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Global Reuse and Optimal Waste Policy

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Abstract:

This paper develops a two-country model to solve for optimal tax policies to achieve the efficient level of economic resources in an economy with global reuse. In the baseline case both the developed and developing economies are able to initiate tax policies to internalize the social costs of waste disposal. Unsurprisingly, optimal policy requires each disposal tax to be set equal to the external marginal cost within each country. The model is then extended to the case where only the developed nation can tax waste. The international optimum can still be obtained by either taxing the importation of the used durable good or subsidizing consumer return of durable waste for eventual disposal back in the developed country. If no policy instruments are available in the developing country, the international optimum is obtained by reducing the disposal tax in the developed country to a level below their external marginal cost of disposal.

Keywords:
Solid waste, environmental taxation, durable goods, reuse

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要旨:
本稿はグローバル・リユースがある経済において経済資源の効率的水準を達成するための最適な税政策を導出する２国モデルを構築する。ベースとなるケースの場合、先進国と途上国の双方が廃棄物の社会的費用を内部化する税政策を実行できるとする。この時、当然ながら、各国内において廃棄物税率が限界外部費用と等しくなるように設定されることが最適政策となる。ここからモデルは先進国のみが廃棄物に課税することができるケースへと拡張される。このケースにおいても、中古耐久財の輸入への課税か、途上国の消費者が耐久財の廃棄物を先進国に戻すことへの補助金のいずれかによって世界全体の最適性を達成できる。途上国における政策手段が全くない場合においても、先進国の廃棄物税率を廃棄物の限界外部費用よりも下げることによって世界全体の最適性を達成できる。

キーワード:
廃棄物、環境税、耐久消費財、リユース

1 Introduction

Advances in communication technologies coupled with reductions in transportation costs have increased the scope of global trade over the past 100 years. Recently global trade has included the export of used durable goods from developed to less developed economies. For example, about 10.2 million used computers - roughly 80% of all used computers collected from firms and households in the United States - were exported to Asia in 2002 (Puckett and Smith, 2002). Roughly one-fourth of all used computers collected from firms and households in Japan were exported to developing nations in 2004 - up from just 8% in 2000 (Yoshida *et al.*, 2009). About 2.5 million used cars and trucks were exported from the United States to Mexico between 2005 and 2008 (Davis and Kahn, 2010).

Exporting used durable goods to developing economies for further consumption, a concept we call "global reuse", provides utility to consumers in developing countries but can have negative social consequences if the resulting waste contains toxic substances and developing nations lack appropriate disposal methods. The cathode ray tubes of televisions and personal computers, for example, contain large amounts of lead oxide and cadmium - substances harmful to the natural environment and human health. The circuit boards of computers and cell phones also contain lead and cadmium. Modern flat-screen panel monitors contain mercury, another harmful pollutant potentially damaging to human nervous systems.[1]

Thus the waste from these durable goods can be hazardous when untreated, or not appropriately treated. Therefore appropriate disposal techniques can be necessary to mitigate external effects of disposal. Such disposal technologies are often available in developed countries. But less developed importing coun-

[1] Inorganic mercury mixed with water is transformed to methylated mercury. Methylated mercury easily accumulates in living organisms and concentrates through the food chain. Cadmium compounds accumulate in the human body, particularly the kidneys, and have irreversible consequences for human health (Puckett and Smith, 2002). Each cathrode ray tube contains about 2kg of lead, enough to damage human central and peripheral nerves, which can have a deleterious effect on the growth and development of children. Lead is also an endocrine disruptor (Yoshida, 2002).

tries such as China, Philipine, India, Pakistan, Mexico or Nigeria rarely possess the technologies, policies, and enforcement infrastructures necessary to control external disposal costs. In Guiyu, China, for example, broken CRTs are regularly dumped on open land or pushed into rivers (Puckett and Smith, 2002). In Nigeria, used televisions and computers are used to fill swamps (Puckett, 2005).

This paper develops a two-country model to solve for optimal taxes and subsidies necessary in an economy with global reuse. The model, we believe, is easy to understand and replicate. Results are intuitive and relevant to policy formation. In the baseline case both the developed and developing economies are able to initiate tax policies to internalize the social costs of waste disposal. Unsurprisingly, optimal policy requires each disposal tax be set equal to the external marginal cost within each country. The model is then extended to the more interesting case where only the developed nation can tax waste. Under this assumption, and when coupled with a disposal tax in the developed country, the government of the developing country can still achieve the international Pareto Optimum by either taxing the importation of the used durable good or subsidizing consumer return of durable waste for eventual disposal back in the developed country. If policy instruments are unavailable to the developing country, the international Pareto Optimum is obtained by reducing the disposal tax in the developed country to a level below their external marginal cost of disposal. Before introducing the model, the next section of this paper summarizes the literature on durable goods and the international market for waste.

