Transboundary movements of waste: second-hand markets and illegal shipments (Preliminary. Comments are welcome)

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Abstract

In a stylized model of international trade, firms in the North indirectly export second-hand products to a representative firm in the South to be reused as intermediate goods, with potential trade gains. The degree of reusability of waste products is a crucial choice variable in the North. This is because with a lack of international vigilance, non-reusable waste can be mixed illegally with the reusable waste. I explore the driving forces for the movement of illegal waste, paying particular attention to the role of local waste regulations, such as the EU's Waste Electrical and Electronic Equipment directive. Under mild conditions, it is shown that increased regulation stringency in the North leads its firm to reduce the degree of reusability of its products. As a result, the flow of non-reusable waste to the South increases, providing another channel for the Pollution Haven Hypothesis.

Keywords: second-hand products, environmental regulation, trade.

JEL classification: F18, L10, O20, Q53

1 Introduction

The phenomenon of transboundary shipment of waste is driven by the scarcity of traditional landfill capacity in industrialized countries, where post-consumption waste has become a major concern. Governments have recently introduced new types of regulations, called extended producer responsibility, which make firms and producers responsible for waste disposal costs. The European Union's Directive on Waste Electrical and Electronic Equipment (WEEE) introduced in 2005 is an example. When firms internalize the cost of eco-friendly waste disposal, they tend to reduce the use of hazardous material and improve the reusability of their products. Also, some regulations directly aim at improving the quality of waste, like the European Union's End of Life Vehicle Directive introduced in 2006, which stipulates that every new vehicle must have recyclable content of 85 percent (95 percent by 2015). The current paper analyzes the impact of such regulations[1] when trade of used products is allowed for.

Although there are second-hand good markets in developed countries, the demand for such goods is often low due to technological obsolescence or regulations (like the technical inspections in many European countries that ensure that vehicles in poor conditions must be taken off the road). However, due to the gap in wealth between industrialized and industrializing economies, developing countries have a positive demand for some products that would be defined as waste in the North. This is the case of many e-waste, used vehicles[2] and recycled materials [Janischweski *et al.* 2003, Beukering and Bouman 2001]. In addition, industrial processes which reuse waste are typically qualified as labor-intensive. Therefore, there is a natural movement of waste from developed to less developed countries.

Two important sets of regulations govern transboundary movements of waste. The Basel Convention and EU regulations both restrict the shipment of waste and their disposal. So as

[1] For more details on the different instruments see Toffel *et al.* (2008).

[2] Janischweski et al. (2003) show that countries in East and West Africa import more second-hand vehicles than new ones. These cars have a particularly poor quality and are often more than 15 years old.

to minimize the environmental impact of waste management, the export of hazardous waste, e-waste and used vehicles from OECD to non-OECD countries is prohibited. However, the difference in the treatment and disposal costs remains one of the driving forces for transboundary shipments. Non-OECD countries often have low-cost, albeit environmentally inadequate, facilities. Czarnomski and Webb (2006) give the example of a PC monitor that costs around £5 to be recycled in the UK versus traders willing to pay up to £3 for a "visibly undamaged" monitor. The export of such e-waste to non-OECD countries often ends up incinerated in open fires, a practice which is unsafe both for the environment and human health [EEA 2009].

When combining i) the difference in local waste regulations, ii) the labor intensity of waste reuse industries and iii) the demand-driving forces, developing countries possess all the necessary characteristics to be pollution havens. Because of environmental concerns in the North, stricter environmental regulations are implemented and increase production costs of dirty industries (waste management) at home. The Pollution Haven Hypothesis stipulates that dirty industries will migrate from developed to less developed countries.

In order to minimize the cost of complying with extended producer responsibility programs, firms may consider legal and illegal[3] shipments of waste. The New York Times reporter Elisabeth Rosenthal (September 27, 2009) has investigated this market. She reports that, according to expert's *estimation*, around 16 percent of the exports are illegal. She also underlines that fewer restrictions on waste exports in the United States and Canada produce a large flow of waste legally exported to developing countries. Other sources say that illegal shipments *reported* by non-OECD countries are in average 22 000 tonnes per year, which represents 0.2 percent of notified waste [EEA 2009]. These illegal activities take different forms: transporting waste on the black market, mixing different types of waste or declaring hazardous waste as non-hazardous. This research concentrates on yet another type

[3]The United States have fewer restrictions on waste exports than Europe because they did not ratify the Basel convention. As a result, waste shipments are generally legal.

of illegal practice: classifying waste as second-hand goods. When products are classified as second-hand goods, they are no longer governed by international waste regulations and can be traded with developing countries.

There are two used good market characteristics that I refer to as the *lack of international vigilance*. The first one is that second-hand goods appear to be a one-size-fits-all category for recyclable, remanufacturable and second-hand products. As a result of these institutional ambiguities, international waste regulations are subject to different interpretations. Hence, authorities and enforcement agencies of the countries misclassify waste as used goods [Fischer *et al.* 2008]. Such misclassifications have been observed for e-waste and used vehicles[4] [Czarnomski *et al.* 2006 and Janischweski *et al.* 2003], and also for used clothes, car tires and other types of waste [Fischer *et al.* 2008]. Authorities from developing countries can also turn a blind eye to this illegal market. Reluctant to improve monitoring, they prefer to protect the imported waste business and the labor market it generates [Yardley, April 23, 2010].

The second characteristic qualified as the lack of international vigilance is that many used products are traded along with new ones. This situation makes it hard to keep track of them. One way to evaluate the scale of these markets is to compare prices. For instance, the average price of all exported television sets from Europe is 339€ whereas the price drops to 28€ when exported to Nigeria, Ghana or Egypt (where more than 1 000 used television sets arrive every day) [EEA 2009]. For both waste and used goods, the lack of precision in this identification renders market analysis difficult [EEA 2009].

