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Consumer waste, backhauling, and pollution havens



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## **CONSUMER WASTE, BACKHAULING, AND POLLUTION HAVENS**

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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 2007, US exports of waste plastics and ferrous waste along the USA-Asia trade route increased by 917% and 482%, respectively. Over the same time period the average freight rate on commercial liners along the USA-Asia trade route fell by 46%, while average freight rates along the Asia-USA trade route increased by 2.9%. 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 shows 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 to export its 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.

*JEL classification codes:* Q56, F18

*Key words:* pollution havens, trade, environment, asymmetric trade costs, e-waste, backhauling

### **I. 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

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years now. An extensive theoretical and empirical literature 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.<sup>1</sup> 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*...which might better be termed ‘waste havens’. The rise and expansion of the technological age has generated a rapidly growing international environmental problem that has been largely unexplored. Namely, ‘waste 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 ‘waste 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 are 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

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<sup>1</sup> The pollution haven literature has focused on the effects of differences in environmental regulations on trade and FDI flows, which include works such as Keller and Levinson (2002), Fredriksson, List, and Millimet (2003), Eskeland, and Harrison (2003), Ederington and Minier (2003), Javorcik and Wei (2004), Ederington, Levinson, and Minier (2004), Kahn and Yutaka Yoshino (2004), Ederington, Levinson, and Minier (2005), McAusland (2008), and Kellenberg (2009), as well as those that have looked at the effects of trade and FDI flows on environmental quality, such as Copeland and Taylor (1999), Antweiler, Copeland, and Taylor (2001), Dean (2002), Cole and Elliott (2003), Cole (2004), Frankel and Rose (2005), Chintrakarn and Millimet (2006), Dietzenbacher and Mukhopadhyay (2007), and Kellenberg (2008).

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 separately 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, 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. The Basel Action Network (BAN) has documented examples of highly polluted 'e-waste villages' in places such as Guiyu (China) and Lagos (Nigeria).

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.<sup>2</sup>

In Table 1 we see that between 1996 and 2007, the average freight rate from Asia to the U.S. (headhaul) increased by 2.9%, while the average freight rate from

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<sup>2</sup> 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).

the U.S. to Asia (backhaul) decreased by 46%. 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 routs are highly correlated, with a simple correlation of 0.81.

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.<sup>3</sup> 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-waste, have ratified the Basel Convention and BAN Amendment. Imports of e-waste are officially illegal in these countries. However, developed

**Table 1. Average freight rates and cargo flows between USA and Asia\*, 1996-2005**

Year	Freight rates (\$/TEU)			Cargo flows (thousand TEU's)		
	Asia-USA	USA-Asia	(USA-Asia)/(Asia-USA) freight rate ratio	Asia-USA	USA-Asia	(USA-Asia)/(Asia-USA) cargo flow ratio
1996	1,636	1,417	0.866	4,104	3,520	0.858
1997	1,403	1,292	0.921	4,662	3,615	0.775
1998	1,495	994	0.665	5,220	3,330	0.638
1999	2,005	814	0.406	5,840	3,370	0.577
2000	2,013	852	0.423	5,590	3,250	0.581
2001	1,718	817	0.476	5,760	3,250	0.564
2002	1,502	769	0.512	8,810	3,900	0.443
2003	1,777	833	0.469	10,190	4,900	0.481
2004	1,896	816	0.430	11,780	4,400	0.374
2005	1,874	803	0.428	12,400	4,200	0.339
2006	1,744	815	0.467	13,900	4,600	0.331
2007	1,683	769	0.457	15,400	4,900	0.318

Correlation between freight rate ratio and cargo flow ratio = 0.81.

Notes: TEU stands for twenty-foot equivalent unit cargo containers. \* 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. Data on freight rates and cargo flows come from the 1997-2008 editions of the UNCTAD *Review of Maritime Transport*.

<sup>3</sup> The U.S. is a signatory to the Basel Convention but has not ratified it.