2 The Literature

In a closed economy, several papers have demonstrated that the optimal policy for internalizing the social costs of waste disposal is a tax on disposal set equal to the external marginal cost of disposal (beginning with Wertz, 1976). Where illegal dumping is problematic, the disposal tax is replaced by a subsidy to recycling coupled with a tax on consumption - a deposit refund program (Fullerton and Kinnaman, 1995). Shinkuma (2007) extends the waste policy literature for a closed-economy to the case of durable goods by demonstrating that advanced disposal fees lead to inefficient choices between reuse and disposal.

The solid waste literature on open economies focuses almost entirely on the international transfer of pure waste, rather than on waste embedded in used goods. Copeland (1991) argues that eliminating trans-national shipments of waste can improve welfare if importing governments do not adequately regulate waste disposal or if such regulations cause illegal dumping in those countries. For the case of durable goods, banning international trade may not be efficient if the additional value consumers place on imported used durable goods exceeds the difference in external costs of disposal between the importing and exporting country. Rauscher (2001) also examines the international trade in hazardous waste.

A collection of other papers examines the strategic use of waste taxes to alter trade patterns. For example, Krutilla (1991) suggests national governments will set waste taxes in exporting industries to levels above the external cost of disposal to reduce supply and therefore improve international terms of trade. Waste taxes in importing industries, on the other hand, are set below external costs to help these industries compete globally. Alternatively, Kennedy (1994) argues that where competition is imperfect, governments could (1) reduce domestic disposal taxes to improve rents to exporting industries while at the same time (2) increase domestic disposal taxes to encourage the transfer of waste to other countries. The first effect is found to outweigh the second effect if the external costs of waste disposal do not extend beyond a nation's borders. Cassing and Kuhn (2003) find that importing countries levy waste taxes below the external marginal cost of disposal and below waste taxes in exporting countries to correct for the market inefficiency caused by imperfect competition in exporting countries. Barrett (1994) and Simpson (1995) also examine the use of environmental waste taxes as substitutes for trade taxes. Although we do not model strategic trade behavior, the paper contributes to this literature by considering the substitutability of waste and trade taxes for reaching international efficiency.

Research into closed economies with durable goods goes back at least as far as Anderson and Ginsburgh (1994). More recently, Thomas (2003) focuses on the relationship between material consumption and transaction costs of second-hand markets and Yokoo (2010) examines the impact of reuse activity on consumer welfare. Shinkuma (2011) is the first to distinguish durable goods from non-durable goods in the context of optimal waste policy in a global setting and finds that an advanced disposal fee is internationally inefficient. Our study expands upon the work of Shinkuma (2011) by considering policy options beyond a producer responsibility measure.

3 The Model

This section develops a baseline model where both a developed and developing country can tax waste. This model expands upon a domestic waste model of Fullerton and Kinnaman (1995), Fullerton and Wu (1998), and Kinnaman (2010). Assume an open economy is comprised of two countries. Country A is endowed with a technology to produce durable goods such as televisions, computers, or automobiles. After consuming the durable good (with quantity d), consumers in Country A either dispose the good as waste in Country A (w^A) or export the used durable good to Country B for additional consumption (e). Thus $d = w^A + e$ (where $w^A, e \geq 0$). Once the used durable good has been consumed again in Country B, and providing utility to consumers in Country B along the way, it eventually becomes waste for disposal in Country B (w^B). Thus, from a materials perspective $e = w^B$. Assume all of this consumption and disposal activity occurs within a single time period. Within the context of a dynamic model, the conditions $d = w^A + e$ and $e = w^B$ could describe a steady state.[2]

[2] See Yokoo (2010) for theoretical treatment of durable good consumption in a dynamic model.

Assume country A is comprised of n identical consumers each with utility (U^A) defined over their own consumption of the durable good (d) and the total quantity of waste disposed in Country A (nw^A),

$$U^A = U^A\left(d, nw^A\right), \text{ where } U_d^A > 0 \text{ and } U_w^A < 0. \tag{1}$$

Assume a global economic resource such as capital or energy (k) constitutes the only input into five production processes.[3] First, the economic resource (with quantity k^d) can be employed to produce the durable good (d) in Country A according to the production function,

$$d = f\left(k^d\right), \text{ where } f' > 0. \tag{2}$$

Second, the economic resource (k^w) can be used to collect and dispose the used durable good as waste in Country A (w^A) according to the production function

$$w^A = g\left(k^w\right), \text{ where } g' > 0. \tag{3}$$

Third, transporting the used durable good from Country A to Country B requires the economic resource (k^e) according to $e = e\left(k^e\right)$. This function can be inverted to solve for k^e,

$$k^e = k^e\left(e\right), \text{ where } k^{e\prime} > 0. \tag{4}$$

In Country B, the representative consumer gains utility (U^B) from consuming the imported used durable good (e), consuming a non-durable good (c), and the aggregate quantity of waste resulting from used durable goods (mw^B, where m denotes the number of identical consumers in Country B and recall that $e = w^B$)

