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Global Reuse and Optimal Waste Policy

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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, 2008).

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 organs.[1]

Thus the waste from these durable goods can be hazardous, and advanced disposal techniques can be necessary to mitigate external effects of disposal. Such disposal technologies are often available in developed countries. But less developed importing countries 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, developed in Section 3 of this paper, both the developed and developing economies are able to initiate tax policies to internalize the social costs of

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[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)

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 in Section 4 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 global 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. The model in Section 5 considers the case when policy instruments are unavailable to the developing country. The global 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 global 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 (2009) 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 globally inefficient. Our study expands upon the work of Shinkuma (2009) by considering policy options beyond a producer responsibility measure.

3. Waste Taxes Available to Both Countries ($t^A_w>0$, $t^B_w>0$)

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). The model does not attempt to explain *why* one country is more economically developed than the other, but assumes incomes and production technologies in each country are determined exogenously.

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. The durable good is initially consumed only in Country A, as Country B is assumed to not possess the technology to produce the durable good, nor do consumers have incomes sufficient to import new durable goods from Country A. Instead the consumers of Country B import used durable goods from Country A.

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 good to Country B for reuse (e). Thus $d = w^A + e$ (where $w^A, e \geq 0$). Once the used durable good has been consumed in Country B, it becomes waste to be disposed in Country B (w^B), thus $e = w^B$. Assume all of this consumption and disposal activity occurs within a single time period. Within the context of a dynamic model, the conditions $d = e + w^A$ and $e = w^B$ could describe a steady state.[2]

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),

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

Assume a global economic resource such as capital or energy (k) constitutes the only input into five production processes. 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,

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

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

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

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

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

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

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 $e = w^B$)

(5) $$U^B = U^B(e, c, mw^B), \text{ where } U^B_e > 0, U^B_c > 0, \text{ and } U^B_w < 0.$$

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,

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

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,

(7) $w^B = b(k^b)$, where $b'>0$.

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

(8) $\bar{k} = k^d + k^w + k^e + k^c + k^b$.

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 $\bar{U}^B$. The social planner is constrained by the materials balance conditions ($d = e + w$ and $e = w^B$), the five production functions (in 2, 3, 4, 6, and 7), and the resource constraint given in (8). Upon substitution, the problem reduces to choosing k^w, k^b, and k^d to maximize the Lagrange function,

$$\mathcal{L} = U^A\{g(k^w)+b(k^b), ng(k^w)\}$$

$$+ \lambda_1[\bar{U}^B - U^B \{h[\bar{k} - k^d - k^w - k^e(b(k^b)) - k^b], b(k^b), mb(k^b)\}]$$

$$+ \lambda_2[f(k^d) - g(k^w) - b(k^b)]$$

where λ_1 and λ_2 are Lagrange multipliers. The latter represents the marginal utility of producing an additional unit of the durable good. The first-order conditions are

(9a) $\mathcal{L}_{kw}$: $U^A_d g' + nU^A_w g' = \lambda_1[-U^B_c h'] + \lambda_2[g']$

(9b) $\mathcal{L}_{kb}$: $U^A_d b' = \lambda_1[-U^B_c h' k^{e\prime} b' - U^B_c h' + U^B_e b' + mU^B_w b'] + \lambda_2[b']$

(9c) $\mathcal{L}_{kd}$: $\lambda_2[f'] = \lambda_1[-U^B_c h']$

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,

(10a) $U^A_d/\lambda_2 = f'/g' + 1 - nU^A_w/\lambda_2$

(10b) $U^A_d/\lambda_2 = f' k^{e\prime} + f'/b' - U^B_e f'/U^B_c h' - mU^B_w f'/U^B_c h' + 1$

These two equations summarize the Pareto Optimal allocation of the economic resources across the five uses in the economy. These conditions will be compared to those of the competitive equilibrium to determine optimal tax rates.

Competitive Equilibrium

Assume a disposal tax is available to the governments of both countries (t^A_w and t^B_w). Assume a representative consumer in Country A faces prices $p_d = 1$ (the numeraire) to purchase the durable good, p^A_w 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.[3] These prices give rise to the consumer's budget constraint,

$$M^A = d + p^A{}_w w_A + p_k k^e(e) - p_e e,$$

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,

$$\mathcal{L} = U^A(w^A + e, \overline{n}\overline{w}^A) + \partial^A[M^A - (w^A + e) - p^A{}_w w^A - p_k k^e(e) + p_e e]$$

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

(11a) $\mathcal{L}_{wA}$: $U^A{}_d = \partial^A[1+ p^A{}_w]$

(11b) $\mathcal{L}_e$: $U^A{}_d = \partial^A[1 + p_k k^{e\prime} - p_e]$.