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., can 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 sometimes as metal or plastic waste. Table 2 shows the physical volume of plastic and ferrous waste exported from the U.S. to Asia between 1996 and 2007. During that time, growth in plastic and metal waste exports increased by 917% and 482%, respectively. Importantly, the increase in waste plastic exports and ferrous waste exports are negatively correlated with the falling average backhaul rate from the U.S. to Asia.<sup>4</sup>

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 paper is related to Levinson (1999a), Levinson (1999b), and Cassing and Kuhn (2003) in that different 'states' make a decision about whether to ship waste to another 'state' or dispose of it at home based on differences in an environmental tax on waste. However, unlike Levinson (1999a) who examines differences in domestic and foreign waste tax elasticities, or Copeland (1991) who examines second best policies for a small open economy in the presence of illegal waste disposal, or Cassing and Kuhn (2003) who examine issues of strategic environmental policy across countries; this paper assumes that each country simply sets the optimal domestic Pigouvian tax based on the domestic marginal social cost of waste. The reason for tying down the optimal domestic Pigouvian tax in each country is to isolate the important but unexplored role of endogenous transport costs for the international trade of waste. Copeland (1991), Levinson (1999a), and Cassing

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<sup>4</sup> It should be noted that there are many types of waste traded internationally and that waste trade does occur from South to North and North to North as documented by Baggs (2009). The model here does not offer a complete explanation for all waste trade patterns but rather particular waste flows, such as e-waste trade, between North and South countries.

**Table 2. Exports of waste plastic and ferrous waste from USA to Asia,\* 1996-2007**

Year	USA-Asia average freight rate (\$/TEU)	Exports from USA to Asia	
		Waste, parings, and scrap of plastics <sup>+</sup> (thousand metric tons)	Ferrous waste and scrap <sup>++</sup> (thousand metric tons)
1996	1,417	114	582
1997	1,292	80	809
1998	994	94	875
1999	814	188	682
2000	852	277	1,062
2001	817	404	1,066
2002	769	459	1,179
2003	833	508	1,279
2004	816	521	1,546
2005	803	634	1,772
2006	815	848	4,733
2007	769	1,163	3,385
Correlation with USA-Asia average freight rate		-0.61	-0.41

Notes: TEU stands for twenty-foot equivalent unit cargo containers. \* 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. Data on plastic and ferrous waste exports are from the U.S. International Trade Commission's DataWeb database, which can be found at [www.usitc.gov](http://www.usitc.gov). <sup>+</sup> Waste, Parings, and Scrap of Plastics are the sum of HTS categories 391510000, 391520000, 391530000, 3915900010, and 3915900090. <sup>++</sup> Waste and Scrap of Alloy Steel is the sum of HTS categories 7204100000, 7204210000, 7204290000, and 7204300000.

and Kuhn (2003) all assume constant transport costs and examine various aspects regarding second best policies, strategic policy, and the efficiency of environmental taxes on waste, but as Tables 1 and 2 clearly suggest, asymmetric transport costs are important factors in waste trade that have not been previously examined.

It is shown 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 next section describes the basic two country general equilibrium model, the autarky and trade equilibriums and explores the effects of trade deficits on transport costs and trade flows. Section III studies the welfare impacts on North and South when North exports its waste to South. Section IV offers conclusions.

## II. The model

Two countries, North ( $N$ ) and South ( $S$ ), produce two goods,  $X$  and  $Y$ , using a composite labor factor<sup>5</sup>,  $L$ , 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:

$$X_p^N = \alpha^N L_x^N, X_p^S = \alpha^S L_x^S, Y_p^N = \beta^N L_y^N, \text{ and } Y_p^S = \beta^S L_y^S \quad (1)$$

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:

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<sup>5</sup> The composite labor factor can be thought of as a combination of labor and capital that is supplied in fixed proportions.

$$U_i^N = (x_{ic}^N)^{\gamma} (y_{ic}^N)^{1-\gamma} - \lambda^N \sum_{i=1}^{L^N} w_i^N, \text{ and } U_j^S = (x_{jc}^S)^{\gamma} (y_{jc}^S)^{1-\gamma} - \lambda^S \sum_{j=1}^{L^S} w_j^S, \quad (2)$$

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.<sup>6</sup> 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  $\delta$  is 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 ( $p_e^N$  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:

$$p_e^N = L^N \lambda^N \text{ and } p_e^S = L^S \lambda^S. \quad (3)$$

Revenues generated by the Pigouvian tax go to the government to be spent on the mitigation of waste<sup>7</sup> (can be thought of as the cost of landfill), which is assumed to have a constant marginal cost equal to the Pigouvian tax.<sup>8</sup> In equilibrium, the Pigouvian tax revenues equal the cost of mitigation of waste.