[3]Throughout this paper we assume this economic resource is freely transferable between Countries A and B. The model could instead allow only the intra-country transfer of the economic resource. An interesting question is how such a change would alter policy results.

$$U^B = U^B\left(e, c, mw^B\right), \text{ where } U_e^B > 0, U_c^B > 0, \text{ and } U_w^B < 0. \tag{5}$$

The non-durable good (c) is produced in Country B using the same global economic resource available to Country A above (with quantity k^c, the fourth use of the resource) according to the production function,

$$c = h\left(k^c\right), \text{ where } h' > 0. \tag{6}$$

Assume this non-durable good does not generate waste sufficient to affect the utility of the consumers of Country B. Examples of such a good could include agricultural products, local services, or leisure.

Waste resulting from the used durable good consumed in Country B is processed and disposed using the economic resource (k^b) according to,

$$w^B = b\left(k^b\right), \text{ where } b' > 0. \tag{7}$$

Finally, assume the total quantity of the global economic resource available to the five production processes is $\overline{k}$ and is fully employed,

$$\overline{k} = k^d + k^w + k^e + k^c + k^b. \tag{8}$$

3.1 Social Efficiency

To achieve the Pareto Optimal allocation of the economic resource across the five production processes, a social planner maximizes the utility of the representative consumer in Country A subject to holding the utility of the representative consumer in Country B constant at $\overline{U^B}$. The social planner is constrained by the materials balance conditions ($d = w^A + e$ and $e = w^B$), the five production functions (in 2, 3, 4, 6, and 7), and the economic resource constraint given in (8). Upon substitution, the problem reduces to choosing k^w, k^b, and k^d to maximize the Lagrange function,

$$
\begin{aligned}
L &= U^A\left\{g\left(k^w\right)+b\left(k^b\right),ng\left(k^w\right)\right\} \\
&+\lambda_1\left[\overline{U^B}-U^B\left\{b\left(k^b\right),h\left(\overline{k}-k^d-k^w-k^e\left(b\left(k^b\right)\right)-k^b\right),mb\left(k^b\right)\right\}\right] \\
&+\lambda_2\left[f\left(k^d\right)-g\left(k^w\right)-b\left(k^b\right)\right]
\end{aligned}
$$

where λ_1 and λ_2 are Lagrange multipliers. The first-order conditions are

$$L_{kw} : U_d^A g' + nU_w^A g' = \lambda_1\left(-U_c^B h'\right) + \lambda_2 g', \tag{9a}$$

$$L_{kb} : U_d^A b' = \lambda_1\left(U_e^B b' - U_c^B h' k^{e\prime} b' - U_c^B h' + mU_w^B b'\right) + \lambda_2 b', \tag{9b}$$

$$L_{kd} : \lambda_2 f' = \lambda_1\left(-U_c^B h'\right). \tag{9c}$$

Divide (9a) through by g', divide (9b) through by b', and solve (9c) for λ_1 and substitute into (9a) and (9b) to eliminate λ_1. We are left with,

$$
\begin{aligned}
\frac{U_d^A}{\lambda_2} &= \frac{f'}{g'} + 1 - n\frac{U_w^A}{\lambda_2} \\
\frac{U_d^A}{\lambda_2} &= \frac{f'}{b'} + f'k^{e\prime} - \frac{U_e^B f'}{U_c^B h'} - m\frac{U_w^B f'}{U_c^B h'} + 1
\end{aligned}
$$

or,

$$\frac{f'}{g'} - n\frac{U_w^A}{\lambda_2} = \frac{f'}{b'} + f'k^{e\prime} - \frac{U_e^B f'}{U_c^B h'} - m\frac{U_w^B f'}{U_c^B h'}. \tag{PO1}$$

This equation summarizes the Pareto Optimal allocation of the economic resources across the five uses in the economy. Although intuitively uninteresting in its own right, this expression can be compared to the condition representing the competitive equilibrium to determine optimal tax rates.

3.2 Competitive Equilibrium

Assume a disposal tax is available to the governments of each country (t_w^A and t_w^B). The government in Country B can also levy a tax on each unit of the used durable good imported from Country A (t_m).

