Consumption Externalities, Backhauling, and Pollution Havens

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Abstract: Pollution havens have received a great deal of attention in the past 15 years. However, the literature has focused almost exclusively on production side externalities and whether dirty industry migrates to countries with lax environmental laws. More recently, concerns have been raised about the rapid explosion of consumption side pollution such as e-waste and its trade in international markets. Between 1996 and 2005, US exports of waste plastics and waste steel along the USA-Asia trade route increased by 2,433% and 513%, respectively. Over the same time period the average freight rate on commercial liners along the USA-Asia trade route fell by 43%, while average freight rates along the Asia-USA trade route increased by more than 14%. This paper develops a two country trade model with endogenous asymmetric transport costs as well as externalities associated with harmful waste generated from consumption. It is shown that even when both governments set optimal Pigouvian taxes on the consumption of the dirty good, endogenous asymmetric transport costs can lower the ‘backhaul’ rate from North to South. This creates an environmental arbitrage condition by which it is cheaper for the North country to export it’s waste to the South rather than dispose of it at home. The model yields a number of clear predictions regarding the relationship between country characteristics, the international terms of trade, the backhaul shipping rate, and the North’s export supply function of waste.

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Keywords: Pollution Havens, Trade, Environment, Asymmetric Trade Costs, E-waste, Backhauling

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Introduction

Concern over pollution havens, typically defined as the movement of dirty industry production to countries with lax environmental regulations, has been at the forefront of political debate regarding international trade and the environment for nearly 20 years now. An extensive theoretical and empirical literature\(^1\) has arisen in the economics profession regarding the potential causes and empirical validity of pollution havens with growing, albeit mixed, evidence that production of dirty goods does in fact migrate (at the margin) to countries with less stringent environmental standards. While prior studies have focused on whether goods that are dirty to produce have migrated to countries with less stringent standards, the literature has been sparse on the causes and consequences of pollution havens generated from trade in waste from consumption. The rise and expansion of the technological age has generated a rapidly growing international environmental problem that has been largely unexplored. Namely, ‘pollution havens’ that are the direct result of trade in consumer generated waste, such as electronic waste (or e-waste), from developed to developing countries.

This paper develops a theory of consumer generated waste trade driven by changes in endogenously determined shipping costs. Trade deficits, shipping market characteristics, country characteristics, and physical characteristics of final goods are shown to play an important role in shipping costs, a crucial component for a country’s decision to export harmful waste or dispose of it at home. In this context, a ‘pollution

haven’ is defined in this paper not as a shift toward the production of dirty goods in a country but rather as a country’s direct import of waste.

The problem of the technological age and the generation of consumption based e-waste is well explained by Carroll [2008]:

More than 40 years ago, Gordon Moore, co-founder of the computer-chip maker Intel, observed that computer processing power roughly doubles every two years. An unstated corollary to “Moore’s law” is that at any given time, all the machines considered state-of-the-art are simultaneously on the verge of obsolescence. At this very moment, heavily caffeinated software engineers are designing programs that will overtax and befuddle your new turbo-powered PC when you try running them a few years from now. The memory and graphics requirements of Microsoft’s recent Vista operating system, for instance, spell doom for aging machines that were still able to squeak by a year ago. According to the U.S. Environmental Protection Agency, an estimated 30 to 40 million PC’s will be ready for “end-of-life management” in each of the next few years.

In 2005, the EPA estimates that the US generated between 1.5 and 1.9 million tons of e-waste (discarded computers, TV’s, VCR’s, cell phones, monitors, etc.) while the UN Environment Programme estimates that as much as 50 million tons of e-waste is generated worldwide each year (Carroll [2008]). From an environmental standpoint, e-waste contains large levels of lead, mercury, and cadmium (among others), all of which can have damaging effects on plant, animal, and human health.

So what becomes of discarded e-waste? Accurate estimates are hard to come by as there is no formal industrial code classification for e-waste. A new computer shipped from the U.S. to India has the same industrial classification code as a used computer. However, informal estimates suggest that anywhere from 20% (Carroll [2008]) to as much as 50-80% (Grossman, 2006) of U.S. e-waste is shipped overseas. The rest is set aside in storage or sent to landfills. The e-waste shipped to developing countries is typically broken down and stripped of what precious metals can be salvaged using low
cost manual labor, the rest burned or discarded directly into the environment (Pellow [2007], Carroll [2008]). Direct exposure to mercury, lead, and cadmium by laborers that take e-waste apart by hand, as well as indirect consumption through water and crop contamination, generate significant human and health risks for importing countries.

Growth in e-waste trade from developed to developing countries since the mid-1990’s has been occurring at a time when the U.S. has had record trade deficits with Asian countries such as China, India, and Malaysia. This has created asymmetric demand for shipping services between the U.S. and Asia and subsequently created a divergence in the average headhaul (Asia to U.S.) vs. backhaul (U.S. to Asia) freight rates for cargo\(^2\). In Figure 1 we see that between 1996 and 2005, the average freight rate from Asia to the U.S. (headhaul) increased by 14%, while the average freight rate from the U.S. to Asia (backhaul) decreased by 43%. At the same time, the volume of cargo along the Asia-U.S. route grew at a faster rate than the volume of cargo along the U.S.-Asia route. Not surprisingly, the divergence in the freight rate ratio and the cargo flow ratio along the headhaul and backhaul trading routes are highly correlated, with a simple correlation of 0.83.

