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Recycling and International Trade Theory

*Kazunori Tanigaki**

Abstract

Recently recycling and the production of secondary materials have increased in many countries. However, there is little analysis examining the effects of recycling on comparative advantage, trade, and welfare. In a model with recycling sectors, the author examines whether the Rybczynski theorem is valid, how the price effects are modified, how a recycling subsidy changes the production structure and comparative advantage. It is found that demand has an effect on final goods production and comparative advantage since consumption goods are transformed into recycling inputs.

1. Introduction

As concerns with environmental problems have increased, governments have encouraged recycling. Even in Japan, recycling acts were constituted. Consumers have to pay extra recycling fees when they buy electrical goods. However, the economic implications of recycling have not been sufficiently examined. In particular, little attention has been paid to recycling or the production of secondary materials in international trade theory. This paper tries to fill this gap.

Exceptions related to our paper include Grace et al. (1978) and Yohe (1978), whose analysis took a partial equilibrium approach. They considered international trade and the international market for secondary materials. They applied the model to the case of waste paper. Van Beukering (2001) analyzes international recycling, though his analysis is not based on international trade theory. Although there has been analysis of recycling (Grant, 1999; Van Beukering and Bouman, 2001), there is little analysis using applied microeconomic and international trade theory.

We focus on the effects of recycling on production, comparative advantage, and welfare. Although we can set up alternative models to examine recycling, we adopt a simple traditional model (Jones, 1965) which is fundamental in international trade theory. In our model, two sectors of recycling are added to the traditional two good and two factor model with one intermediate good. The intermediate good is not produced in a small country, but rather is reproduced by the recycling sectors. So our paper is related to international trade theory with intermediate good and our model is a kind of expansion of intermediate analysis. To recycle, factor inputs labor and capital are necessary so that recycling can change goods production and trade.

This paper has the following purposes: to take recycling into consideration in international trade theory; to investigate whether trade theorems such as the Rybczynski theorem are valid; and to examine the effects of recycling on production, income distribution, and welfare.

* Tanigaki: Ritsumeikan University, 1-1-1 Nojihigashi Kusatsu, Shiga, 525-8577 Japan. Tel: +81 77-561-4844; Fax: +81 77-561-4844; E-mail: tanigaki@ec.ritsumei.ac.jp. The author would like to thank an anonymous referee for valuable comments which improved this paper. Helpful comments were also provided by participants at the annual convention of KIEA (Korean International Economics Association). The author would also like to thank M. Okawa, K. Shimomura, H. Sugeta, M. Ohyama, and R. Waschik.

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We show that production is affected by recycling and income propensity. Assuming normal goods and some other conditions, the gross Rybczynski theorem becomes consistent with the net Rybczynski theorem. We find that demand has an effect on final goods production and that it could alter comparative advantage. We examine price effects with recycling and investigate how income distribution is altered. We also examine the welfare effects of recycling and the optimal recycling ratio. These ratios depend on social waste and direct recycling costs. If the marginal waste cost is sufficiently large and the income propensity is positive, the optimal recycling ratio could be positive.

In the next section, some comparative static analyses of exogenous variables are shown. In section 3, the effects of factor endowments are considered. The effects of traded prices and intermediate prices are discussed in section 4, and the effects of recycling ratio in section 5. Welfare effects and the optimal recycling ratio are presented in section 6, and section 7 concludes.

2. The Model

We consider a small country. There are two traded final consumption goods. There is one intermediate good which is imported or which is recycled. We assume that the production sectors for secondary materials exist, as long as subsidy is allowed. We do not consider trade in goods for recycling. Production functions for final consumption goods are homogeneous of degree one, given by

$$X_1 = X_1(L_1, K_1, M_1), \quad X_2 = X_2(L_2, K_2, M_2),$$

where X_i is the production of final good i ($i = 1, 2$), K_i is capital input into final good i, L_i is labor input, and M_i is intermediate input in final good i. Production functions for goods for recycling are given by

$$R_1 = R_1(I_{R1}, L_{R1}, K_{R1}), \quad R_2 = R_2(I_{R2}, L_{R2}, K_{R2}),$$

where R_i is production of goods for recycling i, K_{Ri} is capital input, L_{Ri} is labor input, and I_{Ri} is input of final consumption i. I_{Ri} is gathered and used to produce secondary materials. To transform consumption goods into intermediate inputs, labor and capital inputs are necessary. We assume that these functions are also homogeneous of degree one. The model is represented as follows:

$$D_1 = D_1(Y, 1, p), \tag{1}$$

$$D_2 = D_2(Y, 1, p), \tag{2}$$

$$Y = wL + rK - S, \tag{3}$$

$$R = R_1 + R_2, \tag{4}$$

$$a_{M1}X_1 + a_{M2}X_2 = M^M + R, \tag{5}$$

$$a_{L1}X_1 + a_{L2}X_2 + a_{LR1}R_1 + a_{LR2}R_2 = L, \tag{6}$$

$$a_{K1}X_1 + a_{K2}X_2 + a_{KR1}R_1 + a_{KR2}R_2 = K, \tag{7}$$

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$$a_{L1}w + a_{K1}r + a_{M1}p_M = 1, \tag{8}$$

$$a_{L2}w + a_{K2}r + a_{M2}p_M = p, \tag{9}$$

$$a_{LR1}w + a_{KR1}r - a_{D1R1}s_1 = p_M, \tag{10}$$

$$a_{LR2}w + a_{KR2}r - a_{D2R2}s_2 = p_M, \tag{11}$$

$$I_{R1} = \alpha_1 D_1, \tag{12}$$

$$I_{R2} = \alpha_2 D_2, \tag{13}$$

$$S = S_1 + S_2, \tag{14}$$

$$S_1 = s_1\alpha_1 D_1, \tag{15}$$

$$S_2 = s_2\alpha_2 D_2, \tag{16}$$

$$R_1 = I_{R1}/a_{D1R1}, \tag{17}$$

$$R_2 = I_{R2}/a_{D2R2}, \tag{18}$$

where D_i is demand for final goods i, Y is income with subsidy burden, S, p is the relative price of good 2 to good 1 and is fixed under the assumption of a small country, a_{ij} is an input-output coefficient of input i for output j, M^M is imports of the intermediate good, p_M is the price of the intermediate good and is also fixed under the assumption of a small country, α_i is recycling ratio to final consumption goods i ($0 < \alpha_i < 1$), sometimes called a recovery ratio, and s_i is the unit subsidy to recycling sector i. The unit subsidy, s_i, is automatically determined so that profits of the sector are equal to zero.

We may think that the cost of gathering used goods increases as the recovery ratio increases. In our model we assume that this cost is constant for simplicity. If we assume increasing costs, our results would not fundamentally change.

Income, Y, is determined by w, r and S.[1] D_1 and D_2 are determined by Y and p. We assume that factor prices are determined by p and p_M in the two equations (8) and (9). From w, r, p_M, (10) and (11), each unit subsidy to recycling production, s_i, is determined so that the sectors of secondary materials can exist under the assumption $a_{LRi}w + a_{KRi}r > p_M$.[2] All input–output coefficients are determined by w, r, p_M, s_1 and s_2.

Since firms receive a subsidy by using inputs of secondary materials, firms want to use all the inputs which are available. We assume that the government assigns these inputs to each recycling firm, and that there is no entrance deterrence. Since this assumption of government assignment may not be satisfactory, we may assume that a public corporation produces the goods for recycling, and that the recycling production sectors are sustained by some laws related to recycling. Sometimes consumers must pay a recycling fee which is enforced by law. This fee becomes a kind of government subsidy. Either way, we can interpret this subsidy system as a way of proxying the actual circumstances of countries.

From the assumption of homogeneity of degree one, we have $R_1 = R_1(I_{R1}, L_{R1}, K_{R1}) = I_{R1}R_1(1, h_{R1}, k_{R1}) = I_{R1}f_1(g_{R1}, k_{R1})$, where $g_{R1} \equiv L_{R1}/I_{R1}$, $k_{R1} \equiv K_{R1}/I_{R1}$. The h-th firm wants to maximize the profit, $\pi = p_M I_{R1h} f_1(g_{R1h}, k_{R1h}) - (wg_{R1h} + rk_{R1h})\, I_{R1h} + s_1 I_{R1h}$, for given I_{R1h}, w and r. Then from the profit maximization conditions, $w = p_M I_{R1h} f_{1l}$ and

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$r = p_M I_{R1h} f_{1k}$, the firm determines the optimal inputs, l_{R1h} and k_{R1h}. Then input coefficients, a_{iRj} in (10) and (11), are obtained.

The recovery ratios, α_1 and α_2, are exogenously determined by the government. The government determines the unit subsidy, s_i, for the firm to earn zero profits. From (15) and (16), the subsidy, S_i, is obtained using the recovery rate, the unit subsidy, and the volume of final goods. The recycling input, I_{Ri}, is determined from (12) and (13). Then the volume of recycling goods, R_1 and R_2 are determined. Thus, the government can control the volume of goods for recycling through the recovery rates. The production of final consumer goods, X_1 and X_2, is obtained from the full employment conditions (6) and (7). Finally the volume of intermediate imports, M^M, is given by (5). In our model, there are 18 equations, 18 endogenous variables, D_1, D_2, Y, w, r, X_1, X_2, M, I_{R1}, I_{R2}, R, R_1, R_2, s_1, s_2, S, S_1, S_2 and 7 exogenous variables, p, p_M, L, K, α_1, α_2. The policy targets are the recovery rates, α_1, α_2.