Assume a representative consumer in Country A faces prices $p_d = 1$ (the numeraire) to purchase the durable good, p_w^A to dispose the resulting waste from the durable good in Country A, and receives p_e for each unit of the used durable good exported to Country B. Assume the consumer must also pay p_k for the economic resource necessary to employ the technology in (4) to prepare and transport the used durable good to Country B.[4] These prices give rise to the consumer's budget constraint,

$$M^A = d + p_w^A w^A + p_k k^e(e) - p_e e,$$

where M^A denotes an exogenously determined level of consumer income. The representative consumer maximizes utility (1) subject to the above budget constraint and the materials balance constraint $d = w^A + e$. Because the number of consumers is large (n), the representative consumer considers its own contribution to the overall waste externality to be zero. The aggregate quantity of waste (nw^A) is therefore exogenous to the representative consumer. The consumer chooses w^A and e to maximize the Lagrange function,

$$L = U^A\left(w^A + e, \overline{nw^A}\right) + \delta^A\left\{M^A - \left(w^A + e\right) - p_w^A w^A - p_k k^e(e) + p_e e\right\}$$

where δ^A, the Lagrange multiplier, denotes the marginal utility of income. The first-order conditions are

[4] The assumption that consumers employ the technology in (4) to export the used durable good is made purely out of convenience. An export firm could be added to the model that employs the same technology and charges a price to the consumer for this service. Optimal taxes defined below would not change.

$$L_{wA} \quad : \quad U_d^A = \delta^A \left(1 + p_w^A\right), \tag{10a}$$

$$L_e \quad : \quad U_d^A = \delta^A \left(1 + p_k k^{e\prime} - p_e\right). \tag{10b}$$

The representative consumer purchases the durable good to the point that the marginal utility of consumption is equal to the price of durable good plus the overall cost of each of the two disposal options. The utility-maximizing consumer will choose between domestic disposal and export for global reuse such that $p_w^A = p_k k^{e\prime} - p_e$.

Assume a representative competitive firm utilizes the production technology defined in (2) to produce the durable good. This firm chooses the quantity of the economic resource to employ (k^d) to maximize profit, $\pi = f\left(k^d\right) - p_k k^d$. Profit is maximized when

$$f' = p_k. \tag{11}$$

Assume a representative competitive firm collects and disposes waste in Country A by employing the economic resource (k^w) and the technology given in (3). This firm also pays a tax of t_w^A on each unit of waste disposed. The firm chooses the quantity of the economic resource to employ (k^w) to maximize profit, $\pi = \left(p_w^A - t_w^A\right) g\left(k^w\right) - p_k k^w$. Profit is maximized when

$$p_w^A = \frac{p_k}{g'} + t_w^A. \tag{12}$$

The representative consumer in Country B maximizes utility (5) subject to $e = w^B$ (all imported used durable goods are eventually disposed in Country B after they are consumed) and the budget constraint,

$$M^B = \left(p_e + t_m\right) e + p_c c + p_w^B w^B,$$

where p_c is price of the non-durable good and once again p_e is the price of the used durable good imported from Country A. The consumer also pays a price of p_w^B to dispose the waste from the durable good.[5] Because the number of consumers in Country B is large (at m), the representative consumer considers the aggregate quantity of used durable goods disposed in Country B (mw^B) to be exogenous. The representative consumer maximizes utility in (5) subject to this budget constraint and the materials balance constraint $e = w^B$. The first-order conditions are

$$\begin{aligned} L_{wB} &: U_e^B = \delta^B \left(p_e + t_m + p_w^B\right), \\ L_c &: U_c^B = \delta^B p_{c,} \end{aligned}$$

where δ^B is a Lagrange Multiplier. First-order conditions can be simplified to,

$$\frac{U_e^B}{U_c^B} = \frac{p_e + t_m + p_w^B}{p_c}, \tag{13}$$

The competitive firm in country B uses the technology in (6) to produce the non-durable good to maximize profit, $\pi = p_c h\left(k^c\right) - p_k k^c$, by choosing k^c such that

$$p_c = \frac{p_k}{h'}. \tag{14}$$

Finally a competitive firm in Country B employs the disposal technology in (7) to dispose waste from the durable good in Country B. The government of Country B can tax this waste to encourage waste producers to internalize the social costs of disposal. Profit $\pi = \left(p_w^B - t_w^B\right) b\left(k^b\right) - p_k k^b$ is maximized when

$$p_w^B = \frac{p_k}{b'} + t_w^B. \tag{15}$$

[5]This price could be very low or even zero. To the extent that waste disposal is free in Country B, this price could be represented by the residual value of disassembled components from the twice used durable goods. The consumer dumping this waste at a given site transfers the right to extract these components to the waste handler who then extracts valuable materials before finally dumping the remaining unvaluable materials in the natural environment.