The United-States and India, along with other countries, have led discussions during the Doha round. They want the WTO to undertake initiatives in order to regulate the movement of used products. Today, the WTO has only a draft version of proposed legislation, in which

[4]Czarnomski *et al.* (2006) observes that a significant amount of what is considered WEEE in OECD countries is exported illegaly to West Africa as second hand goods. Also, Janischweski *et al.* (2003) note that transactions where vehicles exported in "top condition" happen to be "cars without an engine" are so common that they name it the Lemon Rule.

it is recommended that the import of used products be banned. As a result, developed countries see the market for their used products reduced.[5] Under proper regulations, there is potential for gains from liberalizing trade in used goods as shown in Clerides (2008).

One rationale behind extended producer responsibility programs is that, by internalizing the cost of waste disposal, firms choose a higher level of reusability. The current paper observes the effect of higher disposal costs in the presence of an international second-hand goods market. In a stylized North-South model, a representative firm in the South can purchase second-hand products from the firm in the North as intermediate goods. Because of a lack of international vigilance, illegal shipments of non-reusable waste are mixed with the exported goods. The model explores the driving forces of illegal waste movements with particular attention to differences in local disposal costs. It also observes the impact of higher international vigilance. Results show that a large difference in waste treatment costs can induce firms in the North to reduce the reusability of their products. An increase in international vigilance can also bring counterintuitive results.

Few authors have studied extended producer responsibility programs. Runkel (2003) studies the influence of four instruments on product durability and welfare. He also explores different competitive environments and shows that the application of an extended producer responsibility program under imperfect competition can lead to a welfare reduction. Fleckinger and Glachant (2010) are concerned with the fact that such programs are precisely designed in order for producers to meet their obligations in their own way. They study a duopoly of producers and compare scenarios where producers manage their waste on their own and where they cooperate through a producer responsibility organization. They conclude that such a cooperation could lead to suboptimal outcomes and justifies government intervention.

[5] While some countries forbid the import of used goods, others apply prohibitive tariffs. Uganda qualifies used goods as sensitive and applies a tariff of 55%, beyond the common external tariff of 25%. (See www.allafrica.com, 12 February 2009)

The theoretical literature on trade in used products is still very scarce. Bond (1983) develops a model based on differences in factor prices and technologies in order to explain trade in equipment between firms. He also tests it empirically. The empirical literature on the topic is more common with Frazer (2008) who explains the decline in apparel production in Africa through used-clothing donations,[6] or Clerides (2008) who describes the gains from trade in used vehicles. To the best of my knowledge, the current paper is the first research project which integrates movements of illegal and reusable waste into an economic model.

Section 2 introduces the model and section 3 solves for the equilibrium. Section 4 presents effects of a change in the disposal cost in the North as well as the consequences of stricter enforcement in international vigilance. Section 6 concludes.

2 The Model

The problem is set in a basic model of international trade where a representative firm in a developing country (the South) imports inputs (used products) from a producer responsibility organization (PRO). The PRO manages waste from the firms in the developed country (the North).

2.1 Firms in the North

New final goods are produced in the North and consumed at home. Each of the n firms produces in quantity x_{Ni} where $\sum_{i=1}^{n} x_{Ni} = x_N$. The firms face a decreasing inverse demand for their new products:

$$p_N = \beta - x_N,$$

[6] Similar to food aid, used-clothing imports harm local producers. The problem of used good imports as an obstacle for economic development is also largely discussed in Janischweski *et al.* (2003).

where β represents the North's market size.

At the end of the products' lifetime, the firms are subject to an extended producer responsibility program. In order to comply with the regulation, they create a PRO[7] recognized by the government, which manages the collection and the disposal of waste. The PRO is a non-profit organization.

A portion of the used products are classified as reusable and can be exported to the South as an input to their production. Let q_i denotes the proportion of goods x_{Ni} that are reusable at the end of their lives. The proportion $1 - q_i$ is non-reusable and, under international regulations, should not be exported to the South. However, the lack of international vigilance causes a fraction $\sigma \in (0, 1)$ of these non-reusable goods to be misclassified. The actual fraction of used goods classified as reusable is $\overset{\circ}{q}_i = q_i + (1 - q_i)\sigma$. As a result, in the basket of imported goods, only a fraction

$$\overline{q} = \sum_{i=1}^{n}(x_{Ni}q_i) / \sum_{i=1}^{n}(x_{Ni}\overset{\circ}{q}_i)$$

can be used as inputs. $\overline{q}$ is referred to as the *purity* of the basket.[8]

It is assumed that products have a natural rate of reusability. This means that in the absence of firms' initial investment in green design, products are reusable at a rate $q_0 \in [0, 1]$. Through green design, firms can increase their fraction of reusable products q_i at the unit production cost $c_N(q_i)$ such that $c_N(q_0) > 0$, $c'_N(q_i) = 0$ for $q_i \leq q_0$, while $c'_N(q_i) \geq 0$ and $c''_N(q_i) \geq 0$ for $q_i > q_0$.

[7]For instance, in France, four PROs are recognized today by the government in order to comply with the WEEE directive. Eco-systèmes gathers many stockholders like LG, Moulinex, Philips and Samsung (see www.eco-systemes.com) while the European Recycling Platform was founded by Braun, Electrolux, HP and Sony (see www.erp-recycling.org). The two others are Ecologic (see www.ecologic-france.com) and Recylum (www.recylum.com). The last one treats only used lamps.

[8]It is assumed that the monopolist does not sort waste in order to improve purity. Sorting is a labor intensive activity and is hence too costly for the firm in the North. As a result, purity depends only on the level of reusability q.

