The Determinants of Trade in Recyclable Wastes, the Structure of Recycling Sectors, and the Effects of Trade Restriction

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This version: November 2008

Abstract

This paper examines theoretically the trade pattern of recyclable waste and the effect of trade restriction on the recycling activities. Moreover, on the trade pattern, we conduct a empirical analysis using a gravity model. In particular, we focus on the trade from developed countries to developing countries. The relationship between the wages and the volume of imports is focused on. The reason is that, if a recycling process can be separated from the production process of final goods or/and the consumption process, it may be located in the labor-abundant, less developed countries. If it is true, the environmental and health problems may become serious.

We demonstrate empirically that, the higher is 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 least developed countries more rapidly than the more "developed" developing countries. Furthermore, it may be that trade restriction for reducing environmental damage is accompanied by a big loss in efficiency.

Keywords: trade in recyclable wastes, recycling technologies.

JEL Classification: F18, Q28

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1. Introduction

In the past few decades, many countries experienced substantial and constant increases in the generation of waste. It is estimated that this trend will continue in the next few decades, that is, both industrial and municipal wastes would increase at the same pace. For example, the generation of industrial waste in the Association of South East Asian Nations (ASEAN) in 2050 will be triplicated as compared with that in 2000.[1] Moreover, the Organization for Economic Co-operation and Development (OECD) estimates that the world waste generation in 2050 is approximately 27 billion tons, which is more than double as the waste generated in 2000 (12.7 billion tons).[2]

At the same time, the world is drastically globalized in terms of trade liberalization, and trade in recyclable wastes is no exception. Therefore, a rapid increase in transboundary movement of recyclable wastes has been observed, in particular from developed countries to developing countries.[3] When it comes to Asian countries, this rapid increase began in 1990's after some of developing countries began to experience rapid economic growth.[4]

There are two main reasons for this increase in trade in recyclable wastes. First, according to the economic growth due to globalization, the demand for not only virgin materials but also recycled materials, which are substitutes for virgin materials, has increased rapidly across the world. Second, trade liberalization has encouraged vertical disintegration of production processes of many industries. It is not rare that each production process is located in a different country. As Hotta et al. (2008) discussed, even a recycling process can be located independently, which means that a recycling

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1 See Hotta et al. (2008).

2 See the Annual Report on the Environment and the Sound Material-Cycle Society in Japan 2008, Overview2, Chapter1 (http://www.env.go.jp/en/wpaper/).

3 Van Beukering (2001) referred to this point.

4 See the Annual Report on the Environment and the Sound Material-Cycle Society in Japan 2008.

process can be separated from the production process of final goods or/and the consumption process. Then, if the recycling process is labor intensive, that process may expand in a labor abundant country.

The latter factor is more problematic than the former factor. The reason is as follows. 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 those countries to procure materials. Then, those industries other than recycling sectors could expand, and per capita income increases. In this sense, the problem of waste (recycling) is similar to other environmental problems which arise according to economic growth.

On the other hand, if the import of recyclable wastes of some developing countries increases because of their labor abundance and the labor intensiveness of recycling activities, the problem caused by waste may become serious. Usually, contrary to recycling processes in developed countries, recycling activities are unskilled labor intensive in the least developed countries. People in those countries do not have the knowledge on toxicity of materials. Therefore, the possibility that recycling activities cause serious environmental damage or/and human health problems is stronger when wasted materials are recycled in unskilled labor abundant countries than when they are recycled in developed countries. Moreover, trade in wasted materials sometimes leads to an increase in illegal dumping in the importing countries.[5]

This paper sheds light on the trade pattern of recyclable wastes both theoretically and empirically. In particular, we focus on the trade from developed countries to developing countries. Then, the following question is focused on: whether or not the least developed country imports more recyclable waste than the other developing

[5] Ray (2008) discussed this point. In terms of theoretical analysis, Copeland (1991) examined the trade in waste when illegal dumping exists.

country does. Moreover, the effects of trade restriction of recyclable wastes on recycling activities are examined, since the change in recycling activities is important in terms of both environmental damage and the loss of efficiency.

A considerable number of studies have been made on the analysis of recycling policies in a closed economy (Dinan (1993), Highfill and McAsey (1997), Conrad (1999), Huhtala (1999), Eichner and Pethig (2001, 2003), Eichner (2005)). However, as far as we know, there have only been a few attempts to investigate trade liberalization of recyclable wastes. Although, Grace et al. (1978) and Huhtala and Samakovlis (2002) referred to policy aspects of trade in recyclable wastes, there are few theoretical analyses which take into consideration the difference in developing countries.[6]

In empirical estimation, we adopt a gravity model. It is widely acknowledged that gravity models have succeeded in explaining trade flows empirically. Especially, we choose five kinds of waste and scrap, and conduct empirical estimations based on commodity level trade data. There are several empirical studies which tackled the recycling problem under open economies (Berglund and Söderholm (2003a,b), van Beukering (2001), and van Beukering and Bouman (2001) among others). As far as we know, however, there is neither study which focuses on the relationship between the wage and commodity level trade flows using gravity models, nor study which examines the difference between developing countries.

We demonstrate empirically that, the higher is 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 least developed countries more rapidly than the more "developed" developing countries.

[6] Moreover, there are several empirical studies which tackled the recycling problem under open economies. See Berglund and Söderholm (2003a,b), van Beukering (2001), and van Beukering and Bouman (2001) among others.

Furthermore, it may be that trade restriction for reducing environmental damage is accompanied by a big loss in efficiency.

The structure of the paper is as follows. Section 2 describes the basic theoretical model. Section 3 investigates the trade pattern of recyclable wastes. Section 4 considers the effect of trade restriction on recycling activities. Section 5 conducts empirical analyses, and Section 6 provides concluding remarks.