While international treaties such as the Basel Convention and the BAN Amendment formally prohibit trade in toxics, including e-waste, the U.S. does not legally recognize the Basel Convention\(^3\). Exports of toxic e-waste are technically legal in the U.S. Countries such as India, China, and Nigeria that have been well documented by non-governmental organizations such as the Basel Action Network to be importers of e-

\(^2\) The terms headhaul and backhaul are in some sense arbitrary as they depend on the point of origin for the ship. Given that most international shipping firms originate outside of the U.S., in this paper the term headhaul will refer to shipments to the U.S. (North) and backhaul will refer to shipments to Asia (South).
\(^3\) The U.S. is a signatory to the Basel Convention but has not ratified it.
waste have ratified the Basel Convention and BAN Amendment. Imports of e-waste are officially illegal in these countries. However, developed nations such as the EU and Japan (also Basel Convention and BAN Amendment signatories) who have stringent laws on the exports of e-waste, as well as exporters in the U.S., often circumvent the laws by reclassifying exports in a different industrial category. For example, Toxics Link, a non-governmental organization, reported that “…a shipment of e-waste was mislabeled ‘metal scrap’ when it arrived at the port city of Chennai, India. The mislabeling of toxics is one of the most common methods of getting such waste past the authorities and through loopholes in the Basel Convention.” Pellow [2007], p. 199.

As stated above, concrete numbers on the volume of e-waste exported are difficult because there is not an industrial code for electronic waste, so e-waste is either classified the same as a new electronic product or as metal or plastic waste. Figure 2 shows the physical volume of metal and plastic waste exported from the U.S. to Asia between 1996 and 2005. During that time, growth in plastic and metal waste exports increased by 2,433% and 513%, respectively. Importantly, the increase in waste plastic exports and waste metal exports are highly correlated with the falling average backhaul rate from the U.S. to Asia.

This paper develops a theory that links this relationship between asymmetric transport costs and an environmental arbitrage condition for waste shipment. A two country general equilibrium trade model between a North and South country is modeled when consumption of one good generates a negative externality and trade costs are asymmetric. The model in this paper is different from Copeland [1991] and Cassing and Kuhn [2003] who have also examined issues in waste trade. Copeland [1991] considers

It is shown in this paper that when the shipping industry is characterized by imperfectly competitive firms with capacity constraints, asymmetries can endogenously arise between the headhaul and backhaul shipping rates between the countries. These asymmetries can affect the environmental arbitrage condition for the North to ship its waste to the South. That is, falling transport costs from North to South increase the potential for North to pay a lower tax for waste disposal in the South, plus shipping costs, rather than pay the higher tax in the North. Further, a North trade deficit with the South in final goods, as well as country and shipping industry characteristics, can influence the backhaul rate and North’s environmental arbitrage condition for shipping waste. Even when both countries set optimal Pigouvian taxes on the consumption of the good that generates the negative externality, the North is made better off and the South is made worse off when the North ships waste to the South. The reason for this result is a deteriorating terms of trade in shipping costs on the South’s import good. When South is unable to set (or enforce) the optimal Pigouvian tax, South welfare declines even further; suffering a loss from both the terms of trade in shipping cost and disutility from waste pollution.
The Model

Two countries, North (N) and South (S), produce two goods, \( X \) and \( Y \), using a composite labor factor\(^4\), \( L \), in perfectly competitive factor and output markets. Let superscripts denote the country and the \( P \) subscripts denote aggregate production levels of \( X \) and \( Y \). The variables \( L_x \) and \( L_y \) represent the total amount of composite labor used in each industry in the two countries and \( \alpha^N, \alpha^S, \beta^N \) and \( \beta^S \) are positive constants. The production functions for the two goods in each country are given by:

\[
X_p^N = \alpha^N L_x^N, \quad X_p^S = \alpha^S L_x^S, \quad Y_p^N = \beta^N L_y^N, \quad \text{and} \quad Y_p^S = \beta^S L_y^S. \tag{1}
\]

Let \( L^N \) and \( L^S \) be the exogenous endowments of the composite labor factor in each country. Composite labor constraints are given by \( L^N = L_x^N + L_y^N \) and \( L^S = L_x^S + L_y^S \). It is assumed that the North has an absolute advantage in the production of both goods such that \( \alpha^N > \alpha^S \) and \( \beta^N > \beta^S \), but the South has a comparative advantage in the production of good \( X \). This last condition implies that \( (\alpha^S / \beta^S) > (\alpha^N / \beta^N) \). Normalize the price of \( Y \) in both countries to 1 and denote the autarky relative producer price of \( X \) in each country as \( p^N \) and \( p^S \), respectively.

Consumers in each country get utility from the consumption of goods \( x \) and \( y \) and disutility from waste, \( w \), generated by consumption of good \( x \). The utility function for each consumer in North and South is given by:

\[
U^{N}_{i} = \left( x^{N}_{i} ight)^{\gamma} \left( y^{N}_{i} \right)^{-\gamma} - \lambda^{N} \sum_{i=1}^{N} w^{N}_i \ , \tag{2}
\]

\(^4\)The composite labor factor can be thought of as a combination of labor and capital that is supplied in fixed proportions.
\[
U_{ij}^S = \left( x_{jc}^S \right)^{\gamma} \left( y_{jc}^S \right)^{1-\gamma} - \lambda^S \sum_{j=1}^{J} w_{j}^S,
\]

where the subscripts \(i\) and \(j\) denote identical individual consumers in North and South, the subscript \(c\) denotes consumption, and \(\lambda^N\) and \(\lambda^S\) represent the constant marginal disutility of waste generated by the consumption of good \(X\) in North and South, respectively. For simplicity, the total number of consumers in North and South is equal to the exogenous supply of the composite factor, \(L^N\) and \(L^S\). It is assumed that \(u_x > 0, u_{xx} < 0, u_y > 0, u_{yy} < 0,\) and \(\lambda > 0\) in both countries. Waste is a constant fraction of consumption of the \(x\) good such that \(w_i^N = \delta^N x_{ic}^N, w_j^S = \delta^S x_{jc}^S,\) and \(0 < \delta \leq 1\). The parameter \(\delta\) can be thought of as the proportion of the \(X\) good that must be disposed of after consumption.