### A. Autarky equilibrium

In the autarky equilibrium, the government chooses the Pigouvian tax rate such that the marginal social cost of waste is equal to the marginal social disutility of waste

<sup>6</sup> 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.

<sup>7</sup> 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. However, the analysis could equally be thought of as a third party “recycler” who receives the tax revenues and has a constant marginal cost of mitigation.

<sup>8</sup> The assumption that the marginal cost of the mitigation of waste 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.

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,  $I$ , is equal to the marginal revenue product of the  $Y$  sector such that  $I^k = \beta^k$  and producer prices for good  $X$  are  $p^k = \frac{\beta^k}{\alpha^k}$  for  $k = N, S$ . Aggregate equilibrium demands for  $X$  and  $Y$  in each country (denoted by the subscript  $d$ ) are

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

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:

$$X_d^k = \frac{L^k \gamma (I^k)}{p^k + p_e^k}, L_{x^*}^k = \frac{L^k \gamma (I^k)}{\alpha^k (p^k + p_e^k)}, Y_{x^*}^k = \beta^k (L^k - L_{x^*}^k), \text{ and } W_{x^*}^k = \delta^k X_{x^*}^k, \tag{5}$$

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.

**B. 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 an 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.<sup>9</sup>

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

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<sup>9</sup> 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.

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  $1 + \tau^{SN} + t^{SN}$  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 ( $X_E^{SN}$ ) and exports of the  $Y$  good from North to South ( $Y_E^{NS}$ ) are:<sup>10</sup>

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

Stopford (1997) has pointed out that containerized liners have come to command a large majority of the value of goods shipped by sea.<sup>11</sup> Liners are often organized into ‘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 2009). In a partial equilibrium model, Hummels, Lugovskyy, and Skiba (2009) 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 liners 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 (1997, p. 363-64) 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.

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<sup>10</sup> Given complete specialization by North and South, incomes in the two countries in equilibrium are  $I^N = \beta^N$  and  $I^S = \alpha^S p^T$ .

<sup>11</sup> 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.

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.<sup>12</sup> There are two important differences that the specification in this paper makes from Hummels, Lugovskyy and Skiba (2009). 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 (2009). 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 (2009) 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  $0 \leq c < 1$ .<sup>13</sup>

It is assumed that North exports low volume goods to South, while South exports high volume goods to North.<sup>14</sup> 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  $Y$  sector goods.

Let  $n$  represent the total number of ships on the route between South and North. Each of the  $l = 1, \dots, n$  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

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<sup>12</sup> The fixed number of ships assumption means that the model best describes short to medium run equilibrium when firms are constrained in the number of ships they have available. In the long run, firms could build new ships to enter the market if transport prices remain high.

<sup>13</sup> 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.

<sup>14</sup> 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.

$$\pi_l = q_{xl}^{SN} (\tau^{SN} - c) + (q_{yl}^{NS} + q_{wl}^{NS}) (\tau^{NS} - c) - F_l. \tag{7}$$

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

$$nq_{xl}^{SN} = X_E^{SN}, nq_{yl}^{NS} = Y_E^{NS}, \text{ and } nq_{wl}^{NS} = W_E^{NS}, \tag{8}$$

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

$$\tau^{SN} = c + \frac{\omega_x \sqrt{L^N \gamma \beta^N}}{nC}. \tag{9}$$

The second term on the right hand side of equation (9) 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 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

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

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

$$\tau^{NS} = c + \frac{\omega_y \sqrt{L^S (1 - \gamma) \alpha^S p^T}}{nC - \left( \frac{\delta^N L^N \gamma \beta^N \omega_x}{p^T + \tau^{SN} + t^{SN} + p_e^N} \right)}. \tag{11}$$

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.<sup>15</sup> The backhaul shipping rate in this case is determined by equation (11).

Balanced trade in the South,  $p^T X_E^{SN} = (1 + \tau^{NS} + t^{NS})Y_E^{NS}$ , implies that:<sup>16</sup>

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

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

$$\tau^{NS} = c + \frac{\omega_y \sqrt{L^N \gamma \beta^N - L^S (1 - \gamma) \alpha^S (\tau^{SN} + t^{SN} + p_e^N)}}{nC}. \tag{13}$$

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

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

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.

<sup>15</sup> 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, 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 third-party recycler.