The representative consumer purchases the durable good to the point that the marginal

[3] 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.

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 $p^A_w = p_k k^{e\prime} - p_e$.

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 , $\pi = f(k^d) - p_k k^d$. Profit is maximized when

(12) $$f' = p_k$$

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^A_w on each unit of waste disposed. The firm chooses the quantity of the economic resource (k^w) to maximize profit, $\pi = (p^A_w - t^A_w)g(k^w) - p_k k^w$. Profit is maximized when

(13) $$p^A_w = p_k/g' + t^A_w.$$

The representative consumer in Country B maximizes utility (5) subject to $e = w^B$ (all imported used durable goods are disposed in Country B) and the budget constraint, $M^B = p_e e + p_c c + p^B_w w^B$, 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^B_w to dispose the waste from the durable good. 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 Lagrange function for this constrained utility-maximization problem is

$$\mathcal{L} = U^B(w^B, c, \overline{m}\overline{w}^B) + \delta^B[M^B - p_e w^B - p_c c - p^B_w w^B].$$

The first-order conditions for utility maximization are

$$\mathcal{L}_{wb}: \quad U^B_e = \delta^B[p_e + p^B_w]$$

(14) $$\mathcal{L}_c: \quad U^B_c = \delta^B[p_c],$$

which can be simplified to the single condition

(15) $$U^B_e/U^B_c = (p_e + p^B_w)/p_c.$$

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

(16) $$p_c = p_k/h'.$$

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

(17) $$p^B_w = p_k/b' + t^B_w.$$

Substitute (16), (17), and (12) into (15) to eliminate p_c, p^B_w, and p_k. Solve the resulting equation for p_e and substitute into (11b) to eliminate p_e. Then substitute (13) into (11a) to eliminate p^A_w and substitute (12) into (11a) and (11b) to eliminate p_k. We are left with

(18a) $$U^A_d/\partial^A = 1 + f'/g' + t^A_w$$

(18b) $$U^A_d/\partial^A = 1 + f'k^e - U^B_e f'/U^B_c h' + f'/b' + t^B_w$$

These equations summarize the allocation of resources in a decentralized economy as a function of the two waste taxes. Compare (18) with (10) and note that the Pareto Optimum can be achieved by the competitive equilibrium when tax rates are $t^A_w = - nU^A_w/\lambda_2$ and $t^B_w = - U^B_w f'/U^B_c h'$. Combining (14), (16), and (12) suggests $f' = U^B_c h'/\delta^B$ allowing the optimal tax rates to be simplified to

$$t^A_w = - nU^A_w/\lambda_2 \qquad \text{and} \qquad t^B_w = - mU^B_w/\delta^B$$

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^A_w and U^B_w, 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 ($U^B_e = 0$), 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.

4. Waste not Taxed in Country B *($t^B_w=0$)*

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). This section explores alternative tax instruments available to government of Country B for achieving the Pareto Optimal allocation of the economic resource when waste is untaxed. The first is a tax on imports of the used durable good. The second is a subsidy paid for the return of waste from the used durable good back to County A.

An Import Tax on the Used Durable Good ($t^A_w>0$, $t^B_w=0$, $t_m>0$)

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. The consumer's budget constraint in Country B is therefore, $M^B = (p_e + t_m)e + p_c c + p^B_w w^B$. 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

$$\mathcal{L}_{wb}: \quad U^B_e = \partial^B[p_e + t_m + p^B_w]$$

$$\mathcal{L}_c: \quad U^B_c = \partial^B[p_c],$$

which can be simplified to,

(19) $$U^B_e/U^B_c = (p_e + t_m + p^B_w)/p_c.$$

The representative competitive waste disposing firm in Country B no longer pays the disposal tax ($t^B_w=0$), but still charges market prices for disposal. Condition (17) therefore reduces to $p^B_w = p_k/b'$.

