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Determinants of Trade in Recyclable Wastes between Developing and Developed Countries

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Abstract

This paper examines the trade volume of recyclable wastes. In particular, we analyze the trade from developed countries to developing countries. The reason is that, when a recycling process is separated from the production process of final goods or/and the consumption process, it would be located in the labor-abundant (i.e., *less* developed developing) countries. Then, the environmental and health problems might become serious in developing countries.

The relationship between the wages and the volume of imports is our focus. We demonstrate that, the higher the wage/per capita income of a developing country, the more recyclable wastes it imports. This implies that there is no evidence for a pollution haven in the sense that the dirty recycling sectors expand in the *less* developed developing countries more rapidly than the *more* developed developing countries. Furthermore, we discuss the possibility that the trade restriction for reducing environmental damage is accompanied by a significant loss in efficiency.

Keywords: trade and recycling, recyclable wastes, gravity model.

JEL Classification: F18, Q28

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1. Introduction

In the past few decades, many countries have experienced substantial and ongoing increases in the generation of waste. The expectation is that this increasing trend for industrial and municipal waste will continue in the near future. For example, industrial waste in 2050 compared with 2000 will triple in the Association of South East Asian Nations (ASEAN) (Hotta et al., 2008). Moreover, the Organization for Economic Cooperation and Development (OECD) estimates that world waste generation in 2050 will be approximately 27 billion tons, more than double the 12.7 billion tons of waste generated in 2000 (OECD, 2008).

At the same time, the world is drastically globalizing in terms of trade liberalization, and trade in recyclable wastes is no exception. Therefore, there has been a rapid increase in the transboundary movement of recyclable wastes, particularly from developed countries to developing countries (Van Beukering, 2001). In Asian countries, this increase began in the 1990s following their rapid pace of economic growth. In practice, governments and international environmental organizations often wish to restrict trade in recyclable wastes (e.g., Electrical and Electric Waste, Restriction of Hazardous Substances Directive). This is because these wastes sometimes cause significant environmental and health problems in the developing countries they are imported.

The two main reasons for the increasing trade in recyclable wastes are as follows. First, given the economic growth resulting from globalization, the demand for not only virgin materials but also recycled materials (as substitutes for virgin materials) has increased rapidly worldwide. Second, trade liberalization has encouraged the vertical disintegration of the production process in many different industries. This is often because each production process is located in a different country. However, even when the recycling process can be located independently, i.e., the recycling process can be separated from the production of final goods or/and consumption (Hotta et al., 2008), if the recycling process is labor intensive, it may expand in a labor-abundant country.

The latter is more problematic than the former for the following reasons. To start with, if the import of recyclable wastes increases due to the economic growth of developing countries, at least trade liberalization makes it easier for industries in these countries to procure materials. Then, industries outside the recycling sector can expand, and per capita income will increase. In this sense, the problem of waste (recycling) is similar to other environmental problems arising from economic growth.

However, if the import of recyclable wastes in some developing countries increases because of their abundance of labor and the labor intensiveness of the recycling activities, the problems caused by waste may become serious. Usually, and contrary to recycling processes in developed countries, recycling activities in the least developed countries are unskilled-labor intensive. People in these countries also lack knowledge of the toxicity of the wasted materials. Therefore, the probability that recycling activities will cause serious environmental damage and/or health problems is greater when wasted materials are recycled in unskilled labor-abundant (developing) countries. In addition, trade in wasted materials sometimes leads to an increase in illegal dumping in the importing countries.[1]

This paper sheds theoretical and empirical light on the trade volume of recyclable wastes. In particular, we focus on the trade from developed countries to developing countries. We then test whether least developed countries import more recyclable waste than other developing countries. Furthermore, we discuss the effects of trade restrictions of recyclable wastes on recycling activities. This is because changes in recycling and production activities are important in terms of both environmental damage and the loss of efficiency.

A considerable number of studies have analyzed recycling policy in a closed economy (e.g., Dinan (1993), Highfill and McAsey (1997), Conrad (1999), Huhtala (1999), Eichner and Pethig (2001, 2003) and Eichner (2005)). However, as far as the authors are aware, there are only a few attempts at investigating the trade liberalization of recyclable wastes. Although Grace et al. (1978) and Huhtala and Samakovlis (2002) referred to the policy aspects of trade in recyclable wastes, there are few theoretical analyses that take into consideration the differences in developing countries.[2] This heterogeneity is important because some countries, like China, are developing relatively faster.

We adopt a gravity model in our empirical methodology. It is widely acknowledged that gravity models have empirically succeeded in explaining trade flows. We select five commodities of waste and scrap and undertake our estimations using commodity-level trade data. Several empirical studies have addressed the recycling problem in open economies (Berglund and Söderholm

[1] See Ray (2008) for a discussion. Copeland (1991) theoretically examines the trade in waste with illegal dumping.

[2] Several empirical studies tackle the recycling problem in open economies. See Berglund and Söderholm (2003a, 2003b), Van Beukering (2001), and Van Beukering and Bouman (2001), among others.

(2003a,b), Van Beukering (2001), and Van Beukering and Bouman (2001)). However, none of these studies focuses on the relationship between the wage and commodity level trade flow using gravity models, nor do they examine the differences among developing countries. We find that the higher the wage/per capita income of a developing country, the more recyclable wastes it imports. This suggests that there is no evidence for a pollution haven in the sense that “dirty” recycling sectors expand in *less* developed developing countries more rapidly than in *more* developed developing countries. Further, it implies that trade restrictions to reduce environmental damage may be accompanied by a significant loss in efficiency.

The structure of the paper is as follows. Section 2 describes the theoretical specification. Section 3 investigates the trade volume in recyclable wastes between developing and developed countries. Section 4 conducts the empirical analysis, Section 5 provides some concluding remarks.

2. Theoretical Specification

There are N_a developing countries and N_A developed countries in the world ($N_a + N_A = N$). In each country, there are $M+1$ industries ($X, Y_1, Y_2, \cdots, Y_M$). We can divide the industry of interest, X, into two production processes: a process that produces final good X from virgin and recycled materials, and a process that produces recycled materials from recyclable wastes. A certain proportion of wasted goods is collected after consumption and becomes “recyclable waste.”

2.1 Demand for Final Good X

We assume a representative consumer of country i maximizes a constant elasticity-of-substitution (CES) utility function:

$$U_i = \left\{ u_{x,i}^{\gamma} + \sum_m u_{y_m,i}^{\gamma} \right\}^{1/\gamma} \qquad -\infty < \gamma < 1, \quad m = 1, 2, \cdots, M ,$$

where $u_{x,i}$ $(u_{ym,i})$ denotes the sub-utility from the consumption of good X (Y_m). Each sub-utility is given by:

$$u_{x,i} = \left\{ \sum_{j=1}^{N} x_{ji}^{\alpha} \right\}^{1/\alpha}, \quad u_{y_m,i} = \left\{ \sum_{j=1}^{N} y_{m,ji}^{\beta} \right\}^{1/\beta}, \quad -\infty < \alpha, \beta < 1,$$

where x_{ji} $(y_{m,ji})$ denotes the amount of good X (Y_m) produced in country j and demanded by the consumer in country i. Expenditures for goods are constrained by income:

$$\overline{E}_i = E_{X,i} + \sum E_{Ym,i} = \sum_j p_{x,ji} x_{ji} + \sum_m \sum_j p_{ym,ji} x_{ym,ji} ,$$

where $p_{x,ji}$ ($p_{ym,ji}$) denotes the consumer price of good X (Y_m).

