is no longer incited to increase the production of the dirty good, leaving more production to the FTA, including country 2. However, world pollution is also worsened, though to a lesser extent[10]. Here again, the technique effect plays a crucial role. As a matter of fact, assuming constant the technique effect, then world pollution would slightly decrease. This would be due to the reduction of production scale due to the formation of the FTA.

The robustness of the results are checked with dynamic simulations, which calculate pollution emissions for different levels of tariffs. As displayed in figure 2, when both the FTA and country 3 increase their external protection, pollution emissions inside the FTA decrease whereas pollution in country 3 and world pollution are strongly worsened. However, when country 3 does not impose any tariff, pollution both inside and outside the FTA slightly increases with the level of the FTA members' external protection.

3.1.4 Non discriminating protection

[9] For this simulation, we assume that $tm^3_{B1} = 0.1\%$, $tm^3_{B2} = 0.05\%$, and $tm^1_{A3} = tm^2_{A3} = 0$.

[10] In this case, the FTA does not improves its terms of trade as previously. This also explains why world pollution increases less than in simulation 2.

A final simulation is carried out in order to compare the specific effects of the FTA and non discriminatory protectionism. We thus assume that all countries charge a tariff. Thus, taking simulation 2b as reference, we assume in simulation 4 that countries 1 imposes a tariff on B's imports and vice-versa[11]. As indicated in figure 1 and illustrated in figures 3 and 4, non discriminatory protection leads country 1 to further reduce the production and exports of the dirty good and increase the production of good B, since country 2 cannot supplies any more this good free of tariff to country 1. Country 2 thus increases (reduces) the production of good A (B). This increase in overall protection also leads country C to increase the production of good 1. The overall effect is a further reduction if pollution inside the FTA, but a further increase in world pollution as compared to the FTA.

3.2 Indirect effects

3.2.1 Changes in consumer aversion for pollution

One possible effect of the implementation of a FTA is the progressive rise of pollution aversion of the consumers inside the FTA. In particular, consumers in the intermediate country (country 2) are likely to progressively behave like Northern consumers (country 1). It is also possible that the latter also become more and more adverse to pollution, as pollution stocks increases in the world.

Simulations have first been made by increasing consumer aversion only for one country in the FTA. Everything being equal, one would intuitively expect a decrease in pollution intensity in this country, because the rise in m should induce an increase in the pollution tax (for a given level of revenue). However, this increasing pollution aversion leads to a decrease in total revenue. Consequently, the pollution tax will decrease in absolute value and in proportion of prices. Thus, pollution intensity in worsened. Furthermore, as firms reduce their abatement technology, they save some factors to increase the production of the dirty good (composition effect). Consequently, in this particular country, pollution increases (see figure 5). However, the impact on world pollution depends on comparative advantage. Indeed, if we assume that pollution aversion increase only in country 1, this country will reinforce its initial comparative advantage and export more to the other countries. This in turn implies a reduction in the production of good A in these countries, which enjoy a reduction in their local pollution; Overall, world pollution is sharply reduced. However, if pollution aversion increase in country 3, the latter increase the production of good A (for which he has a comparative disadvantage). This leads to a sharp increase in the

[11] We suppose here that $tm^3_{B1} = tm^2_{B1} 0.05\%$, $tm^3_{B2} = tm^1_{A2} = 0.1\%$, and $tm^1_{A3} = tm^2_{A3} = 0,1\%$.

pollution in this country (because of the dirty technology), and world pollution increase despite the reduction of the pollution in the other countries.

If we now assume that pollution aversion increases proportionately in country 1 and 2, then pollutions emissions are almost unchanged in the FTA, while decreasing in country 3. Thus, world pollution is decreasing.

3.2.2 Changes in producer aversion for pollution

Producer aversion for pollution may be measured by γ and η, which respectively denote the elasticity of pollution abatement and the elasticity of pollution emissions to pollution taxes (as a proportion of producer prices). Thus, if we assume a fall in these elasticities, then for a given pollution tax, the producer saves more factors to pollution abatement and reduces pollution emission.

Taking simulation 3 as reference, simulations made for country 1 clearly indicate that an increase in the producer aversion for pollution reduces pollution in this country. Overall, this leads to a decrease in both FTA and world pollution emissions. However, if we assume that γ and η fall in more than one country, results are much less straightforward.

To conclude, we have shown that the implementation of a FTA increases world pollution emissions, as compared to full trade liberalization, even if it may reduce pollution emissions inside the FTA. A second result is that in case of tariff retaliation from the third country, world pollution is further increased. The intuition underlying these results is that protection incites the country with the cleanest technology to leave some production to countries with dirtier techniques. Another explanation, though minor, may be found in the improvement of the partners' terms of trade, which lead countries to increase the production of the polluting good. Finally, a FTA can lead to a decrease in world pollution only if its implementation is followed by an increase in consumer or producer pollution aversion in the partner countries.