We could construct a model in which the subsidy is exogenously determined and the recovery rate is endogenous. This may seem more intuitive. The fixed subsidy could be interpreted as a short-term policy variable. The government expends the subsidy to the recycling sectors according to the budget compilation of the year. But in the long term, the policy target of the government may be a recycling ratio. The government would intend to raise the ratio gradually. Moreover, under a fixed subsidy, disposable income does not change because the subsidy is not affected. So the analysis for a fixed subsidy is easier since recycling production is constant. At least, in our model with a fixed subsidy, some representative international trade theories such as Stolper-Samuelson and Rybczynski theorems are not significantly changed. To analyze the endogenous recovery rate case, another model would be necessary. Thus, we do not treat this case here.

3. The Effects of Factor Endowment Changes

In this section we examine the Rybczynski theorem in the presence of a recycling sector. How is the Rybczynski theorem modified for an increase in labor endowment? In our model, factor prices are determined by goods prices. Then, from equations (A1)–(A3) in the Appendix, we have:

$$\begin{aligned} dY &= (1/\{1 + s_1\alpha_1(\beta_1/p_1)(1+\eta_1) + s_2\alpha_2(\beta_2/p_2)(1+\eta_2)\})dY_0 \\ &= (1/\{1 + s_1\alpha_1(\beta_1/p_1)(1+\eta_1) + s_2\alpha_2(\beta_2/p_2)(1+\eta_2)\})wdL, \\ dY/dL &> 0, \\ dD_i &= \delta_i dY (i = 1, 2). \end{aligned}$$

Since $dI_{Ri} = \delta_i wdL$ and the government intends to keep the recycling ratio constant, the input, I_{Ri}, must be increased under the assumption of normal goods. That is, $\delta_i > 0$ or $(1 + \eta_i) > 0$. Then the government subsidy expenditure is increased. In equilibrium, we have $w = \partial F_i/\partial L_{Ri}$, $r = \partial F_i/\partial K_{Ri}$. Then, the effects of dL on dL_{Ri} and dK_{Ri} are given by

$$\begin{pmatrix} F_{iLL} & F_{iLK} \\ F_{iKL} & F_{iKK} \end{pmatrix}\begin{pmatrix} dL_{Ri} \\ dK_{Ri} \end{pmatrix} = -\begin{pmatrix} F_{iLIR} \\ F_{iKIR} \end{pmatrix} dI_{Ri} = -\begin{pmatrix} F_{iLIR} \\ F_{iKIR} \end{pmatrix}\delta_i wdL.$$

Thus we obtain:

$$\Delta_1\begin{pmatrix} dL_{Ri} \\ dK_{Ri} \end{pmatrix} = -\begin{pmatrix} F_{iLL} & -F_{iLK} \\ -F_{iKL} & F_{iKK} \end{pmatrix}\begin{pmatrix} F_{iLIR} \\ F_{iKIR} \end{pmatrix} dI_{Ri} = \begin{pmatrix} -F_{iLL}F_{iLRi} + F_{iLK}F_{iKLR} \\ F_{iKL}F_{iLLRi} - F_{iKK}F_{iKLR} \end{pmatrix}\delta_i wdL,$$

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where $\Delta_1 = F_{iLL}F_{iKK} - F_{iKL}F_{iKL}$ and is positive under the assumption of concavity. From the assumptions $F_{mj} > 0$ $(m, j = L, K)$ and normal goods, we find that $dL_{Ri}/dL > 0$, $dK_{Ri}/dL > 0$. Similarly, we have $dL_{Ri}/dK > 0$, $dK_{Ri}/dK > 0$. Then with normal goods we obtain:

$$dR_i = F_{iIRi}dI_{Ri} + F_{iLRi}dL_{Ri} + F_{iKRi}dK_{Ri} > 0. \tag{19}$$

From (6) and (7), we obtain:

$$\begin{pmatrix} a_{L1} & a_{L2} \\ a_{K1} & a_{K2} \end{pmatrix}\begin{pmatrix} dX_1 \\ dX_2 \end{pmatrix} = \begin{pmatrix} dL \\ dK \end{pmatrix} - \begin{pmatrix} a_{LR1} \\ a_{KR1} \end{pmatrix} dR_1 - \begin{pmatrix} a_{LR2} \\ a_{KR2} \end{pmatrix} dR_2.$$

Then, we have:

$$\Delta_2 \begin{pmatrix} dX_1 \\ dX_2 \end{pmatrix} = \begin{pmatrix} a_{K2} & -a_{L2} \\ -a_{K1} & a_{L1} \end{pmatrix}\begin{pmatrix} dL - a_{LR1}dR_1 - a_{LR2}dR_2 \\ dK - a_{KR1}dR_1 - a_{KR2}dR_2 \end{pmatrix}, \tag{20}$$

where $\Delta_2 = a_{L1}a_{L2}(k_2 - k_1)$, $k_1 = K_1/L_1$, $k_2 = K_2/L_2$. Here we assume that the second final sector is capital-intensive, so, $k_2 > k_1$.