When international vigilance increases, the monopolist must devote more time to sorting activities, which adds a unit transaction cost to traded goods: $c_\sigma(\sigma) = 1/\sigma$.

2.2 The PRO and the contracts

Within the basket of goods classified as reusable, the PRO exports w_e used goods at price p_e^w. The subscript e refers to the export values. The non-exported products must be disposed in an eco-friendly manner, at constant unit cost of disposal d_N.

In the absence of international trade, the cost of managing waste would be $d_N x_N$. The net benefit of trade therefore includes not only the price of exports net of transaction cost $(p_e^w - c_\sigma(\sigma))$, but also the save in disposal cost d_N. Formally, the net export revenues are defined as

$$XR \equiv (p_e^w + d_N - c_\sigma(\sigma))w_e. \tag{1}$$

Since the PRO is a non-profit organization, export revenues must be redistributed to producers through a predefined redistribution schedule chosen by the stockholders or the owners. The individual schedule is $s(XR; q_i)$ where $\sum_{i=1}^n s(XR; q_i) = XR$.

Three types of contract are considered between the PRO and the firms:

A) The PRO does not differentiate between products' level of reusability and redistribute according to an average revenue. The individual redistribution schedule of export revenues is $s(XR; q_i) = s_i XR$ where $\sum_{i=1}^n s_i = 1$. A particular case of contract A proposes a binary differentiation of products, *e.g.* green-design if $q_i \geq q_g$ and non green-design otherwise. The redistribution schedule therefore takes the form $s_{gi}XR$ if the product is green and $s_{bi}XR$ if it is brown where $s_{gi} \geq s_{bi}$.

B) The PRO proposes a redistribution schedule where products are differentiated with respect to their level of reusability and where the marginal benefit of an increased

level of reusability is individually given back to firms. Redistribution is such that $\partial s(XR; q_i)/\partial q_i = \partial XR/\partial q_i$.

C) The PRO encourages firms' cooperation on the level of reusability.[9]

When firms are identical and the equilibrium is symmetric, the redistribution can simply be interpreted as a reduction in the price that the PRO charges to firms.

2.3 The representative firm in the South

The firm in the South is a representative firm of a market in perfect competition. It employs used products as an input where x_S final goods are sold at exogenous price p_S. The firm can either apply some transformation processes like cleaning, remanufacturing or repairing; or it can act as an intermediary in shipping, handling and reselling. One used good is necessary for the production of one output. Production costs are divided in three parts. First, they have to acquire used products from the North. They buy a basket (or a container) of these used products that are previously classified as reusable. They pay p_m^w for each of the w_m imported good. The subscript m refers to the import values.

The second part of production costs reflects the sorting and the transformation processes, which decreases with $\overline{q}$. The representative firm has perfect information about the purity of baskets (at lower prices, baskets with lower purity can be interesting). Once sorted as reusable, goods require different degrees of intervention – from simple cleaning to change in parts – and the marginal production cost increases with x_S. These transformation costs take the form: $c_S(x_s; \overline{q}) = x_s^2/4\overline{q}$.

[9] Prior to 2009, the first type of contracts prevailed between PROs and producers. Since 2009 in France, PROs must encourage EEE producers to invest in green-design in order to improve recyclability, products' lifetime and reusability [Grenelle 1 law, article 41, 2009]. New contracts are now related to the second type where the price schedule depends on products differentiation (green-designed versus non green-designed). However, in the EEE sector products differentiation is costly and the third type of contracts might emerge in a near future.

The South can also adopt an extended producer responsibility program d_S which constitutes the third part of total costs. It is assumed that the South has laxer environmental regulations so that their waste disposal cost is lower than in the North when transaction costs are accounted for: $d_S + c_\sigma \leq d_N$.

Since basket purity reduces the risk of having lemons finding their way to the final good market, the inverse demand function for the final good in the South is: $p_S = \alpha - x_s/2\overline{q}$.[10]

2.4 The market structure

The market structure is described by the following four stage game. Local disposal costs, d_S and d_N, and the state of international (lack of) vigilance, σ, are given. In the first stage, each firm in the North selects the level of reusability q_i. The type of contract between the PRO and the firms will determine the outcome. In the second stage, firms compete à la Cournot and choose their quantity x_{Ni}.

In the third stage, the PRO selects the level of exports, w_e.

The representative firm in the South is a price taker on the international market. In the final stage, the level of imports as well as the quantity of output, w_m and x_S, are determined in the South.

Since the PRO is the leader, its decision when selecting the level of exports incorporates the representative firm's reaction function.

[10] This inverse demand function allows for further welfare analysis in section 5. Similar results are obtained in section 4 by using an inelastic demand.

3 The equilibrium

The profit functions for the firm in the North and in the South are respectively:

$$\begin{aligned}
\pi_{Ni} &= p_N x_{Ni} - c_N(q_i)x_{Ni} + s(XR; q_i) - d_N x_{Ni} \\
&\quad \text{where } p_N = \beta - x_N,\ XR = (p_e^w + d_N - c_\sigma(\sigma))w_e \\
&\quad \text{and } w_e \leq \overset{\circ}{q} x_N \qquad (2) \\
\pi_S &= p_S x_S - c_S(x_S; \overline{q}) - (p_m^w + d_S)w_m \\
&\quad \text{where } c_S(x_s; \overline{q}) = x_s^2/2\overline{q} \\
&\quad \text{and } x_S \leq \overline{q} w_m \qquad (3)
\end{aligned}$$

Equation 2 means that the PRO cannot export more than the proportion of used goods classified as reusable. It is assumed that the international market is small enough so that equation 2 is not binding in equilibrium. The scenario of a corner solution, when the South imports all goods classified as reusable is not considered here.[11] Equation (3) says that the firm's output in the South is limited by the amount of reusable inputs $\overline{q}w_m$.