Annex : the complete general equilibrium model[12]
Pollution and Cobb-Douglas demand functions :

$$Z_1 = e_{A1} Q_{A1} \tag{A.1}$$
$$Z_2 = e_{A2} Q_2 \tag{A.2}$$
$$Z_3 = e_{A3} Q_{A3} \tag{A.3}$$
$$\theta_{A1} = \left(\frac{PQ_{A1}}{t_{A1}}\right)^{\gamma_{A1}} \tag{A.4}$$
$$\theta_{A2} = \left(\frac{PQ_{A2}}{t_{A2}}\right)^{\gamma_{A2}} \tag{A.5}$$
$$\theta_{A3} = \left(\frac{PQ_{A3}}{t_{A3}}\right)^{\gamma_{A3}} \tag{A.6}$$
$$e_{A1} = \left(\frac{PQ_{A1}}{t_{A1}}\right)^{\eta_{A1}} \tag{A.7}$$
$$e_{A2} = \left(\frac{PQ_{A2}}{t_{A2}}\right)^{\eta_{A_2}} \tag{A.8}$$
$$e_{A3} = \left(\frac{PQ_{A3}}{t_{A3}}\right)^{\eta_{A_3}} \tag{A.9}$$
$$t_{A1} = \frac{m_1}{\beta_1 + \psi_1 - m_1} \frac{Y_1}{Z_1} \tag{A.10}$$
$$t_{A2} = \frac{m_2}{\beta_2 + \psi_2 - m_2} \frac{Y_2}{Z_2} \tag{A.11}$$
$$t_{A3} = \frac{m_3}{\beta_3 + \psi_3 - m_3} \frac{Y_3}{Z_3} \tag{A.12}$$

$$C_{A1} = \frac{\beta_1}{(\beta_1 + \psi_1 - m_1)} \frac{Y_1}{PC_{A1}} \tag{A.13}$$
$$C_{B1} = \frac{\psi_1}{(\beta_1 + \psi_1 - m_1)} \frac{Y_1}{PC_{A1}} \tag{A.14}$$
$$C_{A2} = \frac{\beta_2}{(\beta_2 + \psi_2 - m_2)} \frac{Y_2}{PC_{A2}} \tag{A.15}$$
$$C_{B2} = \frac{\psi_2}{(\beta_2 + \psi_2 - m_2)} \frac{Y_2}{PC_{A2}} \tag{A.16}$$
$$C_{A3} = \frac{\beta_3}{(\beta_3 + \psi_3 - m_3)} \frac{Y_3}{PC_{A3}} \tag{A.17}$$
$$C_{B3} = \frac{\psi_3}{(\beta_3 + \psi_3 - m_3)} \frac{Y_{B3}}{PC_{A3}} \tag{A.18}$$

[12] The complete model includes 99 equations with 99 endogeneous variables. The definitions of the variables are given in the text, with subscripts A and B denoting the goods, and subscripts 1, 2, 3 denoting the countries.

Prices :

$$PQ_{A1} = \frac{w_1 l_{A1} + r_1 k_{A1} + t_{A1} e_{A1}(\theta_{A1})}{1-\theta_{A1}} \tag{A.25}$$

$$PQ_{A2} = \frac{w_2 l_{A2} + r_2 k_{A2} + t_{A2} e_{A2}(\theta_{A2})}{1-\theta_{A2}} \tag{A.20}$$

$$PQ_{A3} = \frac{w_3 l_{A3} + r_3 k_{A3} + t_{A3} e_{A3}(\theta_{A3})}{1-\theta_{A3}} \tag{A.21}$$

$$PQ_{B1} = w_1 l_{B1} + r_1 k_{B1} \tag{A.22}$$

$$PQ_{B2} = w_2 l_{B2} + r_1 k_{B2} \tag{A.23}$$

$$PQ_{B3} = w_3 l_{B3} + r_3 k_{B3} \tag{A.24}$$

$$PC_{A1} = PW_A * chge_1 \tag{A.25}$$

$$PC_{A2} = (PW_A * chge_2)\left(1 + tm^1_{A2}\right) \tag{A.26}$$

$$PC_{A3} = \frac{PC^1_{A3} * \left(PC^1_{A3} * \exp^1_{A3}\right) + PC^2_{A3} * \left(PC^2_{A3} * \exp^2_{A3}\right)}{(PC^1_{A3} * \exp^1_{A3}) + (PC^2_{A3} * \exp^2_{A3})} \tag{A.27}$$