2. The Theoretical Model

There are three countries in the world; one developed country, denoted by country A, one developing country, denoted by country B, and the rest of the world. Each of developed and developing countries is populated a continuum of individuals, whose number is measured by $N_i(i = A, B)$. Each individual is endowed with a certain units of labor, and consumes good Z, which is numeraire, and good X. The utility of each individual is defined as

$$U = u(x) + z, \qquad u' > 0, \quad u'' < 0,$$

where x and z are the amounts of consumption of goods X and Z, respectively. Then, the inverse demand function for good X is

$$p_x = u'(x). \tag{1}$$

The total number of labor is sufficiently large relative to that employed in the production of recycled materials, which are used for producing good X. Thus, the wage ($w_i(i = A, B)$) is fixed, although the wage in one country is different from the other country. It is assumed that

$$w_A > w_B. \tag{2}$$

$1/w_i$ unit(s) of labor is used for producing one unit of good Z, which is produced competitively, and traded freely between countries A and B. Thus, the price of Z is equal to one in both countries.

One unit of good X is produced from virgin/recycled/mixed material. The production technology is the same for countries A, and B, and the production function is given by

$$X = F(R,V), \qquad F_R > 0,\ F_V > 0,\ F_{RR} < 0,\ F_{VV} < 0,\ F_{RV} > 0,,$$

where X, R, and V are the output of final good X, the input of recycled material, and the input of virgin material, respectively.[7] Assuming that the production technology exhibits constant returns to scale, the production of one unit of final good X is represented as:

$$1 = f(r,v), \tag{3}$$

where r and v are the input of recycled and virgin materials for unit production of good X, respectively. Assuming that virgin material can be imported from the rest of the world at a constant price, p_V, the condition for the profit maximization is:

$$\frac{f_v}{f_r} = \frac{p_V}{p_R} \tag{4}$$

where p_R is the price of recycled material. Final good X is produced competitively. Then, the price of final good X is given by:

$$p_X = p_R r + p_V v\,. \tag{5}$$

It is assumed that final good X and recycled material R are traded freely between countries A and B. Therefore, those prices are the same in both countries.

After good X is consumed, they become wasted materials. If they are collected, they can be recycled, which are referred to as recyclable waste hereafter. The recovery rate in each country is m_i[8]. Thus, the supply of recyclable waste in country i is

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7 For simplicity, we do not consider the input of labor for producing the final good X. Even if the input is taken into consideration, the results do not change essentially.

8 The recovery rate greatly depends on the environmental consciousness of consumers, and the collecting system of municipalities. Therefore, the recovery rate can be considered to

represented as

$$M_i^S = (r + v) m_i N_i x. \tag{6}$$

The recycling activity inputs one unit of recyclable waste to produce one unit of recycled material. It is assumed that recyclable wastes of both countries are perfect substitutes. Furthermore, the production of recycled material requires some units of labor (L_i) and an industry-specific production factor such as physical capital, the supply of which is fixed ($\overline{K}_i$). The production technology is the same for countries A, and B, and the production function is given by[9]

$$R_i = L_i^{\alpha} \overline{K}_i^{1-\alpha}.$$

Then, the profit function is given by

$$\pi_i = (p_R - p_{M,i}) L_i^{\alpha} \overline{K}_i^{1-\alpha} - w_i L_i.$$

Assuming that the recycled material is supplied competitively, and solving the profit maximization problem, the demand for labor, the supply of recycled material (R_i), and the demand for recyclable waste (M_i^D) are obtained:

$$L_i = \alpha^{1/(1-\alpha)} \cdot \left(\frac{p_R - p_{M,i}}{w} \right)^{1/(1-\alpha)} \cdot \overline{K}_i, \tag{7}$$

$$R_i = M_i^D = \alpha^{\alpha/(1-\alpha)} \cdot \left(\frac{p_R - p_{M,i}}{w} \right)^{\alpha/(1-\alpha)} \cdot \overline{K}_i. \tag{8}$$

Since the supply of recycled material is equal to the input of recyclable waste, if

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respond to a change in the wage less quickly than the production of goods and materials does. Moreover, we focus not on the collecting sector but on the recycling sector in this paper. Therefore, this rate is assumed to depend on neither the price of the recyclable waste, nor the wage. We, however, discuss the case in which changes in the recovery rate in Sections 3 and 4.

9 Although it is assumed that the production technologies are the same in both countries for simplicity, they could be different in both countries.

there is no trade in recyclable wastes, the following condition holds:

$$R_i = M_i^S = (r+v)\cdot m_i N_i x. \qquad (9)$$

Thus, when there is no trade in recyclable wastes, Equations (1), (3) - (5), and (7) – (9) for both countries, and the recycled material's market clearing condition, which is that the total supply of recycled material of both countries are equal to the total demand for recycled material, determine p_X, p_R, $p_{M,i}$, x, r, v, R_i, and L_i, given the following exogenous variables: p_V, w_i, N_i, m_i, $\overline{K}_i$.

3. Trade Patterns and the Trade Volume of Recyclable Wastes

3.1 Basic Trade Patterns

In this subsection, we investigate trade patterns of recyclable wastes when one country's exogenous variables change marginally. In particular, we focus on changes in the wage, the amount of the specific factor ($\overline{K}$), the number of individuals, and the recovery rate.

To abstract the effect of exogenous variables, it is assumed that both countries are symmetric, and we focus on country A. Then, under free trade in recycled materials and no trade in recyclable wastes, the equilibrium conditions are given by:

$$r(N_A + N_B)x = R_A + R_B \qquad (10)$$

$$R_A = (r+v)N_A x m_A \qquad (11)$$

$$R_B = (r+v)N_B x m_B., \qquad (12)$$

The first condition is that the total demand for recycled materials in both countries is equal to the total supply. The second and third equations are that the demand for and the supply of recyclable wastes are equal in each country.

First, from (3) through (5), we obtain the following lemma.

Lemma 1. *The following inequalities hold:*

$$\frac{dp_X}{dp_R} > 0, \; \frac{dr}{dp_R} < 0, \; \frac{dv}{dp_R} > 0.$$

See Appendix A for details.

For the recycling activities, it is obvious from (8) that the following inequalities hold: $\partial R_i / \partial p_{M,i} < 0$, $\partial R_i / \partial p_R > 0$, $(i = A, B)$. Then, from these conditions and Lemma 1, the following results are obtained:

$$\frac{dp_{M,A}}{dw_A} < 0, \; \frac{dp_{M,B}}{dw_A} > 0, \tag{13}$$

$$\frac{dp_{M,A}}{d\overline{K}_A} > 0, \; \frac{dp_{M,B}}{d\overline{K}_A} < 0, \tag{14}$$

$$\frac{dp_{M,A}}{dN_A} < 0, \; \frac{dp_{M,B}}{dN_A} > 0, \tag{15}$$

$$\frac{dp_{M,A}}{dm_A} < \frac{dp_{M,B}}{dm_A} < 0. \tag{16}$$

See Appendix B for details. Consequently, we establish the following proposition.