The government in each country attempts to maximize social welfare by charging an optimal Pigouvian tax \((p_e^N \text{ and } p_e^S)\) on consumers for the waste they generate. Each representative government sets the marginal Pigouvian tax rate equal to the marginal social disutility of waste such that:

\[
p_e^N = L^N \lambda^N \quad \text{and} \quad p_e^S = L^S \lambda^S.
\]

Revenues generated by the Pigouvian tax go to the government to be spent on the mitigation of waste (can be thought of as landfill) which is assumed to have a constant marginal cost equal to the Pigouvian tax.

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\(^5\) For tractability, the marginal disutility of waste in each country is assumed to be constant, but one might imagine that this could be an increasing function of income.

\(^6\) The mitigation of waste can simply be thought of as the cost of landfill. It is assumed here that each government collects the taxes and pays for the costs of mitigation. We could equally think of a third party “recycler” who receives the tax revenues and has a constant marginal cost of mitigation.
**Autarky Equilibrium**

In the autarky equilibrium, government chooses the Pigouvian tax rate such that the marginal social cost of waste is equal to the marginal social disutility of waste (given in equation (3)), consumers choose $X$ and $Y$ to maximize individual utility, and firms in the $X$ and $Y$ sectors maximize profit. Each consumer’s income, $I_k$, is equal to the marginal revenue product of the $Y$ sector such that $I_k = \beta_k$ and producer prices for good $X$ are $p_k = \frac{\beta_k}{\alpha}$ for $k = N, S$. Aggregate equilibrium demands for $X$ and $Y$ in each country (denoted by the subscript $d$) are

$$X_d^k = \frac{L^k \gamma(I^k)}{p_k + p_e^k}, \quad Y_d^k = L^k (1 - \gamma)(I^k) \quad \text{for } k = N, S.$$ (4)

Equilibrium in the goods markets and the factor market imply that the equilibrium values of $X$, $Y$, $L_x$, and total waste, $W$, (where equilibrium values are denoted by a “*”) are:

$$X^*_k = \frac{L^k \gamma(I^k)}{p_k + p_e^k}, \quad L^*_x = \frac{L^k \gamma(I^k)}{\alpha_k (p_k + p_e^k)}, \quad Y^*_k = \beta_k \left( \frac{L^k - L^*_x}{p_k + p_e^k} \right), \quad \text{and } W^*_k = \delta^k X^*_k, \quad (5)$$

for $k = N, S$.

Recall from above that it is assumed that the constant marginal cost of waste mitigation in each country is just equal to the Pigouvian tax. This implies that the revenues generated from $X$ consumption just equal the cost of disposing of the waste from $X$ consumption in each country.

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7 The assumption that the marginal cost of the mitigation of waste being is constant and equal to the Pigouvian tax is for simplicity. The qualitative aspects of the environmental arbitrage condition outlined later in the paper still go through if the marginal cost is not equal to the Pigouvian tax.
Transport Costs and the Trade Equilibrium

Two types of trade costs are present in the trade equilibrium. The first are unit transport costs ($\tau^{SN}$ and $\tau^{NS}$) that are endogenously determined by a imperfectly competitive shipping industry. The superscripts $SN$ and $NS$ denote the unit transport costs of shipping from South to North and North to South, respectively. The second type of trade costs’ are exogenous trade costs $t^{SN}$ and $t^{NS}$ that can broadly be thought of as other factors such as tariffs, port costs, or infrastructure costs associated with trade in each direction$^8$.

The relationship between the world producer trading price of the $X$ good, $p^T$, and the two autarky relative producer prices in each country is $p^S \leq p^T \leq p^N$. Final prices paid by consumers in each country for the $X$ good are $p^T + \tau^{SN} + t^{SN}$ for North consumers and $p^T$ for South consumers, while prices paid for the $Y$ good are 1 for North consumers and $1 + \tau^{NS} + t^{NS}$ for South consumers.

To keep the analysis tractable, equilibria for which North and South completely specialize in goods $Y$ and $X$, respectively, will be considered. Exports of the $X$ good from South to North ($X^SN_E$) and exports of the $Y$ good from North to South ($Y^NS_E$) are$^9$:

$$X^SN_E = \frac{L^N \beta^N}{p^T + \tau^{SN} + t^{SN} + p^N} \quad \text{and} \quad Y^NS_E = \frac{L^S(1 - \gamma)(\alpha^S p^T)}{1 + \tau^{NS} + t^{NS}}. \quad (6)$$

Stopford [1997] has pointed out that containerized liners have come to command a large majority of the value of goods shipped by sea$^{10}$. Liners are often organized into

$^8$ Any revenues that may thought to be generated by $t^{SN}$ and $t^{NS}$ (tariff revenue for example) are assumed to be lost and not returned to consumers.

$^9$ Given complete specialization by North and South, incomes in the two countries in equilibrium are $I^N = \beta^N$ and $I^S = \alpha^S p^T$. 

$^{10}$
‘conferences’, which are groups of shipping companies who set fixed prices. One view of this conference structure is that the conference organization facilitates collusion in which liners can exert market power by fixing prices above average cost (see Laing [1977], Stopford [1997], and Hummels, Lugovskyy, and Skiba [2007]). In a partial equilibrium model, Hummels, Lugovskyy, and Skiba [2007] find evidence that transportation markups are increasing in product prices and tariffs and decreasing in the number of shippers on a route.