Following the same substitutions patterns described above, the allocation of resources as function of tax rates resulting from the competitive equilibrium is

(20a) $$U^A_d/\partial^A = 1 + f'/g' + t^A_w$$

(20b) $U^A_d/\partial^A = 1 + f'k^e - U^B_e f'/U^B_c h' + f'/b' + t_m$

By comparing (20) to the Pareto Opimal condition in (10), the optimal waste tax in County A (t^A_w) is unaffected and still equal to the external cost of disposal. But because County B is unable to assess a waste tax, the import tax is necessary for the decentralized economy to achieve the Pareto Optimum. 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 (thus, $t_m = t^B_w$). Both taxes (t_m and t^B_w) increase 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.

A Subsidy to Waste Returns (t^A_w>0, t^B_w=0, t_e=0, t_r >0)

Consider an alternative policy approach where absent a disposal tax (t^B_w=0) the government in Country B can subsidize the return to Country A of the waste from the used durable good. 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,

(22) $$w_r = r(k^r) \text{ where } r'>0.$$

The representative consumer in Country B now chooses whether to dispose the waste in Country B or return the waste to Country A, $e = w_B + w_r$ (with $w_B, w_r \geq 0$). Based upon the materials balance constraints above, the total quantity of waste returned to Country A (call it R for the moment) is the total quantity of the used durable good exported to Country B (ne) less the total quantity disposed in Country B (mw_B). Because $e = w_B + w_r$, we have $R = n(w_B + w_r) - mw_B$, which can be simplified to $R = (n-m)w_B + nw_r$. The representative consumer in Country A experiences disutility from both sources of waste. Thus,

(23) $$U^A = U^A(d, nw_A + R) = U^A(d, nw_A + (n-m)w_B + nw_r),$$

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

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

$$\mathcal{L} = U^A\{g(k^w) + b(k^b) + r(k^r), ng(k^w) + (n-m)b(k^b) + nr(k^r)\}$$

$$+ \lambda_1[\overline{U}^B - U^B\{h[k - k^d - k^w - k^e(b(k^b) + r(k^r)) - k^b - k^r], b(k^b) + r(k^r), mb(k^b)\}]$$

$+ \lambda_2[f(k^d) - g(k^w) - b(k^b) – r(k^r)],$

Where $\overline{U}^B$ is a constant 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

(24a) $\mathcal{L}_{kw}$: $U^A{}_d g' + nU^A{}_w g' = \lambda_1[-U^B{}_c h'] + \lambda_2[g']$

(24b) $\mathcal{L}_{kb}$: $U^A{}_d b' + (n-m)U^A{}_w b' = \lambda_1[-U^B{}_c h' k^{e}{}' b' - U^B{}_c h' + U^B{}_e b' + mU^B{}_w b'] + \lambda_2[b']$

(24c) $\mathcal{L}_r$: $U^A{}_d r' + nU^A{}_w r' = \lambda_1 [-U^B c\ h' k^{e}{}' r' - U^B{}_c h' + U^B{}_e r'] + \lambda_2[r']$

(25d) $\mathcal{L}_{kd}$: $\lambda_1[U^B{}_c h'] + \lambda_2[f'] = 0$

Divide (24a) by g', (24b) by b', (25c) by r', and solve (24d) for λ_1 and substitute into the three remaining conditions to get

(25a) $U^A{}_d/\lambda_2 + nU^A{}_w/\lambda_2 = f'/g' + 1$

(25b) $U^A{}_d/\lambda_2 + (n-m)U^A{}_w/\lambda_2 + mU^B{}_w f'/U^B{}_c h' = f' k^{e}{}' + f'/b' - U^B{}_e f'/U^B{}_c h' + 1$

(25c) $U^A{}_d/\lambda_2 + nU^A{}_w/\lambda_2 = f' k^{e}{}' + f'/r' - U^B{}_e f'/U^B{}_c h' + 1$

These three equations summarize the efficient global allocation of the economic resource. These conditions will be compared below with those representing a competitive economy.

