Intra-Industry Trade in Dirty Goods and Environmental Policies

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Abstract

In this paper we study the effect of intra-industry trade in an environmental-quality differentiated good on the pollution level in a two-country framework when there are strategic interactions between the firms in the two countries. The pro-competitive effect of intra-industry trade expands the scale of production and, therefore, increases pollution in both the countries. Effect on the strategic choice of environmental qualities of the good is, on the other hand, asymmetric for the two producers. Impact of environmental policies like pollution content production tax and tariff on trade and pollution levels are also studied. .

1 Introduction

Linkages between trade and environment and effect of environmental policies on trade have been widely discussed in the last two decades. Copeland and Taylor (1994, 2003, 2004) discuss in great detail the various linkages between trade and environment and show how income differences and sometimes environmental policies affect the trade flows. The possible impact of trade liberalization on pollution levels have also been analysed by a host of economists, Low and Yeats (1992), Dean (1992, 1999) and Copeland and Taylor (1999) to name a few.

Trade liberalization generally affects the environment in three ways. Increased trade leads to a greater scale of economic activity that increases the production of all goods and services, including pollution-intensive goods, and therefore, degrades the environment. This is the *scale effect*, which gives us a negative relation between trade liberalisation and the environment. However, production techniques also change with trade liberalization and a subsequent increase in real income. The increased real income causes an increase in the demand for better environmental quality and firms opt for cleaner techniques of production. If investment liberalization also takes place, foreign investment may bring modern technologies which are likely to be cleaner than older versions. This positive *technique effect* works against the scale effect and Copeland and Taylor (2003) show that the relative strength of these two effects depends on how government policy is formed and how quickly it changes to new conditions. In addition to the scale and the technique effects, there is a change in the relative size of the economic sectors following a reduction in trade barriers. Trade liberalisation changes the relative prices between goods produced in different sectors, so that producers and consumers face a new trade-off. This is the *composition effect,* which tends to increase pollution in the country which has a comparative advantage in dirtier goods and lower the same in the country which has a comparative advantage in cleaner goods, with such advantages emanating from fundamental sources like factor endowments, technology and tastes.

In this paper I examine the impact of trade on local pollution levels in a somewhat different context. None of the above discussions have considered the possibility of intra-industry trade in dirty goods, or the possibility that the *degree of dirtiness* of the same good can be different depending on the technology used in its production. To demonstrate this, I first consider a single consumption good which can vary in its environmental quality leading to different levels of environmental degradation. This environmental quality is a choice variable for the producing firms. Second, the strategic interactions between home and foreign firms after opening up of trade in terms of their choices of both the environmental qualities and output levels are considered. More precisely, I consider an extended reciprocal dumping model of intra-industry trade a la Brander (1981) and Brander and Krugman (1983).

There is one firm in each country and the firms produce a single environmental-quality differentiated dirty good. The environmental quality, which is observable to all, is judged by the extent of pollution it generates and a good of a better environmental quality is a *cleaner* good. In autarky, the firms are non-discriminating monopolists in their respective countries. Post trade, the firms play a two-stage game in each country. In the first stage they choose their abatement technology, which determines the environmental-quality of their product, and incur a sunk cost. It is assumed that a cleaner good can only be produced with a better abatement technology, which can be obtained at a greater sunk cost. In the second stage they choose their level of output. In this framework, the strategic effects of the opening up of trade changes the environmental qualities as well as output levels to be sold in the two countries. The pollution levels are, therefore, affected due to such changes in the environmental quality and total supplies. This paper shows that while scale of production increases after trade liberalization in both countries, increasing the pollution levels through the scale effect, the environmental quality of the dirty good improves in one country while it falls in the other. Thus, the technique effect actually *increases* the level of pollution in one of the countries. Since I have considered a partial equilibrium framework where only the market for the dirty good is considered, it has not been possible for me to show how the composition effect works in changing pollution levels after trade liberalization. An imposition of a pollution content production tax increases the exports and lowers imports of the country imposing the tax. While a tax imposed by the country producing the lower-quality good always lowers the pollution in the other country, in all other cases, that is the impact of tax by country producing higher quality on the pollution levels in both countries and the tax in the low-quality country on the pollution there, depends on the relative importance of the scale and technique effects.

The rest of the paper is organised as follows. Section 2 sets out the model under autarky, while in sections 3 and 4 we analyse the effects of trade liberalisation on the environment and the effects of environmental policies like pollution content production taxes and tariffs on the volume of trade and pollution levels respectively. Finally in section 6 we conclude the paper.

2. The Model under Autarky

Consider two countries, labelled 1 and 2, with one firm in each country. These firms produce an environmental-quality differentiated good X, which generates pollution during production. The quality of X is indexed by $A \in [0, \overline{A}]$ with $\overline{A}$ being the quality of the cleanest good that can be produced by the present state of technology. A cleaner variety of X (higher A) uses a more sophisticated cleansing technology and generates less local pollution per unit of production. The total pollution generated by this industry thus, depends on the quality of the good being produced and the volume of production. Such characterisation of environmental-quality as an attribute of the good has been done previously in Arora and Gangopadhyay (1995) and Sen and Acharyya (2012).

In order to capture the *scale effect,* we consider here a continuum of consumers, with the scale of production depending on the market coverage. We assume that each consumer buys, if at all, only one unit of X and the scale of production vary with the size of the market covered by the firms. The consumers have identical incomes but different tastes. The utility function is specified as:

$$U = \theta A - p$$
$$= 0 \quad \text{if they don't buy.} \quad ; \tag{1}$$

In country *j*, the taste parameter θ is uniformly distributed with unit density and $\theta \in [0, \bar{\theta}_j]$.