Proposition 1. *When trade barriers on recyclable wastes are removed, a country exports the recyclable wastes when (a) the wage is higher than that in the other country, (b) the amount of* $\overline{K}$ *is greater than that in the other country, (c) the population is greater than that of the other country, (d) the recovery rate is higher than that of the other country. .*

(a) , (b), and (d) are obvious. The intuition of (c) is as follows. A small increase in the number of individuals increases the demand for final good X. This implies that the demand for the recycled material increases given p_R. This effect raises the price of recyclable waste. On the other hand, an increase in N also increases the supply of wasted materials in the country. This effect lowers the price of recyclable waste. Equation (15) implies that the latter effect dominates the former effect. In the other country, only the former effect works.

3.2 Wages, the Amount of the Specific Factor, and the Trade Volume

In the real world, there are many developing countries, and wages and the amounts of the specific factor are different among those developing countries. To clarify the trade structure of recyclable wastes and the effect of trade restriction, it is important to consider the relationship between the difference in wages and the trade volume of recyclable wastes.

Suppose that the developing country (country B) imports recyclable wastes. From Proposition 1, the lower is the wage and the greater is the amount of K, the more recyclable wastes a country imports. In general, the less developed is a country, the more labor-abundant it is, and the lower the wage is in the country. In this respect, a less "developed" developing country imports more recyclable wastes. On the other hand, the more developed is a developing country, the greater is the amount of K. In this respect, a more "developed" developing country imports more recyclable wastes.

Suppose that an increase in the wage is accompanied with an increase in K [10]. Then, from (7) and (8), for any given prices (p_R, p_M), the effects of an increase in the wage on L_B and R_B under free trade in recyclable wastes are given by:

$$\frac{dL_B}{dw_B} = \left(\frac{p_R - p_M}{\alpha w_B}\right)^{\frac{1}{1-\alpha}} \cdot \left(-\frac{1}{1-\alpha}\frac{\overline{K}_B}{w_B} + \frac{d\overline{K}_B}{dw_B}\right),$$

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[10] In general, this assumption is considered to correspond to real situations.

$$\frac{dR_B}{dw_B} = \left(\frac{p_R - p_M}{\alpha w_B}\right)^{\frac{\alpha}{1-\alpha}} \cdot \left(-\frac{\alpha}{1-\alpha}\frac{\overline{K}_B}{w_B} + \frac{d\overline{K}_B}{dw_B}\right)$$

Since recyclable wastes are traded freely, the prices of recyclable waste are the same in both countries, that is $p_{M,A} = p_{M,B} = p_M$. It is clear that the directions of changes depends on the size of $\hat{\overline{K}}_B / \hat{w}_B$, where $\hat{\overline{K}}_B = d\overline{K}_B / \overline{K}_B$ and $\hat{w}_B = dw_B / w_B$. Thus, the following proposition is established.

Proposition 2. *For any give prices of the recycled material and recyclable waste, if* $\hat{\overline{K}}_B / \hat{w}_B > 1/(1-\alpha)$ *(resp.* $\alpha/(1-\alpha) < \hat{\overline{K}}_B / \hat{w}_B < 1/(1-\alpha)$*,) holds, the more developed is a country, the more (resp. more) recycled material it produces, and the more (resp. the less) labor is inputted for the production of recycled material. Furthermore,* $\hat{\overline{K}}_B / \hat{w}_B > \alpha/(1-\alpha)$ *holds, the more developed is a country, the less recycled material it produces, and the less labor is inputted for the production of recycled material.*

Let us take into consideration changes in prices. When recyclable wastes are traded freely, the equilibrium conditions are given by

$$r(p_R)\overline{N}x(p_R) = R_A(p_R, p_M) + R_B(p_R, p_M) \ , \tag{17}$$

$$R_A(p_R, p_M) + R_B(p_R, p_M) = (r(p_R) + v(p_R))x(p_R) \cdot (N_A m_A + N_B m_B). \tag{18}$$

Then, using these equations, it is obtained that

$$\frac{dp_R}{dw_B} = 0, \tag{19}$$

$$\frac{dp_M}{dw_B} > 0 \ (< 0), \quad if \ \frac{dR_B}{dw_B} > 0 \ (< 0). \tag{20}$$

See Appendix C for details. Inequality (19) implies that a change in w_B does not influence the consumption, and accordingly, the supply of recyclable wastes in each country. Inequality (20) implies that whether or not the trade volume increases due to an increase in w_B depends on the sign of dR_B/dw_B. Consequently, the following proposition holds.

Proposition 3. *If* $\hat{\bar{K}}_B/\hat{w}_B > 1/(1-\alpha)$ *(resp.* $\hat{\bar{K}}_B/\hat{w}_B < 1/(1-\alpha),$*) holds, an increase in* w_B*, and accordingly an increase in* $\bar{K}_B$*, increase (resp. decreases) the volume of trade in recyclable wastes.*

3.3 Further Discussion on Trade Patterns

According to Proposition 1, an increase in the number of consumers increases (resp. decreases) the export (resp. the import) of recyclable wastes. It has been, however, assumed so far that recycled materials and good X can be traded freely without any trade cost. If this assumption is dropped, the effect of a change in the number of consumers may be different from obtained in Proposition 1.

Suppose that the costs of transporting recycled materials and good X are very high, and they are produced in the same country where their products are consumed. Moreover, suppose that the recovery rate in country B is lower than that in country A. In this case, country B imports recyclable wastes, if the utilization rate ($r/(r+v)$) of recycled material is higher than the recovery rate. Then, an increase in the number of consumers in country B increases the difference between the supply of and the demand for recyclable wastes. Thus, an increase in the number of consumers increases the import volume of recyclable wastes. This result is contrary to that obtained in Proposition 1.

As noted above, the difference between the utilization rate and the recovery rate could be important. In general, the recovery rate becomes higher, as the wage of the country becomes higher, since workers with higher wages are likely to be better educated and more environmentally-conscious. In such a case, an increase in the number of consumers in both the developed and developing countries increases the volume of trade in recyclable wastes, since an increase in the supply of recyclable wastes is greater (resp. smaller) than an increase in the demand for recyclable wastes in the developed (resp. developing) country.

