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Title: Strategic Use of Recycled Content Standards under International Duopoly

Abstract: We examine the strategic use of recycled content standards (RCSs) under international duopoly. RCSs require firms supplying the domestic market to use a certain proportion of recycled materials as inputs. We demonstrate that, when there is no trade in recycled materials, two identical countries both set strategically stricter or more lax RCSs. However, when there is trade in recycled materials, it may be the case that one country sets a stricter RCS while the other sets a more lax RCS. When a world supply constraint on recycled materials is not binding, the main source of the asymmetric distortion in RCSs is a *demand effect for recycled materials*.

Keywords: recycling; recycled content standard; international trade; strategic trade policy.

JEL classification: F12; F13; F18.

1 Introduction

In recent years, many countries have experienced substantial increases in recycling, partly because governments have implemented policies to encourage recycling. However, since firms tend to be reluctant to use recycled materials, governments have recognized the need for policy measures that stimulate demand for recycled materials. The imposition of recycled content standards (RCSs) is such a policy. RCSs require that a particular consumption good sold in the domestic market contains a certain percentage of recycled material. For example, in the United States (US), 12 states and Washington DC enforce mandatory RCSs on newsprint as of 2004.[1] The strictest standards are adopted by California, Connecticut, and Missouri, which require newsprint to contain at least 50% of recycled paper.

Green procurement requirements are also a similar policy tool. For example, in the US, more than 40 states have State Paper Procurement Laws, which require a certain percentage of paper purchased by state agencies to be recycled. In many cases, qualification standards for "recycled paper," such as the requirement for at least 50% recycled content, are also specified in these laws. Another example is the Law on Promoting Green Purchasing, which became effective in Japan in April 2001.[2] This law requires the public sector to buy products that contain a certain percentage of recycled materials or recyclable products. A wide variety of products are covered by the Law, including stationery, office furniture, office automation machines, home electronic appliances, and

[1] See the web site of American Forest & Paper Association (AF&PA) at http://www.afandpa.org/. Thirteen other states have also implemented voluntary RCSs on newsprint. See also Laplante and Luckert [16].

[2] The formal name is the "Law Concerning the Promotion of Procurement of Eco-Friendly Goods and Services by the State and Other Entities." For details, see http://www.env.go.jp/en/lar/green/index.html (Ministry of the Environment).

vehicles.[3] Since public consumption expenditure accounts for at least 17% of GDP in Japan, the effect of the Law could be substantial.[4]

While RCSs and green procurements are primarily aimed at reducing domestic waste by stimulating domestic demand for recycled materials, they may have some additional effects if consumption goods and/or recycled materials are internationally traded. Indeed, the volume of recycled materials, including paper, aluminum, copper, and zinc, which are internationally traded, is growing (van Beukering [21]).

For example, Canada produced 8.5 million tons of newsprint in 2002, 62% of which was exported to the US. The share of Canadian producers in the US newsprint market was 49% in 2002. At the same time, Canada used 5.1 million tons of recyclable paper in 2002, 33% of which was imported, mainly from the US. The US recovered 47.6 million tons of paper and board from domestic sources in 2002, 24% of which was exported.[5] Thus, RCSs on newsprint and State Paper Procurement Laws in the US affect Canadian firms as well as US firms. Canadian newsprint producers import recyclable paper from the US in order to comply with RCSs in the US (Laplante and Luckert [16]).[6]

This paper investigates the choice of RCSs where there is trade in goods and recycled

[3]Example of the standards set by the Law are: (i) at least 10% recycled content from used polyethylene terephthalate (PET) bottles must be used for carpets and curtains; and (ii) 100% recycled content must be used for printing paper.

[4]The share was calculated from 2003 data, using OECD national account statistics.

[5]The Canadian data on newsprint were obtained from the Forest Products Association of Canada and the data on recyclable paper were taken from the Paper Recycling Association of Canada. The US data on the newsprint market were obtained from FAOSTAT, the database provided by the Food and Agriculture Organization of the United Nations (FAO), and the data on recyclable paper were from AF&PA.

[6]Japanese exports of recyclable paper and board are also increasing significantly. In 2003, Japan exported 1.97 million tons of used paper and board, 52% of which was exported to China. These data are taken from trade statistics provided by the Customs and Tariff Bureau, Ministry of Finance, Japan (http://www.customs.go.jp/index_e.htm). As far as old newspaper is concerned, 0.36 million tons were exported, which is almost 10 % of total newspaper consumption.

materials. In particular, we are interested in the strategic aspects of RCSs. As already mentioned, when goods and/or recycled materials are traded, governments may have an incentive to use RCSs for reasons other than encouraging the domestic use of recycled materials.[7] We analyze the conditions under which RCSs are distorted, relative to the RCSs that maximize global welfare.

The strategic use of environmental policy has been examined by, e.g., Barrett [1], Kennedy [13], and Ulph [20]. Existing studies have examined how environmental policies, such as emission taxes and standards, are distorted for strategic purpose when there is trade. The strategic effects identified in previous studies include a *rent capture effect* and a *pollution shifting effect*. These effects are typically observed when market structures are imperfectly competitive. These strategic effects motivate governments to distort environmental policy, in relation to policies that fully internalize the externality.

Our study relates to the literature on strategic environmental policy. Unlike existing studies, we examine the strategic aspects of policies that are designed to affect consumption stages; existing studies have mainly focused on policies aimed at affecting production stages.

Unlike existing studies, a *demand effect for recycled materials* and a *terms-of-trade effect* are important in our analysis. The former effect arises if, when trade in recycled materials takes place, a country that exports recycled materials may be able to increase not only the domestic firm's demand but also the foreign firm's demand for recycled materials generated in its own country by changing its RCS. An importing country of recycled materials, by contrast, may only increase its import demand for recycled mate-

[7] This analysis can also be applied to interstate (interprovincial, interprefectural) trade in recycled materials.

rials by raising its RCS. Therefore, countries exporting and importing recycled materials may experience asymmetric effects on waste reduction, and accordingly, environmental damage. The latter effect, which is similar to the usual one under international trade, stems from trade in recycled materials. That is, an increase in the international price of recycled materials benefits the county that exports recycled materials.

In this paper, we focus on the former effect and briefly discuss the latter effect. We do so for three main reasons. First, the purpose of setting RCSs is to encourage the use of recycled materials. In other words, this type of policy is used to eliminate an excess supply (surplus) of recycled materials. The demand effect for recycled materials is important in this case. In practice, some countries have often had surpluses of recycled materials.[8] Second, in the absence of artificial trade barriers, no trade in recycled materials takes place only if supply constraints are not binding in either country. Thus, a clear-cut comparison can be made between trade and absence of trade in recycled materials when at least one country has an excess supply of recycled materials. Third, other studies have analyzed the *terms-of-trade effect* in a similar framework (e.g., Cassing and Kuhn [2]). Moreover, while the terms-of-trade effect is important in the context of trade and the environment, it is not an effect that is specific to environmental issues.

To analyze the effect that is specific to this issue, we assume that the two countries are identical except with respect to the supply of recycled materials. A number of factors, such as market scale and capacity constraints, potentially make the supply of recycled

[8]For example, there was an excess supply of used paper throughout the 1990s in Japan and in the early 1990s in the US. In the US, the success of recycling collection programs produced and excess supply, which led to RCSs on newsprint (See Jacques et al. [12]). Moreover, the number of recovered PET bottles has always exceeded that of recycled PET bottles (See the web site of the Japan Containers and Packaging Recycling Association at http://www.jcpra.or.jp/).

materials differ between countries. One is differences in recovery rates. Table 1 shows recovery rates for aluminum beverage cans and paper in selected countries in 2002. The table shows wide diversities in recovery rates for both materials. Similar differences are observed for other materials. Since differences in recovery rates can generate trade in recycled materials in a straightforward way, we incorporate these differences to our analysis. We first consider the case in which there is no trade in recycled materials and then consider the one in which there is trade in recycled materials.

The main results are as follows. First, if governments set their RCSs non-cooperatively, the RCSs may be stricter or more lax than is required to maximize global welfare. This depends on the structure of demand, price differences between virgin and recycled materials, and the shape of the environmental damage function. Second, while the RCSs in the two countries are distorted in the same direction when there is no trade in recycled materials, they may be distorted in opposite directions when there is trade in recycled materials. That is, it may be the case that the country exporting recycled materials imposes a stricter RCS and the importing country imposes a more lax RCS than those that would be imposed under cooperation, or *vice versa*. A *demand effect for recycled materials* is a major source of asymmetric distortion in RCSs when the world supply constraint for recycled materials is not binding.

There are few theoretical studies of recycling and trade. Examples include Di Vita [3], van Beukering [21], and Huhtala and Samakovlis [9], none of which has examined the strategic use of RCSs. Our study is also related to the literature on local content requirements (LCRs) (e.g., Grossman [8], Krishna and Itoh [14], and Richardson [18]). LCRs require firms to use a certain proportion of locally made intermediate inputs.

RCSs differ from LCRs because RCSs do not specify from where the required types of intermediate inputs should be procured. Thus, findings relating to LCRs do not necessarily apply to RCSs.

The rest of the paper is organized as follows. Section 2 describes the model. Section 3 examines the conditions under which governments have incentives to use RCSs strategically when there is no trade in recycled materials. Section 4 investigates the case in which trade in recycled materials takes place. Section 5 provides concluding remarks.

2 The Model

There are two countries that are identical in all respects except the supply of recycled materials. The home country is denoted by h and the foreign country is denoted by f. One firm is located in each country and produces a homogeneous good X. The inverse demand function in each country is given by

$$p_i = P[X_i], \qquad P' < 0, \quad \text{for} \quad i = h, f, \tag{1}$$

where p_i and X_i denote the consumer price and the total consumption of good X in country i, respectively.[9] Throughout this paper, square brackets apply to functions.

Each firm uses one unit of material to produce one unit of good X. Material can be virgin, recycled, or a mixture of the two. Each country imports the virgin material from the rest of the world. The world price of the virgin material is fixed at w_V.[10]

[9] We assume that the price of good X is independent of how much recycled material is included in good X. Allowing price to depend on the proportion of recycled material included in the good is straightforward, and although this extension increases the number of conditions required to derive our main results, those results are not greatly affected.

[10] In reality, most virgin materials are exhaustible. However, since we are focusing on waste rather than on exhaustible resources, for simplicity, we assume a constant price of virgin materials.

The recycled material is only supplied within the two countries. One unit of recycled material is produced from one unit of wasted good X.[11] It is assumed that recycled materials are supplied under perfect competition. The price of recycled material in each country is denoted by w_R^i, $i = h, f$. It is costly to recycle materials from waste goods. We assume that a constant marginal cost of recycling, which is denoted by $c_R(= c_R^i, i = h, f)$. We also assume that transportation costs are zero. When a supply constraint for recycled materials is not binding in country i, $w_R^i = c_R^i$ holds. Moreover, no trade in recycled materials takes place only if supply constraints are not binding in either country.[12] Thus, $w_R^h = w_R^f \equiv w_R$ holds whether or not there is trade in recycled materials. We also assume that $w_V < c_R \leq w_R$ holds. Thus, unless it is compulsory to use recycled materials, firms have no incentives to use them.

Let MC_i^j be firm j's marginal cost for supplying to country i's market. We have

$$MC_i^i = MC_i^j = \mu_i w_R + (1 - \mu_i) w_V, \quad i, j = h, f, \tag{2}$$

where $\mu_i \in [0, 1]$ denotes the RCS set by country i. Since the general aim of RCSs is to ensure that goods consumed in the domestic market contain a certain percentage of recycled materials, the marginal costs differ not in production country but in consumption country. The profit function of firm j is

$$\begin{aligned} \pi^j &= P[X_j]x_j^j + P[X_i]x_i^j - \{\mu_j w_R + (1 - \mu_j) w_V\} x_j^j, \\ &\quad - \{\mu_i w_R + (1 - \mu_i) w_V\} x_i^j, \quad i, j = h, f, \end{aligned} \tag{3}$$

where x_i^j is the output of firm j for the market in country i and $X_i = x_i^j + x_i^i$.

[11] In practice, it is impossible to produce one unit of recycled material from one unit of a wasted good X in terms of material balance. For example, producers must remove the ink from used paper to produce re-usable paper. However, our results do not depend on this assumption, which is made only for simplicity.

[12] This is shown in Appendix B.