The effects of dL, dK on dX_1, dX_2 are given by:

$$\begin{aligned} \Delta_2 dX_1 &= a_{K2}(dL - a_{LR1}dR_1 - a_{LR2}dR_2) + a_{L2}(-dK + a_{KR1}dR_1 + a_{KR2}dR_2) \\ &= a_{K2}dL - a_{L2}dK + (a_{L2}a_{KR1} - a_{K2}a_{LR1})dR_1 + (a_{L2}a_{KR2} - a_{K2}a_{LR2})dR_2 \\ &= a_{K2}dL - a_{L2}dK + a_{L2}a_{LR1}(k_{R1} - k_2)dR_1 + a_{L2}a_{LR2}(k_{R2} - k_2)dR_2, \end{aligned} \tag{21a}$$

$$\Delta_2 dX_2 = -a_{K1}dL + a_{L1}dK + a_{L1}a_{LR1}(k_1 - k_{R1})dR_1 + a_{L1}a_{LR2}(k_1 - k_{R2})dR_2, \tag{21b}$$

where $k_{Ri} = K_{Ri}/L_{Ri}$ and $dR_i > 0$ from (19). If $dK = 0$, then we can conclude that dX_1/dL is positive under the conditions $k_2 > k_1$ and $k_{R1}, k_{R2} > k_2$, normal goods. Similarly we obtain that dX_2/dL is negative under the conditions $k_2 > k_1$ and k_{R1}, $k_{R2} > k_1$, normal goods. If $dL = 0$, we can say that dX_1/dK is negative and dX_2/dK is positive, under the conditions of $k_2 > k_1$ and k_{R1}, $k_{R2} < k_1$, k_2. From the above results, we derive the following proposition:

Proposition 1. *Final production is affected by income propensity. Under the conditions of normal goods, and k_{R1}, $k_{R2} > k_1$, k_2, the gross Rybczynski theorem for dL becomes consistent with the net Rybczynski theorem. For dK, the net and gross theorems are consistent under the condition of k_{R1}, $k_{R2} < k_1$, k_2. Thus, the gross and the net Rybczynski theorems are not consistent for both $dK > 0$ and $dL > 0$.*

In the proposition, the net Rybczynski theorem is related only to $(k_2 - k_1)$. Suppose that labor endowment is increased. Then, the production of secondary materials, dR_1 and dR_2, is raised under the assumption of normal goods. If both sectors in recycling are more capital intensive than the final goods sectors, the increase in recycling production demands capital more than labor. Then, since the capital–labor ratio in the final output sector is lower than in the recycling sector, the final output of the labor intensive goods increases.

The result for an increase in the endowment of capital is symmetric. For consistency between the net and gross theorems, k_{R1}, $k_{R2} < k_1$, k_2 is necessary. The sign of the

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inequality is reversed. Thus, the gross and the net Rybczynski theorems are not consistent for both increases in factor endowments, $dK > 0$ and $dL > 0$.

4. The Effects of Changes in Final and Intermediate Goods Prices

This section considers some price effects. Although the usual price effects remain, there are indirect price effects, since the subsidy, disposable income, demand, and recycling production change.

4.1 The Effects of Changes in the Prices of Final Goods

In our model, we assume that w and r are determined by the prices of traded goods and intermediate goods. From cost-minimization, the two equations (8) and (9), in rate of change terms, are given by:

$$\begin{pmatrix} \theta_{L1} & \theta_{K1} \\ \theta_{L2} & \theta_{K2} \end{pmatrix} \begin{pmatrix} \hat{w} \\ \hat{r} \end{pmatrix} = \begin{pmatrix} \theta_{M1} \\ \theta_{M2} \end{pmatrix} \hat{p}_M + \begin{pmatrix} 0 \\ \hat{p} \end{pmatrix}, \tag{22}$$

where ($\wedge$) signifies the rate of change, and θ_{ij} signifies the i-th cost share of the j-th industry. For $\hat{p}_{\mathrm{M}} = 0$, equation (22) can be rewritten as:

$$\Delta_3 \begin{pmatrix} \hat{w} \\ \hat{r} \end{pmatrix} = \begin{pmatrix} \theta_{K2} & -\theta_{K1} \\ -\theta_{L2} & \theta_{L1} \end{pmatrix} \begin{pmatrix} 0 \\ \hat{p} \end{pmatrix} = \begin{pmatrix} -\theta_{K1} \\ \theta_{L1} \end{pmatrix} \hat{p},$$