$$PC^1_{A3} = (PW_A * chge_3)(1 + tm_{A3})\left(1 + tm^1_{A3}\right) \tag{A.28}$$

$$PC^2_{A3} = (PW_A * chge_3)(1 + tm_{A3})\left(1 + tm^2_{A3}\right) \tag{A.29}$$

$$PC_{B1} = \frac{PC^2_{B1} * \left(PC^2_{B1} * \exp^2_{B1}\right) + PC^3_{B1} * \left(PC^3_{B1} * \exp^3_{B1}\right)}{(PC^2_{B1} * \exp^2_{B1}) + (PC^3_{B1} * \exp^3_{B1})} \tag{A.30}$$

$$PC^2_{B1} = (PW_B * chge_1)(1 + tm_{B1})\left(1 + tm^2_{B1}\right) \tag{A.31}$$

$$PC^3_{B1} = (PW_B * chge_1)(1 + tm_{B1})\left(1 + tm^3_{B1}\right) \tag{A.32}$$

$$PC_{B2} = (PW_B * chge_2)\left(1 + tm^3_{B2}\right) \tag{A.33}$$

$$PC_{B3} = (PW_B * chge_3)\left(1 + tm^2_{B3}\right) \tag{A.34}$$

$$PQ_{A1} = PW_A * chge_1 \tag{A.35}$$

$$PQ_{A2} = (PW_A * chge_2)\left(1 + tm^1_{A2}\right) \tag{A.36}$$

$$PQ_{A3} = \frac{PC^1_{A3} * \left(PC^1_{A3} * \exp^1_{A3}\right) + PC^2_{A3} * \left(PC^2_{A3} * \exp^2_{A3}\right)}{(PC^1_{A3} * \exp^1_{A3}) + (PC^2_{A3} * \exp^2_{A3})} \tag{A.37}$$

$$PQ_{B1} = \frac{PC^2_{B1} * \left(PC^2_{B1} * \exp^2_{B1}\right) + PC^3_{B1} * \left(PC^3_{B1} * \exp^3_{B1}\right)}{(PC^2_{B1} * \exp^2_{B1}) + (PC^3_{B1} * \exp^3_{B1})} \tag{A.38}$$

$$PQ_{B2} = (PW_B * chge_2)\left(1 + tm^3_{B2}\right) \tag{A.39}$$

$$PQ_{B3} = (PW_B * chge_3)(1 + tm_{B3}) \tag{A.40}$$

Factor demand

$$k_{A1} = \left[\left(\frac{\alpha_{A1}}{1-\alpha_{A1}}\right)\frac{w_1}{r_1}\right]^{1-\alpha_{A1}} \tag{A.41}$$
$$k_{B1} = \left[\left(\frac{\alpha_{B1}}{1-\alpha_{B1}}\right)\frac{w_1}{r_1}\right]^{1-\alpha_{B1}} \tag{A.42}$$
$$l_{A1} = \left[\left(\frac{1-\alpha_{A1}}{\alpha_{A1}}\right)\frac{r_1}{w_1}\right]^{\alpha_{A1}} \tag{A.43}$$
$$l_{B1} = \left[\left(\frac{1-\alpha_{B1}}{\alpha_{B1}}\right)\frac{r_1}{w_1}\right]^{\alpha_{B1}} \tag{A.44}$$
$$K_{A1} = k_{A1} * Q_{A1} \tag{A.45}$$
$$K_{B1} = k_{B1} * Q_{B1} \tag{A.46}$$
$$L_{A1} = l_{A1} * Q_{A1} \tag{A.47}$$
$$L_{B1} = l_{B1} * Q_{B1} \tag{A.48}$$
$$k_{A2} = \left[\left(\frac{\alpha_{A2}}{1-\alpha_{A2}}\right)\frac{w_2}{r_2}\right]^{1-\alpha_{A2}} \tag{A.49}$$
$$k_{B2} = \left[\left(\frac{\alpha_{B2}}{1-\alpha_{B2}}\right)\frac{w_2}{r_2}\right]^{1-\alpha_{B2}} \tag{A.50}$$
$$l_{A2} = \left[\left(\frac{1-\alpha_{A2}}{\alpha_{A2}}\right)\frac{r_2}{w_2}\right]^{\alpha_{A2}} \tag{A.51}$$
$$l_{B2} = \left[\left(\frac{1-\alpha_{B2}}{\alpha_{B2}}\right)\frac{r_2}{w_2}\right]^{\alpha_{B2}} \tag{A.52}$$
$$K_{A2} = k_{A2} * Q_{A2} \tag{A.53}$$
$$K_{B2} = k_{B2} * Q_{B2} \tag{A.54}$$
$$L_{A2} = l_{A2} * Q_{A2} \tag{A.55}$$
$$L_{B2} = l_{B2} * Q_{B2} \tag{A.56}$$
$$k_{A3} = \left[\left(\frac{\alpha_{A3}}{1-\alpha_{A3}}\right)\frac{w_3}{r_3}\right]^{1-\alpha_{A3}} \tag{A.57}$$
$$k_{B3} = \left[\left(\frac{\alpha_{B3}}{1-\alpha_{B3}}\right)\frac{w_3}{r_3}\right]^{1-\alpha_{B3}} \tag{A.58}$$
$$l_{A3} = \left[\left(\frac{1-\alpha_{A3}}{\alpha_{A3}}\right)\frac{r_3}{w_3}\right]^{\alpha_{A3}} \tag{A.59}$$
$$l_{B3} = \left[\left(\frac{1-\alpha_{B3}}{\alpha_{B3}}\right)\frac{r_3}{w_3}\right]^{\alpha_{B3}} \tag{A.60}$$
$$K_{A3} = k_{A3} * Q_{A3} \tag{A.61}$$
$$K_{B3} = k_{B3} * Q_{B3} \tag{A.62}$$
$$L_{A3} = l_{A3} * Q_{A3} \tag{A.63}$$
$$L_{B3} = l_{B3} * Q_{B3} \tag{A.64}$$