The representative consumer solves the two-step maximization problem through backward induction. In the second stage, the consumer maximizes each sub-utility given the expenditure for each type of good (X, Y_m):

$$Max\ u_{x,i} \quad s.t.\ \sum_j p_{x,ji} x_{ji} = E_{X,i}, \quad Max\ u_{ym,i} \quad s.t.\ \sum_j p_{ym,ji} x_{ji} = E_{Ym,i} .$$

The demand function for good X is then obtained:

$$x_{ji} = p_{x,ji}^{-1/(1-\alpha)} \cdot E_{X,i} \cdot \overline{P}_{X,i} , \tag{1}$$

where $\overline{P}_{X,i} = \sum p_{x,ji}^{-\alpha/(1-\alpha)}$ is the consumer price index of good X in country i. Thus, the sub-utility for good X is:

$$u_{x,i} = \left\{ \sum_j x_{ji}^{\alpha} \right\}^{1/\alpha} = \left\{ \sum_j E_{X,i}^{\alpha} \cdot \overline{P}_{X,i}^{\alpha} \cdot p_{x,ji}^{-\alpha/(1-\alpha)} \right\}^{1/\alpha} = E_{X,i} \cdot \theta_{X,i} ,$$

where $\theta_{X,i} = \overline{P}_{X,i} \cdot \left\{ \sum_j p_{x,ji}^{-\alpha/(1-\alpha)} \right\}^{1/\alpha}$ and the sub-utility for good Y_m is:

$$u_{ym,i} = \left\{ \sum_j y_{m,ji}^{\beta} \right\}^{1/\beta} = \left\{ \sum_j E_{Ym,i}^{\beta} \cdot \overline{P}_{Ym,i}^{\beta} \cdot p_{ym,ji}^{-\beta/(1-\beta)} \right\}^{1/\beta} = E_{Ym,i} \cdot \theta_{Ym,i} ,$$

where $\theta_{Ym,i} = \overline{P}_{Ym,i} \cdot \left\{ \sum_j p_{ym,ji}^{-\beta/(1-\beta)} \right\}^{1/\beta}$.

In the first stage, the consumer determines $E_{X,i}$ and $E_{Ym,i}$ to maximize their utility:

$$Max\ U_i = \left\{ u_{x,i}^{\gamma} + \sum_m u_{y_m,i}^{\gamma} \right\}^{1/\gamma} \qquad s.t.\ \ E_{X,i} + \sum_m E_{Ym,i} = \overline{E}_i ,$$

then:

$$E_{X,i} = \frac{\theta_{X,i}^{\gamma/(1-\gamma)}}{\theta_{X,i}^{\gamma/(1-\gamma)} + \sum_m \theta_{Ym,i}^{\gamma/(1-\gamma)}} \cdot \overline{E}_i , \quad E_{Ym,i} = \frac{\theta_{Ym,i}^{\gamma/(1-\gamma)}}{\theta_{X,i}^{\gamma/(1-\gamma)} + \sum_m \theta_{Ym,i}^{\gamma/(1-\gamma)}} \cdot \overline{E}_i .$$

2.2 Supply of Final Good X and Demand for Recycled Material R

The production process of final good X inputs requires labor, a specific factor to this process, and virgin and recycled materials.[3] The supply of the specific factor is fixed. Further, we assume that the scale of each industry is relatively very small, and accordingly the amount of labor inputted into each industry is relatively very small compared with the total amount of labor in a country. Therefore, the wage is exogenous for each industry.

By mixing recycled material (r_{ji}) and virgin material (v), we obtain one unit of material (Z_i) for the production of X :

$$Z_i = \prod r_{ji}^{\mu} \cdot \bar{v}_i^{\,1-N\mu}, \qquad 0 < N\mu < 1,$$

where r_{ji} denotes the amount of recycled material produced in country j and used in country i and $\bar{v}_i$ denotes the amount of virgin material used in country i, respectively. We assume that virgin material can be imported at a constant price (p_v), and the amount of import is exogenous. The amount of each type of material is determined so that the unit cost is minimized:

$$Min \sum_j p_{r,ji} r_{ji} + p_v \bar{v} \qquad s.t. \;\; Z_i = 1,$$

where $p_{r,ji}$ denotes the price of recycled material produced in country j and used in country i. Solving the minimization problem, the demand function is:

$$r_{ji} = p_{r,ji}^{-1} \cdot \overline{P}_{R,i} \cdot \bar{v}^{-(1-N\mu)/N\mu}, \qquad \overline{P}_{R,i} = \left(\prod p_{r,ki}^{-\mu}\right)^{-1/N\mu}, \tag{2}$$

and the unit cost is:

$$p_{Z,i} = \sum_j p_{r,ji} r_{ji} + p_v \bar{v} = N\overline{P}_{R,i} \bar{v}^{-(1-N\mu)/N\mu} + p_v \bar{v}.$$

The production of good X is perfectly competitive. Given the unit cost of the material, the constant elasticity-of-transformation (CET) joint production function gives the industry production structure:

$$\pi_{x,i} = \sum_j q_{x,ij} X_{ij} - \left(w_i l_{x,i}\left(\overline{K}_{x,i}\right) + p_{Z,i}\right)\left(\sum_j X_{ij}^{\phi}\right)^{\psi/\phi}, \;\; 1 < \varphi < \psi, \quad l'_{x,i} < 0, \tag{3}$$

where $q_{x,ij}$ and X_{ij} denote the producer's price and the output of X produced in country i and consumed in country j, respectively. The variables w_i, $l_{x,i}$, and $\overline{K}_{x,i}$ denote the wage, the labor input into the production of X, and the amount of the specific factor for the production of X,

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[3] The specific factor could be physical capital and/or knowledge.

respectively. As noted, the wage and the amount of the specific factor are exogenous in terms of each sector. The condition that $\psi > 1$ then implies that marginal cost is increasing, and profit (producer's surplus) is paid to the specific factor owners.[4] When $l'_{x,i} < 0$, it implies that the greater the amount of the specific factor, the lower the unit input of labor.

Solving the profit-maximization problem, the supply function is:

$$X_{ij} = q_{x,ij}^{1/(\phi-1)} \cdot \overline{Q}_{X,i} \cdot \frac{1}{\omega_{x,i}\psi}, \tag{4}$$

where $\overline{Q}_{X,i} = \left(\sum_k q_{x,ik}^{\phi/(\phi-1)} \right)^{-(\psi-\phi)/(\phi(\psi-1))}$. This is the producer price index of final good X, and $\omega_{x,i} = w_i l_{x,i}(\overline{K}_{x,i}) + p_{Z,i}$ is the unit cost. From (2) and (3), the demand for the recycled material is:

$$Rd_{ji} = p_{r,ji}^{-1} \cdot \overline{P}_{R,i} \cdot \overline{v}^{-(1-N\mu)/N\mu} \cdot \left(\sum_k X_{ik}^{\phi} \right)^{\psi/\phi}. \tag{5}$$

2.3 Supply of Recycled Material *R* and Demand for Recyclable Waste *B* in Developing Countries.

In the production process of recycled materials, recyclable wastes are used. In developing countries, one unit of recycled material ($r_{s,i}$) is made by mixing imported recyclable wastes (b_{ji}) from developed countries and domestic recyclable waste (b_{ii}). The supply of the domestic recyclable waste is fixed in each period, and its price ($p_{g,i}$) is constant.[5] We assume there is no trade in recyclable waste among developing countries. In the following, subscript A is attached to the index of developed countries (i_A, j_A), and subscript a to the index of developing countries (i_a, j_a) if needed.

Foreign and domestic recyclable wastes are imperfect substitutes, and the technology of mixing

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[4] The condition $\phi < \psi$ ensures that the exports of final goods to different two countries are imperfect substitutes. That is, an increase in the export price for one foreign country decreases the export to other foreign countries.