Importantly, prior work has not modeled the role that imbalances in supply and demand play in determining prices on headhaul vs. backhaul routes. That is, on some legs of a liner’s journey the ship may be full, while on other ‘backhaul’ routes demand for liner space may be far more limited. Combining these notions of price discrimination and imbalances in trade routes Stopford points out that

Price is particularly important for lower value commodities where the transport cost contributes to determining whether trade is viable…prices are subject to intense competition and liner companies often discount heavily to win the business, especially when they have spare capacity on one leg of the voyage. Stopford [1997], p. 363-64.

In this paper, market power by a fixed number of shipping firms and ship capacity constraints are jointly modeled. The specification is similar to Hummels, Lugovskyy and Skiba [2007] in that there are a fixed number of liner companies that compete in a Cournot fashion for shipments along a fixed trading route. There are two important differences that the specification in this paper makes from Hummels, Lugovskyy and

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10 Other forms of sea transport such as bulk cargo and tramp ships are also involved in sea transport of goods. However, Stopford [1997] states that as of the mid-1990’s liners constituted better than 60% of the value of goods traded by sea and were growing in popularity due to the containerized units of shipping, reliable trade routes, and standardized timetables.
Skiba. First, this paper focuses on shipments of two homogeneous products rather than a large number of differentiated products. This implies that the specification here is better suited for explaining inter-industry trade between countries rather than intra-industry trade modeled in Hummels, Lugovskyy, and Skiba. This is an important distinction, but one that is appropriate given that the majority of developed to developing country final goods trade (where e-waste is also traded) is inter-industry, rather than intra-industry, in nature.

The second difference from Hummels, Lugovskyy, and Skiba is that ship capacity constraints are explicitly modeled here to account for differences in supply and demand in each direction. To do this, each ship is assumed to have a total volume capacity of $C$, a round-trip fixed cost of $F$, and a marginal cost of shipping in each direction of $0 \leq c < 1$.

It is assumed that North exports low volume goods to South, while South exports high volume goods to North. Denote the per unit shipping volume of the $X$ and $Y$ goods as $\omega_x$ and $\omega_y$, respectively, where $\omega_x > \omega_y$. For example, the $Y$ sector consists of low physical volume goods such as software, microchips, services, or entertainment (movies, music, etc) goods, while the $X$ sector consists of higher volume goods such as televisions, stereos, household appliances, computers, and monitors. The main idea is that $X$ sector goods will fill a larger volume of space on a containerized liner than the same dollar amount of $Y$ sector goods.

11 Constraining the marginal unit shipping cost to less than one implies that the marginal cost of transport cannot be more than the price of the numeraire good.

12 We can equally think of the physical volume of goods as the weight of goods. To maintain consistency, it will be referred to as the volume of goods throughout the paper.
Let $n$ represent the total number of ships on the route between South and North$^{13}$. Each of the $l=1,\ldots,n$ shipping companies simultaneously choose the volume of $X$ cargo to haul on the trip from South to North, $q_{xl}^{SN}$, as well as the volume of $Y$ cargo, $q_{yl}^{NS}$ and waste cargo, $q_{wl}^{NS}$, to haul from North to South. Profit maximization for each of the $n$ shipping firms requires maximizing the profit function

$$
\pi_i = q_{xl}^{SN} (r^{SN} - c) + (q_{yl}^{NS} + q_{wl}^{NS})(r^{NS} - c) - F_i.
$$

Equilibrium in the shipping market requires that aggregate supply of shipped goods equals aggregate demand for shipped goods such that

$$
nq_{xl}^{SN} = X_E^{SN}, \; nq_{yl}^{NS} = Y_E^{NS}, \text{ and } nq_{wl}^{NS} = W_E^{NS},
$$

where $W_E^{NS}$ is the total quantity of waste shipped from North to South. Each of the $n$ ships has a physical shipping constraint, such that the volume of goods on any given leg of the trip can be no greater than the physical capacity of the ship. This implies physical capacity constraints of $q_{xl}^{SN} \omega_x \leq C$ on the headhaul and $q_{yl}^{NS} \omega_y + q_{wl}^{NS} \omega_x \leq C$ on the backhaul. Maximization of equation (7) for each of the $n$ shipping firms, combined with equilibrium conditions in equation (8) and the physical capacity constraints implies an equilibrium headhaul rate equal to

$$
\tau^{SN} = c + \frac{\omega_x \sqrt{L^N \gamma \beta^N}}{nC}.
$$

The second term on the right hand side of equation (8) is the mark-up over marginal cost. The headhaul transport mark-up is increasing in the per unit volume of $X$ goods, the size of the North population, the share of $X$ in consumption, and the

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$^{13}$ For simplicity, $n$ is assumed to be a continuous variable.
productivity of the North’s $Y$ sector but decreasing in the number and size of ships along the trading route.