In autarky, the firms enjoy a monopoly in their own country. Suppose that the two firms have identical cost structures. The cost of quality improvement, in this case the investment in abatement technology, is incurred before the actual production and thus, the environmental-quality level is chosen before the production process starts. The cost of quality can, thus, be regarded as a sunk cost. We assume for the sake of simplicity, that there are no further costs of production. Since every environmental quality is associated with a different technology which involves a sunk cost, we assume that the monopolist is non-discriminatory and offers a single environmental quality. Since the firms in the two countries have identical cost structures and the consumers have identical taste patterns, an analysis of the equilibrium choice of output and environmental-quality provided by the firm in one country will suffice.

The consumers in each country have to decide whether to buy the good X or not. A consumer with a taste parameter θ will buy if he derives at least his reservation utility, which in this case is zero, from consuming the good. That is, he will buy if

$$U = \theta A - p \geq 0 \tag{2}$$

The consumers in country *j* who are indifferent between buying the good and not buying at all have a taste parameter $\tilde{\theta}_j$ such that $\tilde{\theta}_j A_j - p_j = 0$. *i.e.* $\tilde{\theta}_j = p_j / A_j$, where A_j is the environmental-quality offered in the *j*th country. Thus, the consumers who have a taste parameter $\theta < \tilde{\theta}_j$ do not buy X at all and the amount of X that is demanded equals:

$$q_j = \bar{\theta}_j - \tilde{\theta}_j = \left[\bar{\theta}_j - (p_j / A_j)\right] \tag{3}$$

Under autarky, each firm, being a monopolist in his own country, will take his decisions in two stages. In the first stage, he sets up the plant and has to choose the abatement technology and thus, the environmental quality of his product. The investment on abatement technology is made in this stage and depends on the environmental-quality of

X that is to be produced, say $A_j^2/2$. This abatement technology cannot be changed in the short run. In the second stage he chooses the price he will charge, given the demand. Thus, in the second stage, he will maximize profits, for a given level of environmental quality where profits are

$$\pi_j = p_j q_j = p_j\left(\bar{\theta}_j - \frac{p_j}{A_j}\right) \tag{4}$$

Setting $\partial\pi_j/\partial p_j = 0$, we get,

$$p_j^a = (0.5)\bar{\theta}_j A_j \tag{5a}$$

and $$q_j^a = (0.5)\bar{\theta}_j \tag{5b}$$

where p_j^a and q_j^a are the price & quality levels in autarky.

In the first stage, the monopolist chooses *A* by maximizing $\Pi_j = \pi_j - A_j^2/2$. Setting $\partial\Pi_j/\partial A_j = 0$, we get,

$$A_j^a = (0.25)\bar{\theta}_j^2 \tag{5c}$$

It is immediate that the price, output and the environmental-quality under autarky depends on the maximum taste parameter $\bar{\theta}_j$ and hence, the size of the market in each country. Therefore,

Proposition 1: *Under autarky, the firm in Country j will offer a higher environmental-quality, charge a higher price and produce more than the firm in Country k if the market size in Country j is larger than in Country k. That is, if* $\bar{\theta}_j > \bar{\theta}_k$.

Proof: Under uniform distribution with unit density, the market size or the total number of consumers in Country *j* equals

$$N_j = \bar{\theta}_j$$

Thus, $$p_j^a = (0.125)\bar{\theta}_j^3 \tag{5d}$$

Thus from (5b) through (5d) it is immediate that,

$$\frac{\partial p_j^a}{\partial N_j} > 0 \ ; \ \frac{\partial q_j^a}{\partial N_j} > 0 \ ; \frac{\partial A_j^a}{\partial N_j} > 0 .$$

Hence the claim. ■

The local pollution in a country increases when a firm increases the level of production (*scale effect)* and falls with an improvement in the environmental quality of its product by the adoption of abatement technology (*technique effect).* Thus, the local pollution in the *ith* country is expressed as:

$$L_j = L_j(q_j^a, A_j) \ ; \quad \partial L_j \big/ \partial q_j^a > 0 , \quad \partial L_j \big/ \partial A_j < 0 \qquad (6)$$

However, in the rest of our analysis in this paper, we will assume that country sizes are identical. That is, $\overline{\theta}_j = \overline{\theta}_k$. This will enable us to isolate the effect of trade liberalization induced competition between firms on the level of pollution from the effect of country sizes on these variables. Note, that under such an assumption, the two firms will supply identical qualities in the two countries under autarky. Given such assumption, which essentially means that we assume identical set of heterogeneous consumers in the two countries, the price, environmental-quality and quantity choices would be the same in the two countries resulting in the same level of local pollution.

3. The Effect of Trade Liberalization

When the countries liberalise trade, the firms have access to the markets in both the countries and will compete with each other for market share in each market. Suppose there is no transport cost. As we assume no inter-country disparity with regard to either consumers or the production cost of the firms, trade liberalization and market integration will simply mean an expansion of the market size for each firm. As there are two firms competing in each country, now, it is no longer profitable for them to continue offering identical environmental-qualities. We assume that after deciding on the environmental-quality in the first stage, the firms choose quantities. That is, we assume Cournot competition between firms in the second stage. In this case, the profits are not driven to zero even if they continue to offer the same (and identical) environmental-qualities as they were offering under autarky. But similar to what was demonstrated by Motta (1993) in the context of endogenous quality choice, we will show that the firms will now offer two distinct qualities to relax competition between them.

Let the firm in Country 1, labelled firm 1, produce a higher environmental-quality A_{1j} than the other firm, firm 2, producing A_{2j} for the market in Country *j*. The consumers now have to make two decisions. First they decide, as in autarky, whether to buy or not. Second, when faced with the alternative environmental qualities provided by the two firms, they have to choose among them.