National income, government taxes and spending :

$$
\begin{aligned}
Y_1 &= r_1K_1 + w_1L_1 + T_1 && \text{(A.65)}\\
Y_2 &= r_2K_2 + w_2L_2 + T_2 && \text{(A.66)}\\
Y_3 &= r_3K_3 + w_3L_3 + T_3 && \text{(A.67)}\\
T_1 &= Z_1t_{A1} + (tm^2_{B1} * \exp^2_{B1} * PW_B * chge_1) && \text{(A.68)}\\
&\quad + (tm^3_{B1} * \exp^3_{B1} * PW_B * chge_1) &&\\
T_2 &= Z_2t_{A2} + (tm^1_{A2} * \exp^1_{A2} * PW_A * chge_2) && \text{(A.69)}\\
&\quad + (tm^3_{B2} * \exp^3_{B2} * PW_B * chge_1) &&\\
T_3 &= Z_3t_{A3} + (tm^1_{A3} * \exp^1_{A3} * PW_A * chge_3) && \text{(A.70)}\\
&\quad + (tm^2_{B3} * \exp^2_{B3} * PW_B * chge_3) &&\\
G_1 &= T_1 && \text{(A.71)}\\
G_2 &= T_2 && \text{(A.72)}\\
G_3 &= T_3 && \text{(A.73)}
\end{aligned}
$$

Trade :

$$
\begin{aligned}
\exp^1_A &= Q_{A1} - C_{A1} && \text{(A.74)}\\
\exp^1_B &= Q_{B1} - C_{B1} && \text{(A.75)}\\
\exp^2_A &= Q_{A2} - C_{A2} && \text{(A.76)}\\
\exp^2_B &= Q_{B2} - C_{B2} && \text{(A.77)}\\
\exp^3_A &= Q_3 - C_{A3} && \text{(A.78)}\\
\exp^3_B &= Q_{B3} - C_{B3} && \text{(A.79)}\\
\exp^2_{B1} &= \left[MS^2_{B1} * \left(\frac{PC_{B1}}{PC^2_{B1}} \right)^{\sigma^2_B} \right] * (-\exp^1_B) && \text{(A.80)}\\
\exp^3_{B1} &= \left[MS^3_{B1} * \left(\frac{PC_{B1}}{PC^3_{B1}} \right)^{\sigma^3_B} \right] * (-\exp^1_B) && \text{(A.81)}\\
\exp^1_B &= -(\exp^2_{B1} + \exp^3_{B1}) && \text{(A.82)}\\
\exp^1_{A3} &= \left[\mu^1_{A3} * \left(\frac{PC_{A3}}{PC^1_{A3}} \right)^{\sigma^1_A} \right] * (-\exp^3_A) && \text{(A.83)}\\
\exp^2_{A3} &= \left[\mu^2_{A3} * \left(\frac{PC_{A3}}{PC^2_{A3}} \right)^{\sigma^2_A} \right] * (-\exp^3_A) && \text{(A.84)}\\
\exp^3_A &= \exp^1_{A3} + \exp^2_{A3} && \text{(A.85)}\\
\exp^2_A &= \exp^2_{A3} - \exp^1_{A2} && \text{(A.86)}\\
\exp^1_A &= \exp^1_{A2} + \exp^1_{A3} && \text{(A.87)}\\
\exp^2_B &= -(\exp^2_{B1} - \exp^3_{B2}) && \text{(A.88)}
\end{aligned}
$$