Once consumed, units of good X are wasted. If they are not recycled, they are disposed of in landfills. Due to the depletion of landfill capacity or to externalities generated by landfills, wasted goods that are not recycled cause environmental damage. Good X, which is wasted at time $t-1$, is recycled to be used as recycled material at time t. Thus, the supply of recycled material at time t cannot exceed $\lambda_i X_{i,t-1}$, where $\lambda_i \in [0,1]$ denotes the recovery rate in country i. We focus on the steady-state equilibrium, in which $X_{i,t-1} = X_{i,t} = X_i$.[13] The supply of recycled materials is $\lambda_i X_i$ in each period. The demand for the recycled material in country i is given by $\mu_i x_i^i + \mu_j x_j^i$. Even if demand exceeds supply, $(1-\lambda_i)X_i$ cannot be recovered and this quantity is disposed of in landfills. Since we assume that recovered material is not preserved for future periods, some proportion of $\lambda_i X_i$ is also disposed of if supply exceeds demand.[14]

Environmental damage experienced by citizens in country i is a function of the actually wasted goods in country i. When the supply constraint is not binding in country i, environmental damage is given by the following:[15]

$$E_i = E_i[X_i - D_i^i[\mu_h, \mu_f] - D_i^j[\mu_h, \mu_f]], \quad i,j = h,f, \quad i \neq j, \tag{4}$$

[13]Given the RCSs of both countries, differences between demand and supply are quickly eliminated because prices for recycled materials change daily. However, it usually takes time for recovery rates to change because this typically requires the behavior of consumers and production and consumption systems to change. The time lag between primary production and recycling may also affect firms' outputs and profits (Gaudt and Long [7]). However, since our purpose is to examine the strategic use of RCSs given the time lag in recycling, we focus on the steady state and ignore dynamic processes. In fact, articles that examine policies related to recycling often focus on the steady state (e.g., Eichner and Pethig [5]).

[14]We do not consider transportation costs. In practice, it is costly to preserve recycled materials. Thus, from both theoretical and practical points of view, firms have no incentives to preserve materials for future periods if world supply exceeds world demand. Even if the price of recycled materials changes due to excess demand or supply, firms do not stock recycled materials if it is costly to do so.

[15]We implicitly make the following two assumptions. First, recycling causes no environmental damage. Second, for simplicity, environmental damage is measured in money terms.

where D_i^j denotes the demand by firm j for the recycled materials generated in country i. We assume that $E_i' > 0$ and $E_i'' > 0$.[16] However, if the demand for recycled materials generated in country i exceeds the supply of recycled materials in country i, environmental damage is given by

$$E_i = E_i[(1-\lambda_i)X_i], \quad i = h, f. \tag{5}$$

The government of country i sets its RCS to maximize social welfare, which is defined as the sum of consumers' surplus (CS), the profit of firm i, and the producers' surplus (PS) for the suppliers of recycled materials, minus the environmental damage suffered by country i, as follows:

$$W^i = \int_0^{X_i} P[y]dy - P[X_i]X_i + \pi^i + (w_R - c_R)\lambda_i X_i - E_i, \qquad \text{for} \qquad i = h, f. \tag{6}$$

Note that the PS for the suppliers of recycled materials is zero when $w_R = c_R$. Moreover, world welfare, W, is given by

$$W = W^h + W^f. \tag{7}$$

The structure of the two-stage game is as follows. In the first stage, both governments simultaneously set their own RCSs. In the second stage, both firms simultaneously determine their outputs. They compete in quantities in Cournot fashion. The solution is the subgame perfect Nash equilibrium (SPNE).

[16]We exclude the possibility that $E_i'' = 0$. Its inclusion would only add the case of RCSs being strategic neutral in Lemma 1. This case is of no interest in the context of the strategic effects of RCSs.

3 RCSs in the Absence of Trade in Recycled Materials

In this section, we examine the case where there is an excess supply of recycled materials in each country. In this case, it is reasonable to assume that each firm procures recycled materials from its own country, since it would pay additional costs to procure them from abroad.[17] Thus, there is no trade in recycled materials, and $w_R = c_R$ in each country.[18] Although we focus on the home RCS, the same results apply for the foreign RCS.

3.1 Effects of RCSs

We first examine the effects of RCSs on CS, firms' profits, and environmental damage.

From (3), the first-order condition (FOC) for maximizing profits is given by

$$\frac{\partial \pi^j}{\partial x_h^j} = P_h + P_h' x_h^j - \mu_h w_R - (1-\mu_h) w_V = 0, \quad j = h, f \tag{8}$$

where $P_i = P[X_i]$ and $P_i' = P'[X_i]$. We obtain the equilibrium outputs for each specified level of μ_h, which are denoted by $\hat{x}_h^h[\mu_h]$ and $\hat{x}_h^f[\mu_h]$. Totally differentiating (8) yields

$$\begin{pmatrix} d\hat{x}_h^h/d\mu_h \\ d\hat{x}_h^f/d\mu_h \end{pmatrix} = \frac{1}{\Omega_h} \begin{pmatrix} 2P_h' + P_h'' \hat{x}_h^f & -(P_h' + P_h'' \hat{x}_h^h) \\ -(P_h' + P_h'' \hat{x}_h^f) & 2P_h' + P_h'' \hat{x}_h^h \end{pmatrix} \begin{pmatrix} w_R - w_V \\ w_R - w_V \end{pmatrix}$$

where $\Omega_h = P_h'^2(3-\epsilon_h)$, in which $\epsilon_h \equiv -X_h P''[X_h]/P'[X_h]$ denotes the elasticity of the slope of the inverse demand function. We assume that the second-order conditions (SOCs) for stability hold: i.e., $2P_h' + P_h'' x_h^h < 0$, $2P_h' + P_h'' x_h^f < 0$, and $P_h'^2(3-\epsilon_h) > 0$.[19]

[17] For example, a firm must pay an additional fixed cost to collect information.

[18] See Appendix A for possible combinations of the two RCSs under which there is no trade in recycled materials.

[19] It is well known that ϵ often plays a crucial role in the analysis of monopoly and oligopoly (Seade [19], Ishikawa and Spencer [10], and Furusawa et al. [6]). When ϵ is constant, the inverse demand function is $P = a_1 X^{1-\epsilon}/(\epsilon - 1) + a_2$ for $\epsilon \neq 1$, and is $P = -b_1 \ln X + b_2$ for $\epsilon = 1$, where $a_i, b_i > 0, i = 1, 2$. If the price elasticity is constant, ϵ is also constant. When $\epsilon < 0$ (resp. $\epsilon = 0$, $\epsilon > 0$), the inverse demand curve is concave (resp. linear, convex). In general, the demand

The effects of a change in μ_h on firm outputs are given by

$$\frac{d\hat{x}_h^j}{d\mu_h} = \frac{w_R - w_V}{P_h'(3-\epsilon_h)} < 0, \quad j = h, f. \tag{9}$$

Since the outputs of both firms fall, the price of good X rises and home CS decreases. Furthermore, using the envelope theorem, from (3), (8), and (9), we obtain

$$\frac{d\pi^j}{d\mu_h} = P'\hat{x}_h^j \frac{d\hat{x}_h^i}{d\mu_h} - (w_R - w_V)\hat{x}_h^j \quad = \quad -\frac{2-\epsilon_h}{3-\epsilon_h} \cdot (w_R - w_V)\hat{x}_h^j \tag{10}$$

for $i, j = h, f,\ i \neq j$. It is clear that whether a change in μ_h increases or decreases profits depends on the demand structure. Since $w_R - w_V > 0$, if $\epsilon_h < 2$ (resp. $\epsilon_h > 2$), profits fall (resp. rise) when μ_h increases. In other words, if the demand curve is highly convex, firms' profits increase as the RCS becomes stricter.

Next, consider environmental damage in the home country. Since $D_i^j = 0$ and $D_i^i = \mu_i x_i^i + \mu_j x_j^i$, from (4), we obtain

$$\frac{dE_h}{d\mu_h} = E_h' \cdot \left\{ \frac{d\hat{X}_h}{d\mu_h} - \hat{x}_h^h - \mu_h \frac{d\hat{x}_h^h}{d\mu_h} \right\} = E_h' \cdot \left\{ (1-\mu_h)\frac{d\hat{x}_h^h}{d\mu_h} + \frac{d\hat{x}_h^f}{d\mu_h} - \hat{x}_h^h \right\} < 0. \tag{11}$$

This follows because $\mu_h \in [0, 1]$, $E_h' > 0$, and $d\hat{x}_h^h/d\mu_h = d\hat{x}_h^f/d\mu_h < 0$. Thus, environmental damage in the home country decreases as μ_h becomes stricter. The effect of an increase in μ_h on E_h can be decomposed into two effects. First, since an increase in μ_h reduces the output of both firms in the home country, the supply of wasted goods in the home country also falls. This effect is represented by $d\hat{X}_h/d\mu_h = d\hat{x}_h^h/d\mu_h + d\hat{x}_h^f/d\mu_h < 0$ in (11). Second, an increase in μ_h changes firm h's demand for recycled materials, which is represented by $\hat{x}_h^h + \mu_h d\hat{x}_h^h/d\mu_h$ in (11). Although the sign of the second effect is ambiguous, the first effect dominates the second one, and hence E_h falls.

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curve is highly convex when $\epsilon > 2$. Moreover, the SOCs imply $\epsilon_h < 3$ and $\epsilon_h x_h^j/X_h < 2$. In our model, $x_h^h = x_h^f$, which implies that $x_h^j/X_h = 1/2$. Thus, if the former condition is satisfied, the latter condition is also satisfied. Consequently, we can discuss the case in which $\epsilon_h < 3$.

Now we consider environmental damage in the foreign country. Differentiating (4) with respect to μ_h yields

$$\frac{dE_f}{d\mu_h} = E'_f \cdot \left\{ -\hat{x}_h^f - \mu_h \frac{d\hat{x}_h^f}{d\mu_h} \right\}. \tag{12}$$

Since $d\hat{x}_h^f/d\mu_h < 0$ holds from (9), the sign of (12) is ambiguous. In this case, only the effect of an increase in μ_h that works through the demand for recycled materials arises. As already discussed, this effect may harm the foreign environment, and hence, E_f may increase as μ_h becomes stricter. Whether a higher μ_h increases or decreases E_f depends on the demand structure and the difference between w_R and w_V.

3.2 The Optimal Degree of RCSs

In this subsection, we investigate the optimal non-cooperative degree of RCSs and compare them with the cooperative RCSs. "Non-cooperative" means that each government chooses its RCS to maximize welfare in its own country, while "cooperative" means that each government chooses its RCS to maximize world welfare.

We compare the non-cooperative RCSs with the cooperative RCSs for the following reasons. In practice, given the increasing trend of trade in goods and recycled materials, countries must cooperate to deal with the problem of waste, because it is an international problem rather than a local problem. Theoretically, cooperative RCSs are efficient but do not represent the first-best solution. However, if countries also agree on side payments, the efficient solution is an important factor of the first-best solution. Moreover, by decomposing the inefficiency into several effects, we can investigate the strategic behavior of the government. In fact, the cooperative solution is used as a common benchmark for evaluating environmental policies in open economies.[20]

From (6), the FOC for the non-cooperative μ_h is given by

$$\frac{\partial W^h}{\partial \mu_h} = -P'\hat{X}_h \frac{d\hat{X}_h}{d\mu_h} + \frac{d\pi^h}{d\mu_h} - \frac{dE_h}{d\mu_h} = 0. \tag{13}$$

We assume that the SOCs are satisfied.[21] Since the outputs supplied to the foreign market ($\hat{x}_f^h$ and $\hat{x}_f^f$) are affected by a change in μ_f, from (13), we obtain

$$\frac{\partial^2 W^h}{\partial \mu_h \partial \mu_f} = -E_h'' \cdot \left\{ (1-\mu_h)\frac{d\hat{x}_h^h}{d\mu_h} + \frac{d\hat{x}_h^f}{d\mu_h} - \hat{x}_h^h \right\} \cdot \left\{ -\hat{x}_f^h - \mu_f \frac{d\hat{x}_f^h}{d\mu_f} \right\}. \tag{14}$$

From (11), (12), (14), and the symmetry of the two countries, we establish

Lemma 1 *The RCSs are strategic complements (resp. substitutes) if and only if an increase in μ_i raises (resp. reduces) the amount of waste generated in country j ($i \neq j$).*

The intuition is straightforward. When an increase in μ_f increases waste in the home country, the home country responds by raising μ_h to reduce the negative effect of an increase in μ_f on its environment. Thus, RCSs are strategic complements in this case. When an increase in μ_f reduces waste in the home country, the home country responds by reducing μ_h. This is because a reduction in domestic waste due to an increase in μ_f enables the home country to make its RCS less strict without damaging its environment. Thus, RCSs are strategic substitutes in this case.[22]

[20] See, for example, Kennedy [13] and Duval and Hamilton [4].

[21] The SOCs in this case are given by $\partial^2 W^h/\partial\mu_h^2 < 0, \partial^2 W^f/\partial\mu_f^2 < 0, \partial^2 W^h/\partial\mu_h^2 \cdot \partial^2 W^f/\partial\mu_f^2 - \partial^2 W^h/(\partial\mu_f\partial\mu_h) \cdot \partial^2 W^f/(\partial\mu_h\partial\mu_f) > 0, \partial^2 W/\partial\mu_h^2 < 0, \partial^2 W/\partial\mu_f^2 < 0,$ and $\partial^2 W/\partial\mu_h^2 \cdot \partial^2 W/\partial\mu_f^2 - (\partial^2 W/(\partial\mu_f\partial\mu_h))^2 > 0$. If ϵ is constant, some conditions are obtained for the SOCs to be satisfied, and it is shown that the sign of $\hat{x}_j^i + \mu_j d\hat{x}_j^i/d\mu_j$ is not important for the satisfaction of the SOCs. A proof is available from the corresponding author upon request.

[22] Note that since $\hat{x}_j^i + \mu_j d\hat{x}_j^i/d\mu_j < 0$ does not hold globally (for example, $\hat{x}_j^i + \mu_j d\hat{x}_j^i/d\mu_j \geq 0$ at $\mu_j = 0$), strategic complementarity does not hold globally.