where $\Delta_3 = (rwL_1L_2/p)(k_2 - k_1) \cdot 3$

From (10), (11) and (22), for $dp_M = 0$, we have:

$$\begin{aligned} \begin{pmatrix} \theta_{SR1}\hat{s}_1 \\ \theta_{SR2}\hat{s}_2 \end{pmatrix} &= \begin{pmatrix} \theta_{LR1} & \theta_{KR1} \\ \theta_{LR2} & \theta_{KR2} \end{pmatrix} \begin{pmatrix} \hat{w} \\ \hat{r} \end{pmatrix} = (1/\Delta_3) \begin{pmatrix} \theta_{LR1} & \theta_{KR1} \\ \theta_{LR2} & \theta_{KR2} \end{pmatrix} \begin{pmatrix} -\theta_{K1} \\ \theta_{L1} \end{pmatrix} \hat{p} \\ &= (1/\Delta_3) \begin{pmatrix} -\theta_{LR1}\theta_{K1} + \theta_{KR1}\theta_{L1} \\ -\theta_{LR2}\theta_{K1} + \theta_{KR2}\theta_{L1} \end{pmatrix} \hat{p}. \end{aligned}$$

Then we have:

$$\begin{aligned} \theta_{SR1}\hat{s}_1/\hat{p} &= (wrL_{R1}L_1)/(\Delta_3)(-k_1 + k_{R1}), \\ \theta_{SR2}\hat{s}_2/\hat{p} &= (wrL_{R2}L_1)/(p\Delta_3)(-k_1 + k_{R2}). \end{aligned} \tag{23}$$

Then, for $k_2 > k_1$ and $\hat{p} > 0$, we have

$$\operatorname{sign} \hat{s}_i = \operatorname{sign}(k_{Ri} - k_1)$$

We can say:

Corollary 1. *Each unit subsidy is affected by tradable prices. For an increase in the price of the capital-intensive good, the unit subsidy is raised if each capital–labor ratio in the recycling sector is larger than the capital–labor ratio for the labor-intensive good.*

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From (3), (15) and (16), we have:[3]

$$(1+s_1\alpha_1\delta_1+s_2\alpha_2\delta_2)dY/dp = Ldw/dp + Kdr/dp - (\alpha_1 D_1 ds_1/dp + \alpha_2 D_2 ds_2/dp). \qquad (24)$$

The terms, Ldw/dp and Kdr/dp, are the usual price effects. In our recycling economy, indirect price effects, $dS/dp = (\alpha_1 D_1 ds_1/dp + \alpha_2 D_2 ds_2/dp)$ and $(s_1\alpha_1\delta_1 + s_2\alpha_2\delta_2)$ are added.

From (17) and (18), we have:

$$\begin{aligned} dR_i/dp &= (dI_{Ri}/dp)\big/a_{DiRi} - I_{Ri}(a_{DiRi})^2(da_{DiRi}/dp), \\ &= \alpha_i(dD_i/dp)\big/a_{DiRi} - I_{Ri}(a_{DiRi})^2\big/(da_{DiRi}/dp) \quad (i=1,2). \end{aligned} \qquad (25)$$

From (6) and (7), we find that X_1 and X_2 are also affected by dR_i. A kind of Rybczynski effect is added to the usual price effects. Thus, from (24) and (25), we can derive the following proposition:

PROPOSITION 2. *When the prices of final goods are changed, indirect price effects through demand and the subsidy are added to the usual price effects. The subsidy, income and input coefficients are affected so that recycling production, R_1 and R_2, are altered.*

4.2 The Effects of Changes in Prices of Intermediate Goods

For $\hat{p}=0$, from (22) we obtain:

$$\Delta_3\begin{pmatrix}\hat{w}\\ \hat{r}\end{pmatrix} = \begin{pmatrix}\theta_{K2} & -\theta_{K1}\\ -\theta_{L2} & \theta_{L1}\end{pmatrix}\begin{pmatrix}\theta_{M1}\\ \theta_{M1}\end{pmatrix}\hat{p}_M.$$

Then we have:

$$\begin{aligned} \Delta_3\hat{w}/\hat{p}_M &= \theta_{K2}\theta_{M1} - \theta_{K1}\theta_{M2} = (rp_M M_1 M_2/p)(k_{M2}-k_{M1}), \\ \Delta_3\hat{r}/\hat{p}_M &= \theta_{L1}\theta_{M2} - \theta_{L2}\theta_{M1} = (wp_M M_1 M_2/p)(l_{M1}-l_{M2}), \\ \Delta_3(\hat{w}-\hat{r})/\hat{p}_M &= (\theta_{K2}+\theta_{L2})\theta_{M1} - (\theta_{K1}+\theta_{L1})\theta_{M2} \\ &= (1-\theta_{M2})\theta_{M1} - (1-\theta_{M1})\theta_{M2}, \\ &= \theta_{M1} - \theta_{M2}, \end{aligned} \qquad (26)$$

where $k_{Mi} = K_i/M_i$, $l_{Mi} = L_i/M_i$. Then income distribution with intermediate goods for recycling is affected by the intermediate price. When sector 1 is labor-intensive, that is, $k_2 > k_1$, we have:

$$\begin{aligned} &sign(\hat{w}/\hat{p}_M) = -sign(k_{M1}-k_{M2}), \\ &sign(\hat{r}/\hat{p}_M) = sign(l_{M1}-l_{M2}), \\ &sign((\hat{w}-\hat{r})/\hat{p}_M) = sign(\theta_{M1}-\theta_{M2}). \end{aligned}$$