Using backward induction, the final stage is solved first. The representative firm's problem is:

$$\begin{aligned}
&\max_{w_m} \pi_S = p_S \overline{q} w_m - \left(\overline{q} w_m\right)^2 / 4\overline{q} - (p_m^w + d_S)w_m \\
&\text{s.t. } x_S \leq \overline{q} w_m.
\end{aligned}$$

In equilibrium, the constraint is binding

$$x_S = \overline{q} w_m \qquad (4)$$

[11] It implies that β is large enough. Formally, $\beta > (p_s \overline{q} + d_N - d_S)\,\frac{2+2\overline{q}\overset{\circ}{q}^2}{q} + c_N(q) + d_N$.

and the first order condition leads to the following reaction demand function for imported goods:

$$p_m^w = p_S\overline{q} - \frac{w_m\overline{q}}{2} - d_S. \tag{5}$$

$$\text{where } \; p_S = \alpha - w_m/2 \tag{6}$$

In equilibrium, the international market clears:

$$w_m = w_e = w \text{ and} \tag{7}$$

$$p_m^w = p_e^w = p^w. \tag{8}$$

In the third stage, the PRO maximizes export revenues by choosing the level of export w. Using equations (1) and (5) to (8), the problem is:

$$\max_w XR = (\alpha\overline{q} + d_N - d_S - c_\sigma)w - \overline{q}w^2.$$

The chosen level of export is:

$$w = \frac{\alpha\overline{q} + d_N - d_S - c_\sigma}{2\overline{q}} \text{ and} \tag{9}$$

$$p^w = \frac{\alpha\overline{q} - d_N - d_S - c_\sigma}{2} \tag{10}$$

The second stage in the game is the firms's problem in the North. The problem of each individual firm becomes:

$$\max_{x_{Ni}} \pi_{Ni} = (\beta - x_N)x_{Ni} - c_N(q_i)x_{Ni} + s(XR; q_i) - d_N x_{Ni}.$$
$$\text{where } XR = \overline{q}w^2$$

where there is a Cournot competition on the choice of x_{Ni}. For the contract C, there will be collusion on the level of reusability, therefore $q_i = q$. The first order conditions for the

choice of individual production x_{Ni} lead to:

$$\begin{aligned} \frac{d\pi_{Ni}}{dx_{Ni}} &= \beta - x_N - x_{Ni} - c_N(q_i) - d_N + \frac{ds}{dXR}\frac{dXR}{d\overline{q}}\frac{d\overline{q}}{dx_{Ni}} = 0 \text{ for A and B} \quad (11) \\ x_{Ni} &= \frac{\beta - c_N(q) - d_N}{n+1} \text{ for C} \quad (12) \end{aligned}$$

In the first stage, the selected level of reusability depends on the type of contracts. In contracts A and B, each firm selects its own level of reusability while taking others' levels as fixed. In the contract C, firms collude and choose the level of reusability that maximizes the sum of profits. The optimality condition is therefore:

$$\begin{aligned} \frac{d\pi_{Ni}}{dq_i} &= -c'_N(q_j)x_{Ni} + \frac{ds}{dXR}\frac{dXR}{d\overline{q}}\frac{\partial\overline{q}}{\partial q_i} = 0 \text{ for } j = \text{A and B} \quad (13) \\ \frac{d\pi_N}{dq} &= -\frac{2n}{n+1}c'_N(q_C)x_{Ni} + \frac{dXR}{d\overline{q}}\frac{\partial\overline{q}}{\partial q} = 0 \text{ for contracts of type C} \quad (14) \end{aligned}$$

The symmetric equilibrium is now analyzed. For simplicity, it is assumed that $s_i = 1/n$ in contract A. Equations (11) and (12) now become:

$$x_{Nj} = \frac{\beta - c_N(q_j) - d_N}{n+1} \text{ for } j = \text{A, B and C} \quad (15)$$

and, knowing that $\partial\overline{q}/\partial q_i = (1/n)(\partial\overline{q}/\partial q)$, the optimality conditions for the choice of q_i are:

$$\begin{aligned} \frac{d\pi_{Ni}}{dq_i} &= -c'_N(q_A)x_{NA} + \frac{1}{n^2}\frac{dXR}{d\overline{q}}\frac{\partial\overline{q}}{\partial q} = 0 \text{ for A} \\ \frac{d\pi_{Ni}}{dq_i} &= -c'_N(q_B)x_{NB} + \frac{1}{n}\frac{dXR}{d\overline{q}}\frac{\partial\overline{q}}{\partial q} = 0 \text{ for B} \quad (16) \\ \frac{d\pi_N}{dq} &= -\frac{2n}{n+1}c'_N(q_C)x_{NC} + \frac{dXR}{d\overline{q}}\frac{\partial\overline{q}}{\partial q} = 0 \text{ for C} \end{aligned}$$

It is assumed that the second order condition for a maximum is respected. The subscripts A, B and C refers to the contracts.

Proposition 1 *Incentives for green design are such that:*

$$q_A \leq q_B \leq q_C.$$

In particular, when $n \to \infty$, only the contract of type C induces green design:

$$q_A = q_B = q_0 \leq q_C.$$

The equilibrium in this industry is characterized by equations (4), (7) to (10), (15) and (16). For the purpose of the analysis, illegal shipments, which is the non-reusable share of exports, take the form:

$$(1 - \overline{q})w$$

4 Disposal cost and international vigilance

The following set of results presents what occurs to the level of reusability when there is a change in the disposal cost or international vigilance. The results are qualitatively independent from the number of firm (when finite) or the type of contract. Therefore, we assume $n = 1$. When the number of firms tends to the infinity, contracts A and B prevent investment in green design. Stricter waste regulation or international vigilance let the level of reusability at its natural rate.