Next, we compare the non-cooperative RCSs with those determined cooperatively. Differentiating (7) with respect to μ_h and evaluating it at the non-cooperative μ_h yields

$$\left.\frac{\partial W}{\partial \mu_h}\right|_{\frac{\partial W^h}{\partial \mu_h}=0} = \frac{d\pi^f}{d\mu_h} - E_f^{'} \cdot \left\{ -\hat{x}_h^f - \mu_h \frac{d\hat{x}_h^f}{d\mu_h} \right\}. \tag{15}$$

From (10), (12), (15), Lemma 1, and given the symmetry of countries, we obtain

Proposition 1 *Suppose that both governments set their own RCSs simultaneously. If the RCSs are strategic complements (resp. substitutes) and $\epsilon_i \leq 2$ (resp. $\epsilon_i \geq 2$) holds in the neighborhood of the non-cooperative equilibrium, both RCSs are stricter (resp. more lax) than the cooperative RCSs.*

The intuition is as follows. When the home government maximizes its own country's welfare, it does not take into account the profits of the foreign firm and the damage to the environment of the foreign country. Thus, if an increase in the strictness of the home RCS reduces the profits of the foreign firm and increases environmental damage in the foreign country, the home country's non-cooperative RCS is stricter than the cooperative RCS. The reverse may also apply, and hence, the home RCS may be more lax than the cooperative RCS. In either case, the foreign country suffers from the distortion in the optimal non-cooperative RCS in the home country. Note that Proposition 1 shows the sufficient conditions required for this result. Hence, even if one of the two conditions is not satisfied, the sign of (15) can be positive or negative.

In this case, since there is no trade in recycled materials, there is no demand for recycled materials generated in country i by firm j. Thus, by the symmetry of the countries, the effect of a change in the RCS of country i on environmental damage in country j is not asymmetric. Therefore, it is clear that in the SPNE, the home non-cooperative RCS is stricter (resp. more lax) than the cooperative RCS if and only if the foreign non-cooperative RCS is stricter (resp. more lax) than the cooperative RCS.

Moreover, one point should be noted about the decomposition of the inefficiency. Because of the symmetry of cost structure between the two firms, the home RCS affects both firms equally, which implies that their profits change in the same direction. Thus, unlike Kennedy [10], there is no "rent capture effect" in our model, in which firm h's profit increases at the expense of firm f's. However, if the RCSs are strategic complements, an increase in μ_i leads to a decrease (resp. an increase) in environmental damage in country i (resp. country j). This effect is considered a *pollution shifting effect*.

4 Trade in Recycled Materials

In this section, we determine the RCSs when there is trade in recycled materials between the two countries. When the world supply constraint for recycled materials is not binding, the main effect is a *demand effect for recycled materials*. By contrast, when the world supply constraint for recycled materials is binding, the main effect is a *terms-of-trade effect*. We investigate these two cases separately.

4.1 World Supply Constraint for Recycled Materials is not Binding

We first examine the case where the difference in the recovery rate is large and, accordingly, there is an excess demand for recycled materials in only one country. Without loss of generality, we assume that the recovery rate is higher in the home country (i.e., $\lambda_h > \lambda_f$) and that the supply constraint is binding in the foreign country.[23]

[23] Appendix A describes possible combinations of μ_h and μ_f. Appendix B shows conditions required for trade to occur.

Since $w_R = c_R$ in this case, the effects of RCSs on firms' outputs and profits are the same as those when there is no trade in recycled materials. On the other hand, the effects of RCSs on environmental damage are different from the effects in the absence of trade and are asymmetric between the two countries. In this case, since the foreign firm imports recycled materials from the home country, $D_h^f = \mu_h \hat{x}_h^f + \mu_f \hat{x}_f^f - \lambda_f \hat{X}_f \neq 0$, while $D_f^h = 0$. Thus, from (4) and (5), we obtain

$$\frac{dE_h}{d\mu_h} = E_h' \cdot \left\{ (1-\mu_h) \left(\frac{d\hat{x}_h^h}{d\mu_h} + \frac{d\hat{x}_h^f}{d\mu_h} \right) - \hat{x}_h^h - \hat{x}_h^f \right\} < 0, \tag{16}$$

$$\frac{dE_f}{d\mu_h} = 0, \tag{17}$$

$$\frac{dE_h}{d\mu_f} = E_h' \cdot \left\{ -\mu_f \left(\frac{d\hat{x}_f^h}{d\mu_f} + \frac{d\hat{x}_f^f}{d\mu_f} \right) - \hat{x}_f^h - \hat{x}_f^f + \lambda_f \left(\frac{d\hat{x}_f^h}{d\mu_f} + \frac{d\hat{x}_f^f}{d\mu_f} \right) \right\}, \tag{18}$$

$$\frac{dE_f}{d\mu_f} = E_f' \cdot (1-\lambda_f) \cdot \left\{ \frac{d\hat{x}_f^h}{d\mu_f} + \frac{d\hat{x}_f^f}{d\mu_f} \right\} < 0. \tag{19}$$

An increase in μ_h has no effect on environmental damage in the foreign country and an increase in μ_f has an ambiguous effect on environmental damage in the home country.

When the foreign government chooses its RCS non-cooperatively, the FOC for the foreign government can be rewritten as

$$\frac{\partial W^f}{\partial \mu_f} = -P_f' X_f \frac{d\hat{X}_f}{d\mu_f} - \frac{2-\epsilon_f}{3-\epsilon_f}(w_R - w_V)\hat{x}_f^f - E_f' \cdot (1-\lambda_f) \cdot \left\{ \frac{d\hat{x}_f^h}{d\mu_f} + \frac{d\hat{x}_f^f}{d\mu_f} \right\} = 0. \tag{20}$$

We assume that the SOCs hold.[24] From (20), we obtain $\partial^2 W^f / \partial \mu_f \partial \mu_h = 0$, which implies that RCSs are strategic neutral for the foreign country. Differentiating world welfare (7) with respect to μ_f and evaluating it at the non-cooperative μ_f yields

$$\left. \frac{\partial W}{\partial \mu_f} \right|_{\frac{\partial W^f}{\partial \mu_f}=0} = \frac{d\pi^h}{d\mu_f} - E_h' \cdot \left\{ -\hat{x}_f^h - \hat{x}_f^f - (\mu_f - \lambda_f) \left(\frac{d\hat{x}_f^h}{d\mu_f} + \frac{d\hat{x}_f^f}{d\mu_f} \right) \right\}. \tag{21}$$

[24]The SOCs in this case are analogous to those in footnote 21, which apply when there is no trade in recycled materials, with slight differences. Details are available from the corresponding author upon request.

Since the sign of $d\pi^h/d\mu_f$ is ambiguous and $E_h' > 0$ and $d\hat{x}_f^h/d\mu_f + d\hat{x}_f^f/d\mu_f < 0$ hold, the sign of (21) is ambiguous. Thus, as in the case in which there is no trade in recycled materials, the foreign RCS may be stricter or more lax than the cooperative RCS.

On the other hand, the RCSs are not strategic neutral for the home country. Since

$$\frac{\partial^2 W^h}{\partial\mu_h \partial\mu_f} = -E_h'' \cdot \left\{(1-\mu_h)\left(\frac{d\hat{x}_h^h}{d\mu_h} + \frac{d\hat{x}_h^f}{d\mu_h}\right) - \hat{x}_h^h - \hat{x}_h^f\right\} \cdot \left\{-\hat{x}_f^h - \hat{x}_f^f - \mu_f\left(\frac{d\hat{x}_f^h}{d\mu_f} + \frac{d\hat{x}_f^f}{d\mu_f}\right)\right\}, \tag{22}$$

we obtain the following lemma.

Lemma 2 *Suppose that the home country exports recycled materials. The RCSs are strategic complements (resp. substitutes) for the home government if and only if an increase in μ_f raises (resp. reduces) the amount of waste generated in the home country.*

The lemma implies that the condition relating to the strategic relationship for the home country is similar to that in the case in which there is no trade in recycled materials (Lemma 1). Thus, when there is trade in recycled materials, the strategic relationship for the home country and that for the foreign country could be asymmetric.

Differentiate (7) with respect to μ_h and evaluate it at the non-cooperative μ_h to yield

$$\left.\frac{\partial W}{\partial \mu_h}\right|_{\frac{\partial W^h}{\partial \mu_h}=0} = \frac{d\pi^f}{d\mu_h}. \tag{23}$$

In this context, we use the fact that waste in the foreign country is given by $(1-\lambda_f)X_f$. Since the sign of $d\pi^f/d\mu_h$ is ambiguous, the home RCS may be stricter or more lax than the cooperative RCS. However, unlike in the case of the home RCS when there is no trade in recycled materials, only a change in the foreign firm's profits determines the difference between the cooperative and the non-cooperative RCSs. This contrasts with the determination of the foreign RCS in the context of (21).

The Nash equilibrium in the first stage is obtained by solving the FOCs simultaneously for both countries. From (21), (23), and Lemma 2, we obtain

Proposition 2 *Suppose that the home country exports recycled materials. If* $\epsilon_i < 2$ *(resp.* $\epsilon_i > 2$*) and RCSs are strategic substitutes (resp. complements) for the home country in the neighborhood of the non-cooperative equilibrium, in the SPNE, the non-cooperative RCS of the home country is stricter (resp. more lax) than the cooperative RCS. The non-cooperative RCS of the foreign country may be more lax (resp. stricter) than the cooperative RCS.*

Thus, it may be the case that one country sets a stricter RCS and the other country sets a more lax RCS than the cooperative RCSs. First, if $\epsilon_i < 2$, then from (10) $d\pi^f/d\mu_h < 0$ holds, and hence, (23) implies that the home RCS in the SPNE is stricter than the cooperative RCS. With regard to the foreign RCS, from (10) the first term in (21) is negative. However, if $\hat{x}_j^i + \mu_j d\hat{x}_j^i/d\mu_j > 0$, the second term is positive. Thus, if the second effect dominates the first one, the RHS of (21) is positive, which implies that the foreign RCS in the SPNE is more lax than the cooperative RCS. From (18), in this case, $dE_h/d\mu_f < 0$, and hence, from Lemma 2, the RCSs are strategic substitutes for the home government. This case is illustrated in Figure 1. The thick curve ($\omega_N^i, i = h, f$) represents the locus of the RCSs of country i when the government sets them non-cooperatively. The dotted curve ($\omega_C^i, i = h, f$) represents the locus of the RCSs of country i when the government sets them cooperatively. Moreover, EN and EC denote the non-cooperative and cooperative equilibria, respectively. Second, if $\epsilon_i > 2$, then from (10), $d\pi^f/d\mu_h > 0$ follows, and hence, (23) implies that the home RCS in the SPNE is more lax than the cooperative RCS. In this case, from (10), the first term in (21) is positive. However, if

$\hat{x}_j^i + \mu_j d\hat{x}_j^i/d\mu_j < 0$, the second term is negative. Thus, if the second effect dominates the first effect, the RHS of (21) is negative, which implies that the foreign RCS in the SPNE is stricter than the cooperative RCS. From (18), in this case, $dE_h/d\mu_f > 0$ holds, and hence, from Lemma 2, the RCSs are strategic complements for the home government.

The asymmetry between the two countries is due to trade in recycled materials. In particular, the *demand effect for recycled materials* plays an important role. The home government can reduce environmental damage in its own country in three ways: by reducing the consumption of good X, by increasing in firm h's demand for recycled materials generated in the home country, and by increasing firm f's demand for recycled materials generated in the home country. However, since the supply constraint is binding in the foreign country, the foreign government can only reduce environmental damage in its own country by reducing the consumption of good X. This asymmetry in the effect of RCSs on the demand for recycled materials is important to the opposing distortions.