4. Trade Restriction and the Recycling Sector

In the real world, governments or/and international environmental institutions may restrict trade in recyclable wastes, since they sometimes causes environmental and health problems in developing countries where those wastes are imported. Trade restriction, however, shrinks the recycling sector of importing countries. Even the production of final good may shrink due to the restriction. This implies that trade restriction reduces welfare/efficiency. Therefore, it is important to investigate whether or not the environmental problem caused by recycling activities can be solved effectively without any great loss in efficiency. In this section, we investigate the effect of gradual trade restriction on the recycling activities in both countries.

In the present context of this paper, three variables could influence the degree of environmental and health problems: the wage, the amount of labor inputted into the production of recycled material, and the amount of the production of recycled material. As noted in the previous section, in general, the higher is the wage, the more environmentally conscious workers are. It can also be said that, the more labor is inputted, and the more recycled materials are produced, the more serious those environmental and health problems are.

Assuming that the developing country (country B) imports recyclable wastes, we introduce a cost (t) with regard to trade in one unit of recyclable waste, which is caused by trade restricting policies, so that $p_{M,B} = p_{M,A} + t$ holds. For simplicity, we use p_M instead of $p_{M,A}$ in this subsection. Then, the difference in prices of recycled material and recyclable waste in developing countries is given by $p_R - p_{M,B} = p_R - p_M - t$. The equilibrium conditions (17) and (18) are rewritten as:

$$r(p_R)\overline{N}x(p_R) = R_A(p_R, p_M) + R_B(p_R, p_M + t) \ , \tag{17'}$$

$$R_A(p_R, p_M) + R_B(p_R, p_M + t) = (r(p_R) + v(p_R))x(p_R)\cdot(N_A m_A + N_B m_B), \tag{18'}$$

First, we examine the effect of a change in t on the difference in prices of recycled material and recyclable waste in the developing country. Using (17) and (18), we obtain the following inequality:

$$\frac{d(p_R - p_M - t)}{dt} < 0.$$

See Appendix D for details and proof. This inequality implies that an increase in t, which means that trade in recyclable waste becomes more restrictive, decreases the marginal revenue of producing recycled material in the developing country.

From (7) and (8), it is clear that, the more is R_B (resp. L_B), the greater is a decrease in R_B (resp. L_B) due to trade restriction. Therefore, the pace of the accumulation of the specific factor ($\overline{K}_B$) is crucial for the effective removal of environmental damage and health problems without a big loss from trade restriction.

Suppose that $\hat{\overline{K}}_B / \hat{w}_B > 1/(1-\alpha)$, which fits for the case in which the specific factor is rapidly accumulated as the wage becomes higher. Then, trade restriction damages the recycling sector in the more "developed" developing country more seriously than in the less "developed" developing country. In such a case, it is likely that trade restriction reduces environmental damage in exchange for a relatively big loss in efficiency. On the other hand, if $\hat{\hat{K}}_B / \hat{w}_B < 1/(1-\alpha)$, trade restriction damages the recycling sector in the more "developed" developing country less seriously than in the less "developed" developing country. Thus, trade restriction may solve environmental problems without a big loss in efficiency. Furthermore, if $\hat{\hat{K}}_B / \hat{w}_B < \alpha/(1-\alpha)$, the more developed a country is, the less is a decrease in labor input for the production of recycled material due to trade restriction. Thus, the environmental damage may be solved effectively.

5. Empirical Evidence on Trade Pattern of Recyclable wastes

We have examined the relationship between trade flows/volumes of recyclable wastes and the variables which are considered to be important for the problems specific to cross-border movement of recyclable wastes. On the other hand, trade flows are influenced by other economic and non-economic factors in the real world. In this section, we empirically extract the effect of those variables on the trade volumes. In particular, we focus on the cross-border movement from developed countries to developing countries.

5.1 Empirical Specification (A Commodity Specific Gravity Model)

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

In Section 2, we derived the demand function for the recyclable waste in each country (Equation (8)). Therefore, the trade volume is given by

$$T_i = \alpha^{\alpha/(1-\alpha)} \cdot \left(\frac{p_R - p_M}{w_i} \right)^{\alpha/(1-\alpha)} \cdot \overline{K}_i - (r+v) \cdot m_i N_i x, \qquad (21)$$

which is positive (resp. negative) if the country imports (resp. exports) recyclable wastes. Prices depend on the number of individuals (N_i), the recovery rate (m_i), the wage, and the amount of specific factor, and production technologies.

Suppose that recyclable wastes of both countries are imperfectly substitutes, and producers input a mixed waste of both home and foreign recyclable wastes to produce one unit of recycled material, Equation (21) can be rewritten as:

$$T_i = \tilde{M}_{ij}\left(p_{M,i}, p_{M,j}\right) \cdot \alpha^{\alpha/(1-\alpha)} \cdot \left(\frac{p_R - \tilde{p}_M}{w_i} \right)^{\alpha/(1-\alpha)} \cdot \overline{K}_i ,$$

where $\tilde{M}_i(\cdot)$ and $\tilde{p}_M$ denote the amount of the input of foreign recyclable waste per unit of production of recycled material, and the price of the mixed waste.

Moreover, from Proposition 3, it is obtained that the volume of trade is positively correlated with the demand for recyclable wastes. Therefore, although we do not directly derive the empirical equation from the theoretical analysis in the previous sections, it is considered to be appropriate that we base our estimation on a method of gravity models.