<sup>16</sup> Balanced trade for the South ensures that the North will clear by Walras’ Law.

**Proposition 1:** *The backhaul rate,  $\tau^{NS}$ , will decrease as a result of:*

- (a) *increases in the per unit volume of X goods,  $\omega_x$ ,*
- (b) *decreases in the per unit volume of Y goods,  $\omega_y$ ,*
- (c) *increases in external trade barriers from South to North,  $t^{SN}$ ,*
- (d) *increases in the number of shipping firms,  $n$ ,*
- (e) *increases in the shipping capacity of each ship,  $C$ , between North and South, and*
- (f) *decreases in the marginal cost of shipping,  $c$ .*

$$\text{Proof: } \frac{\partial \tau^{NS}}{\partial \omega_x} < 0, \frac{\partial \tau^{NS}}{\partial \omega_y} > 0, \frac{\partial \tau^{NS}}{\partial t^{SN}} < 0, \frac{\partial \tau^{NS}}{\partial n} < 0, \frac{\partial \tau^{NS}}{\partial C} < 0, \text{ and } \frac{\partial \tau^{NS}}{\partial c} = 1.$$

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. Grossman and Helpman (1991) type transfer of production of higher volume (weight) manufacturing goods to less developed countries in the South, with specialization and export of knowledge intensive goods and services (lower weight) by the developed North, could contribute to differences in headhaul vs. backhaul shipping rates and, ultimately, the incentive for North to ship its waste to the South.

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 demand for shipping. Given a fixed shipping capacity along the liner routes, shipping firms will have to lower transport prices to fill their ships, increasing the likelihood that the North will ship waste to the South.

Propositions 1(d) and 1(e) further imply 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. In fact, the capacity of fully cellular container ships worldwide increased from 3.09 million TEU in 1996 to 7.17 million TEU in 2005 (UNCTAD 1998 and 2006). More ships with greater capacity along the North/South route drives down per unit headhaul and backhaul markups, improving the North’s environmental arbitrage condition for shipping waste to the South.

Improvements in the efficiency of shipping, such as standardized containerization and mechanization of ship loading, that lower the unit cost of transport decreases

the cost of shipping waste products from North to South. An interesting corollary to proposition 1(f) 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,  $\tau^{NS}$ .*

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 similar South country further away.

Equation (13) suggests that improvements to the technology in the North and South can also have implications for the backhaul rate. These affects are summarized in Propositions 2 and 3.

**Proposition 2:** *For sufficiently large values of  $Y$  sector productivity in the North,  $\beta^N$ , the backhaul rate,  $\tau^{NS}$ , is increasing in  $\beta^N$ . For sufficiently small values of  $Y$  sector productivity in the North,  $\beta^N$ , the backhaul rate,  $\tau^{NS}$ , is decreasing in  $\beta^N$ .*

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

Proposition 2 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 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 3:** *Increases in the productivity of the  $X$  sector in the South,  $\alpha^S$ , decreases the backhaul rate,  $\tau^{NS}$ .*

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. Productivity increases in the South drive down the relative price of  $X$ , inducing South consumers to demand more  $X$  and less  $Y$ . As a result, demand for North  $Y$  goods declines and shipping firms must lower the markup on the backhaul rate to fill the ship on the North to South voyage.<sup>17</sup>

**C. Trade deficits and trade in waste**

From 1996 to 2007, 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 priced at the current price plus interest,  $r$ . The inter-temporal trade balance condition can be written  $p^T X_E^{SN} = (1 + \tau^{NS} + t^{NS}) Y_E^{NS} + (1 + r) p^T G$ .<sup>18</sup> This implies that the equilibrium world price of  $X$  from (12) is now

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

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

$$\tau^{NS} = c + \frac{\omega_y \sqrt{L^N \gamma \beta^N \phi - L^S (1 - \gamma) \alpha^S (\tau^{SN} + t^{SN} + p_e^N)}}{nC}, \text{ and} \tag{13'}$$

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

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

**Proposition 4:** *Increases in the North's current trade deficit with the South ( $G$ ) or increases in the interest rate ( $r$ ) decrease the backhaul rate,  $\tau^{NS}$ .*

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<sup>17</sup> See equation (6).

<sup>18</sup> 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 price of  $(1+r) p^T$ .