4.2 World Supply Constraint for Recycled Materials is Binding

In this subsection, we analyze the case in which total demand for recycled materials exceeds the total supply of recycled materials at w_R. In this case, from (5), it is clear that environmental damage in both countries depends on the consumption of X. Thus, governments can reduce environmental damage by reducing their own consumption. However, it is still possible for both home and foreign non-cooperative RCSs to diverge from cooperative RCSs in opposite directions. In this context, the *terms-of-trade effect* is an important factor. For simplicity, we assume that both home and foreign firms, which produce good X, behave as price takers in the market for recycled materials.[25]

In this case, since the price of recycled materials changes due to a change in each RCS, a change in the home (resp. foreign) RCS affects the supply of good X to the foreign (resp. home) market of good X. Let $\tilde{x}_i^j[\mu_h, \mu_f]$ denote the equilibrium outputs in the second stage given the home and foreign RCSs. Then, the effect of a change in μ_h on outputs, profits, and environmental damage is given by

$$\frac{d\tilde{x}_h^j}{d\mu_h} = \frac{w_R - w_V + \mu_h dw_R/d\mu_h}{P_h'(3-\epsilon_h)}, \quad \frac{d\tilde{x}_f^j}{d\mu_h} = \frac{\mu_f dw_R/d\mu_h}{P_f'(3-\epsilon_f)},$$

$$\frac{d\pi^j}{d\mu_h} = -\frac{2-\epsilon_h}{3-\epsilon_h}(w_R - w_V + \mu_h \frac{dw_R}{d\mu_h})\tilde{x}_h^j - \frac{2-\epsilon_f}{3-\epsilon_f}\mu_f \frac{dw_R}{d\mu_h}\tilde{x}_f^j,$$

$$\frac{dE_i}{d\mu_h} = E_i'(1-\lambda_i)\frac{d\tilde{X}_i}{d\mu_h},$$

where $\tilde{X}_i = \tilde{x}_i^i + \tilde{x}_i^j$. Since the demand for recycled material may decrease at a certain price of recycled materials due to an increase in the strictness of the RCS, the price of recycled materials may fall when an RCS becomes stricter. This implies that, when μ_i becomes stricter, the supply of good X to country j's market may increase.[26]

If each government acts non-cooperatively, the FOC is given by

$$\begin{aligned}\frac{\partial W^i}{\partial \mu_i} &= \left\{-P_i'\tilde{X}_i - E_i'(1-\lambda_i) + (w_R - c_R)\lambda_i\right\} \cdot \frac{d\tilde{X}_i}{d\mu_i} + \left(\frac{\mu_i \tilde{x}_i^i}{3-\epsilon_i} + \frac{\mu_j \tilde{x}_j^i}{3-\epsilon_j}\right) \cdot \frac{dw_R}{d\mu_i} \\ &\quad -\frac{2-\epsilon_i}{3-\epsilon_i}(w_R - w_V)\tilde{x}_i^i - (\mu_i \tilde{x}_i^i + \mu_j \tilde{x}_j^i - \lambda_i \tilde{X}_i) \cdot \frac{dw_R}{d\mu_i} = 0. \qquad (24)\end{aligned}$$

[25] For example, in Japan, the Japan Containers and Packaging Recycling Association administers the recycling system of PET bottles, and holds auctions of used PET bottles. Buyers (recycling firms) make bids for those used bottles. In this case, it is likely that buyers, and hence final goods producers, behave as if they are price takers in the market for recycled materials. See the association's web site (http://www.jcpra.or.jp/) for more details.

[26] We are grateful to an anonymous referee for his or her helpful comment on this point. Even if both firms h and f have bargaining power in the market for recycled materials and the price of recycled materials remains at w_R, both home and foreign firms may increase the supply of good X to the foreign market strategically when the home RCS becomes stricter. This is because marginal revenue from supplying good X to the home market may fall substantially.

Differentiate (7) with respect to μ_i and evaluate it at the non-cooperative μ_i to yield

$$\begin{aligned}\left.\frac{\partial W}{\partial \mu_i}\right|_{\frac{\partial W_i}{\partial \mu_i}=0} &= \left\{-P_j'\tilde{X}_j - E_j'(1-\lambda_j) + (w_R - c_R)\lambda_j\right\} \cdot \frac{d\tilde{X}_j}{d\mu_i} + \left(\frac{\mu_j \tilde{x}_j^j}{3-\epsilon_j} + \frac{\mu_i \tilde{x}_i^j}{3-\epsilon_i}\right) \cdot \frac{dw_R}{d\mu_i} \\ &\quad -\frac{2-\epsilon_i}{3-\epsilon_i}(w_R - w_V)\tilde{x}_i^j - (\mu_j \tilde{x}_j^j + \mu_i \tilde{x}_i^j - \lambda_j \tilde{X}_j) \cdot \frac{dw_R}{d\mu_i}. \qquad (25)\end{aligned}$$

In (25), the third term is the direct effect of μ_i on firm j's profit, which appeared in the analysis of the previous section. The first term represents the effects on CS, environmental damage, and PS for producers of recycled materials in country j through a change in the supply of good X to the market in country j. Note that μ_i affects $\tilde{X}_j$ only through a change in w_R. The second and last terms represent effects that operate through a change in w_R. The second term represents the indirect effect on firm j's profit. The last term is a *terms-of-trade effect*.

The signs of the second and third terms in (25) are the same for both countries whether they export or import recycled materials. Although the sign of the first term is ambiguous, the sign of the last term in (25) clearly differs between the exporting and importing countries. When the price of recycled materials increases because RCSs become stricter, the latter term is negative (resp. positive) for the exporting (resp. importing) country. Thus, a *terms-of-trade effect* provides the country that exports (resp. imports) recycled materials with an incentive to set its RCS that is stricter (resp. more lax) than the cooperative RCS. This is because the exporting (resp. importing) country ignores the negative (resp. positive) effect of its own RCS on the welfare of the other country.[27] Consequently, it is possible that home and foreign non-cooperative RCSs are distorted in opposite directions.[28]

[27]When the price of recycled materials falls because RCSs become stricter, both countries have the opposite incentives.

[28]Since (24) for country i and (25) for country j share common terms, the comparison of them is useful. See Appendix

5 Conclusions

In this paper, we have investigated the strategic use of recycled content standards (RCSs) in a model of two-country reciprocal trade under international duopoly. In a simple framework, we have demonstrated that governments have an incentive to distort RCSs for reasons other than stimulating the domestic use of recycled materials, and that the non-cooperative RCSs may be stricter or more lax than the globally optimal RCSs, depending on various factors, such as the demand structure and the price difference between virgin and recycled materials.

An interesting result in this paper is that when two countries are identical in all respects except the recovery rates of recycled materials, the RCSs adopted non-cooperatively by the governments of these countries may be distorted in opposite directions if these countries trade not only in consumption goods but also in recycled materials. In other words, it may be that, relative to the cooperative RCS, the exporting country of the recycled material chooses a stricter RCS and the importing country chooses a more lax RCS, or *vice versa*. We have emphasized the importance of the *demand effect for recycled materials.* However, if they trade in consumption goods but not in recycled materials, the non-cooperative RCSs are distorted in the same direction.

The results in this paper imply that the RCSs that are currently effective in a number of countries may not be globally optimal levels. In particular, our study indicates that when the demand curve is not highly convex, countries that export recycled materials may impose excessively strict RCSs and importing countries may impose excessively lax RCSs. It seems that this result fits the current situation. That is, as argued in

C for more details about the comparison when the inverse demand function is linear.

the introduction, the US and Japan impose strict RCSs, including RCSs for newsprint and green procurement requirements for various products. At the same time, the US and Japan are large exporters of recycled materials.[29] However, importers of recycled materials, including Canada and China, impose only lax RCSs or none at all. We suggest that the current RCSs in exporting and importing countries are distorted in opposite directions and not globally optimal.

Under the current world system, waste management and recycling are treated as domestic issues. Consequently, RCSs, which are intended to facilitate the utilization of recycled materials, are not internationally coordinated. Our analysis suggests that problems may arise under the current system. The international coordination of RCSs will improve social welfare in countries that export or import recycled materials. However, such coordination requires that waste management and recycling are recognized as international issues.

We have demonstrated that trade in recycled materials can alter non-cooperative RCSs. Similar results may apply to other environmental policies. Consider, for example, the case of regulating production-generated emissions by tradable emission permits.[30] Without trade in permits, each country faces the same strategic incentive to distort emission standards (Barrett [1]; Kennedy [13]). Thus, non-cooperative emission standards are necessarily distorted in the same direction. With trade in permits, it may be

[29] One may argue that the US case is inconsistent with our model, because US recovery rates are relatively low for some materials (Table 1). Despite these low recovery rates, the US exports a large amount of recycled materials mainly because supplies of recycled materials are high. In this sense, our results apply to the US. For example, in 2002, the US recovered more paper and board than any other country: 47.6 million tons. Corresponding figures for other countries (millions of tons) are: Canada, 3.4; China, 10.1; Germany, 13.7; Japan, 20.0; UK, 5.9. See the caption below Table 1 for data sources.

[30] We are grateful to an anonymous referee for pointing out this application.

the case that exporting (resp. importing) countries of permits issue fewer (resp. more) permits than the cooperative number. The main driving force is a *terms-of-trade effect* in permits. However, similar to the demand effect for recycled materials, a *demand effect for permits* may also contribute to asymmetric distortion in the unusual case in which the importing country issues less than the technologically feasible number of permits. In that case, a change in permits in the exporting country affects the terms of trade but does not affect the partner country's import demand for permits, whereas a change in permits in the importing country affects both the terms of trade and its import demand for permits but does not affect its domestic emission level.

As already mentioned, there is no rent capture effect in our model. Our model can be extended to include such an effect. The rent capture effect strengthens the strategic motive to distort RCSs and hence may exacerbate the problem caused by non-cooperative decision-making.[31] For example, if shipments of recycled materials are subject to transportation costs, the marginal cost of the firm producing a consumption good in the country that imports recycled materials is higher than that in the exporting country. In fact, since the recycled materials are relatively heavy and bulky, their transportation is often costly. In that case, RCSs may affect firms' profits differently, and thereby generate a rent capture effect. Consequently, the exporting country of the recycled materials may have an additional incentive to make its RCS higher. Our future task is to examine this effect in detail and to investigate which effects are more important in practice.

[31]Using data on RCSs and garbage collection programs, Jacque [11] suggested that US recycled content newsprint regulations are a trade barrier.

Appendix

A Possible Combinations of Home and Foreign RCSs

In this Appendix, we examine possible combinations of μ_h and μ_f. The relationship between the demand for and supply of recycled materials at time t is:

$$\lambda_h \breve{X}_{h,t-1}[w_{R,t-1};\mu_h,\mu_f]+\lambda_f \breve{X}_{f,t-1}[w_{R,t-1};\mu_h,\mu_f] \geq \mu_h \breve{X}_{h,t}[w_{R,t};\mu_h,\mu_f]+\mu_f \breve{X}_{f,t}[w_{R,t};\mu_h,\mu_f], \tag{A.1}$$

where $\breve{X}_{i,t}[w_{R,t};\mu_i,\mu_j]$ denotes $\hat{X}_{i,t}[w_{R,t};\mu_i]$ or $\tilde{X}_{i,t}[w_{R,t};\mu_i,\mu_j]$. In the steady state, $w_{R,t-1} = w_{R,t} = w_R$ and, accordingly, $\breve{X}_{i,t-1} = \breve{X}_{i,t} = \breve{X}_i$. In what follows, we divide the possible combinations of home and foreign RCSs into three cases.

First, any combination of μ_h and μ_f is possible when total world supply exceeds total world demand if $w_R = c_R$. Since the price of the recycled materials depends on neither μ_h nor μ_f, when

$$(\lambda_h - \mu_h)\hat{X}_h[\mu_h] = -(\lambda_f - \mu_f)\hat{X}_f[\mu_f], \tag{A.2}$$

total world demand is exactly equal to total world supply at w_R. It is clear that this equality holds if $\mu_h = \lambda_h$ and $\mu_f = \lambda_f$. From (A.2), we obtain

$$\frac{d\mu_h}{d\mu_f} = -\frac{\hat{X}_f - (\lambda_f - \mu_f)\frac{d\hat{X}_f}{d\mu_f}}{\hat{X}_h - (\lambda_h - \mu_h)\frac{d\hat{X}_h}{d\mu_h}}. \tag{A.3}$$

Two results relating to the sign of (A.3) can be obtained. First, if both $\lambda_h = \mu_h$ and $\lambda_f = \mu_f$, the slope is negative. Second, if the demand for recycled materials increases as an RCS becomes stricter (that is, if $\hat{X}_i + \mu_i d\hat{X}_i/d\mu_i > 0$ holds for all μ_i), the slope is also negative. In Figure A.1, the horizontal (resp. vertical) axis represents the home (resp. foreign) RCS, and the thick curve, CGHK, represents equality (A.2) when $\hat{X}_i +$

$\mu_i d\hat{X}_i/d\mu_i > 0$. If $\lambda_h - \mu_h = -(\lambda_f - \mu_f)$ and $\mu_h = \mu_f$, the equality (A.2) holds, since $\mu_h = \mu_f$ implies $\hat{X}_h = \hat{X}_f$. Thus, the curve goes through both H and G, where $\mu_h = \mu_f$ on the line labeled α and $\lambda_h - \mu_h = -(\lambda_f - \mu_f)$ on the line labeled β. Moreover, from (A.3), since $\mu_h = \lambda_h$ and $\mu_f = \lambda_f$ implies $\mu_h > \mu_f$, $d\mu_h/d\mu_f < -1$ at H. Moreover, $d\mu_h/d\mu_f > -1$ at G, since $\lambda_f - \mu_f < 0$ and $\lambda_h - \mu_h > 0$ at G.

Consequently, in the area ACKMO, the total supply of recycled materials exceeds total demand for recycled materials at w_R. Therefore, any combinations of RCSs are possible, and the supply constraint is not binding.

Second, we focus on the area □DEIH in Figure A.1. Since this area is located in the upper-right of the curve CGHK, if $w_{R,t-1} = w_{R,t} = w_R$, demand for recycled materials exceeds supply of recycled materials. Thus, the price of the recycled materials is likely to increase. However, since $\mu_h > \lambda_h$ and $\mu_f > \lambda_f$, if $w_{R,t-1} = w_{R,t}$, demand exceeds supply whatever the price of the recycled materials. This implies that there is no steady-state equilibrium, which implies that there are no feasible combinations of RCSs.

Third, combinations of home and foreign RCSs may be possible in the areas CDH and HIK, since the gap between demand and supply may be adjusted by a change in the price of the recycled materials. However, within those areas, some combinations must be eliminated because they are not feasible.