Our empirical commodity specific gravity model of waste and scrap is as follows:

$$\begin{aligned} Z_{IJ} &= B \cdot GDP_I^{\alpha 1} GDP_J^{\alpha 2} N_I^{\alpha 3} N_I^{\alpha 4} RAW_I^{\alpha 5} RAW_J^{\alpha 6} W_I^{\alpha 7} W_J^{\alpha 8} d_{IJ}^{\alpha 9} \times \\ &\exp\left[\alpha_{10} BORDER_{IJ} + \alpha_{11} APEC + \alpha_{12} EU + \alpha_{13} V_{IJ}\right] \varepsilon_{IJ} \qquad (27) \\ &I = 1, \cdots, M_1 \ and \ J = 1, \cdots, M_2 \end{aligned}$$

where

Z_{IJ} = the quantity of country I's commodity imported by country J;

GDP_I = the per capita gross domestic product for country I;

GDP_J = the per capita gross domestic product for country J;

N_I = the population of exporting country I;

N_J = the population of importing country J;

RAW_I = the total input of a raw material in exporting country I;

RAW_J = the total input of a raw material in importing country J;

W_I = the manufacturing wage in exporting country I;

W_J = the manufacturing wage in importing country J;

d_{IJ} = the shortest distance between country I's commercial centers and country J's import point;

$BORDER_{IJ}$ = the border dummy takes value 1 if countries I and J share a border and 0 otherwise;

$APEC$ = the dummy variable equals 1 for intra-APEC flows and 0 otherwise;

EU = the dummy variable equals 1 for intra-EU flows and 0 otherwise;

V_{IJ} = the real exchange rate volatility;

ε_{IJ} = the error term.

Since we focus on the trade flow from a developed country to a developing country, all exporting countries are "developed" countries, and all importing countries are "developing" countries.

5.2 Data

We obtained the bilateral export data (constant $) from the "Direction of Trade" (DoT) CD-ROM dataset developed by the International Monetary Fund (IMF). Second, we obtained 4 population and real GDP per capita (constant $) from the Penn World Table 6.1 wherever possible. Where these data were unavailable, we filled in with the World Development Indicators and the IMF's International Financial Statistics. Finally, we obtained landlocked dummy, border dummy, and distance are from CIA's World

Factbook. This gravity dataset is most comprehensive as far as we know. The period is eleven years from 1995 through 2005.

We choose five kinds of waste and scrap: waste, parings and scrap of polymers of ethylene; waste, parings and scrap of polymers of vinyl chloride; waste, parings and scrap of polymers of other plastics; ferrous waste and scrap; remelting scrap ingots of iron or steel; copper waste and scrap. Harmonized System Codes are shown in Table 1. The markets of these wastes are large in many countries, and international markets have been established. Thus, it is considered that these wastes are fit for the objective of this paper.[11] Sample sizes vary from waste to waste, from 50 to 119 due to data availability. The sample size of each waste is shown in Table 2. According to World Bank List of Economies, we classify “high income countries” as developed countries, and others are classified as developing countries.

As discussed in Section 3, an increase in the market size of final goods influences the demand and supply of recyclable waste, and accordingly 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 of per capita GDP and population to represent the market size. According to the theoretical result, the estimated coefficients of both independent variables of both exporting and importing countries are expected to have a positive sign, if the costs of transporting recycled materials and consumer goods are high. On the other hand, if those costs are very low, and if recycled materials and consumer goods can be traded freely, the effect of an increase in the supply of recyclable wastes is relatively great. In such a case, the sign of those independent variables of importing countries may be negative.

[11] Waste paper is also a good candidate for this analysis. There is, however, no enough data to conduct the empirical analysis.

The raw materials are generally substitutes for recycled materials given the amount of products of final goods. Therefore, the expected sign of the estimated coefficient of raw material is positive (resp. negative) for the exporting (resp. importing) country.

The most important factor is the manufacturing wage of importing countries. If the less "developed" country imports more recyclable waste, the estimated coefficient of the manufacturing wage of the importing country is expected to be negative. On the other hand, if the less developed country imports less recyclable waste, the estimated coefficient is expected to be positive. If the former case is true, the least developed countries import a large amount of recyclable waste, and the recycling sector is located in a country separated from the production and consumption processes of final goods. On the other hand, if the latter case is true, the more "developed" developing countries import a large amount of recyclable waste. This implies that the import volume increases according to the expansion of industries. In other words, the recycling sector is not separated from final goods industries or/and consumption places.

Other variables are distance, APEC dummy, EU dummy, and rear exchange rate volatility. The expected sign of the estimated coefficients of those variables are negative, positive, positive, and negative, respectively.

5.3 Empirical Results

The estimated results are shown in Table 2. We conducted three methods: a random effect model (RANDOM), a GLS-based TSCS models (XTGLS), and General Method of Moments (GMM). The last one is the most robust, and the three methods indicate the same sign on almost all of important coefficients. Therefore, we mainly report the result based on the estimated coefficients by GMM.

The estimated coefficients of per capita GDP for both exporting and importing countries have the positive signs. Almost all coefficients are significant at 1%. It should be noted that the meaning of these positive signs is different from the results obtained in ordinary gravity estimations. As discussed in Section 3 (3.3), it can be said that the difference between recovery and utility rates are important factor to determine the trade flow of recyclable waste. Moreover, the magnitudes of some coefficients are greater than 1.0, which implies that the quantities of waste and scrap traded are often sensitive to changes in the market scale in both countries.

On the other hand, some estimated coefficients of population are positive and the others are negative. A few coefficients of them are insignificant. This coefficient may indicate the effect of an increase in the supply of recyclable waste. The magnitude of the estimated coefficient of population, however, is generally smaller than that of per capita GDP.

The estimated coefficient of manufacturing wage of the importing country is positive. In particular, the coefficients are significant at 1% for the case of copper waste, and waste, parings and scrap of polymers of ethylene. Thus, it is proved that, the more developed is a country, the more recyclable wastes the country imports. Therefore, the recycling sector is not separated from final good industries or/and consumption places, and there is no evidence for a pollution haven in the sense that the dirty recycling sectors expand in the least developed countries more rapidly than the more “developed” developing countries.

6. Concluding Remarks

In this paper, using a simple trade model, we have examined the trade pattern of recyclable waste and the structure of recycling activities in developing countries.

First, we investigated the basic trade pattern of recyclable wastes between countries. It is obtained that when trade barriers on recyclable wastes are removed, a country exports the recyclable waste when (a) the wage is higher than that in the other country, (b) the amount of the specific factor is greater than that in the other country, (c) the population of the country is greater than that of the other country, (d) the recovery rate is higher than that of the other country.

Secondly, we examined the conditions under which the least developed countries import more recyclable waste than the more "developed" developing countries. The pace of the accumulation of the specific factor according to an increase in the wage is crucial for the relationship between the trade volume and the wage.