[5] In reality, the amount of domestic recyclable waste may depend on the amount of consumption of good X and the recovery rate. We discuss this further in Subsection 2.6. Moreover, we can consider the price as the cost of collecting curbside waste by municipalities. This cost may also depend on the environmental consciousness of consumers and the amount of consumption.

the wastes to produce the recycled material is:[6]

$$r_{s,i_a} = \prod_{j_A} b_{j_A i_a}^{\kappa} \cdot \bar{b}_{i_a i_a}^{1-N_A \cdot \kappa}, \qquad 0 < N_A \kappa < 1.$$

Inputs are determined such that unit cost is minimized:

$$Min \sum_{j_A} p_{b,j_A i_a} b_{j_A i_a} + p_{g,i_a} \bar{b}_{i_a i_a} \quad s.t. \quad r_{s,i_a} = 1,$$

where $p_{b,j_A i_a}$ denotes the price of imported recyclable waste from country j_A to country i_a. Solving the minimization problem, the demand function obtained is:

$$b_{j_A i_a} = p_{b,j_A i_a}^{-1} \cdot \bar{P}_{B,i_a} \cdot \bar{b}_{i_a i_a}^{-(1-N_A \kappa)/N_A \kappa} \qquad \bar{P}_{B,i} = \left(\prod_{j_A} p_{b,j_A i_a}^{-\kappa} \right)^{-1/N_A \kappa}, \tag{6}$$

and the unit cost is:

$$p_{rs,i_a} = \sum_{j_A} p_{b,j_A i_a} b_{j_A i_a} + p_{g,i_a} \bar{b}_{i_a i_a} = N_A \cdot \bar{P}_{B.i_a} \cdot b_{i_a i_a}^{-(1-N_J \kappa)/N_J \kappa} + p_{g,i_a} \bar{b}_{i_a i_a}.$$

The production of recycled material is perfectly competitive. Given the unit cost of the material, the industry production structure is:

$$\pi_{r,i_a} = \sum_j q_{r,i_a j} Rs_{i_a j} - \left(w_{i_a} l_{r,i_a} \left(\bar{K}_{R,i_a} \right) + p_{rs,i_a} \right) \left(\sum_j Rs_{i_a j}^{\rho} \right)^{\tau/\rho}, 1 < \rho < \tau, \quad l'_{r,i_a} < 0, \tag{7}$$

where $q_{r,i_a j}$ and $Rs_{i_a j}$ denote the producer price and amount of recycled material produced in country i_a and used in country j, respectively. Moreover, $l_{r,i}$, and $\bar{K}_{R,i}$ denote the labor input into the production of recycled material and the amount of the specific factor in the production of the recycled material, respectively. The condition $\tau > 1$ implies that marginal cost is increasing, and profit (producer's surplus) is paid to the specific factor owners.[7] Solving the profit maximization problem, the supply function is:

$$Rs_{i_a j} = q_{r,i_a j}^{1/(\rho-1)} \cdot \bar{Q}_{R,i_a} \cdot \frac{1}{\omega_{r,i_a} \tau}, \tag{8}$$

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[6] In general, the qualities of recyclable wastes generated in any pair of countries differ because the quality of the consumed goods, the manner of consumption, and the means of discarding waste vary across countries.

[7] The condition $\rho < \tau$ ensures that the exports of recycled materials to different two countries are imperfect substitutes. That is, an increase in the export price for one foreign country decreases the export to other foreign countries.

where $\overline{Q}_{R,i_a} = \left(\sum_k q_{r,i_a k}^{\rho/(\rho-1)} \right)^{-(\tau-\rho)/(\rho(\tau-1))}$, and $\omega_{r,i_a} = w_{i_a} l_{r,i_a} \left(\overline{K}_{R,i_a} \right) + p_{rs,i_a}$. From (6) and (7), the demand for recyclable waste is:

$$Bd_{j_A i_a} = p_{b,j_A i_a}^{-1} \cdot \overline{P}_{B,i_a} \cdot b_{i_a i_a}^{-(1-N_A\kappa)/N_A\kappa} \left(\sum_k Rs_{i_a k}^{\rho} \right)^{\tau/\rho}. \qquad (9)$$

2.4 Supply of Recycled Material R and Demand for Recyclable Waste B of Developed Countries

We assume that each developed country uses only its domestic recyclable waste to produce the recycled material:

$$r_{s,i_A} = b_{i_a i_a}, \qquad p_{rs,i_A} = p_{g,i_A}. \qquad (10)$$

As we obtain the supply function in the same way as the developing countries, the demand for domestic recyclable waste is:

$$Bd_{i_A i_A} = \left(\sum_k Rs_{i_A k}^{\rho} \right)^{\frac{\tau}{\rho}}. \qquad (11)$$

We assume that the potential supply of recyclable waste in each developed country is greater than total demand. Therefore, p_{g,i_A} is the marginal cost (assumed constant) of municipalities collecting curbside waste.

2.5 Export of Developed Country Recyclable Waste

As detailed, in developed countries the domestic producers of recycled material are able to obtain the domestic recyclable waste at a constant price, p_{g,i_A}. However, these wastes have to go through some processing activities to enable export to developing countries. This is because the laws on recycling and wastes and the quality of wasted goods are different across countries. This processing activity is competitive, and the production structure is:

$$\pi_{b,i_A} = \sum_{j_a} q_{b,i_A j_a} Bs_{i_A j_a} - \left(w_{i_A} l_{b,i_A} \left(\overline{K}_{B,i_A} \right) + p_{g,i_A} \left(\mathrm{Re}_{i_A}, \overline{E}_{i_A} \right) \right) \left(\sum_{j_a} Bs_{i_A j_a}^{\sigma} \right)^{\delta/\sigma}, 1 < \sigma < \delta, \ l'_{b,i_A} < 0,$$

where $q_{B,i_A j_a}$ and $Bs_{i_A j_a}$ denote the producer price and amount of recyclable waste produced in developed country i_A and used in developing country j_a, respectively. Variables l_{b,i_A}, $\overline{K}_{B,i_A}$, and

Re_{i_A} denote the labor input into the production of recyclable waste, the amount of the specific factor used for the production of recyclable waste, and the recovery rate, respectively. The last variable is the ratio of the collected wasted goods for recycling to the total amount of wasted goods. The marginal cost of collecting curbside waste depends on the recovery rate and income, and accordingly, the amount of consumption of final good X.[8] The condition $\delta > 1$ implies that marginal cost is increasing, and the profit (producer's surplus) is paid to the specific factor owners.[9] Solving the profit maximization problem, the supply function is:

$$Bs_{i_A j_a} = q_{b,i_A j_a}^{1/(\sigma-1)} \cdot \overline{Q}_{B,i_A} \cdot \frac{1}{\omega_{b,i_A}\delta}, \tag{12}$$

where $\overline{Q}_{B,i_A} = \left(\sum_{k_a} q_{b,i_A k_a}^{\sigma/(\sigma-1)} \right)^{-(\delta-\sigma)/(\sigma(\delta-1))}$, and $\omega_{b,i_A} = w_{i_A} l_{b,i_A}\left(\overline{K}_{B,i_A}\right) + p_{g,i_A}\left(\mathrm{Re}_{i_A}, \overline{E}_{i_A}\right)$.

2.6 Waste Generation

Consumers discard goods X after they are consumed. After they are collected, some go to landfills and the others into the recycling process. When wasted goods move into the recycling process, they become recyclable wastes. Strictly speaking, if we consider time, the supply of recyclable waste is set at the beginning of each period, and does not depend on the consumption and recovery rate of the present period. The reasoning is that supply in the current period is the result of consumption and collecting activities in the previous period.