Clear market functions :

$$K_1 = K_{A1} + K_{B1} \tag{A.89}$$
$$L_1 = L_{A1} + L_{B1} \tag{A.90}$$
$$K_2 = K_{A2} + K_{B2} \tag{A.91}$$
$$L_2 = L_{A2} + L_{B2} \tag{A.92}$$
$$K_3 = K_{A3} + K_{B3} \tag{A.93}$$
$$L_3 = L_{A3} + L_{B3} \tag{A.94}$$
$$0 = (PW_A * chge_1 * \exp_{A1}) + (PW_B * chge_1 * \exp_{B1}) \tag{A.95}$$
$$0 = (PW_A * chge_2 * \exp_{A2}) + (PW_B * chge_2 * \exp_{B2}) \tag{A.96}$$
$$0 = (PW_A * chge_3 * \exp_{A3}) + (PW_B * chge_3 * \exp_{B3}) \tag{A.97}$$
$$0 = \exp_A^1 + \exp_A^2 + \exp_A^3 \tag{A.98}$$
$$0 = \exp_B^1 + \exp_B^2 + \exp_B^3 \tag{A.99}$$

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		simulation 1 full liberalization	simulation 2a FTA with country 3's retaliation	simulation 2b	simulation 3 FTA without retal.	simulation 4 non discrim. protection
country 1						
Z1	**pollution**	**5,671517**	**5,668674**	**5,66867**	**5,671454**	**5,665538**
ea1	technique effect	5,749244	5,74804	5,748036	5,749218	5,746799
SA1	scale effect	1,611121	1,61102	1,61102	1,611118	1,610905
φA1	composition effect	0,612295	0,612154	0,612154	0,612292	0,611991
ΘA1	pollution abatement	0,173936	0,173972	0,173972	0,173937	0,17401
tea1	pollution tax	0,063962	0,066207	0,083003	0,063587	0,062483
CA1	consumption good A	0,483336	0,483296	0,483296	0,483335	0,483238
CB1	consumption good B	1,645912	1,645863	1,645863	1,645911	1,64574
QA1	production good A	0,98648	0,986193	0,986193	0,986474	0,98586
QB1	production good B	0,911613	0,911887	0,911887	0,911619	0,912204
U1	utility	0,770035	0,770034	0,770034	0,770035	0,769994
expA1	exports good A	0,503144	0,502896	0,502896	0,503139	0,502622
expB1	exports good B	-0,734299	-0,733976	-0,733976	-0,734292	-0,733537
country 2						
Z2	**pollution**	**0,914601**	**0,914872**	**0,914572**	**0,914878**	**0,914606**
ea2	technique effect	6,892099	6,893021	6,892037	6,893004	6,892118
SA2	scale effect	1,283622	1,283627	1,28362	1,283628	1,283621
φA2	composition effect	0,103381	0,103398	0,103379	0,103399	0,103382
ΘA2	pollution abatement	0,145094	0,145074	0,145095	0,145075	0,145093
tea2	pollution tax	0,012632	0,013439	0,002743	0,012473	0,011227
CA2	consumption good A	0,385087	0,385098	0,385082	0,385102	0,385087
CB2	consumption good B	1,311341	1,311315	1,311328	1,311328	1,311341
Q12	production good A	0,132703	0,132724	0,1327	0,132726	0,132703
QB2	production good B	1,679675	1,679653	1,679678	1,679352	1,679675
U2	utility	0,69034	0,690329	0,69033	0,690338	0,69034
expA2	exports good A	-0,252384	-0,252374	-0,252382	-0,252376	-0,252384
expB2	exports good B	0,368334	0,368338	0,368351	0,368323	0,368334
country 3						
Z3	**pollution**	**4,680556**	**4,69328**	**4,693726**	**4,680425**	**4,708888**
ea3	technique effect	25,409567	25,443624	25,444804	25,40922	25,485073
SA3	scale effect	1,449883	1,449902	1,449902	1,449882	1,449926
φA3	composition effect	0,127048	0,127221	0,127227	0,127046	0,127434
ΘA3	pollution abatement	0,039355	0,039303	0,039301	0,039356	0,039239
tea3	pollution tax	0,002365	0,002388	0,001671	0,002366	0,002364
CA3	consumption good A	0,434965	0,434981	0,434981	0,434965	0,435009
CB3	consumption good B	1,481192	1,481178	1,481179	1,481192	1,481193
QA3	production good A	0,184204	0,184458	0,184467	0,184202	0,18477
QB3	production good B	1,847157	1,846816	1,846804	1,84716	1,846396
U3	utility	0,801483	0,801473	0,801473	0,801483	0,801483
expA3	exports good A	-0,25076	-0,250523	-0,250514	-0,250763	-0,250238
expB3	exports good B	0,365965	0,365638	0,365625	0,365968	0,365203
PWB	world price good B	0,685203	0,685166	0,685167	0,685203	0,685203
WZ	**world pollution**	**11,266673**	**11,276826**	**11,276968**	**11,266757**	**11,289032**
FTAZ	**poll. inside the FTA**	**6,586118**	**6,583546**	**6,583242**	**6,586332**	**6,580144**
pollution (constant technique)						
Z1	country 1		5,669860	5,669860	5,671484	5,667946
Z2	country 2		0,914750	0,914577	0,914760	0,914604
Z3	country 3		4,686997	4,687219	4,680486	4,694922
WZ	world pollution		11,271608	11,271656	11,266729	11,277473