Thirdly, we conduct an empirical analysis to support the theoretical result. It is proved that, the more developed is a country, the more recyclable wastes the country imports. Therefore, the recycling sector is not separated from final good industries or/and consumption places.

Finally, we consider how effectively trade restriction works in each developing country to shrink the recycling activity which is harmful to the environment and human health. In the case in which the import volume in recyclable wastes increases according to the development of a country, trade restriction may be accompanied by a big loss in efficiency.

We did not take into consideration the micro behavior of waste collectors and recyclers in the labor intensive recycling sector. It is also likely that the recycling activity in the more "developed" developing country exhibits an increasing-returns-to-scale. When it comes to empirical analyses, the estimation of the recycling technology (the supply function of recycled materials) should be estimated. It is our future task to conduct analyses taking into consideration these factors.

Appendix A

In Equations (3), (4), (5), there are four endogenous variables (p_X , p_R, r, v) and one exogenous variable (p_V). Assuming perfect competition, p_X , r , and v are determined by these three conditions given p_R . Total differentiation of those equations with respect to p_R yields

$$\begin{pmatrix} 0 & f_r & f_v \\ 0 & p_V f_{rr} - p_R f_{vr} & p_V f_{rv} - p_R f_{vv} \\ -1 & p_R & p_V \end{pmatrix} \begin{pmatrix} dp_X / dp_R \\ dr/dp_R \\ dv/dp_R \end{pmatrix} = \begin{pmatrix} 0 \\ f_v \\ -r \end{pmatrix}$$

Thus, it is obtained that

$$\frac{dp_X}{dp_R} > 0, \ \frac{dr}{dp_R} < 0, \ \frac{dv}{dp_R} > 0.$$

Appendix B

Total differentiation of (10), (11), and (12) with respect to w yields

$$\begin{pmatrix} \Gamma & -\partial R_A/\partial p_M & \partial R_B/\partial p_{M,B} \\ \Gamma_{R,A} & \Gamma_{M,A} & 0 \\ \Gamma_{R,B} & 0 & \Gamma_{M,B} \end{pmatrix} \begin{pmatrix} dp_R/dw \\ dp_{M,A}/dw \\ dp_{M,B}/dw \end{pmatrix} = \begin{pmatrix} \partial R_A/\partial w_A \\ -\partial R_A/\partial w_A \\ 0 \end{pmatrix},$$

where

$$\Gamma = \frac{dr}{dp_R}(N_A + N_B)x + r(N_A + N_B)\frac{dx}{dp_R} - \frac{\partial(R_A + R_B)}{\partial p_R} < 0,$$

$$\Gamma_{R,A} = \frac{\partial R_A}{\partial p_R} - \frac{d(r+v)}{dp_R} N_A x m_A - (r+v) N_A m_A \frac{dx}{dp_R} > 0,$$

$$\Gamma_{R,B} = \frac{\partial R_B}{\partial p_R} - \frac{d(r+v)}{dp_R} N_B x m_B - (r+v) N_B m_B \frac{dx}{dp_R} > 0,$$

$$\Gamma_{M,A} = \frac{\partial R_A}{\partial p_{M,A}} - (r+v) N_A x \frac{\partial m_A}{\partial p_{M,A}} < 0, \qquad \Gamma_{M,B} = \frac{\partial R_B}{\partial p_{M,B}} - (r+v) N_B x \frac{\partial m_B}{\partial p_{M,B}} < 0.$$

Since the total supply of the recycled material in both countries is equal to the total demand, $r(N_A + N_B)x = (r+v)x \cdot (N_A m_A + N_B m_B)$ holds. Moreover, $\partial R_A/\partial w_A < 0$ holds, since a small increase in the reward for any type of human capital increases the marginal cost of producing recycled material. Then, under the assumption that two countries are symmetric, it is obtained that

$$\begin{vmatrix} \Gamma & -\partial R_A/\partial p_{M,A} & \partial R_B/\partial p_{M,B} \\ \Gamma_{R,A} & \Gamma_{M,A} & 0 \\ \Gamma_{R,B} & 0 & \Gamma_{M,B} \end{vmatrix} < 0, \qquad \begin{vmatrix} \Gamma & \partial R_A/\partial w_A & \partial R_B/\partial p_{M,B} \\ \Gamma_{R,A} & -\partial R_A/\partial w_A & 0 \\ \Gamma_{R,B} & 0 & \Gamma_{M,B} \end{vmatrix} > 0,$$

$$\begin{vmatrix} \Gamma & \partial R_A/\partial p_{M,A} & \partial R_A/\partial w_A \\ \Gamma_{R,A} & \Gamma_{M,A} & -\partial R_A/\partial w_A \\ \Gamma_{R,B} & 0 & 0 \end{vmatrix} < 0 \cdot$$

Thus, $\dfrac{dp_{M,A}}{dw_A} < 0$, and $\dfrac{dp_{M,B}}{dw_A} > 0$. In the case of a change in the amount of $\overline{K}$, $\partial R_A/\partial \overline{K}_A > 0$ holds. Thus, $\dfrac{dp_{M,A}}{d\overline{K}_A} > 0$, and $\dfrac{dp_{M,B}}{d\overline{K}_A} < 0$.

Next, total differentiation of (10), (11), and (12) with respect to N_A yields

$$\begin{pmatrix} \Gamma & -\partial R_A/\partial p_{M,A} & \partial R_B/\partial p_{M,B} \\ \Gamma_{R,A} & \Gamma_{M,A} & 0 \\ \Gamma_{R,B} & 0 & \Gamma_{M,B} \end{pmatrix} \begin{pmatrix} dp_R/dN_A \\ dp_{M,A}/dN_A \\ dp_{M,B}/dN_A \end{pmatrix} = \begin{pmatrix} -rx \\ (r+v)xm_A \\ 0 \end{pmatrix}.$$

When the two countries are symmetric, $rx = (r+v)xm_A$ holds. Then,

$$\begin{vmatrix} \Gamma & -rx & \partial R_B/\partial p_{M,B} \\ \Gamma_{R,A} & (r+v)xm_A & 0 \\ \Gamma_{R,B} & 0 & \Gamma_{M,B} \end{vmatrix} > 0, \quad \begin{vmatrix} \Gamma & \partial R_A/\partial p_{M,A} & -rx \\ \Gamma_{R,A} & \Gamma_{M,A} & (r+v)xm_A \\ \Gamma_{R,B} & 0 & 0 \end{vmatrix} < 0$$

Thus, $\dfrac{dp_{M,A}}{dN_A} < 0$, and $\dfrac{dp_{M,B}}{dN_A} > 0$.