First, in the area △FGH, since $\mu_h > \mu_f$, the marginal cost of supplying good X to the home market is greater than that of supplying to the foreign market. Therefore, $\tilde{X}_f > \tilde{X}_h$. Moreover, since $-(\lambda_f - \mu_f) > \lambda_h - \mu_h$, it follows that

$$-(\lambda_f - \mu_f)\tilde{X}_f > (\lambda_h - \mu_h)\tilde{X}_h. \qquad (A.4)$$

Equation (A.4) implies that total demand for recycled materials exceeds the total supply of recycled materials whatever the price of the recycled materials provided firms supply good X to both the home and foreign markets. Moreover, the lowest price of the recycled materials, at which the supply of good X to the home market is zero, is lower than the price at which the supply of good X to the foreign market is zero. Therefore, in this area, there is no steady-state equilibrium.

Moreover, in equilibrium, the market for recycled materials should be stable in terms of the price adjustment mechanism, given both μ_h and μ_f. Given (A.1) and $d\tilde{X}_{i,t}/dw_{R,t} = -\mu_i/P_i'(3-\epsilon_i)$, the condition for the slope of the inverse supply curve to be steeper than the slope of the inverse demand curve is as follows:

$$\frac{P_h'(3-\epsilon_h)\mu_f}{P_f'(3-\epsilon_f)\mu_h} \gtrless -\frac{\lambda_h-\mu_h}{\lambda_f-\mu_f}, \quad \text{if} \quad \lambda_h \gtrless \mu_h \quad \text{and} \quad \lambda_f \lesseqgtr \mu_f. \tag{A.5}$$

Thus, any area not satisfying this condition must be eliminated from consideration.

For example, consider a linear demand curve ($\epsilon_i = 0$). For any given μ_h and μ_f, $P_h' = P_f'$. In the area CDFG, $\mu_f > \mu_h$ and $-(\lambda_f - \mu_f) > \lambda_h - \mu_h$. Moreover, in the area HIK, $\mu_h > \mu_f$ and $-(\lambda_f - \mu_f) > \lambda_h - \mu_h$ hold. Thus, (A.5) is satisfied in these areas. However, in the shaded area, since $\mu_h > \mu_f$ and $-(\lambda_f - \mu_f) < \lambda_h - \mu_h$, (A.5) is not met.

B Trade in Recycled Materials

In this Appendix, focusing on the steady state, we determine the areas in which trade in recycled materials takes place.

First, we examine the case in which the total world supply constraint is not binding when $w_R = c_R$; this is so in area ACKMO in Figure A.1. We mainly focus on the case in which the home country is a possible importer of recycled materials. If $\lambda_h(\hat{x}_h^h + \hat{x}_h^f) < \mu_h \hat{x}_h^h + \mu_f \hat{x}_f^h$, the home country imports recycled materials. If

$$\lambda_h \hat{X}_h = \lambda_f \hat{X}_f, \tag{B.1}$$

the supply of recycled materials is the same in the two markets, and trade in recycled materials does not take place. Totally differentiating (B.1) yields

$$\frac{d\mu_h}{d\mu_f} = \frac{\lambda_f \frac{d\hat{X}_f}{d\mu_f}}{\lambda_h \frac{d\hat{X}_h}{d\mu_h}} > 0. \tag{B.2}$$

The dotted curve represents (B.1) for $\lambda_h > \lambda_f$. The supply of recycled materials in the home (resp. foreign) market exceeds that in the foreign (resp. home) market in the area above and to the left (resp. below and to the right) of the dotted curve in Figure A.1.[32]

In the model as it stands, it is important to note that the firm h's demand for recycled materials equals the firm f's demand. Thus, if there is trade in recycled materials, the home country exports (resp. imports) recycled materials in the area above and to the left (resp. below and to the right) of the dotted curve in Figure A.1.

Suppose that $\lambda_h(\hat{x}_h^h + \hat{x}_h^f) = \mu_h \hat{x}_h^h + \mu_f \hat{x}_f^h$. Totally differentiating this equality yields

$$\frac{d\mu_h}{d\mu_f} = \frac{\hat{x}_f^h + \mu_f \frac{d\hat{x}_f^h}{d\mu_f}}{(2\lambda_h - \mu_h)\frac{d\hat{x}_h^h}{d\mu_h} - \hat{x}_h^h}. \tag{B.3}$$

We focus on the case where demand for recycled materials increases as an RCS becomes stricter. To make the comparison clear, using $\hat{X}_i = 2\hat{x}_i^j$ and $d\hat{X}_i/d\mu_i = 2d\hat{x}_i^j/d\mu_i$, rewrite (A.3) as

$$\frac{d\mu_h}{d\mu_f} = \frac{\hat{x}_f^h - (\lambda_f - \mu_f)\frac{d\hat{x}_f^h}{d\mu_f}}{(\lambda_h - \mu_h)\frac{d\hat{x}_h^h}{d\mu_h} - \hat{x}_h^h}. \tag{A.3$'$}$$

In this case, the numerator of (B.3) is positive and the denominator of (B.3) is negative. Thus, the sign of (B.3) is negative. Moreover, at J in Figure A.1, the numerator of

[32]If $\lambda_h = \lambda_f$, (b.1) is the same as the line labeled α.

(B.3) is smaller than that of (A.3)' and the absolute value of the denominator of (B.3) is greater than that of (A.3)'. Thus, the absolute value of the slope of the curve on which total world supply equals total world demand (the curve CGHK in Figure A.1) is greater than the absolute value of the slope of the curve on which home supply equals home demand (the curve JL in Figure A.1) at J in Figure A.1.

The condition for the case in which the foreign country imports recycled materials is obtained analogously. Figure A.1 provides an example. JKL (resp. BCJ) represents the area in which the home country imports (resp. exports) recycled materials.

Now, consider the case in which the world supply constraint for recycled materials is binding at w_R. Since a change in μ_i affects X_j, (B.2) can be rewritten as follows:

$$\frac{d\mu_h}{d\mu_f} = \frac{-\lambda_h \frac{d\tilde{X}_h}{d\mu_f} + \lambda_f \frac{d\tilde{X}_f}{d\mu_f}}{\lambda_h \frac{d\tilde{X}_h}{d\mu_h} - \lambda_f \frac{d\tilde{X}_f}{d\mu_h}}. \qquad (B.4)$$

This is not necessarily positive.

The effects of a change in RCSs on the price of recycled materials are

$$\frac{dw_R}{d\mu_h} = \frac{(\lambda_h - \mu_h)\frac{\partial \tilde{X}_h}{\partial \mu_h} - \tilde{X}_h}{\psi}, \quad \frac{dw_R}{d\mu_f} = \frac{(\lambda_f - \mu_f)\frac{\partial \tilde{X}_f}{\partial \mu_f} - \tilde{X}_f}{\psi}, \qquad (B.5)$$

where $\psi = -(\lambda_h - \mu_h)\partial\tilde{X}_h/\partial w_R - (\lambda_f - \mu_f)\partial\tilde{X}_f/\partial w_R$, which is negative for stability (A.5). Thus,

$$\lambda_i \frac{d\tilde{X}_i}{d\mu_i} = 2\lambda_i \cdot \frac{w_R - w_V + \mu_i(dw_R/d\mu_i)}{P_i'(3-\epsilon_i)}, \quad \lambda_i \frac{d\tilde{X}_i}{d\mu_j} = 2\lambda_i \cdot \frac{\mu_i(dw_R/d\mu_j)}{P_i'(3-\epsilon_i)}, \qquad (B.6)$$

for $i, j = h, f, i \neq j$. Substituting (B.5) into (B.6), we obtain

$$\frac{d\tilde{X}_h/d\mu_h}{d\tilde{X}_f/d\mu_h} \neq \frac{d\tilde{X}_h/d\mu_f}{d\tilde{X}_f/d\mu_f}.$$

This implies that the denominator and the numerator of (B.4) cannot simultaneously be zero. Thus, there is no two-dimensional area that corresponds to the absence of trade in recycled materials in CDFG, HIK, and the shaded area in Figure A.1. In general, trade in recycled materials takes place when the world supply constraint for recycled materials is binding.

Two important points should be noted. First, the larger the difference in the recovery rates of both countries, the more likely is trade in recycled materials to take place. In particular, the country with the highest (resp. lowest) recovery rate is likely to export (resp. import) recycled materials. For example, suppose that $\lambda_h = 1$ and $\lambda_f = 0$. Unless $\mu_h = \mu_f = 0$, trade in recycled materials takes place.

Second, the greater is the environmental damage from one unit of waste, the more likely is trade in recycled materials. RCSs become stricter as environmental damage worsens, which implies that demand for recycled materials increases. Thus, it is likely that the supply constraint binds in at least one country.

C Terms-of-Trade Effect

In this Appendix, focusing on the *terms-of-trade effect*, we discuss the direction of distortion. We assume that the inverse demand curve is linear ($P_i = A - aX_i, \epsilon_i = 0$) in both countries, and that the price of recycled materials rises when RCSs become stricter. This implies that

$$\frac{dw_R}{d\mu_h} = \frac{2(\lambda_h - \mu_h)(w_R - w_V) + 3a\tilde{X}_h}{-2(\lambda_h - \mu_h)\mu_h - 2(\lambda_f - \mu_f)\mu_f} > 0, \tag{C.1}$$

$$\frac{dw_R}{d\mu_f} = \frac{2(\lambda_f - \mu_f)(w_R - w_V) + 3a\tilde{X}_f}{-2(\lambda_h - \mu_h)\mu_h - 2(\lambda_f - \mu_f)\mu_f} > 0, \tag{C.2}$$

where we have used equality between total world supply and demand in equilibrium ($\lambda_h\tilde{X}_h + \lambda_f\tilde{X}_f = \mu_h\tilde{X}_h + \mu_f\tilde{X}_f$). Note that the denominator of both equations is positive from the stability condition. As discussed in Appendix A, possible combinations of home and foreign RCSs are represented either by the area CDFG ($\mu_h < \mu_f, \lambda_h > \mu_h, \lambda_f < \mu_f$) or by the area HIK ($\mu_h > \mu_f, \lambda_h < \mu_h, \lambda_f > \mu_f$) in Figure A.1.

First, consider the exporting (home) country. Since $\epsilon_i = 0$, all of the four terms in (25) for the home country ($\partial W/\partial \mu_h$) and (24) for the foreign country ($\partial W^f/\partial \mu_f$) are the same except for multipliers ($d\tilde{X}_k/d\mu_k, x_l^k, dw_R/d\mu_k, k, l = i, j$). Moreover, since $\partial W^f/\partial \mu_f = 0$ at the non-cooperative equilibrium, it is useful to compare them with each other to determine the direction of the distortion of μ_h. In (24) for the foreign (importing) country, since the second term is positive and the third and fourth terms are negative, the magnitude of the *terms-of-trade effect* is one of the factors that determines the sign of the first term. If the volume of trade in recycled materials is large, the first term is likely to be positive. Given (C.1), (C.2), and $\tilde{X}_h/\tilde{X}_f = \tilde{x}_h^f/\tilde{x}_f^f$, it follows that

$$\frac{\mu_f \frac{dw_R}{d\mu_h}}{w_R - w_V + \mu_f \frac{dw_R}{d\mu_f}} < \frac{\frac{dw_R}{d\mu_h}}{\frac{dw_R}{d\mu_f}} < \frac{\tilde{x}_h^f}{\tilde{x}_f^f} \quad \text{if} \quad \mu_h > \mu_f, \quad \text{and}$$
$$\frac{\tilde{x}_h^f}{\tilde{x}_f^f} < \frac{\mu_f \frac{dw_R}{d\mu_h}}{w'_R - w_V + \mu_f \frac{dw_R}{d\mu_f}} < \frac{\frac{dw_R}{d\mu_h}}{\frac{dw_R}{d\mu_f}} \quad \text{if} \quad \mu_h < \mu_f.$$

If $\mu_h > \mu_f$, the third term is magnified to the greatest degree and the first term is magnified to the least degree in (25). The negative terms are magnified to a greater degree than the positive terms in the latter case. Thus, $\partial W/\partial \mu_h$ evaluated at the non-cooperative equilibrium is negative, which implies that the home government ignores the negative effect of its own non-cooperative action on the welfare of the foreign country. Therefore, the non-cooperative home RCS is stricter than the cooperative RCS. By contrast, if $\mu_h < \mu_f$, relative to the FOC for the foreign country, the second and fourth terms are magnified to a greater degree than the other two terms, and the third term is magnified to a lesser degree in (25). However, if trade in recycled materials is sufficiently high, the result is the same as that in the case of $\mu_h > \mu_f$.