If, however, the cycle is a very short time, we can consider the steady state. Generally, higher per capita income implies a higher recovery rate. This is because the environmental consciousness of consumers increases with per capita income. Moreover, higher per capita income implies larger total consumption. We obtain this from the theoretical specification in Subsection 2.1. Therefore, the situation in the steady state is:

$$\mathrm{Re}_i\left(\overline{E}_i\right) \cdot \sum_j X_{ji}\left(\overline{E}_i\right) = \overline{b}_{ii},$$

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[8] The recovery rate is the ratio of wasted goods separated for recycling by consumers to total consumption of final goods. This depends on the environmental consciousness of consumers, which we consider to depend on income.

[9] The condition $\sigma < \delta$ ensures that the exports of recyclable wastes to different two countries are imperfect substitutes. That is, an increase in the export price for one foreign country decreases the export to other foreign countries.

for developing countries, and:

$$\mathrm{Re}_i\left(\overline{E}_i\right)\cdot\sum_j X_{ji}\left(\overline{E}_i\right) > Bd_{ii} + \sum_k Bs_{ik}\ ,$$

for developed countries.

3. Trade Volumes

Having obtained the import demand and export supply of good X, recycled material R, and recyclable waste B between countries i and j, we investigate the impact of differences in the exogenous variables on trade volume. According to the purpose of this paper, we particularly focus on the trade volume of recyclable wastes from developed to developing countries ($B_{j_A i_a}$).

For simplicity, we assume each country is a small country. Therefore, a change in the trade volume in final goods or materials between country i and j does not affect the price index.

3.1 Equilibrium Trade Volumes

From (1) and (4), the demand and supply of trade in final good X from country j to country i is:

$$Xd_{ji} = p_{x,ji}^{-1/(1-\alpha)}\cdot E_{X,i}\cdot\overline{P}_{X,i}\,,\quad Xs_{ji} = q_{x,ji}^{1/(\phi-1)}\cdot\overline{Q}_{X,j}\cdot\frac{1}{\omega_{x,j}\psi}\,.$$

Taking into consideration the existence of trade cost, including transportation costs—that is $p_{x,ji} = C_{x,ji}q_{x,ji}$ $(C_{x,ji} > 1)$—the condition for demand and supply to be equal is given by:

$$p_{x,ji}^{-1/(1-\alpha)}\cdot E_{x,i}\cdot\overline{P}_{X,i} = C_{x,ji}^{-1/(\phi-1)}p_{x,ji}^{1/(\phi-1)}\cdot\overline{Q}_{X,j}\cdot\frac{1}{\omega_{x,j}\psi}\,.$$

Recalling that $\alpha < 1 < \phi$, the trade volume and price are:

$$X_{ji} = \overline{P}_{x,i}^{(1-\alpha)/(\phi-\alpha)}\cdot C_{x,ji}^{-1/(\phi-\alpha)}\cdot\overline{Q}_{x,j}^{(\phi-1)/\phi-\alpha}\cdot\left(E_{x,i}\right)^{(1-\alpha)/(\phi-\alpha)}\cdot\left(\omega_{x,j}\psi\right)^{-(\phi-1)/(\phi-\alpha)} \tag{13}$$

$$p_{x,ji} = \left(\frac{C_{x,ji}{}^{-1/(\phi-1)}\overline{Q}_{x,j}}{\overline{P}_{X,i}\cdot E_{x,i}\cdot\omega_{x,j}\psi}\right)^{-(1-\alpha)(\phi-1)/(\phi-\alpha)}\,. \tag{14}$$

Let us turn to the recycled material. Assuming that $p_{r,ji} = C_{r,ji}q_{r,ji}$ $(C_{r,ji} > 1)$, from (5) and (8), the demand and supply of trade in recycled material from country j to country i is:

$$Rd_{ji} = p_{r,ji}^{-1}\cdot\overline{P}_{R,i}\cdot\overline{v}_i^{(N\mu-1)/(N\mu)}\cdot\overline{X}_i\,,\quad Rs_{ji} = C_{r,ji}^{-1/(\rho-1)}p_{r,ij}^{1/(\rho-1)}\cdot\overline{Q}_{R,j}\cdot\frac{1}{\omega_{r,j}\tau}\,,$$

where $\overline{X}_i = \left(\sum_k X_{ik}^{\phi} \right)^{\psi/\phi}$. Thus, recalling that $N\mu < 1 < \rho$, the trade volume and price are:

$$R_{ji} = \overline{P}_{R,i}^{1/\rho} \cdot \overline{v}_i^{-(1-N\mu)/N\mu\rho} \cdot C_{r,ji}^{-1/\rho} \cdot \overline{Q}_{R,j}^{(\rho-1)/\rho} \cdot \overline{X}_i^{1/\rho} \cdot \left(\omega_{r,j}\tau\right)^{-(\rho-1)/\rho}, \tag{15}$$

$$p_{r,ji} = \left(\frac{C_{r,ji}^{-1/(\rho-1)} \overline{Q}_{R,j}}{\overline{P}_{R,i} \cdot \overline{v}_i^{(N\mu-1)/N\mu} \cdot \overline{X}_i \cdot \omega_{r,j}\tau} \right)^{-(\rho-1)/\rho}. \tag{16}$$

Finally, we examine the trade in recyclable waste. Assuming that $p_{b,j_A i_a} = C_{b,j_A i_a} q_{b,j_A i_a} \left(C_{b,j_A i_a} > 1\right)$, from (9) and (12):

$$Bd_{j_A i_a} = p_{b,j_A i_a}^{-1} \cdot \overline{P}_{B,i_a} \cdot b_{i_a i_a}^{-(1-N_A\kappa)/N_A\kappa} \cdot \overline{R}s_{i_a}, \quad Bs_{j_A i_a} = C_{b,j_A i_a}^{-1/(\sigma-1)} p_{b,j_A i_a}^{1/(\sigma-1)} \cdot \overline{Q}_{B,j_A} \cdot \frac{1}{\omega_{b,j_A}\delta},$$

where $\overline{R}s_i = \left(\sum_k Rs_{ik}^{\rho} \right)^{\tau/\rho}$. Thus, recalling that $N_A\kappa < 1 < \phi$, the trade volume and the price are:

$$B_{j_A i_a} = \overline{P}_{B,i_a}^{1/\sigma} \cdot \overline{b}_{i_a i_a}^{-(1-N_A\kappa)/N_A\kappa} \cdot C_{b,j_A i_a}^{-1/\sigma} \cdot \overline{Q}_{B,j_A}^{(\sigma-1)/\sigma} \cdot \overline{R}s_{i_a}^{1/\sigma} \cdot \left(\omega_{b,j_A}\delta\right)^{-(\sigma-1)/\sigma} \tag{17}$$

$$p_{b,j_A i_a} = \left(\frac{C_{b,j_A i_a}^{-1/(\sigma-1)} \overline{Q}_{B,j_A}}{\overline{P}_{B,i_a} \cdot b_{i_a i_a}^{-(1-N_A\mu)/N_A\mu} \cdot \overline{R}s_{i_a} \cdot \omega_{b,j_A}\delta} \right)^{-(\sigma-1)/\sigma}. \tag{18}$$