4.1 Disposal cost and the Pollution Haven Hypothesis

One of the rationales behind extended producer responsibility is that, by internalizing the cost of waste disposal, firms choose a higher level of reusability. Let us see what happens, in the presence of a secondary market in developing countries, when the North applies stricter

waste management and, therefore, higher disposal costs.

We have:

$$\begin{aligned} \operatorname{sign}\frac{dq}{dd_N} &= \operatorname{sign}\frac{\partial^2\pi_N}{\partial q\partial d_N} \text{ where} \\ \frac{\partial^2\pi_N}{\partial q\partial d_N} &= \frac{c'_N(q)}{2} + \frac{\partial\overline{q}}{\partial q}\left(\frac{-2\left(d_N - d_S - c_\sigma\right)}{4\overline{q}}\right) \end{aligned} \tag{17}$$

Proposition 2 *For all q, there exists a unique $\phi > 0$ such that*

$$\frac{dq}{dd_N} \gtreqless 0 \Longleftrightarrow d_N - d_S - c_\sigma \lesseqgtr \phi$$

in particular, for $d_N - d_S - c_\sigma = 0$, $dq/dd_N > 0$. Note that ϕ depends on the initial value of q, determined by the equilibrium prior to the change in policy.

Proof. We know that $c'_N(q)$ and $\partial\overline{q}/\partial q$ are positive. Therefore, equation (17) strictly decreases when $d_N - d_S - c_\sigma$ increases. Since $dq/dd_N > 0$ when $d_N - d_S - c_\sigma = 0$, then $dq/dd_N = 0$ when $d_N - d_S - c_\sigma = \phi > 0$. ■

One can see that when the South regulates as much as the North net of transaction cost, i.e. $d_N - c_\sigma = d_S$, the level of reusability q increases unambiguously with the strength of local waste regulation d_N. However, when the difference in disposal costs is large enough, more stringent waste regulation in the North reduces the choice of reusability and induces an increased amount of illegal shipments. These observations are explicitly formulated in the following proposition.

Proposition 3 *In equilibrium, the effect of an increased disposal cost in the North d_N depends on the difference between local disposal costs when the transaction cost is taken into account, $d_N - d_S - c_\sigma$:*

- *When the extended producer responsibility is similar between the two countries, i.e. when $d_N - d_S - c_\sigma < \phi$, the firm in the North, which internalizes the South's disposal*

cost, does not benefit from a large difference between local and foreign disposal costs. Therefore, the firm will increase the level of reusability of its products q and propose baskets with higher purity $\overline{q}$. Because exports are potentially higher, the total effects on the amount of illegal shipments, $(1-\overline{q})w$, as well as on the price of exports p^w, are ambiguous.

- *When the extended producer responsibility is largely different between the two countries, i.e. when $d_N - d_S - c_\sigma > \phi$, the firm in the North benefits from a large difference between its local disposal cost and the internalized South's cost. The monopolists' strategy will therefore aim at exporting non-reusable goods, cheaper to be disposed of in the South. The firm in the North will reduce the reusability of its products q and reduce the purity of exported baskets $\overline{q}$. This strategy lowers the price of exports p^w and causes an increased demand of used goods. With a higher level of exports and lower purity, illegal shipments $(1-\overline{q})w$ increase unambiguously. If purity were to stay high, the demand in the South would get saturated quickly and the level of exports would remain too low relative to the increasing disposal cost in the North and the possibility to "dump" non-reusable waste in the South.*

In the light of Proposition 3, the initial intention of an extended producer responsibility program is respected when the difference in local regulations shows little difference. As the disposal cost increases in the North, the monopolist is more likely to consider illegal shipments instead of improving the level of reusability. This result is in line with the Pollution Haven Hypothesis since the difference in environmental regulation between developed and less-developed countries brings a flow of pollution (waste) towards poor countries.

Proposition 4 *In equilibrium, an increased disposal cost in the South always increases the level of reusability.*

$$sign\frac{dq}{dd_S} = sign\frac{\partial^2 \pi_N}{\partial q \partial d_S} \text{ where } \frac{\partial^2 \pi_N}{\partial q \partial d_S} = \frac{\partial \overline{q}}{\partial q}\left(\frac{2\left(d_N - d_S - c_\sigma\right)}{4\overline{q}}\right) \geq 0$$

4.2 International vigilance

This section presents what occurs when international vigilance increases. We have:

$$\begin{aligned}
\text{sign}\frac{dq}{d\sigma} &= \text{sign}\frac{\partial^2\pi_N}{\partial q\partial\sigma} \text{ where} \\
\frac{\partial^2\pi_N}{\partial q\partial\sigma} &= \frac{\partial^2\overline{q}}{\partial q\partial\sigma}\left(\frac{(\alpha\overline{q})^2-(d_N-d_S-c_\sigma)^2}{4\overline{q}}\right) \\
&\quad+\frac{\partial\overline{q}}{\partial q}\frac{\partial\overline{q}}{\partial\sigma}\left(\frac{(\alpha\overline{q})^2+(d_N-d_S-c_\sigma)^2}{4\overline{q}}\right)-\frac{\partial\overline{q}}{\partial q}\frac{1}{\sigma^2}\left(\frac{2\left(d_N-d_S-c_\sigma\right)}{4\overline{q}}\right).
\end{aligned} \tag{18}$$

The first term represents the variation in the marginal revenue of exports due to a variation in the marginal effect of the level of reusability q. Looking at the optimality condition for the choice of q (equation 16), we know that $(\alpha\overline{q})^2-(d_N-d_S-c_\sigma)^2$ is positive in equilibrium. The second term in equation (18) is always negative. It represents the variation in the marginal revenue of exports due to a variation in the terms of trade. The third term is always negative and shows the impact of a change in the transaction cost.