Second, consider the importing (foreign) country. Similar to the case of the exporting country, it is useful to compare (24) for the home country with (25) for the foreign country. In (24) for the home country, since the second and fourth terms are positive and the third term is negative, if the volume of trade in recycled materials is large, the first term is likely to be negative. Given (C.1) and (C.2), it is easily shown that

$$\frac{\tilde{x}_f^h}{\tilde{x}_h^h} < \frac{\mu_h \frac{dw_R}{d\mu_f}}{w_R - w_V + \mu_h \frac{dw_R}{d\mu_h}} < \frac{\frac{dw_R}{d\mu_f}}{\frac{dw_R}{d\mu_h}}, \quad \text{if} \quad \mu_h > \mu_f, \quad \text{and}$$
$$\frac{\mu_h \frac{dw_R}{d\mu_f}}{w_R - w_V + \mu_h \frac{dw_R}{d\mu_h}} < \frac{\frac{dw_R}{d\mu_f}}{\frac{dw_R}{d\mu_h}} < \frac{\tilde{x}_f^h}{\tilde{x}_h^h}, \quad \text{if} \quad \mu_h < \mu_f.$$

If $\mu_h > \mu_f$, the second and fourth terms are magnified to a greater degree and the third term is magnified to the least degree in (25). The positive terms are magnified to a greater degree than the negative terms in the latter case. Thus, $\partial W/\partial \mu_f$ evaluated at the non-cooperative equilibrium is positive, which implies that the foreign government ignores the positive effect of its own non-cooperative action on the welfare of the home country. Therefore, the non-cooperative foreign RCS is more lax than the cooperative RCS. By contrast, if $\mu_h < \mu_f$, relative to the FOC for the home country, the third term is magnified to a greater degree than the other three terms, and the first term is magnified to a lesser degree in (25). However, if trade in recycled materials is sufficiently high, the result is the same as that in the case of $\mu_h > \mu_f$.

Although there are other factors that distort the two RCSs in opposite directions, it is clear that the *terms-of-trade effect* is an important factor. This effect makes the RCS of the country that exports (resp. imports) recycled materials stricter (resp. more lax).

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Table 1: Recovery Rates of Aluminum Beverage Can and Paper in Selected Countries in 2002

(%)

	Canada	China	France	Germany	Italy	Japan	Spain	Sweden	UK	US
Aluminum Can	N/A	N/A	30	78	50	83	25	86	42	53
Paper and Board	44	24	50	72	45	65	52	69	48	48

Source: (i) Aluminum: (European countries) European Aluminium Association, (Japan and the US) Aluminum Can Recycling Association of Japan; (ii) Paper: (Canada) Paper Recycling Association of Canada, (China) Japan Pulp and Paper Company Ltd., (European countries) Confederation of European Paper Industries, (Japan) Paper Recycling Promotion Center, (US) AF&PA.

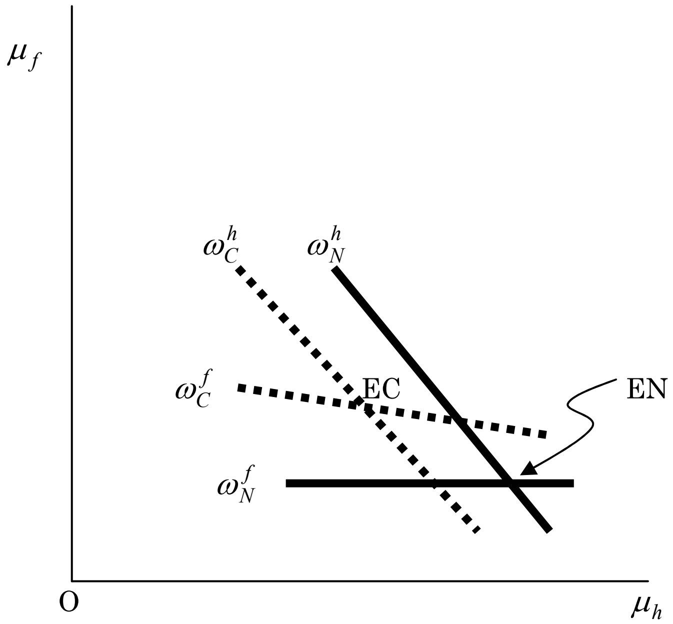

Figure 1. One possible case of non-cooperative and cooperative equilibria when trade in recycled materials exists.

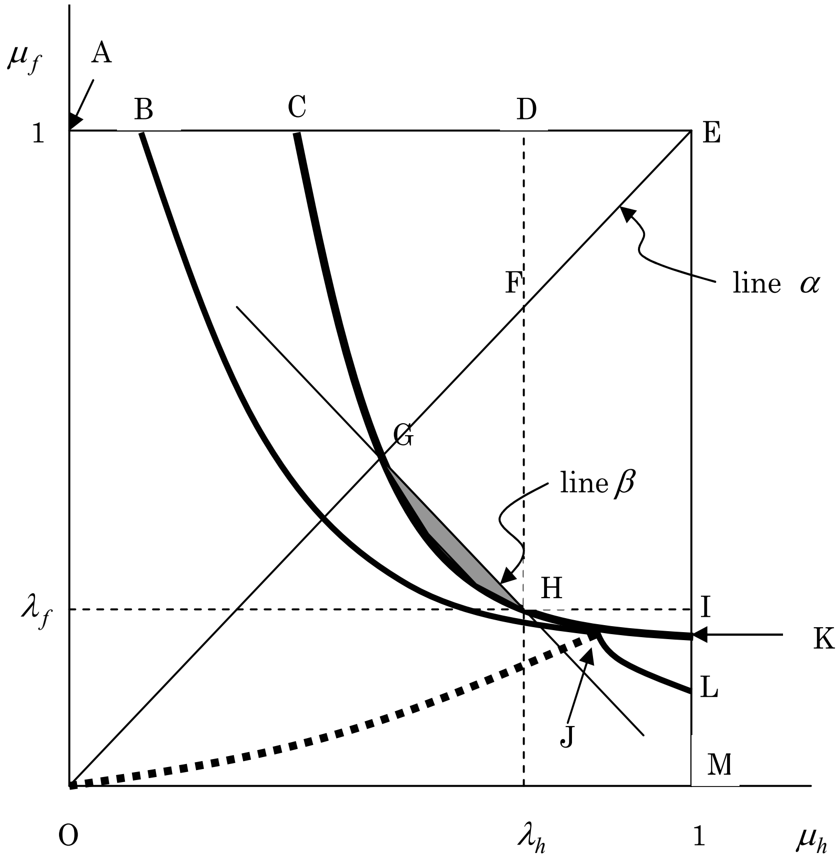

Figure A.1. Possible Combinations of RCSs and Trade in Recycled Materials

Technical Appendix: On Second Order Conditions

In this report, focusing on the case of $w_R = c_R$, we derive some conditions for second order conditions (SOCs) to be satisfied in a special case in which the elasticity of the slope of the inverse demand function is constant and equal to or greater than zero, that is, $\epsilon \geq 0$.

In particular, the purpose of this report is to demonstrate that the sign of $x_i^j + \mu_i dx_i^j / d\mu_i$ is not an important factor for SOCs to be satisfied, although the difference in material prices and the marginal environmental damage are important factors. In the following, we examine the case in the absence of trade in recycled materials first and, next, we examine the case in the presence of trade in recycled materials.

1. The case in the absence of trade in recycled materials

1.1 Non-cooperative behavior

Let us begin with the case in which no trade in recycled materials occurs and governments act non-cooperatively. The SOCs for this case are as follows:

$$\frac{\partial^2 W^h}{\partial \mu_h^2} < 0, \tag{1}$$

$$\frac{\partial^2 W^f}{\partial \mu_f^2} < 0, \tag{2}$$

$$\frac{\partial^2 W^h}{\partial \mu_h^2} \cdot \frac{\partial^2 W^f}{\partial \mu_f^2} - \frac{\partial^2 W^h}{\partial \mu_f \partial \mu_h} \cdot \frac{\partial^2 W^f}{\partial \mu_h \partial \mu_f} > 0. \tag{3}$$

From (13 in the text), we obtain the following equation:

$$\frac{\partial^2 W^h}{\partial \mu_h^2} = -P'' \hat{X}_h \left(\frac{d\hat{X}_h}{d\mu_h} \right)^2 - P' \left(\frac{d\hat{X}_h}{d\mu_h} \right)^2 - P' \hat{X}_h \frac{d^2 \hat{X}_h}{d\mu_h^2}$$

$$
\begin{aligned}
&-\frac{(2-\epsilon)(w_R-w_V)}{3-\epsilon}\frac{d\hat{x}_h^h}{d\mu_h} \\
&-E_h'\left\{(1-\mu_h)\frac{d^2\hat{x}_h^h}{d\mu_h^2}+\frac{d^2\hat{x}_h^f}{d\mu_h^2}-2\frac{d\hat{x}_h^h}{d\mu_h}\right\} \\
&-E_h''\left\{(1-\mu_h)\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}-\hat{x}_h^h\right\}^2 \qquad (4)
\end{aligned}
$$

Since ϵ is constant,

$$
\begin{aligned}
\frac{d^2\hat{x}_h^h}{d\mu_h^2} &= -\frac{(w_R-w_V)P''\frac{d\hat{X}_h}{d\mu_h}}{P'^2(3-\epsilon)} \\
&= -2\frac{P''}{P'}\left(\frac{d\hat{x}_h^h}{d\mu_h}\right)^2, \qquad (5)
\end{aligned}
$$

and

$$
\frac{d^2\hat{X}_h}{d\mu_h^2} = -\frac{P''}{P'}\left(\frac{d\hat{X}_h}{d\mu_h}\right)^2. \qquad (6)
$$

Substituting (5) and (6) into (4), and using the fact that $d\hat{x}_h^h/d\mu_h = d\hat{x}_h^f/d\mu_h$ and $d\hat{x}_h^h/d\mu_h + d\hat{x}_h^f/d\mu_h = d\hat{X}_h/d\mu_h$, we obtain

$$
\begin{aligned}
\frac{\partial^2 W^h}{\partial \mu_h^2} &= -P'(6-\epsilon)\left(\frac{d\hat{x}_h^h}{d\mu_h}\right)^2 \\
&\quad +E_h'\left\{\frac{2P''(2-\mu_h)}{P'}\left(\frac{d\hat{x}_h^h}{d\mu_h}\right)^2+2\frac{d\hat{x}_h^h}{d\mu_h}\right\} \\
&\quad -E_h''\left\{(1-\mu_h)\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}-\hat{x}_h^h\right\}^2, \qquad (7)
\end{aligned}
$$

or

$$
\begin{aligned}
\frac{\partial^2 W^h}{\partial \mu_h^2} &= \left\{-\frac{(6-\epsilon)(w_R-w_V)}{3-\epsilon}-\frac{2E_h'\epsilon(2-\mu_h)(w_R-w_V)}{\hat{X}_hP'(3-\epsilon)}+2E_h'\right\}\frac{d\hat{x}_h^h}{d\mu_h} \\
&\quad -E_h''\left\{(1-\mu_h)\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}-\hat{x}_h^h\right\}^2. \qquad (8)
\end{aligned}
$$

The second term (line) of (8) is negative. Moreover, since $\epsilon \geq 0$ from the assumption, the second term in the braces of the first line is positive. Thus, the sufficient condition for (1) to be satisfied is

$$-\frac{(6-\epsilon)(w_R-w_V)}{3-\epsilon}+2E'_h \geq 0. \tag{9}$$

Since we have assumed that both countries are symmetrical except for the recovery rates, the similar condition is obtained for (2) to be satisfied:

$$-\frac{(6-\epsilon)(w_R-w_V)}{3-\epsilon}+2E'_f \geq 0. \tag{10}$$

One point should be noted. From (13 (in the text)), for an interior solution to be obtained, the following inequality must be satisfied at least for a certain range of μ_i:

$$-\frac{(6-\epsilon)(w_R-w_V)}{3-\epsilon}+E'_i < 0. \tag{11}$$

Thus, conditions should be rewritten as follows:

$$\frac{(6-\epsilon)(w_R-w_V)}{2(3-\epsilon)} \leq E'_i < \frac{(6-\epsilon)(w_R-w_V)}{3-\epsilon}. \tag{12}$$

On the other hand,

$$\frac{\partial^2 W^i}{\partial\mu_i\partial\mu_j} = -E''_i\left\{(1-\mu_i)\frac{d\hat{x}^i_i}{d\mu_i}+\frac{d\hat{x}^j_i}{d\mu_i}-\hat{x}^i_i\right\}\left\{-\hat{x}^i_j-\mu_j\frac{d\hat{x}^i_j}{d\mu_j}\right\}. \tag{13}$$

Therefore, if

$$\begin{aligned}&\left\{(1-\mu_h)\frac{d\hat{x}^h_h}{d\mu_h}+\frac{d\hat{x}^f_h}{d\mu_h}-\hat{x}^h_h\right\}^2\left\{(1-\mu_f)\frac{d\hat{x}^f_f}{d\mu_f}+\frac{d\hat{x}^h_f}{d\mu_f}-\hat{x}^f_f\right\}^2\\ &>\left\{(1-\mu_h)\frac{d\hat{x}^h_h}{d\mu_h}+\frac{d\hat{x}^f_h}{d\mu_h}-\hat{x}^h_h\right\}\left\{(1-\mu_f)\frac{d\hat{x}^f_f}{d\mu_f}+\frac{d\hat{x}^h_f}{d\mu_f}-\hat{x}^f_f\right\}\left\{-\hat{x}^f_h-\mu_h\frac{d\hat{x}^f_h}{d\mu_h}\right\}\left\{-\hat{x}^h_f-\mu_f\frac{d\hat{x}^h_f}{d\mu_f}\right\},\end{aligned} \tag{14}$$

and (12) holds for both countries, (3) is satisfied. From (11 in the text), if $\hat{x}^i_j + \mu_j d\hat{x}^i_j/d\mu_j \geq 0$ holds, the condition (14) necessarily holds. Even if $\hat{x}^i_j + \mu_j d\hat{x}^i_j/d\mu_j < 0$, if the absolute value is not so large, the condition holds.