As in Proposition 2, the intermediate price has similar effects on production and factor prices. Then we can say:

PROPOSITION 3. *When the price of the intermediate goods for recycling is raised, the effects on wage and capital rental are similar to those of an increase in the capital-intensive price if $k_{M1} > k_{M2}$, $l_{M1} > l_{M2}$ and $\theta_{M1} < \theta_{M2}$. There are also some indirect effects similar to those of traded goods.*

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For small M_1 and large M_2, the signs of the inequalities, $k_{M1} > k_{M2}$, $l_{M1} > l_{M2}$ and $\theta_{M1} < \theta_{M2}$, tends to hold, since the rise in p_M is similar to that of the capital-intensive good price when M_1 is small and M_2 large.

The assumption of an exogenous price of p_M may be too strict. In reality the supply of goods for recycling will have some effects on the domestic price of the intermediate good. In this case the recycling policy can affect the market of the intermediate good and p_M. Then the recycling policy will have an effect on w, r, and income distribution.

5. The Effects of the Recovery Ratio

5.1 The Relationship Between the Recovery Ratio and the Subsidy

In this section we show that an increase in the recovery ratio of a sector could reduce the subsidy. From equations (3) and (14)–(16), we have:

$$(1+s_1\alpha_1\delta_1+s_2\alpha_2\delta_2)dY/d\alpha_1=-s_1D_1<0. \tag{27}$$

From $dY/d\alpha_1 = -dS/d\alpha_1$, we obtain:

$$dS/d\alpha_1>0$$

That is, the expansion of the recovery rate through the subsidy must increase the total subsidy. The effect of the recycling sector 1 on the subsidy is given by:

$$dS_1/d\alpha_1=s_1\{D_1+\alpha_1\delta_1(dY/d\alpha_1)\} \tag{28}$$

$$=s_1D_1(1+s_2\alpha_2\delta_2)/(1+s_1\alpha_1\delta_1+s_2\alpha_2\delta_2). \tag{28$'$}$$

From (28), we find that if the income propensity of good 1 or the recovery ratio is sufficiently positive, the subsidy in sector 1 could be reduced to raise the recovery rate. From (28)′, we find that if $(1 + s_2\alpha_2\delta_2) < 0$, or the income propensity of good 2 is sufficiently negative, the subsidy is reduced. Moreover, from $S_1 = s_1\alpha_1D_1$ and $I_{R1} = \alpha_1D_1$, the recycling input can be reduced by an increase in the recovery rate. The sign of dS_2 depends on δ_2, that is, $sign(dS_2/d\alpha_1) = sign(-\delta_2)$ since $dY/d\alpha_1 < 0$. Then we have:

COROLLARY 2. *When the recovery ratio of a sector is increased, the total subsidy always increases. But, if the income propensity in the other sector is negative, it is possible that the subsidy of the sector in which the recycling ratio is increased is reduced.*

5.2 The Effect of Recycling on Production

In this section we consider the effect of the subsidy on production, trade, and welfare. Suppose the government promotes recycling and increases the recycling ratio α_1, keeping α_2 constant. From the above analysis, we find that $dS_1/d\alpha_1 > 0$ and $dS_2/d\alpha_1 < 0$ when δ_2 is positive. Then from equations (12), (15), and (17), we obtain $dR_1 = dI_{R1}(1/a_{D1R1}) = d(\alpha_1 D_1)(1/a_{D1R1}) = dS_1(1/a_{D1R1}s_1)$. The effect on final production is given by

$$\Delta_2\begin{pmatrix}dX_1\\dX_2\end{pmatrix}=-\begin{pmatrix}a_{K2}&-a_{L2}\\-a_{K1}&a_{L1}\end{pmatrix}\begin{pmatrix}a_{LR1}\\a_{KR1}\end{pmatrix}dR_1-\begin{pmatrix}a_{K2}&-a_{L2}\\-a_{K1}&a_{L1}\end{pmatrix}\begin{pmatrix}a_{LR2}\\a_{KR2}\end{pmatrix}dR_2.$$