Finally, total differentiation of (10), (11), and (12) with respect to m yields

$$\begin{pmatrix} \Gamma & -\partial R_A/\partial p_{M,A} & \partial R_B/\partial p_{M,B} \\ \Gamma_{R,A} & \Gamma_{M,A} & 0 \\ \Gamma_{R,B} & 0 & \Gamma_{M,B} \end{pmatrix} \begin{pmatrix} dp_R/dm_A \\ dp_{M,A}/dm_A \\ dp_{M,B}/dm_A \end{pmatrix} = \begin{pmatrix} 0 \\ (r+v)N_A x \\ 0 \end{pmatrix}.$$

Then,

$$\begin{vmatrix} \Gamma & 0 & \partial R_B/\partial p_{M,B} \\ \Gamma_{R,A} & (r+v)N_A x & 0 \\ \Gamma_{R,B} & 0 & \Gamma_{M,B} \end{vmatrix} > 0, \quad \begin{vmatrix} \Gamma & -\partial R_A/\partial p_{M,A} & 0 \\ \Gamma_{R,A} & \Gamma_{M,A} & (r+v)N_A x \\ \Gamma_{R,B} & 0 & 0 \end{vmatrix} > 0$$

Thus, using the condition $rx = (r+v)xm_A$, and the assumption of symmetry,

$\frac{dp_{M,A}}{dm_A} < \frac{dp_{M,B}}{dm_A} < 0$ is obtained.

Appendix C

Totally differentiation of (17) and (18) with respect to w_B yields

$$\begin{pmatrix} \Psi_{11} & \Psi_{12} \\ \Psi_{21} & \Psi_{22} \end{pmatrix} \begin{pmatrix} dp_R / dw_B \\ dp_M / dw_B \end{pmatrix} = \begin{pmatrix} \partial R_B / \partial w_B \\ -\partial R_B / \partial w_B \end{pmatrix},$$

where

$$\Psi_{11} = \frac{dr}{dp_R} \overline{N} x + r \overline{N} \frac{dx}{dp_R} - \frac{\partial (R_A + R_B)}{\partial p_R}, \qquad \Psi_{12} = -\frac{\partial (R_A + R_B)}{\partial p_M}$$

$$\Psi_{21} = \frac{\partial (R_A + R_B)}{\partial p_R} - \frac{d(r+v)}{dp_R} \cdot x (N_A m_A + N_B m_B) - (r+v)(N_A m_A + N_B m_B) \frac{dx}{dp_R}$$

$$\Psi_{22} = \frac{\partial (R_A + R_B)}{\partial p_M}.$$

From Lemma 1, and $\partial R_A / \partial p_M < 0,\ \partial R_A / \partial p_R > 0,\ \partial R_B / \partial (p_M + t) < 0,\ \partial R_B / \partial p_R > 0$, it is obtained that

$$\Omega = \begin{vmatrix} \Psi_{11} & \Psi_{12} \\ \Psi_{21} & \Psi_{22} \end{vmatrix} > 0.$$

Since $dr / dp_R < 0,\ dv / dp_R > 0,\ \overline{N} > N_A m_A + N_B m_B$, it is obtained that

$$\frac{dp_R}{dw_B} = 0$$

$$\frac{dp_M}{dw_B} = -\frac{1}{\Omega} \cdot \frac{\partial R_B}{\partial w_B} \left\{ \frac{dr}{dp_R} \overline{N} x - \frac{d(r+v)}{dp_R} \cdot x (N_A m_A + N_B m_B) \right\} > 0 (< 0), \quad if \ \frac{dR_B}{dw_B} > 0 (< 0).$$

Appendix D

In this Appendix, following Subsection 4.1, we use p_M for the price of recyclable waste in country A. Total differentiation of (17)' and (18)' with respect to t yields

$$\begin{pmatrix} \Psi_{11} & \Psi_{12} \\ \Psi_{21} & \Psi_{22} \end{pmatrix} \begin{pmatrix} dp_R / dt \\ dp_M / dt \end{pmatrix} = \begin{pmatrix} \partial R_B / \partial t \\ -\partial R_B / \partial t \end{pmatrix}.$$

Thus, it is obtained that

$$\frac{dp_R}{dt} = 0$$

$$\frac{d(p_M + t)}{dt} = \frac{1}{\Omega} \cdot \frac{\partial R_A}{\partial p_M} \left\{ \frac{dr}{dp_R} \overline{N} x - \frac{d(r+v)}{dp_R} \cdot x(N_A m_A + N_B m_B) \right\} > 0.$$

Therefore,

$$\frac{dp_R}{dt} - \frac{d(p_M + t)}{dt} < 0$$

necessarily holds.

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Table 1. Harmonized System Codes of Waste and Scrap

Commodity: 391510	Waste, Parings and Scrap of Polymers of Ethylene
Commodity: 391530	Waste, Parings and Scrap of Polymers of Vinyl Chloride
Commodity: 391590	Waste, Parings and Scrap of Polymers of Other Plastics
Commodity: 720449	Ferrous Waste and Scrap, Remelting Scrap Ingots of Iron or Steel
Commodity: 740400	Copper Waste and Scrap