Figure 1: pollution effects of a FTA as compared to other trade policies

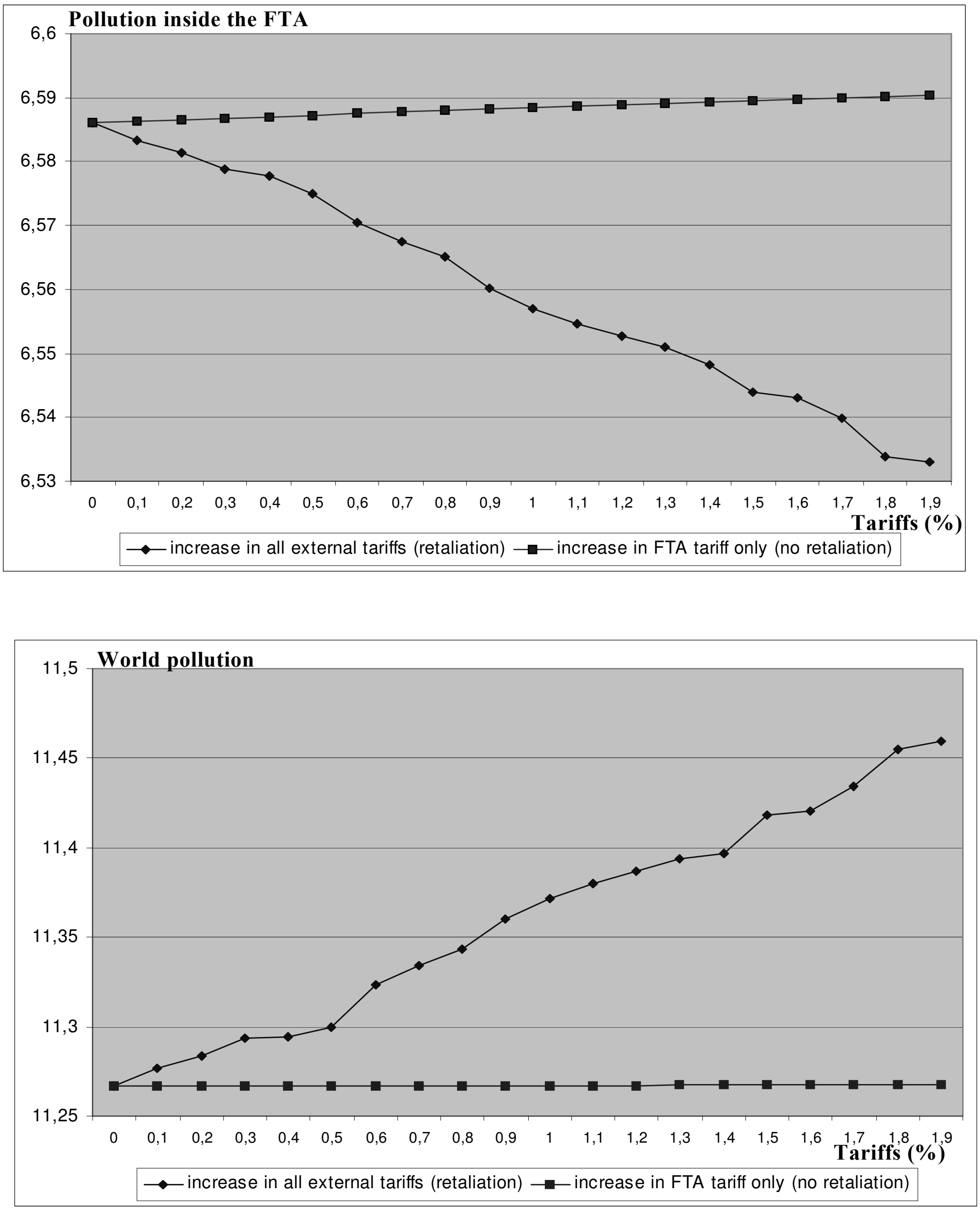

Figure 2: Pollution effects of a rise in external tariffs

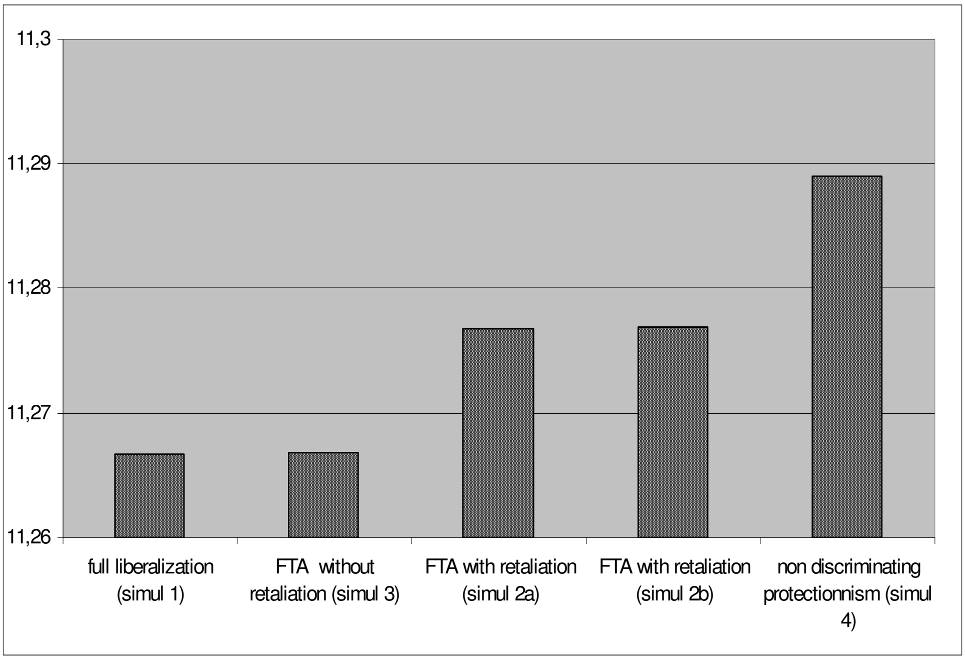

Figure 3: Simulations of world pollution for various trade policies

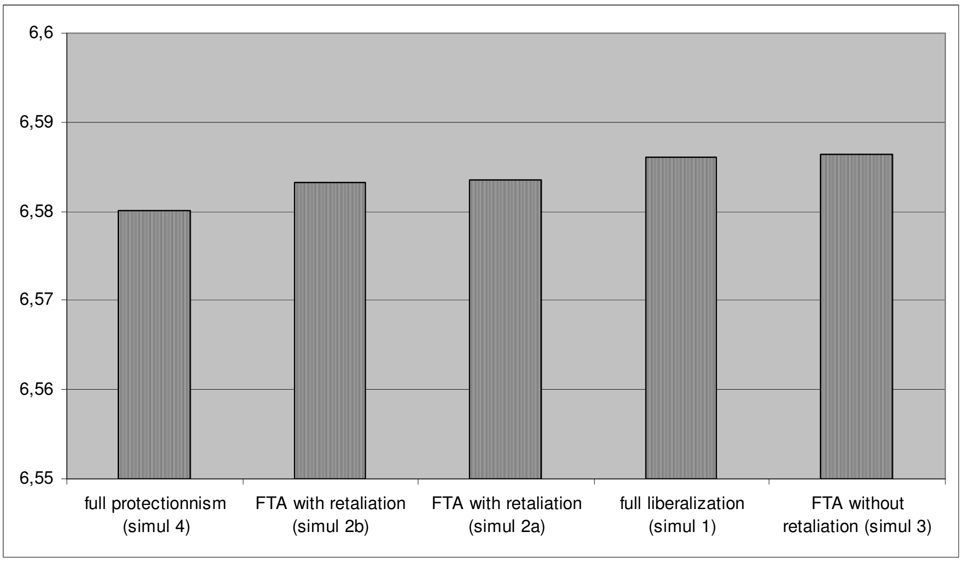

Figure 4: Pollution in countries 1 and 2 for various trade policies

		constant m	increasing m in :				increase in γ and η
		ref. simul.	country 1	country 2	country 3	countries 1 + 2	country 1
country 1							
Z1	**pollution**	**5,671517**	**5,678416**	**5,666556**	**5,623800**	**5,672492**	5,670363
ea1	technique effect	5,749244	5,749559	5,747143	5,729003	5,748355	5,746995
SA1	scale effect	1,611121	1,611391	1,610889	1,608877	1,611140	1,611185
φA1	composition effect	0,612295	0,612903	0,612071	0,610138	0,612487	0,612385
ΘA1	pollution abatement	0,173936	0,173926	0,173999	0,174550	0,173963	0,174004
tea1	pollution tax	0,063962	0,063469	0,063371	0,003775	0,063419	0,003968
PQ1A	prod. price good A	2,114192	2,098134	2,093135	0,123899	2,095600	0,131158
PQ1B	prod. price good B	1,448651	1,437352	1,434092	0,084821	1,435699	0,089865
QA1	production good A	0,986480	0,987626	0,985978	0,981637	0,985860	0,986666
QB1	production good B	0,911613	0,910522	0,912091	0,916221	0,912204	0,911437