Let p_{ij} be the price of the environmental-quality offered by firm *i* to consumers of country *j,* (*i, j* = 1,2). Though a consumer is willing to pay more for a variety of higher environmental-quality, he will actually purchase the good of quality A_{1j} from firm 1 instead of quality A_{2j} from firm 2, $(A_{1j} > A_{2j})$, if 'net' utility from A_{1j} is at least as large as that from A_{2j} :

$$\theta A_{1j} - p_{1j} \geq \theta A_{2j} - p_{2j} \quad \text{`} \tag{7}$$

In both these decisions, that of market participation and selection of environmental quality, it is assumed that the consumer indifferent between purchasing or not actually purchases, and the one indifferent between the qualities A_{1j} and A_{2j} selects the higher quality A_{1j}.

The consumers in Country *j* who are indifferent between buying the lower quality good and not buying at all have a taste parameter θ_2 such that $\theta_2 A_{2j} - p_{2j} = 0$. *i.e* .$\theta_2 = p_{2j} / A_{2j}$. Again, the consumers who are indifferent between buying A_{1j} at p_{1j} and A_{2j} at p_{2j} have a taste parameter θ_1 such that $\theta_1 A_{1j} - p_{1j} = \theta_1 A_{2j} - p_{2j}$. So, $\theta_1 = (p_{1j} - p_{2j})/(A_{1j} - A_{2j})$. Thus, the consumers who have a taste parameter $\theta < \theta_2$ do not buy X at all, those with θ such that $\theta_2 < \theta < \theta_1$ buy the low quality good A_{2j} from the firm 2 while those with $\theta > \theta_1$ buy the high quality good A_{1j} from the firm 1. The amount of X that is demanded in Country j of the two firms is then,

$$q_{1j} = \bar{\theta} - \theta_1 = \bar{\theta} - \frac{p_{1j} - p_{2j}}{A_{1j} - A_{2j}} \tag{8a}$$

$$q_{2j} = \theta_1 - \theta_2 = \frac{p_{1j} - p_{2j}}{A_{1j} - A_{2j}} - \frac{p_{2j}}{A_{2j}} \tag{8b}$$

where q_{ij} is the quantity of X demanded by the consumers of the jth country from the ith firm. The inverse demand functions can be written from equations (8a) and (8b) as

$$p_{1j} = \bar{\theta}A_{1j} - q_{1j}A_{1j} - q_{2j}A_{2j} \tag{9a}$$

$$p_{2j} = (\bar{\theta} - q_{1j} - q_{2j})A_{2j} \tag{9b}$$

The firms play a two-stage game. In stage 1, they decide on the quality level to be offered in each country. In this stage, they incur a sunk cost on environmental-quality as in autarky. In the second stage, they choose the quantities to be produced. The equilibrium choice of quality levels and quantities by the firms can be derived by backward induction of the above game.

In Stage 2, the firms maximize $\pi_i = \sum_j p_{ij}q_{ij}$. Setting $\partial\pi_i / \partial q_{ij} = 0$, we get,

$$\frac{\partial \pi_1}{\partial q_{11}} = \bar{\theta}A_{11} - 2A_{11}q_{11} - A_{21}q_{21} = 0 \tag{10a}$$

$$\frac{\partial \pi_1}{\partial q_{12}} = \bar{\theta}A_{12} - 2A_{12}q_{12} - A_{22}q_{22} = 0 \tag{10b}$$

$$\frac{\partial \pi_2}{\partial q_{21}} = \bar{\theta}A_{21} - A_{21}q_{11} - 2A_{21}q_{21} = 0 \tag{10c}$$

$$\frac{\partial \pi_2}{\partial q_{22}} = \bar{\theta}A_{22} - A_{22}q_{12} - 2A_{22}q_{22} = 0 \tag{10d}$$

Note that the first-order conditions (10a) and (10c) and (10b) and (10d) form pairs of independent and symmetric subsystems. This has two implications. First, the output and price choice of each firm in one market is independent of those in the other market. These choices depend only on the environmental-quality selected by the two firms for that particular market (or country). This result follows from the "segmented market" property due to sunk cost of quality development and zero production cost. Second, the output and price choices made by each firm are the same for the two markets. This result follows from the "symmetric market" property under the assumption of identical set of consumers in the two markets. Market segmentation and symmetric properties were first demonstrated by Brander (1981) and Brander and Krugman (1983) in a strategic trade model. The same results hold in our case of (strategic) trade in environmental-quality in differentiated goods. The following Lemma formalizes these results.

Lemma 1: *Nash equilibrium pairs of quantities and corresponding prices in country-i are independent of those in country-j.*

Proof: Using the first-order conditions (10a) and (10c) for country 1, we obtain the Nash equilibrium pair of quantities and corresponding (market clearing) prices as:
Solving the equations, we get,

$$q_{11}^* = \frac{\bar{\theta}(2A_{11} - A_{21})}{4A_{11} - A_{21}};\; q_{21}^* = \frac{\bar{\theta}A_{11}}{4A_{11} - A_{21}} \tag{11a}$$

$$p_{11}^* = \frac{\bar{\theta}(2A_{11} - A_{21})A_{11}}{4A_{11} - A_{21}};\; p_{21}^* = \frac{\bar{\theta}A_{11}A_{21}}{4A_{11} - A_{21}} \tag{11b}$$

Similarly, from (10b) and (10d) we obtain,

$$q_{12}^* = \frac{\bar{\theta}(2A_{12} - A_{22})}{4A_{12} - A_{22}};\; q_{22}^* = \frac{\bar{\theta}A_{12}}{4A_{12} - A_{22}} \tag{11c}$$

$$p_{12}^* = \frac{\bar{\theta}(2A_{21} - A_{22})A_{12}}{4A_{12} - A_{22}};\; p_{22}^* = \frac{\bar{\theta}A_{12}A_{22}}{4A_{12} - A_{22}} \tag{11d}$$

Thus, $\{q_{11}^*, q_{21}^*, p_{11}^*, p_{21}^*\}$ depend only on the environmental qualities offered by the two firms in country 1, A_{11}^* and A_{21}^* while $\{q_{12}^*, q_{22}^*, p_{12}^*, p_{22}^*\}$ depend on the environmental qualities offered in country 2, A_{12}^* and A_{22}^*. Hence the claim. ♦