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Then we have:

$$\Delta_2 dX_1 = a_{L2}a_{LR1}(k_{R1}-k_2)dR_1 + a_{L2}a_{LR2}(k_{R2}-k_2)dR_2,$$
$$\Delta_2 dX_2 = a_{L1}a_{LR1}(k_1-k_{R1})dR_1 + a_{L1}a_{LR2}(k_1-k_{R2})dR_2.$$

From the above analysis, we find that $dR_1/d\alpha_1 > 0$ and $dR_2/d\alpha_1 < 0$ for $\delta_2 > 0$. Then for $k_2 > k_1$ and $\delta_2 > 0$, we obtain

$$k_{R1} > k_2 > k_1 > k_{R2} \quad \rightarrow \quad dX_1/d\alpha_1 > 0, \quad dX_2/d\alpha_1 < 0.$$
$$k_{R2} > k_2 > k_1 > k_{R1} \quad \rightarrow \quad dX_1/d\alpha_1 < 0, \quad dX_2/d\alpha_1 > 0.$$

If the recycling sector 1 is more capital-intensive and the recycling sector 2 is more labor-intensive than the two final production sectors, capital is scarce and labor abundant in the final sector due to the increase in production of R_1 and reduction of R_2. Then, $d\alpha_1$ causes an increase in production of the labor-intensive and a reduction of the capital-intensive goods. Thus we can say:

Proposition 4. *Suppose that two capital–labor ratios of two final production sectors are between the capital–labor ratios of two recycling sectors. Then, under the condition $\delta_2 > 0$, production of one of the two final goods is reduced and the other is increased by the increase in the recovery ratio.*

6. Welfare[4]

Since $(1-\alpha_1)D_1$ and $(1-\alpha_2)D_2$ are the volume of waste, we define the social waste cost as $C_1((1-\alpha_1)D_1) + C_2((1-\alpha_2)D_2)$. We assume $C_i' > 0$ and $C_i'' > 0$. Then social welfare, W, is defined as:

$$W = Y - C_1((1-\alpha_1)D_1) - C_2((1-\alpha_2)D_2). \tag{29}$$

Then, the welfare effect is given by:

$$dW/d\alpha_1 = dY/d\alpha_1 + \{C_1'(1-\alpha_1)\delta_1 + C_2'(1-\alpha_2)\delta_2\}(-dY/d\alpha_1) + D_1C_1'. \tag{30}$$

The welfare effect is divided into the direct subsidy burden ($dY/d\alpha_1$), the indirect subsidy burden and the reduction of the social waste cost. The second term is positive and shows the reduction in waste cost due to the negative income effect. We call this indirect waste reduction. If the cost of indirect waste is sufficiently large so that $\{C_1'(1-\alpha_1)\delta_1 + C_2'(1-\alpha_2)\delta_2\} \geq 1$, welfare is always improved. In this case the reduction in the waste cost through the negative income effect outweighs the distortionary effect of the subsidy.

If the subsidy is initially introduced ($\alpha_1 = \alpha_2 = 0$), we have an alternative necessary condition for welfare improvement:[5]

$$1 < C_1'\delta_1 + C_2'\delta_2 + C_1'/s_1.$$

The terms $C_1'\delta_1 + C_2'\delta_2 + C_1'/s_1$ are total waste reduction effects for $\alpha_1 = \alpha_2 = 0$. Thus as long as the total waste reduction effects are larger than 1, the introduction of recycling is always welfare improving.

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If the waste cost is increased or people think waste more serious, then we need to determine how the optimal recycling ratio changes. Let γ_1 denote a welfare parameter for the waste cost of final good 1. By rewriting C_1' as $\gamma_1 C_1'$ in (30), we have:

$$\partial(dW/d\alpha_1)/\partial\gamma_1 = -C_1'(1-\alpha_1)\delta_1(dY/d\alpha_1) + D_1 C_1' > 0.$$

Let α_{op1} denote the optimal recycling ratio in sector 1. Then by using the stability condition $\partial(dW/d\alpha_1)/\partial\alpha_1 < 0$ and $dW/d\alpha_{op1} = 0$, we have:

$$d\alpha_{op1}/d\gamma_1 > 0.$$

We find that the optimal recovery rate is increased by an exogenous increase in waste cost. This result is coincident with our intuition. Thus we derive our final proposition:

PROPOSITION 5. *When welfare is defined as net income plus social welfare cost, the welfare effects of the recycling policy can be divided into a direct subsidy burden, an indirect reduction effect of waste through a decrease in income, and a direct waste reduction effect. The optimal recovery rate is increased by an exogenous increase in the waste cost.*

7. Concluding Remarks

We have examined the relationship between recycling and international trade theory. It is shown that the export goods or comparative advantage can be changed by a subsidy to the recycling sector. It is also shown that price effects are altered in an economy with a recycling sector. We consider the effects of an increase in the recycling ratio. We examine the welfare effects of recycling and the optimal recovery rate. We show that the optimal rate depends on waste cost.