The equilibrium backhaul rate from North to South is dependent on whether North ships its waste to South or not. If the North does not ship its waste to South, implying that $W_{E}^{SN} = 0$ in equation (8), then the backhaul rate is given by

$$\tau^{NS} = c + \frac{\omega_{x} \sqrt{L^{S}(1-\gamma)\alpha^{S}p^{T}}}{nC}. \quad (10)$$

If the North does ship its waste to South (implying that $W_{E}^{SN} = \delta^{N}X_{E}^{SN}$) then the backhaul rate is given by

$$\tau^{NS} = c + \frac{\omega_{x} \sqrt{L^{S}(1-\gamma)\alpha^{S}p^{T}}}{nC - \left(\frac{\delta^{N}L^{N}\beta^{N}\omega_{x}}{p^{T} + \tau^{SN} + t^{NS} + p_{e}^{N}}\right)}. \quad (11)$$

Whether the backhaul rate is given by equation (10) or equation (11) is dependent on the North’s environmental arbitrage opportunities. Recall that the North government receives revenues on each unit of $X$ consumed in the North of $p_{e}^{N}$, and that the marginal cost of waste mitigation is also equal to $p_{e}^{N}$. The environmental arbitrage condition implies that if $p_{e}^{N} < p_{e}^{S} + \tau^{NS} + t^{NS}$, then the North government will keep its waste at home and just break even. In this case, the backhaul shipping rate is determined by equation (10). If $p_{e}^{N} > p_{e}^{S} + \tau^{NS} + t^{NS}$, then the North government would rather pay the lower waste mitigation fee in the South ($p_{e}^{S}$) plus transport costs ($\tau^{NS} + t^{NS}$) and ship the waste back to the South. This would yield the North government a return of
\[ p_e^N - p_e^S - \tau_{NS} - t_{NS} > 0 \] on each unit of \( X \) consumed in the North\(^{14}\). The backhaul shipping rate in this case is determined by equation (11).

Balanced trade in the South, \( p^T X^E_{SN} = (1 + \tau_{NS} + t_{NS}) y^E_{SN} \), implies that\(^{15}\):

\[ p^T = \frac{L^N \gamma \beta^N}{L^S (1 - \gamma) \alpha^S} - \tau^S N - t^S N - p_e^N. \tag{12} \]

Inserting equation (12) into equation (10) we get the equilibrium backhaul rate when North does not ship its waste to the South:

\[ \tau_{NS} = c + \frac{\omega \sqrt{L^N \gamma \beta^N - L^S (1 - \gamma) \alpha^S (\tau^S N + t^S N + p_e^N)}}{nC}. \tag{13} \]

Inserting equation (12) into (11) we get the equilibrium backhaul rate when North does ship its waste to the South:

\[ \tau_{NS} = c + \frac{\omega \sqrt{L^N \gamma \beta^N - L^S (1 - \gamma) \alpha^S (\tau^S N + t^S N + p_e^N)}}{nC - \delta^N L^S (1 - \gamma) \alpha^S \omega_x}. \tag{14} \]

Consider the North who currently does not ship waste to the South, such that \( p_e^N < p_e^S + t_{NS} + \tau_{NS} \) and \( \tau_{NS} \) is given by equation (13). For a fixed \( p_e^N, p_e^S, \) and \( t_{NS} \), what factors may lead to a decrease in \( \tau_{NS} \) such that \( p_e^N > p_e^S + t_{NS} + \tau_{NS} \) and North decides to start shipping its waste to the South? First, consider the difference in the weight of final goods being shipped between North and South.

\(^{14}\) Two things are important to point out here. Any ‘profits’ from environmental arbitrage by the North are assumed to be captured by the North government and returned lump-sum to consumers. Second, as pointed out in footnote 3, although we are attributing the arbitrage of waste to the North government, we could equally think of a third party ‘recycler’ who makes the same arbitrage decision. In the case of the third party recycler, the returns from waste arbitrage would simply be profits to the recycler.

\(^{15}\) Balanced trade for the South ensures that the North will clear by Walras Law.
**Proposition 1:** Increases in the per unit volume of X goods, $\omega_x$, or decreases in the per unit volume of Y goods, $\omega_y$, decrease the backhaul rate, $\tau^{NS}$, and improves the environmental arbitrage condition for North to ship its waste to the South.

**Proof:** $\frac{\partial \tau^{NS}}{\partial \omega_x} < 0$ and $\frac{\partial \tau^{NS}}{\partial \omega_y} > 0$.

Proposition 1 implies that if the South has a comparative advantage in larger volume goods that take up more room on ships, the backhaul rate from North to South will be lower, making it cheaper to ship waste back to the South. Specialization and export of knowledge intensive goods and services by the developed North or Grossman and Helpman [1991] type transfer of higher volume (weight) manufacturing goods to less developed countries in the South could contribute to differences in headhaul vs. backhaul shipping rates and, ultimately, the incentive for North to ship its waste to the South.

**Proposition 2:** Increases in external trade barriers from South to North, $t^{SN}$, decrease the backhaul rate, $\tau^{NS}$, and improves the environmental arbitrage condition for North to ship its waste to the South.

**Proof:** $\frac{\partial \tau^{NS}}{\partial t^{SN}} < 0$.

External trade barriers, $t^{SN}$, are broadly defined here as any ‘cost’ of trade other than transport. Thus, as costs associated with poor port infrastructure, tariffs, customs inspections or product standards in transporting goods from South to North rise, the real return to exporters in the South declines and the final cost to importers in the North increases. This has the effect of eroding the gains from trade and decreases trade flows. Given a fixed shipping capacity along the liner routes, shipping firms will have to lower transport prices to fill their ships.
Proposition 3: Increases in the number of shipping firms, n, or the shipping capacity of each ship, C, between North and South decreases the backhaul rate, $\tau_{NS}$, and improves the environmental arbitrage condition for North to ship its waste to the South.

Proof: $\frac{\partial \tau_{NS}}{\partial n} < 0$ and $\frac{\partial \tau_{NS}}{\partial C} < 0$.

Proposition 3 implies that popular North/South trading routes that have experienced growth in the number and size of ships are more likely to see declining backhaul rates and increased trade in waste from North to South.

Proposition 4: Decreases in the marginal cost of shipping, c, decreases the backhaul rate, $\tau_{NS}$, and improves the environmental arbitrage condition for North to ship its waste to the South.