Substitute (14), (15) and (11) into (13) to eliminate p_c, p_w^B, and p_k. Solve the resulting equation for p_e and substitute into (10b) to eliminate p_e. Then substitute (12) into (10a) to eliminate p_w^A and substitute (11) into (10a) and (10b) to eliminate p_k. We are left with

$$\begin{aligned} \frac{U_d^A}{\delta^A} &= 1 + \frac{f'}{g'} + t_w^A, \\ \frac{U_d^A}{\delta^A} &= 1 + f'k^{e\prime} - \frac{U_e^B f'}{U_c^B h'} + \frac{f'}{b'} + t_w^B + t_m, \end{aligned}$$

or,

$$\frac{f'}{g'} + t_w^A = f'k^{e\prime} - \frac{U_e^B f'}{U_c^B h'} + \frac{f'}{b'} + t_w^B + t_m. \qquad \text{(CE1)}$$

This equation summarizes the allocation of resources in a decentralized economy as a function of the two waste taxes. Combining (PO1) and (CE1) by eliminating like terms yields the following options for optimal policy,

$$t_w^A - t_w^B - t_m = -n\frac{U_w^A}{\lambda_2} + m\frac{U_w^B f'}{U_c^B h'}. \qquad (16)$$

The Pareto Optimum can be achieved by using a continuum of combinations of these three taxes.

3.3 Policy Strategies

3.3.1 Case 1: Waste Taxes Available to Both Countries ($t_w^A > 0, t_w^B > 0, t_m = 0$)

If waste taxes are available to both countries, then the Pareto Optimum can be achieved be setting[6]:

[6] Combining (14), (16), and (12) suggests $f' = U_c^B h'/\delta^B$ thus allowing $t_w^B = -mU_w^B f'/U_c^B h'$ to be written intuitively as $t_w^B = -mU_w^B/\delta^B$.

$$t_w^{A*} = -n\frac{U_w^A}{\lambda_2}; \quad t_w^{B*} = -m\frac{U_w^B}{\delta^B}; \quad t_m^* = 0.$$

Controlling for a few changes in notations and a few other features of the model, this result is similar to Fullerton and Kinnaman (1995), who solve for the optimal tax in a closed economy. A country sets a tax rate on waste disposal equal to the external marginal cost of waste disposal (nU_w^A and mU_w^B, respectively). The Lagrange multipliers convert the units of taxation from utiles to dollars.

Notice that the optimal waste tax does not depend upon the durable nature of the exported good. If consumers in Country B gain no utility from the imported material ($U_e^B = 0$), the optimal tax policy remains the same. Thus, it makes little difference to formation of optimal policy whether computers and televisions are being exported as pure waste products or as used goods with additional consumptive value. That the international transfer of waste is treated differently by the policy community than the international transfer of goods embedded with waste is beyond the explanatory scope of the model.

3.3.2 Case 2: Waste not Taxed in Country B ($t_w^A > 0, t_w^B = 0, t_m > 0$)

Consider the same economy as described above with the added assumption that the government of Country B is unable to tax waste disposal. Perhaps the economy lacks the necessary technology (scales for weighing trucks entering and exiting landfills, for example) or the government lacks the resources to discourage illegal dumping that might arise with the implementation of a waste tax (Copeland, 1991).

To discourage imports, assume that the government in Country B can levy a tax (t_m) on each unit of the used durable good imported from Country A. By comparing (CE1) with (PO1), the optimal waste tax in County A (t_w^A) can still equal to the external cost of disposal. The optimal import tax is set equal to the external marginal cost of waste disposal in Country B, as was the original waste tax from the previous section

$$t_w^{A*} = -n\frac{U_w^A}{\lambda_2}; \quad t_w^{B*} = 0; \quad t_m^* = -m\frac{U_w^B}{\delta^B}.$$

Either taxes (t_m or t_w^B) increases the overall cost of consuming the used durable good to the consumer in Country B. The consumer responds to either tax by substituting the non-durable good (c) for the used durable good (e) in consumption.

This tax equivalency disappears if consumers in Country B face alternatives for disposing waste (currently $e = w^B$). If, for example, recycling were an option in Country B, then the waste tax would lead to efficient quantities of waste, consumption, and recycling, but the import tax would not lead to an inefficient choice between waste and recycling in Country B. The economy using only waste taxes in Country A and import taxes in Country B will not achieve the Pareto Optimum.