Given these choices of quantities, we now look for the Nash equilibrium qualities in the first stage. While choosing A_{ij}, firm-i incurs the sunk cost $A_{ij}^2/2$. Thus, each firm maximizes $\Pi_i = \sum_j \left(p_{ij}^* q_{ij}^* - \frac{A_{ij}^2}{2} \right)$. By Lemma 1, it is obvious that Π_i has two components, $\pi_{i1} = (p_{i1}^* q_{i1}^* - A_{i1}^2/2)$ and $\pi_{i2} = (p_{i2}^* q_{i2}^* - A_{i2}^2/2)$, which are the profits of firm-i from domestic sales and exports. From the profit maximization conditions, one can say that

Lemma 2: *The Nash equilibrium pair of environmental-quality in one market is independent of that in the other.*

Proof: As shown in Appendix A, maximization of profits $\Pi_i = \sum_j \left(p_{ij}^* q_{ij}^* - A_{ij}^2/2 \right)$ by choosing the environmental qualities A_{i1} and A_{i2} by firm i, (i = 1,2) leads to the following set of first order conditions:

$$\frac{\bar{\theta}^2 (2A_{11} - A_{21})(8A_{11}^2 - 2A_{11}A_{21} + A_{21}^2)}{(4A_{11} - A_{21})^3} - A_{11} = 0 \tag{12a}$$

$$\frac{\bar{\theta}^2 (2A_{12} - A_{22})(8A_{12}^2 - 2A_{12}A_{22} + A_{22}^2)}{(4A_{12} - A_{22})^3} - A_{12} = 0 \tag{12b}$$

$$\frac{\bar{\theta}^2 A_{11}^2 (4A_{11} + A_{21})}{(4A_{11} - A_{21})^3} - A_{21} = 0 \tag{12c}$$

$$\frac{\bar{\theta}^2 A_{12}^2 (4A_{12} + A_{22})}{(4A_{12} - A_{22})^3} - A_{22} = 0 \tag{12d}$$

Equations (12a) and (12c) are the reaction functions of the two firms in environmental-quality in country 1 while (12b) and (12d) are their reaction functions in country 2. It is evident that the pair of reaction functions represented by (12a) and (12c) solve for A_{11} and A_{21} independently of the pair (12b) and (12d). Similarly, the environmental qualities offered by the two firms in Country 2, A_{12} and A_{22}, can be obtained from (12b) and (12d) without any reference to the other pair of reaction functions.

Hence the result. ■

Once again this result reflects the segmentation property of the model due to the cost structure. This independence result has some far reaching implications for unilateral regulatory policies, as we will see later.

Let $A_{ij}^*, (i, j = 1,2),$ denote the Nash equilibrium quality levels chosen by the two firms under free trade. The values of A can be calculated from the equation pairs by setting $A_{1j} = \mu A_{2j}$, for $\mu > 1$. As shown in the Appendix A, the relevant solution of $\mu = 2.7924$, which when substituted in the reaction functions yield the Nash equilibrium environmental-quality levels as, [1]

$$A_{11}^* = A_{12}^* = 0.2519\bar{\theta}^2 \tag{13a}$$

and $$A_{21}^* = A_{22}^* = 0.0902\bar{\theta}^2 \tag{13b}$$

The solution is shown in Figure 1. The curve labelled $R_1(A_{2j})$ represents the reaction functions of firm 1, as given by equations (14a) and (14b) and the curve $R_2(A_{1j})$ represents the reaction function of firm 2, as in (14c) and (14d).[2] Given our presumption that $A_{1j} > A_{2j}$, the relevant range of solution values is the region below the 45^0 line through the origin where $R_1(A_{2j})$ is a steeply rising curve and $R_2(A_{1j})$ is negatively sloped for most parts.[3]

[1] The calculation of the equilibrium values of A and q has been done with the help of Mathematica 4.
[2] The reaction functions have been plotted using Scientific Workplace 3.0.
[3] See Appendix B for the slopes of the reaction functions.