3.2 Income, Wages, and Trade Volumes of Recyclable Wastes

For the purposes of simplicity, we omit the subscripts A and a from the indices of the developed and developing countries in this subsection. From (15), (17), and (18), and the definitions of $\overline{P}_B$, $\overline{Q}_R$, and $\overline{Q}_B$, we obtain:

$$B_{ji} = C_{b,ji}^{-1/\sigma} \cdot b_{ii}^{-(1-N_A\kappa)(2\sigma-1)/(N_A\kappa\sigma)} \cdot \left(\omega_{r,i}\tau\right)^{-\rho(\tau-1)/\rho} \cdot \left(\omega_{b,j}\delta\right)^{-(\delta-1)/\delta} \cdot \Gamma, \tag{19}$$

where:

$$\Gamma = \left(\sum_k \overline{P}_{R,k} \cdot \overline{v}_k^{(N\mu-1)/(N\mu)} \cdot C_{r,ik}^{-1} \cdot \overline{X}_k \right) \cdot \left(\sum_i \overline{P}_{B,i} \cdot b_{ii}^{-(1-N_A\mu)/(N_A\mu)} \cdot C_{b,ji}^{-1} \cdot \overline{R}_{S,i} \right)^{(\sigma-\delta)/(\delta(\sigma-1))} \cdot \prod_j \left(\frac{C_{b,ji}^{-1/(\sigma-1)} \cdot \overline{Q}_{B,j}}{\omega_{b,j}\delta} \right)^{-(\sigma-1)/(\sigma N_A)}. \tag{20}$$

If transportation costs are the same for all countries, Γ is also the same for all developing countries as it includes the trade of good X between any two countries, the export of recycled material from all developing countries, and the export of recyclable waste between any pair of developed and developing countries.

First, we consider the case where all transportation costs are equal to zero:

$C_{x,ji} = C_{r,ji} = C_{b,ji} = 1$. This also implies that the distance between countries does not matter, and trade obstacles through policy do not exist. Moreover, this implies that we can separate the recycling sector, which produces recycled materials from recyclable wastes, from the production process and consumption process of final good X.

In this case, and as noted above, Γ is the same for all developing countries. Thus, when focusing on the developing country factors, the supply of domestic recyclable waste (b_{ii}) and the production cost of recycled material in developing country i ($\omega_{r,i}$) determine the volume of trade. Recalling that $\tau > 1$ and $\sigma > 1$, from $\omega_{r,i} = w_i \, l_{r,ii}\left(\overline{K}_{R,i}\right) + p_{rs,i}$, the following proposition holds.

Proposition 1. *Suppose all transportation costs are equal to zero, then (a) the smaller the unit labor cost* $w_i l_{r,i}\left(\overline{K}_{R,i}\right)$ *in developing country* i*, and (b) the smaller the recovered recyclable waste of developing country* i*, the greater the trade in recyclable waste between developing country* i *and developed country* j.

Thus, if free trade prevails with zero transportation costs, the condition of the sector that produces the recycled material determines the volume of trade. In general, the supply of recyclable waste increases with per capita income (GDP) in a developing country. This is because consumption is greater and the recovery rate is higher than in other developing countries. Thus, the higher the wage in country i, the more recyclable waste recovered. Furthermore, and more importantly, this sector is usually more labor intensive than other sectors/industries. In such a case, it is likely that the higher the wage in country i, the larger the unit labor cost of the labor intensive sector ($w_i l_{r,i}\left(\overline{K}_{R,i}\right)$). Therefore, the lower the wage in a developing country, the more recyclable waste it imports. We need to note that although we assume $C_{b,ji} = 1$, the transportation cost, and accordingly the distance between the two countries, influences the trade volume if it is greater than one.

Second, we consider the case of the free trade of the final good X without any transportation costs. Consequently, we can separate the production process and the consumption process. It is, however, difficult to separate the recycling sector from the production process of final good X. In other words, $C_{r,ji}(i \neq j)$ is very large. Hence, $\overline{R}s_i = \left(\sum_k Rs_{ik}^{\rho}\right)^{\tau/\rho}$ is almost the same as Rs_{ii}^{τ}. On the other hand, and similar to the first case, we assume $C_{x,ji} = C_{b,ji} = 1$. In this case:

$$\left(\sum_k \overline{P}_{R,k}\overline{v}_k^{(N\mu-1)/(N\mu)}C_{r,ik}^{-1}\overline{X}_k\right)^{\tau/\rho} = \left(\overline{P}_{R,i}\overline{v}_i^{(N\mu-1)/(N\mu)}C_{r,ii}^{-1}\overline{X}_i + \sum_k \overline{P}_{R,k}\overline{v}_k^{(N\mu-1)/(N\mu)}C_{r,ik}^{-1}\overline{X}_k\right)^{\tau/\rho} \qquad (21)$$

holds. Since $C_{r,ji}(i \neq j)$ is very large, it is clear that the production of good X in country i mainly determines the value of (21). Thus, using the definition of $\overline{P}_{R,i}$, Equation (19) can be rewritten as:

$$B_{ji} \approx C_{b,ji}^{-1/\sigma} \cdot b_{ii}^{-(1-N_A\kappa)(2\sigma-1)/(N_A\kappa\sigma)} \cdot \left(\omega_{r,i}\tau\right)^{-\rho(\tau-1)/\rho} \cdot \left(\omega_{b,j}\delta\right)^{-(\delta-1)/\delta} \cdot \overline{v}_i^{-\rho(1-N\mu)/(N\mu)} \cdot \overline{X}_i^{\rho+1} \cdot C_{r,ii}^{-1} \cdot \Psi \qquad (22)$$

where:

$$\Psi = \prod_j C_{r,ji}^{1/N} \cdot \prod_j \left(\frac{\overline{Q}_{R,j}}{\omega_{r,j}\tau}\right)^{-(\rho-1)/N} \cdot \left(\sum_i \overline{P}_{B,i} \cdot b_{ii}^{-(1-N_A\mu)/(N_A\mu)} \cdot C_{b,ji}^{-1} \cdot \overline{R}_{S,i}\right)^{(\sigma-\delta)/(\delta(\sigma-1))} \cdot \prod_j \left(\frac{C_{b,ji}^{-1/(\sigma-1)} \cdot \overline{Q}_{B,j}}{\omega_{b,j}\delta}\right)^{-(\sigma-1)/(\sigma N_A)}, \qquad (23)$$

and this is the same for all developing countries. Then, from (13) and (14), and the definitions of $\overline{X}$ and $\overline{Q}_X$, we obtain:

$$\overline{X}_i = \left(\omega_{x,i}\psi\right)^{-\psi(\psi-1)/(\psi-\alpha)} \cdot \left(\sum_k \left(C_{x,ik}^{-1/(1-\alpha)} \cdot \overline{P}_{x,k} \cdot E_{x,k}\right)^{\phi/(\phi-\alpha)}\right)^{\psi/\phi} \cdot \left(\sum_k \left(C_{x,ik}^{-1/(1-\alpha)} \cdot \overline{P}_{x,k} \cdot E_{x,k}\right)^{\phi(1-\alpha)/(\phi-\alpha)}\right)^{\psi(\phi-\psi)/(\phi(\psi-\alpha))}$$

where $\sum_k \left(C_{x.ik}^{-1/((1-\alpha))} \cdot \overline{P}_{x.k} \cdot E_{x,k}\right)$ is included in any developing country's recyclable waste trade equation. Thus, recalling that $\omega_{x,i} = w_i l_{x,i}\left(\overline{K}_{x,i}\right) + p_{Z,i}$, when focusing of the factors of developing countries (a) the supply of domestic recyclable waste (b_{ii}), (b) the production cost of recycled material ($\omega_{r,i}$), (c) the amount of imports of virgin materials ($\overline{v}_i$), and (d) the production cost of the final good, determines the volume of trade ($\omega_{x,i}$).