3.3.3 Case 3: No policy Options in Country B ($t_w^A > 0, t_w^B = 0, t_m = 0$)

Suppose Country B is unable to assess the waste tax or the import tax, perhaps due a previous trade agreement. Mexico, for example, eliminated trade restrictions on all 10-15 year-old vehicles in 2005 in accordance with the implementation of NAFTA (Davis and Kahn (2010)). The only remaining tax instrument available to the global economy is the disposal tax levied on waste disposed in County A. By examining Equation (16), the Pareto Optimum can still be achieved by setting the disposal tax in Country A as follows

$$t_w^{A*} = -n\frac{U_w^A}{\lambda_2} + m\frac{U_w^B}{\delta^B}; \quad t_w^{B*} = 0; \quad t_m^* = 0.$$

The waste tax in County A can be positive or negative depending upon the magnitudes of the waste externality in each country. The waste tax in Country A is negative (a subsidy) when $mU_w^B/\delta^B > nU_w^A/\lambda_2$, or when the waste disposal externality in Country B is larger than in County A. The waste subsidy serves to internalize to consumers in Country A the external costs of disposal in Country B. Consumers in Country A respond to the subsidy by efficiently reducing exports of the used durable goods to Country B. As was the case with the import tax discussed above, the efficiency of this waste tax relies upon there being no recycling options in Country B.

That an open country should set a waste tax above or below the domestic external cost of disposal has been found in previous studies, but for other reasons. Krutilla (1991) demonstrates that waste taxes are set above external marginal costs of disposal to reduce imports and therefore improve the terms of trade. Kennedy (1993) suggests waste taxes be set below the external marginal cost of waste to subsidize domestic industries. Cassings and Kuhn (2003) suggest waste taxes fall below the external marginal cost of waste to compensate for the market distortion caused by imperfect competition in the exporting country.

Consider the interesting case when the external disposal costs are equal across the two countries ($-mU_w^B/\delta^B = -nU_w^A/\lambda_2$). The optimal waste tax in this case is zero. The competitive market place void of tax policies in either country results in the efficient allocation of the economic resource. If these two external effects are nearly equal, and if Country A is choosing between its domestically efficient waste tax and no tax, then it might indeed be internationally efficient to opt for no waste tax.

4 An Economy Endowed with Technology to Return Waste

Assume a technology is available to utilize the global economic resource (k^r) to transport the waste from the used durable back to Country A for disposal,

$$w_r = r\left(k^r\right) \text{ where } r' > 0. \tag{17}$$

The representative consumer in Country B now chooses whether to dispose the waste in Country B or return the waste to Country A, thus $e = w^B + w_r$ (with $w^B, w_r \geq 0$). The representative consumer in Country A experiences disutility from both sources of waste,

$$U^A = U^A \left(d, nw^A + mw_r \right). \tag{1'}$$

Finally, the waste disposal firm in Country A must now process waste from consumers in Country A plus waste returned from consumers in Country B. Thus,

$$w^A + w_r = g \left(k^w \right). \tag{3'}$$

All other tastes and technologies in this economy are identical to that modeled above.

4.1 Social Efficiency

The Pareto Optimal allocation of economic resources is found by maximizing the Lagrange function

$$\begin{aligned} L &= U^A \left\{ g\left(k^w\right) + b\left(k^b\right), ng\left(k^w\right) - nr\left(k^r\right) + mr\left(k^r\right) \right\} \\ &\quad + \lambda_1 \left[\overline{U^B} - U^B \left\{ b\left(k^b\right) + r\left(k^r\right), h\left(k\right), mb\left(k^b\right) \right\} \right] \\ &\quad + \lambda_2 \left[f\left(k^d\right) - g\left(k^w\right) - b\left(k^b\right) \right], \end{aligned}$$

where once again $\overline{U^B}$ is a constant, $k = \overline{k} - k^d - k^w - k^e \left(b\left(k^b\right) + r\left(k^r\right) \right) - k^b - k^r$ and λ_1 and λ_2 are Lagrange multipliers. This function is maximized over k^w, k^b, k^r, and k^d. The first-order conditions are

$$L_{kw} \quad : \quad U_d^A g' + nU_w^A g' = \lambda_1 \left(-U_c^B h'\right) + \lambda_2 g',$$

$$L_{kb} \quad : \quad U_d^A b' = \lambda_1 \left(U_e^B b' - U_c^B h' k^{e\prime} b' - U_c^B h' + mU_w^B b'\right) + \lambda_2 b',$$

$$L_{kr} \quad : \quad (m-n)\, U_d^A r' = \lambda_1 \left(U_e^B r' - U_c^B h' k^{e\prime} r' - U_c^B h'\right),$$

$$L_{kd} \quad : \quad \lambda_2 f' = \lambda_1 \left(-U_c^B h'\right).$$

These four equations can be combined by eliminating like terms to get

$$m\frac{U_w^B f'}{U_c^B h'} - n\frac{U_w^A}{\lambda_2} - \frac{f'}{b'} + \frac{f'}{g'} = (m-n)\,\frac{U_w^A}{\lambda_2} - \frac{f'}{r'}. \qquad \text{(PO2)}$$

This equation summarizes the efficient global allocation of the economic resource, and will be compared below with the condition representing a competitive economy.