Proposition 5 *For $\overline{q}>0.5$, there exists combinations of q and σ such that*

$$\frac{dq}{d\sigma}>0\Longrightarrow\overline{q}>0.5 \tag{19}$$

The effect of an increase in international vigilance (a reduction in σ) on reusability q depends on the initial value of purity $\bar{q}$, prior to the change in policy:

- *When the initial purity is small, i.e. when $\overline{q}<0.5$, an increase in international vigilance unambiguously leads to an improvement in the level of reusability.*
- *When the initial purity is large, i.e. $\overline{q}>0.5$, an increase in international vigilance may lead to a reduction in the level of reusability. In particular, for any given σ, a larger initial q raises the risk of having $dq/d\sigma>0$.*

Proof: Rearranging equation (18), we see that $\frac{dq}{d\sigma} > 0 \Leftrightarrow \frac{\partial^2 \overline{q}}{\partial q \partial \sigma}\left(\frac{\partial \overline{q}}{\partial q}\right)^{-1} > -\frac{\partial \overline{q}}{\partial \sigma}\left(\frac{(\alpha\overline{q})^2+(d_N-d_S-c_\sigma)^2}{(\alpha\overline{q})^2-(d_N-d_S-c_\sigma)^2}\right)+\frac{1}{\sigma^2}\left(\frac{2(d_N-d_S-c_\sigma)}{(\alpha\overline{q})^2-(d_N-d_S-c_\sigma)^2}\right)$. The right hand side is always positive. For the specific form of $\overline{q}$, the left hand side positive only when $\overline{q} > 0.5$ since

$$\frac{\partial^2 \overline{q}}{\partial q \partial \sigma} \gtreqless 0 \Leftrightarrow \overline{q} \gtreqless 0.5. \tag{20}$$

It is to be noted that in the range of combinations of q and σ where $\overline{q} > 0.5$, an increase in the level of reusability q, while holding σ fixed, leads to an increase of the left hand side and a decrease of the right hand side. Therefore, the risk of having $dq/d\sigma > 0$ increases with the level of reusability q.

When purity is large, equation (20) becomes positive, which means that, with an increase in international vigilance, an increase in the level of reusability has a smaller effect on purity. When purity is large enough, this incites the firm in the North to reduce the level of reusability.

Most variables of interest in this model depend on purity $\overline{q}$, which varies not only with the level of reusability q, but also with international vigilance σ. A change in international vigilance affects purity directly through $\partial\overline{q}/\partial\sigma$ and indirectly through $(\partial\overline{q}/\partial q) * (dq/d\sigma)$. When an increase in international vigilance leads to a reduction in reusability, the two effects work in opposite directions.

Proposition 6 *The total effect of an increase in international vigilance (a reduction in σ) on purity $\overline{q}$ is positive if only if*

$$\frac{d\overline{q}}{d\sigma} = \frac{\partial \overline{q}}{\partial q}\frac{dq}{d\sigma} + \frac{\partial \overline{q}}{\partial \sigma} \leq 0 \Longleftrightarrow \frac{\partial q}{\partial \sigma} \leq \frac{q(1-q)}{\sigma}.$$

The effects on trade and illegal shipments vary according to the following rule:

- *If $\frac{\partial q}{\partial \sigma} < \frac{q(1-q)}{\sigma}$, purity increases with international vigilance. In this case, the quantity*

of exports w decreases as well as illegal shipments, $(1-\overline{q})w$.

- *If $\frac{\partial q}{\partial \sigma} > \frac{q(1-q)}{\sigma}$, purity decreases as international vigilance increases. In this case, the quantity of exports w increases as well as illegal shipments, $(1-\overline{q})w$.*

From Propositions 5 and 6, if purity is initially small, then it increases with international vigilance, i.e. $\overline{q} < .5 \Rightarrow dq/d\sigma < 0 < q(1-q)/\sigma$. If international vigilance keeps increasing, purity raises and the equilibrium may reach combinations of q and σ where reusability decreases with international vigilance.

In some contexts, an improvement in international vigilance will have the opposite effect than what was intended from such a regulation. From Proposition 5, we know that this scenario occurs only when purity is initially high, i.e. $dq/d\sigma > q(1-q)/\sigma > 0 \Longrightarrow \overline{q} > .5$. All else equal, improving international vigilance directly increases purity. The monopolist who wants to keep a lower level of purity will therefore reduce its level of reusability. When purity is already high, the benefit of reducing purity through q can be larger than the benefit, through the terms of trade, of keeping it high. In this case, more international vigilance intensifies illegal shipments.

5 Welfare analysis

5.1 Profits, consumer surplus and pollution

In equilibrium, profits, consumer surplus and pollution can be summarized by the followings:

$$\begin{array}{ll} \pi_N = x_N^2 + \bar{q}w^2 & \pi_S = \bar{q}w^2/4 \\ CS_N = x_N^2/2 & CS_S = \bar{q}w^2/2 \\ Q_N = Q(d_N)(x_N - w) & Q_S = Q(d_S)w \\ Q_{World} = Q(d_N)x_N + (Q(d_S) - Q(d_N))w & \end{array}$$

Equations π and CS represent the welfare of firms and consumers while Q_N and Q_S are the environmental damage functions which are taken into account only by environmentalists in the North or in the South. It is assumed that environmentalists only care about local pollution. Q_{World} is the damage function for "pure" environmentalists, *i.e.* environmentalists who care about global pollution. Stricter waste regulation reduces pollution, hence $Q'(\cdot) \leq 0$.