Proposition 2. *Suppose that it is difficult for any country to separate the recycling sector from the production process of final goods. In developing country i (a) the greater the volume of domestic recyclable waste recovered, (b) the smaller the unit labor cost $w_i l_{r,i}\left(\overline{K}_{R,i}\right)$, (c) the smaller the amount of imports of virgin materials, and (d) the smaller the unit labor cost $w_i l_{x,i}\left(\overline{K}_{X,i}\right)$, the greater the trade in recyclable waste between developing country i and developed country j.*

The effects of the supply of domestic recyclable waste and the production cost of recycled material are identical to the first case. The effect of the import of virgin material is intuitive, as virgin materials and recycled materials are substitutes.

We should consider the unit labor cost of the final good sector carefully. For instance, the final good sector may be relatively capital intensive compared with the recycling sector. In such a case, it is likely that the higher the wage in country i, the lower $w_i l_{x,i}\left(\overline{K}_{X,i}\right)$. This is because the amount of the specific factor used for the production of final good X may be much larger when compared with developing countries with lower wages. If this effect dominates the effect arising from the difference in the unit cost of the recycling sector, which is usually labor intensive, the following result holds: the higher the wage in a developing country, the more recyclable waste it imports.

Finally, we consider the case where it is difficult to separate the production process and the consumption process from the recycling process. Put differently, both $C_{x,ji}(i \neq j)$ and $C_{r,ji}(i \neq j)$ are very large. Here, $\overline{X}_i = \left(\sum_k X_{ik}^{\phi}\right)^{\psi/\phi}$ is almost equal to X_{ii}^{ψ}. Similarly to the second case, Equation (22) holds, although:

$$\overline{X}_i = \left(\omega_{x,i}\psi\right)^{-\frac{\psi(\psi-1)}{\psi-\alpha}} \cdot \left(C_{x,ii}^{-1/(1-\alpha)} \cdot E_{x.i}^{(\phi-\alpha)/(\phi(1-\alpha))} \cdot \sum_j \left(\frac{C_{x.ji}^{-1/(\phi-1)} \cdot \overline{Q}_{x,j}}{\omega_{x,j}\psi} \right)^{\alpha(\phi-1)/(\phi(1-\alpha))} \right)^{\frac{\psi(\alpha((\psi-1)+\phi(1-\alpha)))}{(\psi-\alpha)(\phi-\alpha)}}, \quad (24)$$

holds from the definition of $\overline{P}_x$.

From (22) and (24), it is clear that in addition to the four factors in the second case, the income of country i influences the trade volume. In the first two cases, the higher the income, the smaller the trade volume, as the higher income leads to a greater supply of recovered recyclable wastes. As an alternative, in this case income affects trade volume through another channel: namely, the demand for final goods and accordingly the demand for materials.

Proposition 3. *Suppose that it is difficult for any country to separate the recycling sector from the production and consumption process of final goods. Then, along with the four factors in the second case, an additional factor affects the trade volume in recyclable wastes: that is, the higher the income in developing country i, the greater the trade in recyclable waste between developing* *country i and developed country j.*

3.3 Trade Restrictions in Recyclable Wastes

The trade in recyclable waste sometimes causes serious environmental damage and health problems in importing countries due to the lack of technology and knowledge in treating recyclable waste, which is sometimes toxic. This situation is particularly serious in the least developed countries and/or for unskilled workers than in more developed developing countries and/or for skilled workers. Because of this, trade restrictions on recyclable waste have been often advocated. For example, the Basel Convention prohibits trade in hazardous wastes for dumping them into the landfills of importing countries. However, there is no prohibition on the trade in recycling waste, although trade in toxic wastes is restricted. Thus, trade volumes have been increasing in spite of efforts by the governments of developed countries to complete the recycling processes in their own country.

However, it is not clear whether trade restrictions through international agreements effectively restrict the trade in recyclable waste from developed countries to the least developed countries. If the first case in the previous subsection holds, it is likely that decreases in imports by less developed developing countries are greater than for more developed developing countries. If the second or third case holds, it may be that the opposite takes place, whereby the trade restriction entails a substantial loss in production efficiency because production costs in more developed developing countries increase greatly. Accordingly, it is important to identify the patterns of trade in recyclable waste when considering trade restrictions to prevent environmental damage and protect human health in importing (developing) countries.

4. Empirical Evidence on the Trade Pattern in Recyclable Wastes

We have examined the relationship between the trade flows of recyclable wastes and the variables considered important for the cross-border movement of recyclable wastes. However, in the real world, other economic and noneconomic factors influence trade flows. In this section, we empirically extract the effect of these variables on trade volumes. We particularly focus on cross-border movements from developed countries to developing countries.

4.1 Empirical Specification: A Commodity Specific Gravity Model

It is widely acknowledged that gravity models have empirically succeeded in explaining trade flows. A considerable number of studies employ gravity models, and Anderson (1979), Bergstrand (1985, 1989, 1990), and Anderson and Wincoop (2003) have theoretically justified the use of gravity equations.

According to (19) and (22), it is appropriate that we base our estimation on a gravity model methodology. The sign of the independent variables depends on which case in Subsection 3.2 holds. Our empirical commodity-specific gravity model of waste and scrap is as follows:

$$B_{JI} = A \cdot GDP_J^{\alpha 1} GDP_I^{\alpha 2} N_J^{\alpha 3} N_I^{\alpha 4} RAW_J^{\alpha 5} RAW_I^{\alpha 6} W_J^{\alpha 7} W_I^{\alpha 8} C_{JI}^{\alpha 9} \times \exp[\alpha_{10} BORDER_{JI} + \alpha_{11} APEC + \alpha_{12} EU + \alpha_{13} V_{JI}] \varepsilon_{JI} , \quad I = 1, \cdots, N_A \; and \; J = 1, \cdots, N_a \quad (25)$$

where:

B_{JI} = quantity of country J's commodity imported by country I;

GDP_J = per capita gross domestic product of country J;

GDP_I = per capita gross domestic product of country I;

N_J = population of exporting country J;

N_I = population of importing country I;

RAW_J = total inputs of raw materials in exporting country J;

RAW_I = total inputs of raw materials in importing country I;

W_J = manufacturing wage in exporting country J;

W_I = manufacturing wage in importing country I;

C_{JI} = shortest distance between country J's commercial centers and country I's import point;

$BORDER_{JI}$ = a border dummy that takes a value of 1 if countries J and I share a border and otherwise;

$APEC$ = a dummy variable that takes a value of 1 for intra-Asia–Pacific Economic Cooperation (APEC) flows and 0 otherwise;

EU = a dummy variable that takes a value of 1 for intra-European Union (EU) flows and 0 otherwise;

V_{JI} = real exchange rate volatility;

ε_{JI} = the error term.

Given we focus on the trade flows from a developed country to a developing country, all exporting countries are developed countries, and all importing countries are developing countries according to the definition used by the World Bank. However, there is another reason why we only choose trade flows from developed to developing countries in our empirical analysis. This is because when it comes to the trade in recyclable waste from developing to developed countries, the reasons for trade are quite different from the trade from developed to developing countries. For instance, developing countries sometimes do not have technology to recycle wasted goods and they are exported to developed countries for dismantling and recycling. For example, goods including lead are sometimes traded. Thus, we classify separately these two kinds of trade in recyclable wastes.

4.2 Data

We obtain bilateral export data (constant $US) from the Global Trade Atlas from GTI Inc. (2003) with alternative Harmonized System Codes (HS Code). Population and real GDP per capita (constant $US) are wherever possible from the *Penn World Table 6.1*. Where these data are unavailable, we use the *World Development Indicators* and the International Monetary Fund's *International Financial Statistics*. Finally, we specify dummies for landlocked, borders, and distance using the US Central Intelligence Agency's *World Factbook*. Wage data is from *LABORSTA*, a database on labor statistics compiled by the International Labour Office Bureau of Statistics. This particular gravity data set is the most comprehensive we know. The sample period is the 11 years from 1995 through 2005 for all commodity products in our panel data set.