Proof:  $\frac{\partial \tau^{NS}}{\partial G} < 0$  and  $\frac{\partial \tau^{NS}}{\partial r} < 0$ .

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  $W_E^{NS} = \delta^N X_E^{SN}$ , conditional on the environmental arbitrage condition, as

$$W_E^{NS} = \begin{cases} \delta^N (L^S(1-\gamma)\alpha^S + (1+r)G) & \text{for } \tau^{NS} < p_e^N - p_e^S - t^{NS} \\ 0 & \text{for } \tau^{NS} \geq p_e^N - p_e^S - t^{NS} \end{cases} \quad (15)$$

**Proposition 5:** *If  $\tau^{NS} < p_e^N - p_e^S - t^{NS}$ , then increases in the North's current trade deficit with the South ( $G$ ) increase 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 4 we see that increases in 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 summarizes 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*

- (a) *increases in the percentage of  $X$  goods wasted,  $\delta^N$ ,*
- (b) *increases in the size of the South population,  $L^S$ ,*
- (c) *increases in the productivity of the South  $X$  sector,  $\alpha^N$ ,*
- (d) *decreases in the share of  $X$  in consumption,  $\gamma$ , or*
- (e) *increases in the interest rate,  $r$ , further increase the volume of waste being shipped from North to South.*

### III. 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  $t_w^{NS}$ . 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:

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

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

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  $p_e^N > p_e^S + \tau^{NS} + t^{NS}$ :

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

$$U_w^S = \left( \frac{L^S \gamma \alpha^S p^T}{p^T + p_e^S} \right)^\gamma \left( \frac{L^S (1-\gamma) (\alpha^S p^T)}{1 + \tau_w^{NS} + t^{NS}} \right)^{1-\gamma} - L^S \lambda^S (W^S + W^N) + p_e^S (W^S + W^N), \quad (17S)$$

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:

$$U_w^N - U^N = (p_e^N - p_e^S - t^{NS} - \tau^{NS}) W^N > 0, \text{ and} \quad (18N)$$

$$U_w^S - U^S = \left( \frac{L^S \gamma \alpha^S p^T}{p^T + p_e^S} \right)^\gamma \left( \frac{L^S (1-\gamma) (\alpha^S p^T)}{1 + \tau_w^{NS} + t^{NS}} - \frac{L^S (1-\gamma) (\alpha^S p^T)}{1 + \tau^{NS} + t^{NS}} \right)^{1-\gamma} < 0. \quad (18S)$$

**Proposition 6:** *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,  $\tau_w^{NS} > \tau^{NS}$ , meaning that the second term in brackets in equation (18S) is negative. Thus, the losses 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.<sup>19</sup> 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  $p_{-e}^S$  as a suboptimal domestic Pigouvian tax in the South such that  $p_{-e}^S < p_e^S$ , 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:

$$U_w^N - U^N = (p_e^N - p_{-e}^S - t^{NS} - \tau^{NS})W^N > 0. \quad (19N)$$

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<sup>19</sup> The analysis is a decentralized equilibrium in which no transfers are considered from North to South. It is conceivable that a lump-sum transfer of a percentage of North profits could be made to the South to compensate them for the transport terms of trade loss on their consumption good. In the absence of such a transfer, South is worse off.

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

$$U_w^S - U^S = \left( \frac{L^S \gamma \alpha^S p^T}{p^T + p_{-e}^S} \right)^\gamma \left( \frac{L^S (1-\gamma) (\alpha^S p^T)}{1 + \tau_w^{NS} + t^{NS}} - \frac{L^S (1-\gamma) (\alpha^S p^T)}{1 + \tau^{NS} + t^{NS}} \right)^{1-\gamma} \quad (19S)$$

$$- (L^S \lambda^S - p_{-e}^S) (W^N) < 0$$

The intuition is simple, the South now faces an even larger terms of trade shipping loss ( $p_{-e}^S < p_e^S$  in the first term in brackets and  $\tau_w^{NS} > \tau^{NS}$  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.

#### IV. 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 obsolete products that may be no more than a few years old. 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 ‘waste havens’ in the South.

Although international data on waste trade is difficult to obtain, this article provides a number of testable hypothesis regarding the relationship between country characteristics, trade deficits, shipping market attributes, and waste flows that could be estimated in future work. In particular, it shows 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 increase 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, the South is made even worse off, losing from both the terms of trade loss and the social disutility of increased waste.

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