Y1	total revenue	3,043456	3,020508	3,012710	0,178109	0,769994	0,188807
expA1	exports good A	0,503144	0,504209	0,502711	0,498974	0,503461	0,503331
expB1	exports good B	-0,734299	-0,736005	-0,733734	-0,728862	-0,734870	-0,734565
country 2							
Z2	**pollution**	**0,914601**	**0,913662**	**0,921726**	**0,909601**	**0,917691**	0,915259
ea2	technique effect	6,892099	6,889140	6,895352	6,876168	6,892248	6,895108
SA2	scale effect	1,283622	1,283362	1,283798	1,282478	1,283580	1,283632
φA2	composition effect	0,103381	0,103341	0,104123	0,103147	0,103732	0,10341
ΘA2	pollution abatement	0,145094	0,145156	0,145025	0,145430	0,145091	0,14503
tea2	pollution tax	0,012632	0,012454	0,012368	0,000743	0,012410	0,000885
PQ2A	prod. price good A	0,600010	0,591061	0,588041	0,035122	0,589508	0,042094
PQ2B	prod. price good B	0,411129	0,404934	0,402911	0,024046	0,403893	0,028848
Q12	production good A	0,132703	0,132624	0,133674	0,132283	0,133148	0,13274
QB2	production good B	1,679675	1,679757	1,678669	1,680110	1,679214	1,679636
Y2	total revenue	0,758633	0,747193	0,743552	0,044369	0,745319	0,053229
expA2	exports good A	-0,252384	-0,252398	-0,251479	-0,252472	-0,251939	-0,252397
expB2	exports good B	0,368334	0,368431	0,367048	0,368792	0,367740	0,368334
country 3							
Z3	**pollution**	**4,680556**	**4,623118**	**4,654742**	**4,793709**	**4,638909**	4,671013