4.2 Competitive Equilibrium

In the decentralized economy, assume once again that the government of Country A can assess a tax on waste disposed in Country A (t_w^A), which would apply to both domestic waste and waste returned from Country B for disposal in Country A. Assume the only policy instrument in Country B is a subsidy (s_r^B) paid for the return of waste from the used durable goods originally exported from Country A (neither a waste tax or import tax are available in Country B). Although politically problematic, the subsidy could also be offered by the government of Country A if Country B lacks the administrative infrastructure to implement such an instrument.

In Country A, conditions for utility and profit maximization are identical to those stated in (10a), (10b), and (11) above. The waste disposal firm in Country A now receives waste from both Country A and Country B. This firm receives price, p_w^A, from consumers in Country A to dispose the durable good and price, p_r, from consumers in Country B to dispose the returned waste. The waste firm must pay the waste tax on both domestic waste (w^A) and waste returned from Country B (w_r). The waste firm employs the economic resource to facilitate two disposal technologies ((3') and now (17)) to maximize profit, $\pi = \left(p_w^A - t_w^A\right) w^A + \left(p_r - t_w^A\right) w_r - p_k k^w - p_k k^r$. Profit is maximized by equating

$$p_w^A = \frac{p_k}{g'} + t_w^A, \tag{18a}$$

$$p_r = \frac{p_k}{r'} + t_w^A. \tag{18b}$$

In Country B, the representative consumer chooses consumption and disposal practices to maximize utility (5) subject to the condition that $e = w^B + w_r$ and the budget constraint,

$$M^B = p_e e + p_c c + p_r w_r + p_w^B w^B - s_r^B w_r,$$

where each unit of waste returned to Country A (w_r) receives the subsidy. The first-order conditions for utility-maximization are

$$L_c \quad : \quad U_c^B = \delta^B p_{c,} \tag{19a}$$

$$L_{wb} \quad : \quad U_e^B = \delta^B \left(p_e + p_w^B\right), \tag{19b}$$

$$L_{wr} \quad : \quad U_e^B = \delta^B \left(p_e + p_r - s_r^B\right). \tag{19c}$$

Other profit-maximizing conditions representing the competitive economy in Country B are the same as above ((14) and (15), but with $t_w^B = 0$).

The system of equations representing the utility or profit maximizing behavior in the decentralized economy (Equations (10a-b), (11), (14), (15), (18a-b), and (19a-c)) can be combined to eliminate all prices from the model. The resulting equation is

$$t_w^A - \frac{f'}{b'} + \frac{f'}{g'} = s_r^B - \frac{f'}{r'}, \qquad \text{(CE2)}$$

where again recall that $t_w^B = 0$. Combining (PO2) with (CE2) yields the following continuum of optimal tax/subsidy rate combinations (using again the simplifying substitution described in Footnote 6).

$$t_w^{A*} - s_r^{B*} = m\frac{U_w^B}{\delta^B} - m\frac{U_w^A}{\lambda_2}. \qquad (20)$$

We consider several alternatives for achieving the Pareto Optimum.

4.3 Policy Strategies

4.3.1 Case 1: Both Policies Available ($t_w^A \neq 0, s_r^B \neq 0$)

The clearest interpretation of Equation (20) is to set the policy combination,

$$t_w^{A*} = m\frac{U_w^B}{\delta^B}; \quad s_r^{B*} = m\frac{U_w^A}{\lambda_2}.$$

Lacking a disposal tax in Country B, waste in Country A is subsidized to reflect the marginal external costs of disposal in Country B. This subsidy will reduce the quantity of used durable goods exported to Country B as consumers in Country A internalize all social costs of disposal. But this disposal subsidy in Country A could inefficiently increase the return of used durable goods to Country A. To remedy this, the optimal subsidy on the return of used durable goods (s_r^{B*}) is also negative - a tax. The tax on the return of the used durable good reflects the external marginal cost of disposal back in Country A. In combination, these two policy instruments yield the Pareto Optimal allocation of resources.

But neither Country A nor Country B has the individual incentive to follow this policy scheme. Suppose, for example, that Country A sets its waste tax equal to the external marginal cost of disposal in Country A ($t_w^A = -nU_w^A/\lambda_2$). The Pareto Optimum can still be obtained if the return subsidy is set as follows

$$t_w^{A*} = -n\frac{U_w^A}{\lambda_2}; \quad s_r^{B*} = -m\frac{U_w^B}{\delta^B} - n\frac{U_w^A}{\lambda_2} + m\frac{U_w^A}{\lambda_2}.$$

The subsidy reflects first the external marginal cost of disposal in Country B. The subsidy must also negate the effect of the waste tax in Country A. Finally, the subsidy must reflect the external marginal cost of returning the waste for disposal in Country A (the third component). But Country B may not factor these Country A effects when setting the value of the return subsidy. The next case therefore examines the social implications of unilateral policy behavior.