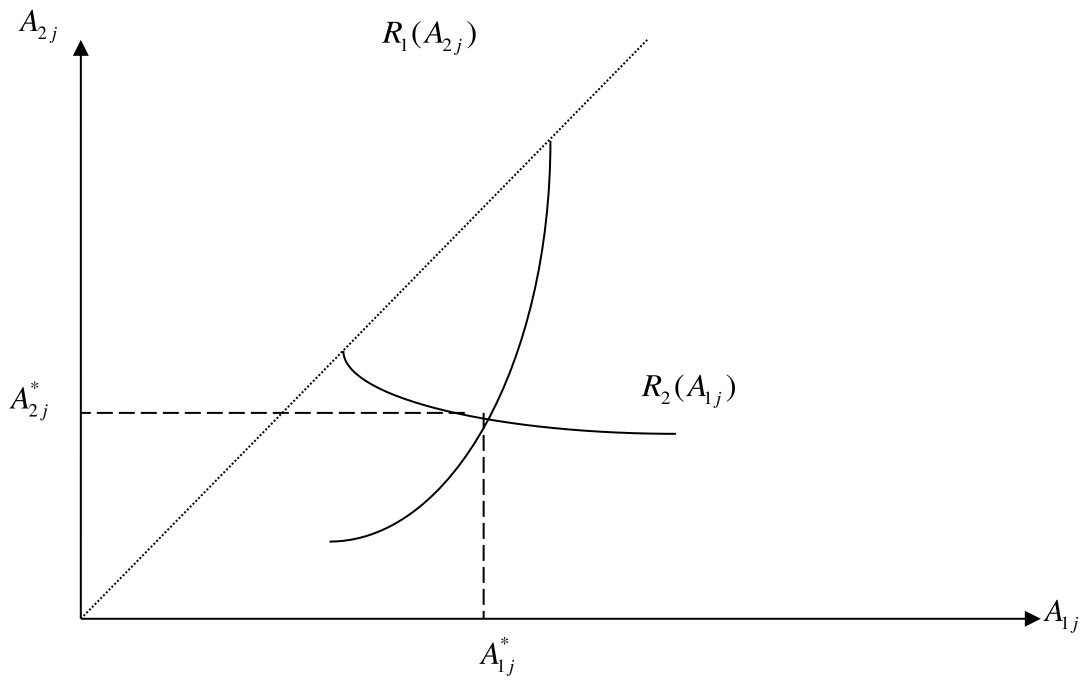

Figure 1: Equilibrium environmental qualities

Proposition 2: *After trade liberalization, the two firms offer two distinct qualities at the sub-game perfect Nash equilibrium. Firm 1 offers a cleaner variety and Firm 2 offers a dirtier variety than under autarky. But each firm offers the same quality to the home and foreign consumers at the unregulated sub-game perfect Nash equilibrium.*

Proof: As shown in (13a) and (13b), the two firms produce two distinct qualities A^*_{1j} and A^*_{2j} but each firm offers the same environmental quality, $A^*_{i1} = A^*_{i2}$, to the two markets. Under autarky, with $\overline{\theta}_i = \overline{\theta} \quad (\forall i = 1,2)$, the environmental-quality offered was,

$$A^a_1 = A^a_2 = 0.25\overline{\theta}^2$$

Comparing this environmental-quality level with that offered by the two firms after trade liberalization, it is immediate that

$$A^*_{1j} > A^a_1 = A^a_2 > A^*_{2j} \quad \forall \ j = 1,2 .$$

Hence the result. ♦

Thus, one firm produces a dirtier variety and the other a relatively cleaner variety after trade liberalization, even when there is no cost advantage. This is the pro-competitive effect. The firms differentiate their products in order to relax the second stage (quantity) competition between them.[4] On the other hand, the choice of identical qualities for the two markets (at the unregulated equilibrium) is due to the assumption of identical sets of consumers or market symmetry property of the model. Note that if the market sizes were different, the quality choice would differ as well. That is, if $\overline{\theta}_1 > \overline{\theta}_2$, then $A_{i1}^* > A_{i2}^* \;\; \forall \;\; i = 1,2$.

Let us now examine the effect of trade liberalisation on the pollution levels. The following Lemma is useful in this regard.

Lemma 3: *The scale of production and the extent of market coverage in the two countries increase after trade liberalization.*

Proof**:** Combining (11a), (11c), (13a) and (13b), the scale of production of the two firms can be written as,

$$q_1^* = q_{11}^* + q_{12}^* = 0.9017\overline{\theta}^2 \tag{14a}$$

$$q_2^* = q_{21}^* + q_{22}^* = 0.5492\overline{\theta}^2 \tag{14b}$$

Here, q_{11}^* and q_{22}^* are the domestic consumption of X in the two countries while q_{12}^* and q_{21}^* are their exports. Comparing these values with those given by (6b) for $\overline{\theta}_i = \overline{\theta}$, it is immediate that, $q_i^* > q_i^a$.

Market covered in each country under autarky is $(1-\widetilde{\theta}) = q_i^a = 0.5\overline{\theta}^2$ (15)

Whereas, the market covered in each country under free trade is, $(1-\theta_2) = q_{1j}^* + q_{2j}^* = 0.7254\overline{\theta}^2$. (16)

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[4] This result is well established in the literature on quality competition. See Shaked and Sutton (1982) and Motta (1993).

Hence the claim. ■

Lemma 3 implies that trade liberalization raises economic activity in both the countries and hence, the local pollution rises in both the countries due to the negative *scale effect.* While the *technique effect* merely reinforces the scale effect in country 2 where the firm specializes in the production of the dirtier variety, it offsets, at least partially, its negative impact in country 1. Whether local pollution rises or falls in country 1 depends on which of the two effects dominate.

Proposition 3: *With trade liberalization, the pollution level in Country 2 rises unambiguously and that in Country 1 rises too, unless the technique effect is strong enough to outweigh the scale effect.*

Proof: In Country 2, both the technique and the scale effects have a negative impact on local pollution as the environmental-quality of X falls after trade liberalization and the production by firm 2 increases. So, the two effects reinforce each other. The local pollution in Country 1 rises due to the scale effect and is partially offset by the technique effect. The change in pollution can be formally written as,

$$dL_j = \left(\partial L_j / \partial q_j\right) dq_j + \left(\partial L_j / \partial A_j\right) dA_j \tag{17}$$

So, the change in pollution in Country 1 is negative when

$$\hat{L}_1 = s\ \hat{q}_1 - |t|\ \hat{A}_1 < 0 \qquad \text{when} \qquad |t| > s\hat{q}_1 / \hat{A}_1$$

as $\widehat{q_1} > 0$ and $\widehat{A_1} > 0$

The change in pollution in Country 2 is,

$$\hat{L}_2 = s\ \hat{q}_2 - |t|\ \hat{A}_2 > 0$$

as $\widehat{q_2} > 0$ and $\widehat{A_2} < 0$

where $s = \frac{\partial L_j}{q_j}\frac{q_j}{L_j}$ is the scale effect and $t = \frac{\partial L_j}{A_j}\frac{A_j}{L_j}$ is the technique effect in the two countries.

Hence the claim. ■

4. Environmental Policy

Since the production of the dirty good X generates pollution, and in most cases this pollution increases with trade liberalization, the countries often adopt environmental policies like taxes and tariffs to control pollution. In this section, we study the impact of pollution content taxes and pollution content tariffs imposed by the two governments.

4.1 Pollution Content Taxes

In this subsection we consider the effect of an imposition of a pollution content tax on local production, that is, a tax that is inversely proportional to the environmental-quality of the dirty good. Such taxes will make the production of "dirty" goods more expensive, and encourage producers to opt for cleaner methods of production. Since there is a strategic interaction between the firms of the two countries, a tax levied on production will affect the environmental quality offered by the other firm as well. . This in turn will affect the scale of production, and hence, pollution in both countries.