In the context of international economies, each interest group has, with more or less weight, an impact on the selection of local and foreign regulations. Through the threat of economic reprisals, the determination of local policies cannot be totally independent of the trading partners. Also, the degree of international vigilance relies on both countries since, at the border, one controls what is going out while the other manages what is coming in.

In the current section, the objective is to determine where rely preferences of each group and what kind of political changes they would militate for through voting, lobbying, striking or other political means.

5.2 A change in disposal cost

Equations in appendix A.1 describe the welfare variation of each group when there is a change in the disposal cost in the North d_N. This leads to the following proposition.

Proposition 7 *In the North, the firm always militate to reduce disposal cost. In the South, preferences of the firm and consumers are always opposite to environmental protection:*

$$sign\frac{d\pi_N}{dd_N} < 0 \text{ and } sign\frac{d\pi_S}{dd_N} = sign\frac{dCS_S}{dd_N} = sing\frac{dQ_S}{dd_N}$$

- *If $dw/dd_N < 0$ (which implies $dq/dd_N > 0$ and $dx_N/dd_N < 0$), the impact on firms and consumers in both countries is negative while the level of pollution is reduced in*

the South and worldwide:

$$sign\frac{d\pi_N}{dd_N} = sign\frac{d\pi_S}{dd_N} = sign\frac{dCS_N}{dd_N} = sign\frac{dCS_S}{dd_N} = sing\frac{dQ_S}{dd_N} = sing\frac{dQ_{World}}{dd_N} < 0$$

- *If* $dx_N/dd_N > 0$ *(which implies* $dq/dd_N < 0$ *and* $dw/dd_N > 0$*), the impact on firms in the South and consumers in both countries is positive. Only firms in the North and environmentalists in the South would militate for a reduction in* d_N *:*

$$-sign\frac{d\pi_N}{dd_N} = sign\frac{d\pi_S}{dd_N} = sign\frac{dCS_N}{dd_N} = sign\frac{dCS_S}{dd_N} = sing\frac{dQ_S}{dd_N} > 0$$

- *If* $dx_N/dd_N < 0$ *and* $dw/dd_N > 0$*, firms and consumers in the North militate with environmentalists in the South for a reduction in* d_N *while firms and consumers in the South, along with environmentalists in the North, prefer stringer disposal regulation in the North.*

$$-sign\frac{d\pi_N}{dd_N} = sign\frac{d\pi_S}{dd_N} = -sign\frac{dCS_N}{dd_N} = sign\frac{dCS_S}{dd_N} = -sing\frac{dQ_N}{dd_N} = sing\frac{dQ_S}{dd_N} > 0$$

Appendix A.2 shows the welfare variation of each group when there is a change in the disposal cost in the South d_S.

Proposition 8 *An increased disposal cost in the South benefits only environmentalists in the South. Firms and consumers in both countries would see a reduction in their welfare:*

$$sign\frac{d\pi_N}{dd_S} = sign\frac{d\pi_S}{dd_S} = sign\frac{dCS_N}{dd_S} = sign\frac{dCS_S}{dd_S} = sing\frac{dQ_S}{dd_S} = sing\frac{dQ_{World}}{dd_N} < 0$$

The impact on environmentalists in the North is ambiguous.

In the scenario where $dw/dd_N < 0$, firms and consumers in both countries would militate for a reduction in d_N and d_S while environmentalists in the South and pure environmentalists

would prefer stringer waste regulations in both countries. Other scenarios bring a larger amount of waste in the South. Therefore interests of environmentalists in the South meet those of firms in the North for a reduction in d_N. Firms and consumers in the South prefer more inputs at lower prices, even when this results from lower purity.

5.3 A change in international vigilance

Equations in appendix A.3 show the welfare variation of each group following a change in the lack of international vigilance σ.

Proposition 9 *Interests of firms in both countries as well as interests of consumers in the South are always opposite to environmental protection in the South:*

$$sign\frac{d\pi_N}{d\sigma} = sign\frac{d\pi_S}{d\sigma} = sign\frac{dCS_S}{d\sigma} = sign\frac{dQ_S}{d\sigma}.$$

- *If $dw/d\sigma < 0$ (which implies $d\overline{q}/d\sigma > 0$ and $dx_N/d\sigma < 0$), an improvement in international vigilance reduces the incentive for reusability (lowers purity) and increases the movement of waste towards the South. Firms and consumers in both countries will prefer more international vigilance while global pollution and pollution in the South would be reduced through lower international vigilance.*

$$sign\frac{d\pi_N}{d\sigma} = sign\frac{d\pi_S}{d\sigma} = sign\frac{dCS_N}{d\sigma} = sign\frac{dCS_S}{d\sigma} = sign\frac{dQ_S}{d\sigma} = sign\frac{dQ_{World}}{d\sigma} < 0$$

- *If $dx_N/d\sigma > 0$ (which implies $dq/d\sigma < 0$ and $dw/d\sigma > 0$), an improvement in international vigilance induces firms to choose a higher level of reusability and to reduce production and exports. Firms and consumers in both countries will prefer less international vigilance while global pollution and pollution in the South would be reduced*

through higher international vigilance.

$$sign\frac{d\pi_N}{d\sigma} = sign\frac{d\pi_S}{d\sigma} = sign\frac{dCS_N}{d\sigma} = sign\frac{dCS_S}{d\sigma} = sign\frac{dQ_S}{d\sigma} = sign\frac{dQ_{World}}{d\sigma} > 0$$

- *If $dx_N/d\sigma < 0$ and $dw/d\sigma > 0$ (which implies $dq/d\sigma > 0$ and $d\overline{q}/d\sigma < 0$), an improvement in international vigilance induces firms to reduce reusability while purity still increases. In this case, production in the North increases while the export of waste is reduced. Firms in both countries and environmentalists in the North will want lower international vigilance. The interests of consumers in the North meet those of environmentalists in the South for an increased international vigilance.*

$$sign\frac{d\pi_N}{d\sigma} = sign\frac{d\pi_S}{d\sigma} = -sign\frac{dCS_N}{d\sigma} = sign\frac{dCS_S}{d\sigma} = -sign\frac{dQ_N}{d\sigma} = sign\frac{dQ_S}{d\sigma} > 0$$

6 Conclusion

This paper considers a North-South model where used durable goods in the North are imported by the firm in the South as an input to production. The lack of international vigilance allows for illegal waste to be mixed with reusable products.