4.3.2 Case 2: Both Country A and Country B Act Independently ($t_w^A > 0, s_r^B > 0$)

Country A may be politically unwilling to set negative waste taxes to discourage the exportation of used durable goods to Country B. If Country A is acting unilaterally, then it may set t_w^A equal to its domestic external marginal cost of disposal ($t_w^A = -nU_w^A/\lambda_2$). Country B, lacking the ability to tax waste disposal or tax the importation of the used durable good but with the ability to subsidize the return of the waste to Country A will act in its own best interest by setting the subsidy at

$$s_r^B = -m\frac{U_w^B}{\delta^B}.$$

This subsidy reflects the external marginal cost of disposal in country B. Facing this subsidy, consumers in Country B internalize the social disposal costs in Country B when choosing whether or not to return waste for disposal in Country A.

According to (20), these two individual strategies are only Pareto Optimal if $mU_w^A/\lambda_2 = nU_w^A/\lambda_2$, or if $m = n$. Thus, if both countries base tax/subsidy rates on only domestic external costs of waste disposal, then, collectively they will reach the Pareto Optimum if the number of representative consumers is equal across the two countries. If $m > n$ (the number of representative consumers in the developing country, Country B, exceeds that of the developed country), then either the return subsidy in Country B must decrease or the optimal waste tax in Country A must increase to reach the Pareto Optimum. The effect on rates is reversed if $m < n$.

Each country's unilateral policy is also socially optimal if disposal technology in Country A has advanced to the point that external costs of waste disposal disappear in Country A ($U_w^A = 0$, $U_w^B/\delta^B > 0$). Acting unilaterally, Country A will set its domestic waste tax at zero ($t_w^A = 0$) and Country B will continue to subsidize waste to reflect the external marginal cost of disposal in Country B ($s_r^B = -mU_w^B/\delta^B$). According to (20), this combination of policy is internationally efficient if U_w^A is indeed equal to zero.

4.3.3 Case 3: No Policy Option in Country B and Benevolent Country A ($t_w^A > 0, t_w^B = 0, s_r^B = 0$)

Perhaps owing to poor administrative infrastructure, assume the government in County B is powerless to set any effective environmental tax/subsidy policy. Assume the economy is still endowed with a technology to return waste from the used durable good back from Country B to Country A. According to (20), a benevolent government in Country A can achieve the Pareto Optimum with the following domestic tax on waste disposal in County A.

$$t_w^{A*} = -m\left(\frac{U_w^A}{\lambda_2} - \frac{U_w^B}{\delta^B}\right); \quad s_r^{B*} = 0.$$

The optimal waste tax in Country A could be positive or negative depending upon the magnitudes of the external disposal costs between the two countries. If, lacking appropriate disposal technologies, the external costs in Country B exceed those of A, then the optimal waste tax in Country A is negative - a subsidy. If the external costs of disposal are roughly equal between the two countries, then the optimal waste tax is zero. An economy endowed with a return technology needs no policy instruments in either country to achieve the

Pareto Optimum. Recall, that this no-policy economy also required $n = m$ to achieve the Pareto Optimum in the economy without the return technology as described in Section 3.

5 Conclusion

This paper developed a model of two countries trading a used durable good for global reuse to solve for various tax systems that allow a competitive equilibrium to achieve the Pareto Optimal allocation of an economic resource. If the importing country is unable to tax waste according the external marginal cost of disposal, then the Pareto Optimum can be achieved by the implementation of an import tax or a subsidy paid for the return of the durable good for disposal in the original country. If the importing country is unable to tax imports or subsidize returns, then the Pareto Optimum can also be achieved by a single disposal tax in the exporting country. This tax is set below the external marginal cost of disposal in Country A to discourage consumers from exporting the used durable good to policy-less Country B.

Many developing countries that import used durable goods lack waste taxes, import taxes, or return subsidies. The remaining question is why. The lack of a waste tax could be due to worries over illegal dumping (Copeland, 1991). The absence of import taxes could be due to trade agreements, and the lack of a return subsidy might be attributable to the lack of public funds necessary to finance the subsidy. Lacking these policies, an inefficiently high quantity of waste from durable goods is disposed in developing countries. Perhaps the dead weight loss associated with the inefficiently high quantity of waste is small when compared to cost of administering a tax. Or perhaps government agents in developing countries do not internalize the social costs of disposal. Citizens bearing the external costs of disposal are unable to put public pressure on government.

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