Suppose the local government in country 1 imposes a pollution content production tax on its local firm:

$$T_1 = \sum_{j=1}^{2} T(\overline{A} - A_{1j}) = 2T\left(\overline{A} - A_1\right) \tag{18}$$

Since the tax is imposed only on local production in Country 1, firm 2 is not subject to it. With no import tariff imposed, the profit function of firm 2 remains the same as before. The profit function of firm 1 now becomes

$$\Pi_1 = \sum_j (p_{1j} q_{1j} - A_{1j}^2 / 2) - 2T(\overline{A} - A_{1j}) \tag{19}$$

Suppose the tax is imposed before the firms choose their environmental-qualities or quantities. That is, the firms make their decisions, given the tax rate. They choose q_{ij} by maximising $\sum_j p_{ij} q_{ij}$ as before. The profit function of firm 2 remains the same as before as it is not burdened with any tax. The stage 2 optimum choice of quantities and prices chosen by the two firms are the same as in (11a) and (11b).

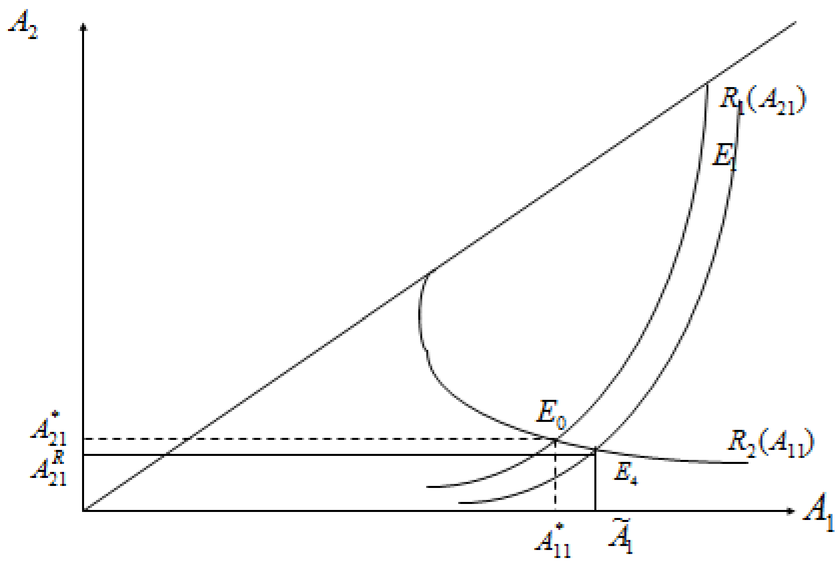

Figure 2: Pollution Content Production tax in Country 1

Since the relative cost of the dirtier varieties increase with the pollution content tax, choice of environmental-quality will now differ. However, the quantities and environmental-qualities supplied by any firm in the two countries will still be identical as the two countries are symmetric. The first order conditions for profit maximisation, given the Nash equilibrium quantities q_{ij}^* and prices, now yields the following reaction functions of the two firms:

$$\frac{\bar{\theta}^2(2A_{1j}-A_{2j})(8A_{1j}^2-2A_{1j}A_{2j}+A_{2j}^2)}{(4A_{1j}-A_{2j})^3}-A_{1j}+T=0 \tag{20a}$$

$$\frac{\bar{\theta}^2 A_{1j}^2(4A_{1j}+A_{2j})}{(4A_{1j}-A_{2j})^3}-A_{2j}=0 \tag{20b}$$

It is immediate that the reaction function of the firm 1 shifts to the right. Therefore, at the new equilibrium E_4, the quality levels chosen by firm 1 will rise while those chosen by firm 2 will fall. (See Figure 2).

Lemma 4: *The scale and technique effects work in opposite directions on the local pollution in both the countries when country 1 imposes a pollution content production tax.*

Proof: The change in the environmental-qualities chosen by the two firms for *j=1,2* are:

$$dA_1=-\frac{1}{\Delta}\left[\frac{2\bar{\theta}^2A_1^2(8A_1+A_2)}{(4A_1-A_2)^4}-1\right]dT>0 \tag{21a}$$

as $\{2A_1^2\bar{\theta}^2(8A_1+A_2)-(4A_1-A_2)^4\}<0$ in the neighbourhood of the equilibrium.

$$dA_2=-\frac{1}{\Delta}\left[\frac{2\bar{\theta}^2A_1A_2(8A_1+A_2)}{(4A_1-A_2)^4}\right]dT<0 \tag{21b}$$

where $\Delta=\left[\frac{8A_2^2(A_1-A_2)-2A_1^2(8A_1+A_2)}{(4A_1-A_2)^4}-1\right]$

The change in the quantities produced by the two firms is, then,

$$dq_1 = \frac{4\bar{\theta}}{(4A_1 - A_2)^2}\left[A_2 dA_1 - A_1 dA_2\right] > 0 \tag{22a}$$

$$dq_2 = \frac{-2\bar{\theta}}{(4A_1 - A_2)^2}\left[A_2 dA_1 - A_1 dA_2\right] < 0 \tag{22b}$$

as $dA_1 > 0$ and $dA_2 < 0$. ■

Thus, in country 1, the local firm improves the environmental-quality of its products and raises the scale of production at the same time, as shown in equations (21a & 22a). Thus, the technique effect lowers the local pollution in that country while the scale effect offsets the benefits of the technique effect. The opposite is observed in country 2 where the environmental-quality of the goods produced and the total output produced falls.