In order to look at the Pollution Haven Hypothesis, special attention is given to large differences in local waste regulation between the two countries. It appears that the current application of extended producer responsibility programs, which makes producers responsible for the cost of waste disposal, opens up the valve to illegal shipments of waste. Conversely, trade with countries applying similar regulations would conserve the initial intention of such programs: more stringent regulations in the North leads to a higher level of reusability.

International vigilance also plays an important role. Better enforcement of international agreements leads to a reduction in illegal shipments of waste and an increase in the level of reusability. However, when the level of reusability is already high, better enforcement makes

higher reusability less attractive. In some cases, lowering the level of reusability provides more benefit than the improvement in the term of trade. The producer using a high level of reusability would therefore present adverse behavior in case of improved international vigilance.

These results partially come from the fact that producers can manage their obligations in their own way. Because the recycling centers are owned by the producers, they have the incentive to export waste illegally in order to reduce the overall cost of waste disposal.

A Appendix

A.1 Change in disposal cost in the North d_N

$\frac{d\pi_N}{dd_N} = w - x_N \leq 0$	$\frac{d\pi_S}{dd_N} = \frac{\bar{q}w}{2}\frac{dw}{dd_N}$
$\frac{dCS_N}{dd_N} = x_N\frac{dx_N}{dd_N}$	$\frac{dCS_S}{dd_N} = \bar{q}w\frac{dw}{dd_N}$
$\frac{dQ_N}{dd_N} = Q'(d_N)\left[x_N - w\right] + Q(d_N)\left\{\frac{dx_N}{dd_N} - \frac{dw}{dd_N}\right\}$	$\frac{dQ_S}{dd_N} = Q(d_S)\frac{dw}{dd_N}$
$\frac{dQ_{World}}{dd_N} = Q'(d_N)\left[x_N - w\right] + Q(d_N)\frac{dx_N}{dd_N} + (Q(d_S) - Q(d_N))\frac{dw}{dd_N}$	
where $\frac{dx_N}{dd_N} = -\frac{c'_N(q)}{2}\frac{dq}{d_N} - 1$ and $\frac{dw}{dd_N} = \frac{-(d_N - d_S - c_\sigma)}{2\bar{q}^2}\frac{d\bar{q}}{d_N} + \frac{1}{2\bar{q}}$	

A.2 Change in disposal cost in the South d_S

$\frac{d\pi_N}{dd_S} = 2\bar{q}w\frac{dw}{dd_S}$	$\frac{d\pi_S}{dd_S} = \frac{2\bar{q}w}{4}\frac{dw}{dd_S}$
$\frac{dCS_N}{dd_S} = \frac{x_N}{2}\frac{dx_N}{dd_S}$	$\frac{dCS_S}{dd_S} = \frac{2\bar{q}w}{2}\frac{dw}{dd_S}$
$\frac{dQ_N}{dd_S} = Q(d_N)\left\{\frac{dx_N}{dd_S} - \frac{dw}{dd_S}\right\}$	$\frac{dQ_S}{dd_S} = Q'(d_S)w + Q(d_S)\frac{dw}{dd_S}$
$\frac{dQ_{World}}{dd_S} = Q(d_N)\frac{dx_N}{dd_S} + (Q(d_S) - Q(d_N))\frac{dw}{dd_S} + Q'(d_S)w < 0$	
where $\frac{dx_N}{dd_S} = -\frac{c'_N(q)}{2}\frac{dq}{dd_S} < 0$ and $\frac{dw}{dd_S} = \frac{-(d_N - d_S - c_\sigma)}{2\bar{q}^2}\frac{d\bar{q}}{dd_S} - \frac{1}{2\bar{q}} < 0$	

A.3 Change in international vigilance σ

$\frac{d\pi_N}{d\sigma} = 2\bar{q}w\frac{dw}{d\sigma}$	$\frac{d\pi_S}{d\sigma} = \frac{2\bar{q}w}{4}\frac{dw}{d\sigma}$
$\frac{dCS_N}{d\sigma} = \frac{x_N}{2}\frac{dx_N}{d\sigma}$	$\frac{dCS_S}{d\sigma} = \frac{2\bar{q}w}{2}\frac{dw}{d\sigma}$
$\frac{dQ_N}{d\sigma} = Q(d_N)\left\{\frac{dx_N}{d\sigma} - \frac{dw}{d\sigma}\right\}$	$\frac{dQ_S}{d\sigma} = Q(d_S)\frac{dw}{d\sigma}$
$\frac{dQ_{World}}{d\sigma} = Q(d_N)\frac{dx_N}{d\sigma} + (Q(d_S) - Q(d_N))\frac{dw}{d\sigma}$	
where $\frac{dx_N}{d\sigma} = -\frac{c'_N(q)}{2}\frac{dq}{d\sigma}$ and $\frac{dw}{d\sigma} = \frac{-(d_N - d_S - c_\sigma)}{2\bar{q}^2}\frac{d\bar{q}}{d\sigma} + \frac{1}{2\bar{q}\sigma^2}$	

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