Proof: $\frac{\partial \tau_{crit}}{\partial c} = 1$.

Improvements in the efficiency of shipping that lower the unit cost of transport decreases the cost of shipping waste products from North to South. An interesting corollary to proposition 4 is obtained if we let the marginal cost of shipping be a positive function of distance, d, such that $c(d)$ and $c'(d) > 0$.

Corollary 1: Decreases in distance that decrease the marginal cost of shipping, $c(d)$, decreases the backhaul rate, $\tau_{NS}$, and improves the environmental arbitrage condition for North to ship its waste to the South.

Corollary 1 implies that, ceteris paribus, a South country that is closer to the North will be more likely to be an importer of North waste than a South country further away.

Equation (13) suggests that improvements to the technology in the North and South can also have implications to for the backhaul rate. These affects are summarized in Propositions 5 and 6.
**Proposition 5:** For sufficiently large values of $Y$ sector productivity in the North, $\beta^N$, the backhaul rate, $\tau^{NS}$, is increasing in $\beta^N$ and deteriorates the environmental arbitrage condition for North to ship its waste to the South. For sufficiently small values of $Y$ sector productivity in the North, $\beta^N$, the backhaul rate, $\tau^{NS}$, is decreasing in $\beta^N$ and improves the environmental arbitrage condition for North to ship its waste to the South.

**Proof:**
\[
\frac{\partial \tau^{NS}}{\partial \beta^N} > 0 \text{ for } \beta^N > \left( \frac{L^S(1-\gamma)\alpha^S \omega'}{2nC \sqrt{\gamma L^N}} \right)^2 \text{ and } \frac{\partial \tau^{NS}}{\partial \beta^N} < 0 \text{ otherwise.}
\]

Proposition 5 implies that the marginal effect of North productivity in the $Y$ sector is conditional on characteristics in the two countries, as well as characteristics of the shipping industry. In particular, increases in productivity in the North’s $Y$ sector will be more likely to increase the backhaul rate and discourage North from shipping waste to the South when: (1) the South population is large relative to the North; (2) the share of $X$ in consumption is small; (3) the South’s $X$ sector productivity is large; (4) the per unit volume of $X$ goods is large; (5) the number of shipping firms is small; or (6) the capacity of liner ships is small. Conversely, increases in productivity in the North’s $Y$ sector will be more likely to decrease the backhaul rate and encourage North to ship waste to the South when: (1) the South population is small relative to the North; (2) the share of $X$ in consumption is large; (3) the South’s $X$ sector productivity is low; (4) the per unit volume of $X$ goods is small; (5) the number of shipping firms is large; or (6) the capacity of liner ships is large.

**Proposition 6:** Increases in the productivity of the $X$ sector in the South, $\alpha^S$, decreases the backhaul rate, $\tau^{NS}$, and improves the environmental arbitrage condition for North to ship its waste to the South.

**Proof:**
\[
\frac{\partial \tau^{NS}}{\partial \alpha^S} > 0.
\]
An interesting policy implication is that countries in the South that improve the efficiency of their export industries drive down the backhaul rate and increase the probability of waste being shipped from the North.

**Trade Deficits and Trade in Waste**

From 1996 to 2005, the U.S. trade deficit with China grew five-fold. If we alter the trade balance condition to allow for North to run a current trade deficit with South, how might this affect the current backhaul rate? Suppose that the North were to run a trade deficit with the South such that the North would repay $G$ units of $X$ goods at a later time. The inter-temporal trade balance condition can be written

$$p^T X_{t}^{NS} = (1 + \tau^{NS} + t^{NS}) e_{t}^{NS} + p^T G.$$  

This implies that the equilibrium world price of $X$ from (12) is now

$$p^T = \frac{L^N \gamma \beta^N}{L^S (1 - \gamma) \alpha^S + G} - \tau^{SN} - t^{SN} - p_e^N, \quad (12')$$

and the backhaul rates given in equations (13) and (14) can now be written

$$\tau^{NS} = C + \frac{\omega \sqrt{L^N \gamma \beta^N \phi - L^S (1 - \gamma) \alpha^S (\tau^{SN} + t^{SN} + p_e^N)}}{nC}, \quad (13')$$

and

$$\tau^{NS} = C + \frac{\omega \sqrt{L^N \gamma \beta^N \phi - L^S (1 - \gamma) \alpha^S (\tau^{SN} + t^{SN} + p_e^N)}}{nC - \delta^N L^S (1 - \gamma) \alpha^S \omega_x}, \quad (14')$$

where $\phi = \frac{L^S (1 - \gamma) \alpha^S}{L^S (1 - \gamma) \alpha^S + G}$. Equations (13’) and (14’) imply the following proposition.

---

16 The term ‘inter-temporal’ is used here to reflect the fact that $G$ will be sent to the South at some future date. In the current period, the North is effectively exporting a commitment of $G$ units in the future at the current price of $p^T$. A zero interest rate is assumed for simplicity but the qualitative effects of a trade deficit, $G$, would be the same with a positive interest rate.
Proposition 7: Increases in the North’s current trade deficit with the South, $G$, decreases the backhaul rate, $\tau^{NS}$, and improves the environmental arbitrage condition for North to ship its waste to the South.