These results are analyzed using a simple static two final goods and two factors model with two intermediate recycling sectors. There could be many trade models which incorporate recycling. For example, a Ricardian or specific factor model could be used. Alternative recycling policies such as a fixed subsidy to the recycling sector would be interesting. Such extensions could be a worthwhile area for future research.

In fact, some recycling sectors are profitable and can exist without a subsidy. Then it may be necessary to analyze recycling sectors with positive or normal profit. We could consider using an overlapping generation or some dynamic models. Instead of a subsidy to recycling sectors, we can examine a sort of recycling tax which is imposed when consumers buy final goods. In our model, secondary materials are not produced in the domestic economy. It would be interesting to see how our results change when secondary materials are produced and exported.

We do not consider international trade in secondary materials. It is known that the trade in secondary materials from developed countries to developing countries has grown (Van Beukering and Bouman, 2001). However, to introduce such trade, many production goods models may be useful. Of course in the model used in this paper, we can treat the case in which secondary materials are produced in a foreign country. But as long as we use our model, results would be obvious and trivial.

Although recycling is closely related to environmental problems, we do not sufficiently consider this relationship. This problem also depends on the extent to which

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recycling is necessary and why recycling should be encouraged by expending costs. A more integrated model of the environment would be necessary.

Appendix

In the Appendix, we examine the relationship between the recycling policy and income. Letting $Y_0 = wL + rK$ be basic income, and $\beta_i(Y) = p_iD_i/Y$ be the consumption ratio of good i to income, we can rewrite equation (3) by using equations (1), (2), (12), (13), and (14), as follows:

$$Y = Y_0 - \left(s_1\alpha_1 D_1 + s_1\alpha_2 D_2\right) = Y_0 - \left(s_1\alpha_1\beta_1(Y) + s_2\alpha_2\beta_2(Y)/p\right)Y. \tag{A1}$$

Thus for constant price we obtain:

$$\begin{aligned} &Y\{1 + (s_1\alpha_1\beta_1(Y) + s_2\alpha_2\beta_2(Y)/p)\} = Y_0, \\ &dY/dY_0 = 1/\{1 + s_1\alpha_1(\beta_1)(1+\eta_1) + s_2\alpha_2(\beta_2/p)(1+\eta_2)\}, \\ &\qquad\quad = 1/(1 + s_1\alpha_1\delta_1 + s_2\alpha_2\delta_2) \\ &\qquad\quad = 1/(1 + \partial S/\partial Y) \end{aligned} \tag{A2}$$

where $\eta_i = (d\beta_i/dY)(Y/\beta_i)$ is the income elasticity of consumption ratio, and δ_i is defined as the income propensity to consume good i. From the stability condition, we have:

$$1 > |\partial S/\partial Y| = |s_1\alpha_1(\beta_1)(1+\eta_1) + s_2\alpha_2(\beta_2/p)(1+\eta_2)|. \tag{A3}$$

We find that dY/dY_0 depends on the change in subsidy of income, $\partial S/\partial Y$. We also find that the smaller is the income elasticity, the larger is dY/dY_0.

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Notes

1. When there are intermediate import goods, M^M, then income or GDP can be written as $Y = p_1X_1 + p_2X_2 - p_MM^M$. Let $M_i = a_{Mi}X_i$ be intermediate goods used in final production sector i. Using the assumption of homogeneity of degree one, the zero-profit condition $p_MR_i + S_i = wL_{Ri} + rK_{Ri}$ and $M_1 + M_2 = M^D$, we have $Y = wL_1 + rK_1 + p_MM_1 + wL_2 + rK_2 + p_MM_2 - p_M(M^D - R_1 - R_2) = wL + rK - S$.

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2. This is one of the models in which a subsidy increases recycling. Although we could analyze a model with positive profits, we do not consider this case for simplicity.
3. From the stability condition of the Appendix, we have $(1 + s_1\alpha_1\delta_1 + s_2\alpha_2\delta_2) > 0$.
4. In this section we could simultaneously consider optimal recycling ratios in both recycling sectors. However, we do not examine this case since the results are ambiguous.
5. From (27), we find that $dY/d\alpha_1 = -s_1D_1$ for $\alpha_1 = \alpha_2 = 0$. Then

$$\begin{aligned} dW/d\alpha_1 &= dY/d\alpha_1[1-\{C_1'(1-\alpha_1)\delta_1 + C_2'(1-\alpha_2)\delta_2\} + D_1C_i'/(dY/d\alpha_1)] \\ &= dY/d\alpha_1[1-\{C_1'(1-\alpha_1)\delta_1 + C_2'(1-\alpha_2)\delta_2\} + s_1C_1']. \end{aligned}$$

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