1.2 Cooperative behavior

Now let us turn to the case in which no trade in recycled materials occurs and governments act cooperatively. The SOCs for this case are as follows:

$$\frac{\partial^2 W}{\partial \mu_h^2} < 0, \tag{15}$$

$$\frac{\partial^2 W}{\partial \mu_f^2} < 0, \tag{16}$$

$$\frac{\partial^2 W}{\partial \mu_h^2} \cdot \frac{\partial^2 W}{\partial \mu_f^2} - \left\{ \frac{\partial^2 W}{\partial \mu_f \partial \mu_h} \right\}^2 > 0. \tag{17}$$

In this case, the first order condition for the domestic government is:

$$\begin{aligned}
\frac{\partial W}{\partial \mu_h} &= -P'\hat{X}_h \frac{d\hat{X}_h}{d\mu_h} + \frac{d\pi^h}{d\mu_h} + \frac{d\pi^f}{d\mu_h} - \frac{dE_h}{d\mu_h} - \frac{dE_f}{d\mu_h} \\
&= -P'\hat{X}_h \frac{d\hat{X}_h}{d\mu_h} - \frac{(2-\epsilon)(w_R - w_V)}{3-\epsilon}\hat{X}_h - E_h' \cdot \left\{ (1-\mu_h)\frac{d\hat{x}_h^h}{d\mu_h} + \frac{d\hat{x}_h^f}{d\mu_h} - \hat{x}_h^h \right\} \\
&\quad -E_f' \cdot \left\{ -\hat{x}_h^f - \mu_h \frac{d\hat{x}_h^f}{d\mu_h} \right\}
\end{aligned} \tag{18}$$

Thus,

$$\begin{aligned}
\frac{\partial^2 W}{\partial \mu_h^2} &= -P''\hat{X}_h \left(\frac{d\hat{X}_h}{d\mu_h} \right)^2 - P' \left(\frac{d\hat{X}_h}{d\mu_h} \right)^2 - P'\hat{X}_h \frac{d^2\hat{X}_h}{d\mu_h^2} \\
&\quad -\frac{(2-\epsilon)(w_R - w_V)}{3-\epsilon}\frac{d\hat{X}_h}{d\mu_h} \\
&\quad -E_h' \left\{ (1-\mu_h)\frac{d^2\hat{x}_h^h}{d\mu_h^2} + \frac{d^2\hat{x}_h^f}{d\mu_h^2} - 2\frac{d\hat{x}_h^h}{d\mu_h} \right\} \\
&\quad -E_h'' \left\{ (1-\mu_h)\frac{d\hat{x}_h^h}{d\mu_h} + \frac{d\hat{x}_h^f}{d\mu_h} - \hat{x}_h^h \right\}^2 \\
&\quad -E_f' \left\{ -\mu_h \frac{d^2\hat{x}_h^f}{d\mu_h^2} - 2\frac{d\hat{x}_h^f}{d\mu_h} \right\} \\
&\quad -E_f'' \left\{ -\hat{x}_h^f - \mu_h \frac{d\hat{x}_h^f}{d\mu_h} \right\}^2
\end{aligned} \tag{19}$$

Substituting (5) and (6) into (19), we obtain

$$\frac{\partial^2 W}{\partial \mu_h^2} = -P'2(4-\epsilon)\left(\frac{d\hat{x}_h^h}{d\mu_h} \right)^2$$

$$
\begin{aligned}
&+E_h'\left\{\frac{2P''(2-\mu_h)}{P'}\left(\frac{d\hat{x}_h^h}{d\mu_h}\right)^2+2\frac{d\hat{x}_h^h}{d\mu_h}\right\}\\
&-E_h''\left\{(1-\mu_h)\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}-\hat{x}_h^h\right\}^2\\
&+E_f'\left\{-\frac{2P''\mu_h}{P'}\left(\frac{d\hat{x}_h^f}{d\mu_h}\right)^2+2\frac{d\hat{x}_h^f}{d\mu_h}\right\}\\
&-E_f''\left\{-\hat{x}_h^f-\mu_h\frac{d\hat{x}_h^f}{d\mu_h}\right\}^2 \qquad (20)
\end{aligned}
$$

or

$$
\begin{aligned}
\frac{\partial^2 W}{\partial \mu_h^2} &= \left\{-\frac{2(4-\epsilon)(w_R-w_V)}{3-\epsilon}-\frac{2E_h'\epsilon(2-\mu_h)(w_R-w_V)}{\hat{X}_hP'(3-\epsilon)}+2E_h'\right.\\
&\left.+\frac{2E_f'\epsilon\mu_h(w_R-w_V)}{\hat{X}_hP'(3-\epsilon)}+2E_f'\right\}\frac{d\hat{x}_h^h}{d\mu_h}\\
&-E_h''\left\{(1-\mu_h)\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}-\hat{x}_h^h\right\}^2-E_f''\left\{-\hat{x}_h^f-\mu_h\frac{d\hat{x}_h^f}{d\mu_h}\right\}^2. \qquad (21)
\end{aligned}
$$

On the other hand,

$$
\begin{aligned}
\frac{\partial^2 W}{\partial \mu_h \partial \mu_f} &= -E_h''\left\{(1-\mu_h)\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}-\hat{x}_h^h\right\}\left\{-\hat{x}_f^h-\mu_f\frac{d\hat{x}_f^h}{d\mu_f}\right\}\\
&-E_f''\left\{(1-\mu_f)\frac{d\hat{x}_f^f}{d\mu_f}+\frac{d\hat{x}_f^h}{d\mu_f}-\hat{x}_f^f\right\}\left\{-\hat{x}_h^f-\mu_h\frac{d\hat{x}_h^f}{d\mu_h}\right\}. \qquad (22)
\end{aligned}
$$

In this case,

$$
\begin{aligned}
&\left[-E_h''\left\{(1-\mu_h)\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}-\hat{x}_h^h\right\}^2-E_f''\left\{-\hat{x}_h^f-\mu_h\frac{d\hat{x}_h^f}{d\mu_h}\right\}^2\right]\\
&\times\left[-E_f''\left\{(1-\mu_f)\frac{d\hat{x}_f^f}{d\mu_f}+\frac{d\hat{x}_f^h}{d\mu_f}-\hat{x}_f^f\right\}^2-E_h''\left\{-\hat{x}_f^h-\mu_f\frac{d\hat{x}_f^h}{d\mu_f}\right\}^2\right]\\
&-\left[-E_h''\left\{(1-\mu_h)\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}-\hat{x}_h^h\right\}\left\{-\hat{x}_f^h-\mu_f\frac{d\hat{x}_f^h}{d\mu_f}\right\}\right.\\
&\left.-E_f''\left\{(1-\mu_f)\frac{d\hat{x}_f^f}{d\mu_f}+\frac{d\hat{x}_f^h}{d\mu_f}-\hat{x}_f^f\right\}\left\{-\hat{x}_h^f-\mu_h\frac{d\hat{x}_h^f}{d\mu_h}\right\}\right]\\
&\times\left[-E_f''\left\{(1-\mu_f)\frac{d\hat{x}_f^f}{d\mu_f}+\frac{d\hat{x}_f^h}{d\mu_f}-\hat{x}_f^f\right\}\left\{-\hat{x}_h^f-\mu_h\frac{d\hat{x}_h^f}{d\mu_h}\right\}\right.
\end{aligned}
$$

$$-E_h''\left\{(1-\mu_h)\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}-\hat{x}_h^h\right\}\left\{-\hat{x}_f^h-\mu_f\frac{d\hat{x}_f^h}{d\mu_f}\right\}\Bigg]$$

$$>0 \tag{23}$$

necessarily holds. Thus, from (21) and (22), the sufficient condition for the SOCs ((15), (16), and (17)) to be satisfied is:

$$-\frac{2(4-\epsilon)(w_R-w_V)}{3-\epsilon}-\frac{2E_i'\epsilon(2-\mu_i)(w_R-w_V)}{\hat{X}_iP'(3-\epsilon)}+2E_i'+\frac{2E_j'\epsilon\mu_i(w_R-w_V)}{\hat{X}_iP'(3-\epsilon)}+2E_j'>0. \tag{24}$$

The second term is necessarily positive, thus the combination of the following two conditions can be a sufficient condition for SOCs to hold:

$$-\frac{(4-\epsilon)(w_R-w_V)}{3-\epsilon}+E_i'\geq 0 \tag{25}$$

$$\frac{\epsilon\mu_i(w_R-w_V)}{\hat{X}_iP'(3-\epsilon)}<1. \tag{26}$$

Two points should be noted. First, similar to the case of non-cooperative behavior, the following inequality must be satisfied at least for a certain range of μ_i:

$$-\frac{2(4-\epsilon)(w_R-w_V)}{3-\epsilon}+E_i'<0. \tag{27}$$

Thus, (25) should be rewritten as follows:

$$\frac{(4-\epsilon)(w_R-w_V)}{3-\epsilon}\leq E_i'<\frac{2(4-\epsilon)(w_R-w_V)}{3-\epsilon}. \tag{28}$$

Second, if $\hat{x}_i^j+\mu_i d\hat{x}_i^j/d\mu_i>0$, from (9 in the text), $-(w_R-w_V)/(\hat{X}_iP'(3-\epsilon))<1/2$ holds. Thus, if $\epsilon<2$, (26) necessarily holds. On the other hand, if $\hat{x}_i^j+\mu_i d\hat{x}_i^j/d\mu_i<0$, $-(w_R-w_V)/(\hat{X}_iP'(3-\epsilon))>1/2$. Thus, if $\epsilon>2$, inequality (26) does not hold. However, since the second term in (24) is positive, it is possible that inequality (24) holds.

Finally, we have to check if there is a certain range of μ_i that satisfies both (12) and

(28). Since:

$$\begin{aligned}
&\frac{6-\epsilon}{2(3-\epsilon)} < \frac{4-\epsilon}{3-\epsilon} < \frac{6-\epsilon}{3-\epsilon} < \frac{2(4-\epsilon)}{3-\epsilon}, \quad if \quad \epsilon < 2, \\
&\frac{6-\epsilon}{2(3-\epsilon)} = \frac{4-\epsilon}{3-\epsilon} < \frac{6-\epsilon}{3-\epsilon} = \frac{2(4-\epsilon)}{3-\epsilon}, \quad if \quad \epsilon = 2, \\
&\frac{4-\epsilon}{3-\epsilon} < \frac{6-\epsilon}{2(3-\epsilon)} < \frac{2(4-\epsilon}{3-\epsilon} < \frac{6-\epsilon}{3-\epsilon}, \quad if \quad 2 < \epsilon < 3.
\end{aligned} \tag{29}$$

Therefore, a certain range of μ_i can exist.

2. The case in the presence of trade in recycled materials

2.1 Non-cooperative behavior

Now let us turn to the case in which recycled materials are traded internationally. We begin with the case in which governments act non-cooperatively. In this case, since

$$\frac{\partial^2 W^f}{\partial \mu_h \partial \mu_f} = 0, \tag{30}$$

it is enough to examine if

$$\frac{\partial^2 W^h}{\partial \mu_h^2} < 0, \quad and \quad \frac{\partial^2 W^f}{\partial \mu_f^2} < 0. \tag{31}$$

From (6 in the text),

$$\begin{aligned}
\frac{\partial^2 W^h}{\partial \mu_h^2} &= -P''\hat{X}_h \left(\frac{d\hat{X}_h}{d\mu_h}\right)^2 - P'\left(\frac{d\hat{X}_h}{d\mu_h}\right)^2 - P'\hat{X}_h \frac{d^2\hat{X}_h}{d\mu_h^2} \\
&\quad - \frac{(2-\epsilon)(w_R - w_V)}{3-\epsilon}\frac{d\hat{x}_h^h}{d\mu_h} \\
&\quad - E_h'\left\{(1-\mu_h)\left(\frac{d^2\hat{x}_h^h}{d\mu_h^2} + \frac{d^2\hat{x}_h^f}{d\mu_h^2}\right) - 2\frac{d\hat{x}_h^h}{d\mu_h} - 2\frac{d\hat{x}_h^f}{d\mu_h}\right\} \\
&\quad - E_h''\left\{(1-\mu_h)\left(\frac{d\hat{x}_h^h}{d\mu_h} + \frac{d\hat{x}_h^f}{d\mu_h}\right) - \hat{x}_h^h - \hat{x}_h^f\right\}^2
\end{aligned} \tag{32}$$