Proof: \[ \frac{\partial \tau^{NS}}{\partial G} < 0. \]

Using the equilibrium $X$ sector exports from equation (6) and the producer price of $X$ from equation (12'), we can solve for the North’s waste export function $W^{NS}_E = \delta^N X^{SN}_E$, conditional on the environmental arbitrage condition, as

\[
W^{NS}_E = \begin{cases} 
\delta^N (L^S (1-\gamma)\alpha^S + G) & \text{for } \tau^{NS} < p_e^N - p_e^S - t^{NS} \\
0 & \text{for } \tau^{NS} \geq p_e^N - p_e^S - t^{NS} 
\end{cases} .
\]

(15)

Proposition 8: If $\tau^{NS} < p_e^N - p_e^S - t^{NS}$, then increases in the North’s current trade deficit with the South, $G$, increases the volume of waste shipped from North to South.

There are two factors contributing to the increase in waste traded from larger trade deficits. First, the more of the $X$ good that the North imports and consumes in the current period by borrowing, the greater the volume of waste they generate in the current period. Second, from Proposition 8 we see that the trade deficit lowers the backhaul rate. The combination of these two effects means more waste is being generated in the North in the current period and the cost of shipping it back to the South is falling.

Corollary 2 below describes the additional characteristics that can lead to a larger volume of waste traded from North to South when the environmental arbitrage condition $\tau^{NS} < p_e^N - p_e^S - t^{NS}$ is satisfied.

Corollary 2: If $\tau^{NS} < p_e^N - p_e^S - t^{NS}$, then

(i) increases in the percentage of $X$ goods wasted, $\delta^N$,
(ii) increases in the size of the South population, $L^S$,
(iii) increases in the productivity of the South $X$ sector, $\alpha^S$, or
(iv) decreases in the share of X in consumption, $\gamma$, further increase the volume of waste being shipped from North to South.

**Welfare**

Let the backhaul rate when North does not ship its waste to South, such that the backhaul rate is given by equation (13'), be denoted by $\tau_{NS}$ and let the backhaul rate when North does ship its waste to South, such that the backhaul rate is given by equation (14'), be denoted by $\tau_{w}$. If the North does not ship waste to the South then welfare in the two countries is given by consumer welfare plus the revenue generated from the waste tax:

$$U^N = \left( \frac{L^N \gamma \beta^N}{p^T + \tau_{SN} + t^SN + p_e^N} \right)^\gamma (L^N (1 - \gamma) \beta^N)^{1 - \gamma} - L^N \lambda^N W^N + p_e^N W^N, \quad \text{(16N)}$$

and

$$U^S = \left( \frac{L^S \alpha \beta^S}{p^T + p_e^S} \right)^\gamma \left( \frac{L^S (1 - \gamma) \beta^S}{1 + \tau_{NS} + t^{NS}} \right)^{1 - \gamma} - L^S \lambda^S \left( \frac{\delta^S L^S \alpha \beta^S}{p^T + p_e^S} \right) + p_e^S W^S. \quad \text{(16S)}$$

Because the Pigouvian tax in each country is just equal to the social disutility of another unit of waste, the last two terms in equations (16N) and (16S) cancel out.

To assess the welfare impacts of a movement from no waste being traded from North to South to a situation where North does ship its waste to South, consider the welfare of each country when $p_e^N > p_e^S + \tau_{NS} + t^{NS}$:

$$U^N_w = \left( \frac{L^N \gamma \beta^N}{p^T + \tau_{SN} + t^SN + p_e^N} \right)^\gamma (L^N (1 - \gamma) \beta^N)^{1 - \gamma} + (p_e^N - p_e^S - \tau_{NS} - \tau^{NS}) W^N, \quad \text{(17N)}$$

and

$$U^S_w = \left( \frac{L^S \alpha \beta^S}{p^T + p_e^S} \right)^\gamma \left( \frac{L^S (1 - \gamma) \beta^S}{1 + \tau_{w} + t^{NS}} \right)^{1 - \gamma} - L^S \lambda^S (W^S + W^N) + p_e^S (W^S + W^N), \quad \text{(17S)}$$
The last term in equation (17N) represents the gain to the North from the environmental arbitrage condition. Like equation (16S), the last two terms in equation (17S) cancel out as the marginal disutility of pollution is compensated by the revenue from the Pigouvian tax on waste.

Subtracting equation (16N) from equation (17N) and equation (16S) from equation (17S) we see the change in welfare for the North and South, respectively, for a movement from a regime in which the North does not ship waste to South to a regime in which the North does ship waste to South:

\[
U_w^N - U_N^N = (p_e^N - p_e^S - t_{NS} - \tau_{NS})W_N^N > 0, \quad (18N)
\]

and

\[
U_w^S - U_S^S = \left( \frac{L_s^{\gamma} \alpha_s^{\tau} p_{\tau}^{\gamma}}{p_{\tau}^{\gamma} + p_e^S} \right) \left( \frac{L_s^{\gamma} (1 - \gamma) \alpha_s^{\tau} p_{\tau}^{\gamma}}{1 + \tau_{wS}^{NS} + t_{NS}^{NS}} - \frac{L_s^{\gamma} (1 - \gamma) \alpha_s^{\tau} p_{\tau}^{\gamma}}{1 + \tau_s^{NS} + t_{NS}^{NS}} \right)^{-\gamma} < 0. \quad (18S)
\]

**Proposition 9:** A movement from a regime where North keeps its waste at home to a regime where North ships its waste to South unambiguously makes the North better off and the South worse off.