In a decentralized economy, assume once again that the government of Country A can assess a tax on waste disposed in Country A ($t^A{}_w$), 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^B_r) paid for the return of waste from the used durable goods originally exported from Country A. 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 (11a), (11b), and (12) above. The waste disposal firm in Country A now receives waste from both Country A and Country B. This firm receives price, p^A_w, 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 (22)) to maximize profit, $\pi = (p^A_w - t^A_w)w_A + (p_r - t^A_w)w_r - p_k k^w – p_k k^r$. Profit is maximized by equating

(26a) $$p^A_w = (p_k/g' + t^A_w)$$

(26b) $$p_r = p_k/r' + t^A_w.$$

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, $M^B = p_e e + p_c c + p_r w_r + p^B_w w^B - s^B_r w_r$, where each unit of waste returned to

Country A (w_r) receives the subsidy. The first-order conditions for utility-maximization are

(27a) $\mathcal{L}_c$: $U^B{}_c = \delta^B[p_c]$

(27b) $\mathcal{L}_{wb}$: $U^B{}_e = \delta^B[p_e + p^B{}_w]$

(27c) $\mathcal{L}_{wr}$: $U^B{}_e = \delta^B[p_e + p_r - s^B{}_r]$

Other profit-maximizing conditions representing the competitive economy in Country B are the same as above ((16) and (17), but with $t^B{}_w = 0$).

Solve for δ^B in (27a) and substitute into (27b) and (27c). Then use (16), (17), (26b), and (12) to eliminate p_c, $p^B{}_w$, p_r and p_k from the remaining two equations. Then use (12) and (26a) to eliminate p_k and $p^A{}_w$ from (11a) and (11b). (11a) becomes

(11a') $U^A{}_d/\partial^A - t^A{}_w = f'/g' + 1$

Then solve (11b) for p_e and substitute into (27b) and (27c) to eliminate p_e. The resulting equations are

(27b') $U^A{}_d/\delta^A = f'k^{e'} + f'/b' - U^B{}_e f'/U^B{}_c h' + 1$

(27c') $U^A{}_d/\delta^A + s^B{}_r - t^A{}_w = f'k^{e'} + f'/r' - U^B{}_e f'/U^B{}_c h' + 1.$

Equations (11a'), (27b)' and (27c)' characterize the allocation of resources in a decentralized economy as a function of the waste tax in Country A and the subsidy for the return of waste in Country B. Notice that the right-hand sides of (11a'), (27b') and

(27c') are equal to those of the Pareto Optimum, (25a), (25b) and (25c). Combining these two sets of three equations to eliminate the identical right-hand sides gives

(28a) $U^A_d/\lambda_2 + nU^A_w/\lambda_2 = U^A_d/\delta^A - t^A_w$

(28b) $U^A_d/\lambda_2 + (n\text{-}m)U^A_w/\lambda_2 + mU^B_w f'/U^B_c h' = U^A_d/\delta^A$

(28c) $U^A_d/\lambda_2 + nU^A_w/\lambda_2 = U^A_d/\delta^A + s^B_r - t^A_w$

Solve (28a) for t^A_w to get

$$t^{A*}_w = -nU^A_w/\lambda_2 - U^A_d(1/\lambda_2 - 1/\delta^A)$$

Only if $\lambda_2 = \delta^A$ (these re both Lagrange multipliers) will the waste tax in Country A be equal to the baseline case. Recall that λ_2 is the marginal utility of the durable good in County A and that that δ^A is the marginal utility of exogenous income in Country A. Given that the durable good is the numeraire (with price of 1) and is the only good that provides utility to the consumer in Country A, the addition of $1 in income to the consumer in County A must provide the equivalent marginal utility as the addition of one unit of the durable good. Thus the marginal utility of income will always equal the marginal utility of consuming the durable good, and $\lambda_2 = \delta^A$. Thus, the tax on waste is identical to the baseline case. Country A taxes waste according to external marginal cost of disposal in County A.

Set (28b) equal to (28c) by eliminating $(U^A_d/\lambda_2 - U^A_d/\delta^A)$ gives

$$s^{B*}_r = - mU^B_w f'/U^B_c h' - (n-m)U^A_w/\lambda_2 + nU^A_w/\lambda_2 + t^{A*}_w$$

which, when recalling that $f' = U^B_c h'/\delta^B$ (from (14), (16), and (12)) allows the optimal subsidy to be simplified to

$$s^{B*}_r = - m(U^B_w/\delta^B - U^A_w/\lambda_2) + t^{A*}_w,$$

where t^{A*}_w is defined as above.