Substituting (5) and (6) into (32), we obtain

$$\frac{\partial^2 W^h}{\partial \mu_h^2} = -P'(6-\epsilon)\left(\frac{d\hat{x}_h^h}{d\mu_h}\right)^2$$

$$
\begin{aligned}
&+E_h'\left\{\frac{4P''(1-\mu_h)}{P'}\left(\frac{d\hat{x}_h^h}{d\mu_h}\right)^2+4\frac{d\hat{x}_h^h}{d\mu_h}\right\}\\
&-E_h''\left\{(1-\mu_h)\left(\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}\right)-\hat{x}_h^h-\hat{x}_h^f\right\}^2, \qquad (33)
\end{aligned}
$$

or

$$
\begin{aligned}
\frac{\partial^2 W^h}{\partial \mu_h^2} &= \left\{-\frac{(6-\epsilon)(w_R-w_V)}{3-\epsilon}-\frac{4E_h'\epsilon(1-\mu_h)(w_R-w_V)}{\hat{X}_h P'(3-\epsilon)}+4E_h'\right\}\frac{d\hat{x}_h^h}{d\mu_h}\\
&-E_h''\left\{(1-\mu_h)\left(\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}\right)-\hat{x}_h^h-\hat{x}_h^f\right\}^2. \qquad (34)
\end{aligned}
$$

On the other hand, from (20 in the text),

$$
\begin{aligned}
\frac{\partial^2 W^f}{\partial \mu_f^2} &= -P''\hat{X}_f\left(\frac{d\hat{X}_f}{d\mu_f}\right)^2-P'\left(\frac{d\hat{X}_f}{d\mu_f}\right)^2-P'\hat{X}_f\frac{d^2\hat{X}_f}{d\mu_f^2}\\
&-\frac{(2-\epsilon)(w_R-w_V)}{3-\epsilon}\frac{d\hat{x}_f^f}{d\mu_f}\\
&-E_f'(1-\lambda_f)\left\{\frac{d^2\hat{x}_f^h}{d\mu_f^2}+\frac{d^2\hat{x}_f^f}{d\mu_f^2}\right\}\\
&-E_f''(1-\lambda_f)^2\left\{\frac{d\hat{x}_f^h}{d\mu_f}+\frac{d\hat{x}_f^f}{d\mu_f}\right\}^2 \qquad (35)
\end{aligned}
$$

Similar to the case of the domestic welfare, this equation can be rewritten as follows:

$$
\begin{aligned}
\frac{\partial^2 W^f}{\partial \mu_f^2} &= -P'(6-\epsilon)\left(\frac{d\hat{x}_f^f}{d\mu_f}\right)^2\\
&+E_f'(1-\lambda_f)\left\{\frac{4P''}{P'}\left(\frac{d\hat{x}_f^f}{d\mu_f}\right)^2\right\}\\
&-E_f''(1-\lambda_f)^2\left\{\frac{d\hat{x}_f^f}{d\mu_f}+\frac{d\hat{x}_f^h}{d\mu_f}\right\}^2, \qquad (36)
\end{aligned}
$$

or

$$
\begin{aligned}
\frac{\partial^2 W^f}{\partial \mu_f^2} &= \left\{-P'(6-\epsilon)-\frac{4E_f'(1-\lambda_f)\epsilon}{\hat{X}_f}\right\}\left(\frac{d\hat{x}_f^f}{d\mu_f}\right)^2\\
&-E_f''(1-\lambda_f)^2\left\{\frac{d\hat{x}_f^f}{d\mu_f}+\frac{d\hat{x}_f^h}{d\mu_f}\right\}^2. \qquad (37)
\end{aligned}
$$

Consequently, we obtain the sufficient conditions for the SOCs to be satisfied:

$$-\frac{(6-\epsilon)(w_R - w_V)}{3-\epsilon} + 4E_h' > 0, \tag{38}$$

$$\epsilon\left\{1 - \frac{4E_f'(1-\lambda_f)}{P'\hat{X}_f}\right\} > 6. \tag{39}$$

One point should be noted. Similar to the case in which no trade in recycled materials exists, from the FOCs, for an interior solution to be obtained, the following inequality must be satisfied at least for a certain range of μ_i:

$$-\frac{(6-\epsilon)(w_R - w_V)}{3-\epsilon} + 2E_i' < 0. \tag{40}$$

Thus, conditions should be rewritten as follows:

$$\frac{(6-\epsilon)(w_R - w_V)}{4(3-\epsilon)} \leq E_i' < \frac{(6-\epsilon)(w_R - w_V)}{2(3-\epsilon)}. \tag{41}$$

2.2 Cooperative behavior

Now let us turn to the case in which governments act cooperatively. The SOCs for this case are as follows:

$$\frac{\partial^2 W}{\partial \mu_h^2} < 0, \tag{42}$$

$$\frac{\partial^2 W}{\partial \mu_f^2} < 0, \tag{43}$$

$$\frac{\partial^2 W}{\partial \mu_h^2} \cdot \frac{\partial^2 W}{\partial \mu_f^2} - \left\{\frac{\partial^2 W}{\partial \mu_f \partial \mu_h}\right\}^2 > 0. \tag{44}$$

$$\begin{aligned}
\frac{\partial^2 W}{\partial \mu_h^2} &= -P''\hat{X}_h\left(\frac{d\hat{X}_h}{d\mu_h}\right)^2 - P'\left(\frac{d\hat{X}_h}{d\mu_h}\right)^2 - P'\hat{X}_h\frac{d^2\hat{X}_h}{d\mu_h^2} \\
&\quad -\frac{(2-\epsilon)(w_R - w_V)}{3-\epsilon}\frac{d\hat{X}_h}{d\mu_h}
\end{aligned}$$

$$
\begin{aligned}
&-E_h'\left\{(1-\mu_h)\left(\frac{d^2\hat{x}_h^h}{d\mu_h^2}+\frac{d^2\hat{x}_h^f}{d\mu_h^2}\right)-2\frac{d\hat{x}_h^h}{d\mu_h}-2\frac{d\hat{x}_h^f}{d\mu_h}\right\} \\
&-E_h''\left\{(1-\mu_h)\left(\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}\right)-\hat{x}_h^h-\hat{x}_h^f\right\}^2 \qquad (45)
\end{aligned}
$$

Substituting (5) and (6) into (45), we obtain

$$
\begin{aligned}
\frac{\partial^2 W}{\partial \mu_h^2} &= -P'2(4-\epsilon)\left(\frac{d\hat{x}_h^h}{d\mu_h}\right)^2 \\
&\quad +E_h'\left\{\frac{2P''2(1-\mu_h)}{P'}\left(\frac{d\hat{x}_h^h}{d\mu_h}\right)^2+4\frac{d\hat{x}_h^h}{d\mu_h}\right\} \\
&\quad -E_h''\left\{(1-\mu_h)\left(\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}\right)-\hat{x}_h^h-\hat{x}_h^f\right\}^2, \qquad (46)
\end{aligned}
$$

or

$$
\begin{aligned}
\frac{\partial^2 W}{\partial \mu_h^2} &= \left\{-\frac{2(4-\epsilon)(w_R-w_V)}{3-\epsilon}-\frac{4E_h'\epsilon(1-\mu_h)(w_R-w_V)}{\hat{X}_h P'(3-\epsilon)}+4E_h'\right\}\frac{d\hat{x}_h^h}{d\mu_h} \\
&\quad -E_h''\left\{(1-\mu_h)\left(\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}\right)-\hat{x}_h^h-\hat{x}_h^f\right\}^2. \qquad (47)
\end{aligned}
$$

On the other hand,

$$
\begin{aligned}
\frac{\partial^2 W}{\partial \mu_f^2} &= -P''\hat{X}_f\left(\frac{d\hat{X}_f}{d\mu_f}\right)^2-P'\left(\frac{d\hat{X}_f}{d\mu_f}\right)^2-P'\hat{X}_f\frac{d^2\hat{X}_f}{d\mu_f^2} \\
&\quad -\frac{(2-\epsilon)(w_R-w_V)}{3-\epsilon}\frac{d\hat{X}_f}{d\mu_f} \\
&\quad -E_f'(1-\lambda_f)\left\{\frac{d^2\hat{x}_f^h}{d\mu_f^2}+\frac{d^2\hat{x}_f^f}{d\mu_f^2}\right\} \\
&\quad -E_f''(1-\lambda_f)^2\left(\frac{d\hat{x}_f^h}{d\mu_f}+\frac{d\hat{x}_f^f}{d\mu_f}\right)^2 \\
&\quad -E_h'\left\{-2\left(\frac{d\hat{x}_f^h}{\mu_f}+\frac{d\hat{x}_f^f}{d\mu_f}\right)-(\mu_f-\lambda_f)\left(\frac{d^2\hat{x}_f^h}{d\mu_f^2}+\frac{d^2\hat{x}_f^f}{d\mu_f^2}\right)\right\} \\
&\quad -E_h''\left\{-\hat{x}_f^h-\hat{x}_f^f-(\mu_f-\lambda_f)\left(\frac{d\hat{x}_f^h}{d\mu_f}+\frac{d\hat{x}_f^f}{d\mu_f}\right)\right\}^2 \qquad (48)
\end{aligned}
$$

or

$$\frac{\partial^2 W}{\partial \mu_f^2} = \left\{-\frac{2(4-\epsilon)(w_R-w_V)}{3-\epsilon} - \frac{4(E_f'(1-\lambda_f)-E_h'(\mu_f-\lambda_f))\epsilon(w_R-w_V)}{\hat{X}_f P'(3-\epsilon)} + 4E_h'\right\}\frac{d\hat{x}_f^f}{d\mu_f}$$
$$-E_f''(1-\lambda_f)^2\left(\frac{d\hat{x}_f^h}{d\mu_f}+\frac{d\hat{x}_f^f}{d\mu_f}\right)^2$$
$$-E_h''\left\{-\hat{x}_f^h-\hat{x}_f^f-(\mu_f-\lambda_f)\left(\frac{d\hat{x}_f^h}{d\mu_f}+\frac{d\hat{x}_f^f}{d\mu_f}\right)\right\}^2. \tag{49}$$

Moreover,

$$\frac{\partial^2 W}{\partial \mu_h \partial \mu_f} = -E_h''\cdot\left\{(1-\mu_h)\left(\frac{d\hat{x}_h^h}{d\mu_h}+\frac{d\hat{x}_h^f}{d\mu_h}\right)-\hat{x}_h^h-\hat{x}_h^f\right\}\cdot\left\{-\hat{x}_f^h-\hat{x}_f^f-(\mu_f-\lambda_f)\left(\frac{d\hat{x}_f^h}{d\mu_f}+\frac{d\hat{x}_f^f}{d\mu_f}\right)\right\}. \tag{50}$$

Thus, from (42), (43), (44), (47), (49), and (50), the following combination of conditions is a sufficient condition for the SOCs to be satisfied:

$$-\frac{(4-\epsilon)(w_R-w_V)}{3-\epsilon}+2E_h' > 0, and \tag{51}$$

$$E_f'(1-\lambda_f)-E_h'(\mu_f-\lambda_f) > 0. \tag{52}$$

Two points should be noted. The first point is about (51). Similar to the case of non-cooperative behavior, the following inequality must be satisfied at least for a certain range of μ_i:

$$-\frac{(4-\epsilon)(w_R-w_V)}{3-\epsilon}+E_i' < 0. \tag{53}$$

Thus, (51) should be rewritten as follows:

$$\frac{(4-\epsilon)(w_R-w_V)}{2(3-\epsilon)} \le E_i' < \frac{(4-\epsilon)(w_R-w_V)}{3-\epsilon}. \tag{54}$$

The second point is about (52). It is clear that $1-\lambda_f > \mu_f-\lambda_f$. Moreover, since we consider the case in which the foreign recovery rate is small, it is likely that the environmental damage in the foreign country is more serious than that in the home country unless $\mu_h = \mu_f = 0$.Thus, it is likely that (52) holds.

Finally, we have to check if there is a certain range of μ_i that satisfies both (41) and (54). Since:

$$\begin{aligned}
&\frac{6-\epsilon}{4(3-\epsilon)} < \frac{4-\epsilon}{2(3-\epsilon)} < \frac{6-\epsilon}{2(3-\epsilon)} < \frac{(4-\epsilon)}{3-\epsilon}, \quad if \quad \epsilon < 2, \\
&\frac{6-\epsilon}{4(3-\epsilon)} = \frac{4-\epsilon}{2(3-\epsilon)} < \frac{6-\epsilon}{2(3-\epsilon)} = \frac{(4-\epsilon)}{3-\epsilon}, \quad if \quad \epsilon = 2, \\
&\frac{4-\epsilon}{2(3-\epsilon)} < \frac{6-\epsilon}{4(3-\epsilon)} < \frac{(4-\epsilon}{3-\epsilon} < \frac{6-\epsilon}{2(3-\epsilon)}, \quad if \quad 2 < \epsilon < 3.
\end{aligned} \tag{55}$$

Therefore, a certain range of μ_i can exist.

3. Discussion

In the case in the absence of trade in recycled materials, the sign of $\hat{x}_i^j + \mu_i d\hat{x}_i^j/d\mu_i$ matters as discussed in the paragraph following (28). However, if the absolute value of $\hat{x}_i^j + \mu_i d\hat{x}_i^j/d\mu_i$ is not so large, the SOCs are satisfied and, from (24), the fact that $\epsilon > 2$ does not preclude those conditions from holding. Moreover, in the case in the presence of trade in recycled materials, the value of $\hat{x}_i^j + \mu_i d\hat{x}_i^j/d\mu_i$ does not matter. In both cases, the difference in material prices and the marginal environmental damage are important factors. In some cases, market scale X_i matters. It should be concluded, from what has been discussed above, that it is reasonable to assume the SOCs to be satisfied in each case.