We choose five commodities of waste and scrap: (1) waste, parings and scrap of polymers of ethylene; (2) waste, parings and scrap of polymers of vinyl chloride; (3) waste, parings and scrap of polymers of other plastics; (4) ferrous waste and scrap; (5) remelting scrap ingots of iron or steel; copper waste and scrap. The HS Codes are shown in Table 1. We choose these products because they have large markets in many countries and international markets exist. Thus, these wastes fit well with the objective of this paper.[10] The number of countries in our panel sample varies by the waste recycled due to data availability, ranging from 50 to 119 countries. Table 1 provides the sample size for each waste. According to the World Bank's *List of Economies*, we classify "high-income countries" as developed countries, and others as developing countries.

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[10] Wastepaper is also a good candidate for this analysis. However, the sample size is too small to conduct an empirical analysis.

As discussed in Section 3, an increase in the market size of final goods may influence the demand and supply of recyclable waste, and therefore trade flows. Moreover, the effect of a change in the market size of a developed (exporting) country and that of a developing country may be asymmetric. We use both per capita GDP and population size to represent the market size. Based on our theoretical results, the expected signs of these independent variables for importing countries are expected to be positive if the costs of transporting recycled materials and consumer goods are high and if demand for domestic recyclable wastes is greater than the supply. This is likely to hold in developing countries. However, if costs are very low and there is free trade in recycled materials and consumer goods, the effect of an increase in the supply of recyclable waste is relatively large. In this case, the expected signs of the independent variables for importing countries may be negative.

Although we did not theoretically analyze the variables of exporting countries in the previous section, the per capita GDP of developed countries could also influence trade volumes. The supply of recyclable waste also appears to be greater than the demand for domestic recyclable waste in developed countries. Accordingly, the expected sign of the coefficient for per capita GDP in exporting countries is positive, as it does not depend on the separation of the recycling sector from the production and/or consumption processes: the higher the per capita GDP the larger the supply of recyclable waste and the greater the export of recyclable waste. The raw materials are generally substitutes for recycled materials given the amount of final good products. Therefore, the coefficients for raw material are positive (resp. negative) for exporting (resp. importing) countries.

The most important factor in this study is the manufacturing wage of importing countries. If less developed developing countries with lower wages import more recyclable waste, the coefficient on the manufacturing wage of the importing country is expected to be negative. On the other hand, if those countries import less recyclable waste, the coefficient is expected to be positive. If the former is true, less developed developing countries import a large amount of recyclable wastes, and the recycling sector is located in a country separated from the production and consumption processes of final goods. If the latter is true, more developed developing countries import a large amount of recyclable waste. This implies that import volumes increase alongside industry expansion. In other words, the recycling sector does not separate from the final goods industry and/or consumption place. The remaining variables are the distance, APEC, and EU dummies and real exchange rate volatility. As in conventional gravity estimation, the expected signs of the estimated coefficients for these variables are negative, positive, positive, and negative, respectively.

4.3 Empirical Results

Table 2 provides the estimated results. We conduct three different methods as a robustness check: a random effects model (RANDOM), a time-series, cross-sectional model using feasible generalized least squares (XTGLS), and general method of moments (GMM). Of these, the GMM is the most robust method, though the other methods yield comparable signs on almost all of the most important coefficients. Therefore, we mainly discuss the GMM results.

We adopt a differenced GMM, as proposed by Arellano and Bond (1991). This method has the advantage that it controls for any endogeneity by including appropriate instrumental variables. We include dependent variables before *t–2* as instrumental variables. In each model, the Sargan test of over-identifying restrictions and the hypothesis of no second-order autocorrelation indicate that the instruments used are valid and that there is no serial correlation in the error term (results not shown). For the over-identification test, we examine the Hansen J-statistics. The null hypothesis is that the instruments are valid, i.e., uncorrelated with the error term. The p-values are larger than 0.10 for all tests, indicating that correctly excluded the instruments from the estimated equation.

Most of the estimated parameters have the expected signs and are statistically significant. The results are also similar to previous studies using gravity models to analyze trade flows. The coefficients of per capita GDP for both exporting and importing countries have positive signs. Almost all of the coefficients are statistically significant at the 1% level. We note that the implications of these positive signs are different from the results obtained in ordinary gravity estimations. As discussed in Section 3, whether the recycling sector is separate from the production sector of final goods is an important factor to determine the trade flow of recyclable waste. The positive sign of the coefficient for importing countries suggests that the demand for recyclable waste in these countries influences the trade flow. This also implies that recycling sectors are likely to be located in a country with the production and consumption of final goods. Moreover, the magnitudes of some coefficients are greater than 1.0. This indicates that the quantities of waste and scrap traded are often sensitive to changes in market scale in both countries. However, some estimated coefficients for population are positive and others are negative. A few are insignificant. These coefficients may indicate the effect of an increase in the supply of recyclable waste. The magnitude of the estimated coefficient for population, however, is generally smaller than that for per capita GDP.[11]

The coefficients for the manufacturing wage of the importing country are positive. For example, the coefficients are significant at the 1% level for copper waste, and waste, parings and scrap of polymers of ethylene. In general, the degree of development in terms of economic growth and industry expansion implies higher wages. Thus, we prove that the more developed a developing country, the more recyclable wastes it imports. Therefore, the recycling sector is not completely separate from the final goods industry and/or consumption place.

We also analyze the effect of regional trade agreements. Free trade variables representing trade flows for specific groups, such as APEC and the EU, are included in the model. APEC dummy variables are included to identify the extent to which membership of APEC has enhanced trade among its members. We hypothesize that economic integration or free trade arrangements under APEC and EU enhance trade flows among member countries because of trade creation effects. The free trade variables APEC and EU represent factors aiding trade flows; we use the distance variable to approximate transportation costs. We retain the adjacency dummy variable in the empirical model, as there is more trade between countries with common borders than countries without common borders or those geographically farther apart.

We estimate the effect of exchange rate volatility following Cho et al. (2002). Our findings show that exchange rate volatility has a negative and significant effect on the flows among countries for the majority of commodities examined. This finding is consistent with Cho et al. (2002) who suggested that exchange rate volatilities impair trade flows in sectoral trade. However, they also found that the negative effect is rather commodity specific and not uniform across individual commodities.

5. Concluding Remarks

This study first theoretically models the trade flow of recyclable wastes. We particularly focus on the trade from developed countries to developing countries because volumes have been increasing drastically over the past few decades. There are two reasons for this increasing trend. The first is that demand increases alongside economic growth in developing countries. The second is the

[11] Another reason is that according to international economics theory and real world observations, larger populations do not necessarily imply greater market scale.

expansion of recycling activities in labor-abundant developing countries according to their comparative advantage.

Subsequently, we provide empirical results using a commodity-specific gravity model of waste and scraps to support our theoretical results. We confirm that (a) the higher the manufacturing wage in a developing country and/or (b) the higher the per capita GDP in a developing country, the greater the import volume of recyclable waste from a developed country. In conjunction with our theoretical findings, this suggests that there is no evidence of pollution havens in the sense that dirty recycling sectors expand in less developed developing countries more rapidly than in more developed developing countries. Moreover, when trade in recyclable waste is restricted, it is likely that decreases in imports by more developed developing countries are greater than in less developed developing countries. Thus, trade restrictions entail significant losses in production efficiency because production costs in more developed developing countries greatly increase. Finally, it is important to capture trade patterns in recyclable waste when considering trade restrictions on those wastes to prevent environmental damage and protect human health in importing (developing) countries.