If, however, Country 2 imposes the pollution content production tax on the goods produced in that country, the reaction function of firm 2 shifts to the right, improving the environmental quality produced by both firms (see Figure 3). In this case,

$$\frac{dA_{1j}}{dT} = \frac{1}{\Delta}\left[\frac{8A_{1j}A_{2j}(A_{1j} - A_{2j})}{(4A_{1j} - A_{2j})^4}\right] > 0 \tag{23a}$$

$$\frac{dA_{2j}}{dT} = \frac{1}{\Delta}\left[\frac{8A_{2j}^2(A_{1j} - A_{2j})}{(4A_{1j} - A_{2j})^4} + 1\right] > 0 \tag{23b}$$

Firm 1 then lowers its production while firm 2 raises its output level in order to maximise their profits.

$$\begin{aligned} dq_1 &= 2\left[\frac{2A_2}{(4A_1 - A_2)^2}dA_1 - \frac{2A_1}{(4A_1 - A_2)^2}dA_2\right]dT \\ &= \frac{2}{\Delta}\left[\frac{-2A_1}{(4A_1 - A_2)^2}\right] < 0 \end{aligned} \tag{24a}$$

$$\begin{aligned} dq_2 &= -2\left[\frac{A_2}{(4A_1 - A_2)^2}dA_1 + \frac{A_1}{(4A_1 - A_2)^2}dA_2\right]dT \\ &= \frac{2}{\Delta}\left[\frac{A_1}{(4A_1 - A_2)^2}\right] > 0 \end{aligned} \tag{24 b}$$

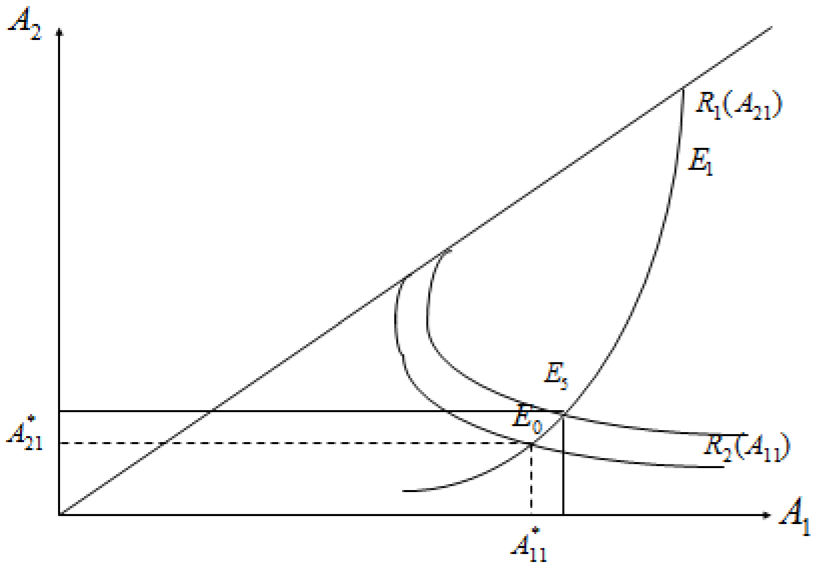

Figure 3: Pollution Content Production Tax in Country 2

Proposition 5: *A pollution content production tax imposed by any one country will increase the exports and reduce imports by that country.*

Proof: As shown in equations (22a) and (24a), quantity produced by the firm in the country imposing the tax increases. That is, its production for domestic consumption, as well as exports increase. On the other hand, as shown in equations (22b) and (24b), quantity produced by the firm in the other country falls. So, the quantity imported by the country imposing the tax falls. ■

Proposition 6: *The pollution in both the countries will fall after Country 1 imposes a pollution content tax only if the technique effect* $|t|: \frac{s|\rho 2|}{|\varphi 2|} > |t| > \frac{s|\rho 1|}{|\varphi 1|}$. *If the tax is imposed by Country 2 instead, the pollution in Country 1 will always fall while that in Country 2 will fall only when the technique effect is strong enough, i.e.* $|t| > \frac{s|\rho 2|}{|\varphi 2|}$.

Proof: The change in the level of pollution due to the tax in Country 1 is :

$$\hat{L}_j = \left(s\rho_j - |t|\varphi_j\right)\hat{T} \qquad \text{where} \quad \rho_j = \frac{\partial q_j}{\partial T}\frac{T}{q_j} \text{ and } \varphi_j = \frac{\partial A_j}{\partial T}\frac{T}{A_j}$$

As shown in Lemma 4, $\rho_1 > 0$ while $\rho_2 < 0$ and $\varphi_1 > 0$ while $\varphi_2 < 0$.

Thus, $\widehat{L_1} < 0$ when $|t| > \frac{s|\rho 1|}{|\varphi 1|}$ and $\widehat{L_2} < 0$ when $|t| < \frac{s|\rho 2|}{|\varphi 2|}$

When Country 2 imposes the tax, $\rho_1 < 0$ while $\rho_2 > 0$ and $\varphi_1 > 0$ while $\varphi_2 > 0$.

So, $\widehat{L_1} < 0$ always while $\widehat{L_2} < 0$ when $|t| > \frac{s|\rho 2|}{|\varphi 2|}$ ■

4.2 Pollution Content Tariff:

To examine whether a pollution content tariff has a different impact, suppose that the government in country 1 imposes a pollution content tariff on imports instead of the production tax. Let T_1 denote the import tariff. Then,

$$T_1 = \tau(\overline{A} - A_{21}) \tag{25}$$

With no production tax, the reaction function of firm 1 will remain the same as in equation (12a &c) in the two countries. While the reaction function of firm 2 in its own country remains unaltered, its reaction function for its exports shifts to the right. The tariff-ridden reaction function is:

$$\frac{A_{11}^2(4A_{11}+A_{21})}{(4A_{11}-A_{21})^2}-A_{21}+\tau=0 \tag{26}$$

The reaction functions of the two firms in country 1 are represented in Figure 4 and are similar to the situation where the country 2 imposes production tax on firm 2. Thus, the quality of imports and local production in country 1 rises. Since there is no intervention in country 2, the two firms will continue to sell goods of quality A_{12}^* and A_{22}^*, that is, the qualities they were offering at the unregulated free trade equilibrium. The change in the level of output supplied by the two firms in country 1 is the same as in the case of the production tax imposed by country 2 and can be expressed by (22a) and (22b), $\forall j=1$. As there is no intervention in country 2, there is no change in the environmental-quality supplied by the two firms to the consumers and hence, in the market coverage in that country will remain the same. As shown in Proposition 5, the local pollution in Country 1 will fall, though the change will be less than that in the case of production tax by country 2 as the environmental-quality of the two firms had improved in both the countries in that case.