There are three components to the optimal subsidy. The first we call the "Country B Effect", which suggests the optimal subsidy will reflect the external marginal cost of disposal in Country B ($-mU^B_w/\delta^B$). The subsidy increases the opportunity cost of disposing waste in Country B and therefore causes consumers to make efficient disposal decisions. The "Country A Effect" suggests the optimal subsidy should also reflect the external costs of returning waste to Country A (U^A_w/λ_2). This effect allows consumers in Country B to internalize the social disposal costs in Country A when choosing whether or not to return waste for disposal in Country A. The third component allows for perfect netting of the two policies. As the waste passes from the consumer in Country B to the disposal site in Country A, it will encounter two policy instruments (s^{B*}_r and t^{A*}_w). This third component suggests that if the waste tax changes in Country A, then the subsidy should also change to leave constant the overall incentive to return waste to Country A.

Thus, two of these three components are based upon the external costs of disposal in Country A. To see this, substitute for t^{A*}_w to find,

$$s^{B*}_r = - mU^B_w/\delta^B + (m-n)U^A_w/\lambda_2.$$

As external costs of disposal rise in Country A, the optimal return subsidy falls to discourage waste from being returned to Country A (mU^A_w/λ_2) and rises to preserve the zero-net-effect of the two policy measures ($-nU^A_w/\lambda_2$). The overall effect on the subsidy is positive if $n>m$ and is negative if $n<m$. Thus if the population of Country B is larger than that of Country A, then the value of the subsidy is inversely related to external disposal costs in Country A.

Consider two interesting special cases. First, assume disposal technology in Country A has advanced to the point that all social costs of waste disposal are internalized by consumers paying the price of waste disposal. Thus, external costs of waste disposal are positive only in Country B ($U^A_w = 0$, $U^B_w/\delta^B > 0$). The optimal subsidy reduces to $s^{B*}_r = - mU^B_w/\delta^B$. The subsidy reflects the full external costs of disposal in Country B. This subsidy rate also occurs in the rare event that $m = n$. Second, assume external costs of waste disposal are positive and equal in both countries ($U^A_w/\lambda_2 = U^B_w/\delta^B$). In this case $s^{B*}_r = t^{A*}_w$. The net incentive for returning waste to Country A is zero as the consumer receives the subsidy but must pay the equal tax for disposal in Country A. Once the waste material from the durable good is in Country B, society is indifferent between disposal in Country A or Country B.

Note that both instruments (t^A_w and s^B_r) allow the competitive economy to achieve the Pareto Optimal allocation of the economic resource. The return subsidy by itself is unable to achieve the Pareto optimum because it fails to force consumers in Country A to internalize the social costs of disposal. But if administering the return subsidy is impossible, then the next section examines the case when the only global policy instrument available is a waste tax (t^A_w) in Country A.

5. Only Disposal Tax in Country A *(t^A_w>0, t^B_w=0, t_m=0, s^B_r=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 (2008)). Furthermore, to compare to the baseline case assume the technology to return waste to Country A (in 22) is no longer available to the economy. The only remaining tax instrument available to the global economy is the disposal tax levied on waste disposed in County A.

The competitive decentralized allocation of the economic resource summarized in (20) is therefore reduced to,

(29a) $$U^A_d/\partial^A = 1 + f'/g' + t^A_w$$

(29b) $$U^A_d/\partial^A = 1 + f'k^e - U^B_e f'/U^B_c h' + f'/b'.$$

Note the only difference is that the t_m variable is now zero.

Recall that the Pareto Optimal allocation of resources is governed by (10). Comparing these two sets of equations suggests the Pareto Optimum can still be achieved by the single waste tax when

$$t^A_w = - nU^A_w/\lambda_2 + mU^B_w/\delta^B.$$

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 $- mU^B_w/\delta^B > - nU^A_w/\lambda_2$, 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 waste 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 ($- mU^B{}_w/\delta^B = - nU^A{}_w/\lambda_2$). 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.

A government that disregards the external costs in Country B will set the waste tax equal to the external costs in Country A. This tax will cause consumers in Country A to inefficiently increase efforts to export the used durable good to Country B where tax policies do not exist. It is not clear that a government will ease domestic environmental policies to improve environmental conditions in other countries, as is called for to achieve a global Pareto Optimum.

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 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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