Unfortunately, we do not take into consideration the micro behavior of waste collectors. It is also likely that recycling activity in more developed developing countries exhibits increasing returns-to-scale technology. It may also be important to estimate the recycling technology (the supply function of recycled materials). Future research needs to consider these factors.

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Table 1. Harmonized System Codes of Waste and Scrap

HSC code	Commodities	Number of Countries
Commodity: 391510	Waste, Parings and Scrap of Polymers of Ethylene	119
Commodity: 391530	Waste, Parings and Scrap of Polymers of Vinyl Chloride	98
Commodity: 391590	Waste, Parings and Scrap of Polymers of Other Plastics	73
Commodity: 720449	Ferrous Waste and Scrap, Remelting Scrap Ingots of Iron or Steel	50
Commodity: 740400	Copper Waste and Scrap	94

Table 2. Empirical Estimates of Gravity Models

Commodity Code Model	740400 RANDOM	740400 XTGLS	740400 GMM	720449 RANDOM	720449 XTGLS	720449 GMM	391510 RANDOM	391510 XTGLS	391510 GMM
Per capita GDP	1.819	2.609	0.063	2.147	2.312	2.278	3.068	3.357	0.984
(Exporting country)	(3.43)***	(8.16)***	(2.79)***	(3.59)***	(6.66)***	(4.53)***	(2.26)**	(2.48)**	(2.97)***
Per capita GDP	2.497	3.632	1.295	1.94	1.941	1.939	2.861	2.8	0.791
(Importing country)	(5.49)***	(12.67)***	(7.47)***	(4.24)***	(6.61)***	(4.53)***	(3.68)***	(3.38)***	(2.17)**
Population	0.85	1.721	1.042	0.833	–1.369	–1.986	–0.116	–3.457	–0.383
(Exporting country)	(2.94)***	(4.68)***	(6.73)***	(2.68)***	(–3.47)***	(–3.52)***	–0.24	(–2.25)**	–1.06
Population	2.181	–0.686	–0.511	1.851	0.026	0.085	2.273	–0.452	0.034
(Importing country)	(6.71)***	(–4.88)***	(–2.47)**	(5.35)***	0.17	0.19	(3.98)***	–0.89	0.11
Raw Material	0.319	2.71E–01	0.286	0.0097	–3.60E-02	–4.50E-02	0.033	0.0251	0.032
(Exporting country)	(2.31)**	(4.43)***	(2.43)**	0.16	–0.49	–0.11	0.45	0.49	1.19
Raw Material	–0.116	–0.173	–0.143	–0.0056	–0.116	–0.121	–0.063	–0.119	0.004
(Importing country)	–0.72	(–2.43)**	–0.23	–0.13	–1.02	–1.11	(–1.85)*	(–3.43)***	0.19
Wage	0.269	0.267	0.288	0.193	–0.978	–0.993	–0.234	–0.314	–0.171
(Exporting country)	(1.67)*	(1.79)*	(1.68)*	1.01	(2.3)**	(2.21)**	–3.17	(–1.75)*	(–2.12)**
Wage	0.504	0.474	0.512	0.146	0.015	0.024	0.708	0.585	0.345
(Importing country)	(3.06)***	(2.99)***	(2.98)***	2.73**	0.05	0.03	(3.17)***	(3.01)***	(3.4)***
Border dummy	0.233	2.933	0.153	4.863	2.741	2.824	5.617	5.29	1.661
	0.06	(2.14)**	0.95	(2.67)***	(1.97)**	(1.99)**	(2.33)**	(2.7)***	(1.95)*
Distance	–1.209	–0.229	–2.161	–2.373	–1.738	–2.214	–2.259	–1.345	–1.925
	–1.11	–0.62	(–4.48)***	(–3.15)***	(–4.08)***	(–3.98)***	(–2.54)**	–1.34	(–3.41)***
APEC dummy	2.738	2.669	1.489	4.032	4.819	4.152	6.407	2.441	3.027
	(2.28)**	(5.75)***	(2.28)**	(4.61)***	(2.81)***	(3.58)***	(3.41)***	(2.39)**	(2.62)**
EU dummy	0.438	0.437	2.757	2.596	–2.249	–2.252	–1.46	–0.29	–0.618
	0.17	0.49	(5.79)***	1.28	(–1.99)**	(–2.01)**	–0.56	–0.13	–0.50
Real exchange rate volatility	–3.24E+01	–37.45	–0.528	–0.511	–0.542	–0.501	–0.499	–0.002	–3.9E-05
	(–3.29)***	(–5.17)***	–0.86	(–13.54)***	(–4.23)***	(–4.96)***	(–13.09)***	(–2.02)**	(–5.93)***

Notes: t-statistics in parentheses. *, **, and *** denote significance at the .10, .05, and .01 percent level, respectively.

Table 2. (… continued)

Commodity Code Model	391530 RANDOM	391530 XTGLS	391530 GMM	391590 RANDOM	391590 XTGLS	391590 GMM
Per capita GDP	1.514	3.213	1.002	0.959	2.508	1.049
(Exporting country)	(1.91)*	0.53	(3.10)***	(1.92)*	(2.55)**	(6.29)***
Per capita GDP	1.271	3.61	0.912	2.569	2.085	0.869
(Importing country)	(2.4)***	(4.55)***	(3.76)***	(6.41)***	(3.77)***	(6.20)***
Population	1.719	–2.727	–0.694	0.643	–1.805	–0.503
(Exporting country)	0.64	–0.39	(–1.73)*	(2.57)***	–1.5	(–2.53)**
Population	2.415	–0.424	–0.457	1.351	–0.594	–0.338
(Importing country)	(3.92)***	–0.9	(–2.17)**	(4.65)***	(1.79)*	(–2.45)**
Raw Material	–0.135	0.105	0.06	0.028	0.116	0.108
(Exporting country)	–0.25	1.47	(2.49)**	0.62	1.03	1.01
Raw Material	–0.574	–0.144	0.024	–0.025	–0.416	–0.125
(Importing country)	(–1.75)*	(–2.01)**	0.73	–1.21	(2.6)***	(3.45)***
Wage	–0.019	–0.208	–0.272	0.102	0.501	0.308
(Exporting country)	(–1.76)*	(–1.84)*	(–1.72)*	0.64	1.19	1.27
Wage	0.219	0.229	0.064	0.338	0.716	0.491
(Importing country)	0.87	0.99	0.57	(1.84)*	(1.95)*	(1.99)*
Border dummy	4.413	2.232	1.686	1.149	4.5	1.227
	1.49	0.8	(2.35)**	0.32	(2.72)***	(2.54)**
Distance	–2.528	0.122	–0.717	–1.054	–0.892	–0.94
	(–2.39)**	0.08	(–2.12)**	(–1.72)*	–1.11	(–3.96)***
APEC dummy	11.45	9.481	1.734	5.692	14.357	2.622
	(5.99)***	(5.51)***	(2.45)**	(2.58)**	(4.04)***	(6.05)***
EU dummy	6.215	12.372	–1.153	3.38	–2.495	–0.26
	0.24	(2.88)***	–0.82	1.21	–0.49	–0.51
Real exchange rate volatility	0.732	–0.513	0.0001	–0.844	9.564	1.01E-06
	1.25	(–4.12)***	0.19	(–2.11)**	1.28	0.29

Notes: t-statistics in parentheses. *, **, and *** denote significance at the .10, .05, and .01 level, respectively.