If the government of country 2 imposes the pollution content tariff on its imports, then the reaction function of firm 1 for its exports will shift to the right. The tariff ridden reaction function is,

$$\frac{(2A_{12}-A_{22})(8A_{12}^2-2A_{12}A_{22}+A_{22}^2)}{(4A_{12}-A_{22})^3}-A_{12}+\tau=0 \tag{27}$$

Since the local production is not affected by the import tariff, the reaction function of firm 2 remains as in equation (12d). Thus, the effect of the pollution content tariff by country 2 is similar to that of the production tax imposed by country 1 and at the new equilibrium the quality of imports from firm 1 rises while that of the local production by firm 2 falls (Figure 3). The quantity sold by firm 1 increases and that sold by firm 2 falls, as shown in equations (24a & b). Again, since the market in country 1 remains unaffected by the tariff imposed on imports in country 2, the environmental qualities offered by the two firms will remain A_{11}^{*} and A_{21}^{*} and quantities will also remain unaltered.

6. Conclusion

This paper shows that intra-industry trade in dirty good increases the scale of production pollution in both countries. As there are strategic interactions between the two firms in the two countries, they produce two distinct qualities to relax competition. While the firm in one country improves the environmental quality of its product, the other firm reduces it. The greater production activity caused by the pro-competitive effect of trade is the main source of such greater environmental damages. A pollution content production tax raises the level of exports and lowers the imports in the country it is imposed. While a tax imposed by the country producing the lower-quality good always lowers the pollution in the other country, in all other cases, that is the impact of tax by country producing higher quality on the pollution levels in both countries and the tax in the low-quality country on the pollution there, depends on the relative importance of the scale and technique effects.

Appendix A

The Nash equilibrium choice of environmental-quality of the two firms under free trade:

From equations (13a) through (13d), we get the Nash equilibrium pair of quantities and the corresponding market clearing prices as,

$$q_{1j}^{*} = \frac{(2A_{1j} - A_{2j})\overline{\theta}}{4A_{1j} - A_{2j}}; \; q_{2j}^{*} = \frac{A_{1j}\overline{\theta}}{4A_{1j} - A_{2j}} \tag{A.1}$$

$$p_{1j}^{*} = \frac{(2A_{1j} - A_{2j})A_{1j}\overline{\theta}}{4A_{1j} - A_{2j}}; \; p_{2j}^{*} = \frac{A_{1j}A_{2j}\overline{\theta}}{4A_{1j} - A_{2j}} \qquad \forall j = 1,2 \tag{A.2}$$

The profit functions of the two firms is then,

$$\Pi_1 = \sum_j \left(p_{1j}^* q_{1j}^* - \frac{A_{1j}^2}{2} \right)$$
$$= \sum_j \left[\left(\frac{2A_{1j}^* - A_{2j}^*}{4A_{1j}^* - A_{2j}^*} \right)^2 A_{1j}^* - A_{1j}^{*\,2}/2 \right] \tag{A.3a}$$

$$\Pi_2 = \sum_j \left(p_{2j}^* q_{2j}^* - \frac{A_{2j}^2}{2} \right)$$
$$= \sum_j \left[\left(\frac{A_{1j}^*}{4A_{1j}^* - A_{2j}^*} \right)^2 A_{2j}^* - A_{2j}^{*\,2}/2 \right] \tag{A.3b}$$

Setting $\partial \Pi_i / \partial A_{ij} = 0$, we get the first order conditions of profit maximisation as (14a) through (3.14d). Setting $A_{ij} = \mu A_{2j}$, we can rewrite the reaction functions as,

$$\frac{\bar{\theta}^2 (2\mu - 1)(8\mu^2 - 2\mu + 1)}{(4\mu - 1)^3} - \mu A_{2j} = 0 \tag{A.4a}$$

$$\frac{\bar{\theta}^2 \mu^2 (4\mu + 1)}{(4\mu - 1)^3} - A_{2j} = 0 \tag{A.4b}$$

Substituting (A.4b) in (A.4a) we get,

$$(2\mu - 1)(8\mu^2 - 2\mu + 1) - \mu^3 (4\mu + 1) = 0 \tag{A.5}$$

Solving for μ, we get two solutions for equation (A.5), $\{\mu = 0.67042,\ 2.7924\}$. As we have assumed that $\mu \geq 1$, the second solution is the relevant one. Substituting $\mu = 2.7924$ in the reaction functions we get the Nash equilibrium qualities as:

$$A_{1j}^* = 0.2519\,\bar{\theta}^2 \text{ and } A_{2j}^* = 0.0902\bar{\theta}^2$$

Appendix B

The slopes of the reaction functions of the two firms in each country are:

$$\left. \frac{dA_{2j}}{dA_{1j}} \right|_{R1} = \frac{A_{2j}}{A_{1j}} + \frac{(4A_{1j} - A_{2j})^4}{8A_{1j}A_{2j}(A_{1j} - A_{2j})} \quad ;\ j=1,2 \tag{B.6a}$$

and $$\left.\frac{dA_{2j}}{dA_{1j}}\right|_{R2} = \frac{2A_{1j}A_{2j}(8A_{1j}+A_{2j})}{2A_{1j}^2(8A_{1j}+A_{2j})-(4A_{1j}-A_{2j})^4}\,. ;\; j=1,2 \qquad \text{(B.6b)}$$

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