From equation (18N), the gains to the North are equal to the difference in revenues created from charging a higher tax in the North and then disposing of the waste at the lower shipping inclusive tax rate in the South. For the South, the key to understanding the negative value in equation (18S) is by looking at the backhaul rate with and without waste trade. For any parameter values of the model, \( \tau_{wS}^{NS} > \tau_{NS}^{NS} \), meaning that the second term in brackets in equation (18S) is negative. Thus, the loses for the South arise not because they import more waste (they are paid their marginal social disutility for each unit), but rather because waste takes up room on the ship, driving up the backhaul rate, making their final consumption good, \( Y \), more expensive.
The analysis above shows that even when both governments charge the optimal Pigouvian tax, the South is made unambiguously worse off due to a decline in the shipping terms of trade on their final good imports. However, in many developing countries, corruption, lack of information and enforcement problems may prevent the South from charging or collecting the optimal Pigouvian tax. In such a situation, it is easy to show that the South is made even worse off. Define $p^S_{*e}$ as a suboptimal domestic Pigouvian tax in the South such that $p^S_{*e} < p^S_e$, then the environmental arbitrage condition for the North improves making it more likely that North will ship its waste to South. If the North does ship waste to the South, the arbitrage gain to the North is greater than if the optimal domestic Pigouvian tax had been charged in the South:

$$U^N_N - U^N - (p^N_e - p^S_{*e} - t^{NS} - \tau^{NS})W^N > 0.$$  (19N)

For the South, the loss is greater than if the optimal Pigouvian tax had be charged:

$$U^S_w - U^S = \left( \frac{L^S p^S_{*e} \alpha^S p^T}{p^T + p^S_{*e}} \right)^{1+\gamma} \left( \frac{L^S (1-\gamma)(\alpha^S p^T)}{1 + \tau^NS + t^{NS}} \right) - (L^S \lambda^S - p^S_{*e})W^N < 0 \quad (19S)$$

The intuition is simple, the South now faces an even larger terms of trade shipping loss ($p^S_{*e} < p^S_e$ in the first term in brackets and $\tau^NS > \tau^{NS}$ in the second term in brackets of equation (19S)) as well as collecting revenues on waste (both domestically and on imports from North) that are less than the marginal social disutility of waste.

**Conclusions**

The generation of e-waste is growing at an exceptional rate worldwide with each passing year as newer and faster electronics are invented that render products that may be no more than a few years old obsolete. An increasing trend has been for developed countries to ship waste to less developed countries where the handling and disposal costs...
of waste are lower. This environmental arbitrage condition for developed countries is improved by conditions in the international market for shipping. This paper identifies country and shipping market characteristics that influence the backhaul rate from North to South that potentially increases the likelihood that North will ship its waste to ‘pollution havens’ in the South.

In particular, it is shown that if the final goods being exported from South to North are higher in volume (take up more cargo space on a ship) than the volume of final goods being shipped from North to South, the North runs a trade deficit with the South, or there are high external trade barriers in shipping from South to North, then the backhaul rate from North to South will decline and improve the possibility for North to ship its waste to the South. Additionally, improvements in the efficiency of the shipping industry that decrease the marginal cost of shipping or increase the capacity of ships along trading routes will additionally decrease the backhaul rate and improve the North’s environmental arbitrage condition for shipping waste to the South.

If the North does ship waste to the South, the North is made unambiguously better off while the South is made worse off, even if both countries charge an optimal Pigouvian tax on waste. The reason for this is not because of the increased in waste per se, but rather due to a deteriorating terms of trade for the South on their final import good. When the South is unable or unwilling to set the optimal Pigouvian tax on the polluting good, it is shown that the South is made even worse off; losing from both the terms of trade loss and the social disutility of increased waste.
References


<table>
<thead>
<tr>
<th>Year</th>
<th>Asia-USA</th>
<th>USA-Asia</th>
<th>(USA-Asia)/(Asia-USA) Freight Rate Ratio</th>
<th>Cargo Flows (thousands of TEU)</th>
<th>Asia-USA</th>
<th>USA-Asia</th>
<th>(USA-Asia)/(Asia-USA) Cargo Flow Ratio</th>
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Correlation between Freight Rate Ratio and Cargo Flow Ratio = 0.83

Note: TEU stands for Twenty-foot Equivalent Unit

*Asia is defined by The United Nations Conference on Trade and Development's Review of Maritime Transport as Iraq, Jordan, Kuwait, Lebanon, Oman, Saudi Arabia, Syrian Arab Republic, Turkey, United Arab Emirates, Yemen, Afghanistan, Bangladesh, Bhutan, India, Iran, Maldives, Nepal, Pakistan, Sri Lanka, China, Korea (DPR), Hong Kong, Macao, Mongolia, Korea, Taiwan, Brunei Darussalam Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand, Timor-Leste, Singapore, and Vietnam.


<table>
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<tr>
<th>Year</th>
<th>USA-Asia Average Freight Rate ($/TEU)</th>
<th>Exports From USA to Asia</th>
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<td>Waste, Parings, and Scrap of Plastics(^1) (thousand metric tons)</td>
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<td>803</td>
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</table>

**Correlation with USA-Asia Average Freight Rate**

-0.77

-0.72

Note: TEU stands for Twenty-foot equivalent unit

*Asia is defined by The United Nations Conference on Trade and Development's Review of Maritime Transport as Iraq, Jordan, Kuwait, Lebanon, Oman, Saudi Arabia, Syrian Arab Republic, Turkey, United Arab Emirates, Yemen, Afghanistan, Bangladesh, Bhutan, India, Iran, Maldives, Nepal, Pakistan, Sri Lanka, China, Korea (DPR), Hong Kong, Macao, Mongolia, Korea, Taiwan, Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand, Timor-Leste, Singapore, and Vietnam.

\(^1\)Waste, Parings, and Scrap of Plastics are the sum of SITC categories 3215910000, 3215920000, 3215930000, 3215900010, and 3215900090.

\(^{++}\)Waste and Scrap of Alloy Steel is the sum of SITC categories 7204210000 and 7204290000.