The Oil Saving Efficiency of Recycling Technology for Waste Plastics *

Toyoaki Washida
Faculty of Economics,
Wakayama University,
930 Sakaedani, Wakayama 640,
Tel : 0734-54-0361,ext.3320, Fax : 0734-54-0390
Email: toyo-w@center.wakayama-u.ac.jp

September 22, 1994

Abstract

After the first oil crisis many companies in Japan started on projects to recycle waste plastics by transforming them into oil. These projects, however, were disrupted after the fall of oil price in the successive periods of the oil crisis. This disruption was mainly caused by inefficiency of the recycling technology in those days. Recently a new technology for recycling, which uses artificial zeolite as catalyst, has been developed and an experimental plant has been constructed. Although the technology has high efficiency in transforming of waste plastics into oil, it cannot produce value added. However we have to understand the difference between the efficiency for value and for material. In this paper, we investigated on the oil efficiency of the technology. The oil efficiency was measured by the quantity of oil which was directly and indirectly necessary to produce one unit of oil by recycling wasted plastics. We use 1985 Input-Output Table and a linear programing model is constracted. Since waste plastics are produced as joint products, we cannot avoid to use linear programming models. The result showed that recycling technology had high efficiency in saving oil. If the total of the waste plastics generated in Japan would be processed by this technology, the amount of oil savings would be 7.57 million Kl which would be 4 % of the total amount of oil used in 1985.

1 Introduction

The total waste plastics discharged by households and by industries in 1988 is $8 \times 10^6 t$ in Japan[1]. Since plastics support our materialistic life from every aspect, we do not expect this amount to decrease substantially. On the one hand it is clearly wasteful to discharge the plastics which fixes energy with high density.

*This paper was presented in the 10th International Conference on Input-Output Techniques, Seville, Spain, 1993. I thank the anonymous referee for helpful comments.

[1] t means metric ton (= tonne) throughout this paper.

On the other hand when the waste plastics is discharged as solid materials, they take up much space and accelerate the use of land fills. To burn them in facilities which can generate electricity is an effective way to save energy. It releases, however, some types of pollutants in the air. Especially if the waste plastics include chlorine (Cl) they possibly generate hazardous organic chlorine compounds depending upon the conditions of burning. Moreover the release of carbon dioxide (CO_2) is unavoidable. Thus we have to seek alternative ways to deal with them[2].

The way which has the strongest potential is to transform them into oil which is the original resource of the plastics. After the first oil crisis in 1973 many companies in Japan started on projects to recycle waste plastics to reproduce oil. These projects, however, were disrupted after the fall of oil price in the successive years. This disruption was mainly caused by the inefficiency of the recycling technology in those days. Recently a new technology for recycling, which uses artificial zeolite as catalyst, has been developed and an experimental plant has been constructed.

Although the technology has high efficiency in transforming waste plastics into oil, it cannot produce value added in this stage of technological progress. We have to pay attention to the difference between the efficiency for value and for material. In this paper, We shall investigate the oil efficiency of this technology. The oil efficiency is measured by the quantity of oil which is directly and indirectly necessary to produce one unit of oil from recycling waste plastics. We use Input-Output Table and a linear programming model is constructed. Since the waste plastics are produced as joint products, we cannot avoid the use of linear programming model.

2 Theoretical Framework of Technology Assessment

Since we use the input-output table, every quantity is basically measured in the monetary unit, if it is not specifically mentioned that other unit is used. Let the number of sectors be n and the number of goods be m. In this stage they do not include waste plastics and their recycling sector. Let $A = (a_{ij})$ be a $m \times n$ input coefficients matrix. We do not necessarily presume $m = n$. a_{ij} means the amount of the ith products required to operate the jth industry for one unit of

[2]See Pearce(1990) and Washida(1992).