Table 2. Results

Commodity Code	740400	740400	740400	720449	720449	720449	391510	391510	391510	391530	391530	391530	391590	391590	391590
Model	random	xtgls	gmm	random	xtgls	gmm	random	xtgls	gmm	random	xtgls	gmm	random	xtgls	gmm
Per capita GDP	1.819	2.609	0.063	2.147	2.312	2.278	3.068	3.357	0.984	1.514	3.213	1.002	0.959	2.508	1.049
(Exporting country)	(3.43)***	(8.16)***	(2.79)***	(3.59)***	(6.66)***	(4.53)***	(2.26)**	(2.48)**	(2.97)***	(1.91)*	0.53	(3.10)***	(1.92)*	(2.55)**	(6.29)***
Per capita GDP	2.497	3.632	1.295	1.94	1.941	1.939	2.861	2.8	0.791	1.271	3.61	0.912	2.569	2.085	0.869
(Importing country)	(5.49)***	(12.67)***	(7.47)***	(4.24)***	(6.61)***	(4.53)***	(3.68)***	(3.38)***	(2.17)**	(2.4)***	(4.55)***	(3.76)***	(6.41)***	(3.77)***	(6.20)***
Population	0.85	1.721	1.042	0.833	−1.369	−1.986	−0.116	−3.457	−0.383	1.719	−2.727	−0.694	0.643	−1.805	−0.503
(Exporting country)	(2.94)***	(4.68)***	(6.73)***	(2.68)***	(−3.47)***	(−3.52)***	−0.24	(−2.25)**	−1.06	0.64	−0.39	(−1.73)*	(2.57)***	−1.5	(−2.53)**
Population	2.181	−0.686	−0.511	1.851	0.026	0.085	2.273	−0.452	0.034	2.415	−0.424	−0.457	1.351	−0.594	−0.338
(Importing country)	(6.71)***	(−4.88)***	(−2.47)**	(5.35)***	0.17	0.19	(3.98)***	−0.89	0.11	(3.92)***	−0.9	(−2.17)**	(4.65)***	(1.79)*	(−2.45)**
Raw Material	0.319	2.71E−01	0.286	0.0097	−3.60E−02	−4.50E−02	0.033	0.0251	0.032	−0.135	0.105	0.06	0.028	0.116	0.108
(Exporting country)	(2.31)**	(4.43)***	(2.43)**	0.16	−0.49	−0.11	0.45	0.49	1.19	−0.25	1.47	(2.49)**	0.62	1.03	1.01
Raw Material	−0.116	−0.173	−0.143	−0.0056	−0.116	−0.121	−0.063	−0.119	0.004	−0.574	−0.144	0.024	−0.025	−0.416	−0.125
(Importing country)	−0.72	(−2.43)**	−0.23	−0.13	−1.02	−1.11	(−1.85)*	(−3.43)***	0.19	(−1.75)*	(−2.01)**	0.73	−1.21	(2.6)***	(3.45)***
Wage	0.269	0.267	0.288	0.193	−0.978	−0.993	−0.234	−0.314	−0.171	−0.019	−0.208	−0.272	0.102	0.501	0.308
(Exporting country)	(1.67)*	(1.79)*	(1.68)*	1.01	(2.3)**	(2.21)**	−3.17	(−1.75)*	(−2.12)**	(−1.76)*	(−1.84)*	(−1.72)*	0.64	1.19	1.27
Wage	0.504	0.474	0.512	0.146	0.015	0.024	0.708	0.585	0.345	0.219	0.229	0.064	0.338	0.716	0.491
(Importing country)	(3.06)***	(2.99)***	(2.98)***	2.73**	0.05	0.03	(3.17)***	(3.01)***	(3.4)***	0.87	0.99	0.57	(1.84)*	(1.95)*	(1.99)*
Border dummy	0.233	2.933	0.153	4.863	2.741	2.824	5.617	5.29	1.661	4.413	2.232	1.686	1.149	4.5	1.227
	0.06	(2.14)**	0.95	(2.67)***	(1.97)**	(1.99)**	(2.33)**	(2.7)***	(1.95)*	1.49	0.8	(2.35)**	0.32	(2.72)***	(2.54)**
Distance	−1.209	−0.229	−2.161	−2.373	−1.738	−2.214	−2.259	−1.345	−1.925	−2.528	0.122	−0.717	−1.054	−0.892	−0.94
	−1.11	−0.62	(−4.48)***	(−3.15)***	(−4.08)***	(−3.98)***	(−2.54)**	−1.34	(−3.41)***	(−2.39)**	0.08	(−2.12)**	(−1.72)*	−1.11	(−3.96)***
APEC dummy	2.738	2.669	1.489	4.032	4.819	4.152	6.407	2.441	3.027	11.45	9.481	1.734	5.692	14.357	2.622
	(2.28)**	(5.75)***	(2.28)**	(4.61)***	(2.81)***	(3.58)***	(3.41)***	(2.39)**	(2.62)**	(5.99)***	(5.51)***	(2.45)**	(2.58)**	(4.04)***	(6.05)***
EU dummy	0.438	0.437	2.757	2.596	−2.249	−2.252	−1.46	−0.29	−0.618	6.215	12.372	−1.153	3.38	−2.495	−0.26
	0.17	0.49	(5.79)***	1.28	(−1.99)**	(−2.01)**	−0.56	−0.13	−0.5	0.24	(2.88)***	−0.82	1.21	−0.49	−0.51
Real exchange rate volatility	−3.24E+01	−37.45	−0.528	−0.511	−0.542	−0.501	−0.499	−0.002	−3.9E−05	0.732	−0.513	0.0001	−0.844	9.564	1.01E−06
	(−3.29)***	(−5.17)***	−0.86	(−13.54)***	(−4.23)***	(−4.96)***	(−13.09)***	(−2.02)**	(−5.93)***	1.25	(−4.12)***	0.19	(−2.11)**	1.28	0.29
Constant	−71.99	−341.65	−39.941	−31.102	−961.528	−968.21	19.445	−1465.13	3.797	−4.136	−858.684	−24.512	−27.71	−1068.95	−27.724
	(−2.87)***	−1.26	(−9.04)***	−1.17	(−2.1)**	(−2.2)**	(0.67)*	(−4.44)***	0.41	−0.15	(−2.48)**	(−3.5)***	−1.17	(−1.93)*	(−6.85)***
AR1			(−2.54)**			(−3.12)**			(−4.1)***			(−7.39)***			(−11.89)***
AR2			−1.42			−1.28			0.88			0.05			−0.48
Sagren			0			0			0			0			0
Number of countries	119			98			73			50			94		
	Raw Material			Raw Material			Raw Material			Raw Material			Raw Material		
	Copper	Copper	Copper	Iron	Iron	Iron	Petroleum	Petroleum	Petroleum	Petroleum	Petroleum	Petroleum	Petroleum	Petroleum	Petroleum

Absolute value of t statistics in parentheses

* significant at 10%; ** significant at 5%; *** significant at 1%