ea3	technique effect	25,409567	25,256246	25,340772	25,468606	25,298488	25,384159
SA3	scale effect	1,449883	1,449531	1,449726	1,449076	1,449628	1,449867
φA3	composition effect	0,127048	0,126281	0,126704	0,129890	0,126492	0,126917
ΘA3	pollution abatement	0,039355	0,039594	0,039462	0,039264	0,039528	0,039395
tea3	pollution tax	0,002365	0,002393	0,002378	0,002352	0,002385	0,002371
PQ3A	prod. price good A	1,526971	1,526596	1,526844	1,525302	1,526535	1,527475
PQ3B	prod. price good B	1,046286	1,045813	1,046103	1,044214	1,045832	1,046596
QA3	production good A	0,184204	0,183048	0,183686	0,188220	0,183367	0,184013
QB3	production good B	1,847157	1,848711	1,847854	1,841754	1,848283	1,847414
Y3	total revenue	2,202860	2,201783	2,202437	2,199006	2,201844	2,203499
expA3	exports good A	-0,250760	-0,251811	-0,251232	-0,246502	-0,251521	-0,250935
expB3	exports good B	0,365965	0,367573	0,366687	0,360071	0,367130	0,366231
PWB	world price good B	0,685203	0,685062	0,685141	0,684595	0,685102	0,68518
WZ	**world pollution**	**11,266673**	**11,215196**	**11,243024**	**11,327110**	**11,229092**	11,256635
FTAZ	**poll. inside the FTA**	**6,586118**	**6,592078**	**6,588282**	**6,533401**	**6,590183**	6,585622

Figure 5: Effects of changes in consumer's and producer's pollution aversion.