activity. We assume that a_{ij} includes the service by fixed capital equipment and it does not include imported products. Let $B = (a_{ij})$ be the $m \times n$ output matrix and b_{ij} denotes the amount of the ith products produced by the jth industry for one unit of activity. In our analysis, since we deal with joint production this matrix cannot be a diagonal one. We cannot avoid using joint production model to analyze the efficiency of recycling technology, as waste materials are inevitably produced as joint products. Let $g = (g_j)$ be a n dimension row vector of import coefficients. The g_j means the amount of imported products required for one unit of activity of the jth industry. We assume that the import of materials charges the same amount of the export measured in monetary unit, and the export and the import have to be in balance. Let a vector e be a basket which expresses the proportion of products exported in 1985. It is a m dimension column vector and it is normalized as $|e| = 1$. It shows that one unit export has to be performed with a distributed form e. Let d be a m dimension vector expressing the final demand for domestic products, and d_{m+1} be the amount of final demand for imported products. Let $c' = (c'_j)$ be a n dimension row vector expressing the amount of imported crude oil required by one unit of activity for each industry [3]. Moreover we use a slightly different $c = (c_j)$ vector. Let the kth industry produce crude oil. Then the difference between c' and c is only in the kth element, that is, $c_k = c'_k + 1$ and $c_j = c'_j, j \neq k$.

First let us specify the primary problem which does not include the recycling industry of waste plastics. The problem is to minimize input crude oil required to produce final demand. The problem is as follows.

$$Minimize \qquad c'x + x_k = cx$$

$$s.t.$$

$$\begin{array}{rrcl} (B-A)x & -ex_{n+1} & \geq & d \\ -gx & +x_{n+1} & \geq & d_{m+1} \end{array}$$

$$x \geq 0, \qquad x_{n+1} \geq 0,$$

where x is an activity vector and x_{n+1} is the amount of export. The objective function expresses the total of imported and domestically produced crude oil. Since one unit of crude oil means that at least one unit of crude oil has to be exploited from the external of this economy (= natural environment), the objective function expresses the total crude oil resources for sustaining the final demand d and d_{m+1}.

[3] The amount of the crude oil is measured by physical terms throughout this paper.

The first equation of the constraint conditions shows that the demand for domestic products have to be less than that of supply. This is a m dimension vector equation. The second equation shows that the total import has to be less than total export. The last equation is the nonnegativity conditions for variables.

Since the system is specified by a linear programming problem, the output configuration has normative characteristics and we cannot say that the actual output configuration tends to converge on the configuration given by this problem as an optimal solution. However the objective of this analysis is not to show how the actual configuration is given, but to show the criterion of technology assessment. In other words, our methods are to show whether the recycling technology of resources is effective under an optimal condition.

Next, the dual system of the problem is as follows.

$$Maximize \qquad vd + v_{m+1}d_{m+1}$$

$$\text{s.t.}$$

$$\begin{array}{llll} v(B-A) & -v_{m+1}g & \leq & c \\ -ve & +v_{m+1} & \leq & 0 \end{array}$$

$$v \geq 0, \qquad v_{m+1} \geq 0,$$

where v is a value vector measured in crude oil and v_{m+1} shows the oil value of imported products. The objective of this problem is to maximize the total oil value of the final demand vector. The first vector equation shows that the output products for each industry cannot fix the oil value more than the total oil value of input materials and services. This is an equation for the conservation of the value.

It is unnecessary to show whether both problems have optimal solutions, for our analysis is not theoretical but empirical. Owing to the duality theorem, if both problems have solutions the maximum of the former problem coincides with the minimum of the latter problem[4]. Although both solutions are closely related we mainly pay attention to the solution of the dual problem, for the value vector can evaluate the basket of products from the viewpoint of macroscopic oil efficiency. v_i can be interpreted as the amount of crude oil which is directly and indirectly required by additional one unit increase of the final demand for the products[5], that is,

$$v_i = \frac{\triangle cx}{\triangle d_i}.$$

[4]See Gale(1960)

[5]See Dorfman, Samuelson and Sollow(1958)

Now let a_{n+2} be the input vector required to produce one unit of oil by recycling. Then va_{n+2} shows the amount of oil charged by using this recycling technology. If the oil value of waste plastics is zero and $1 > va_{n+2}$ holds, then it means that the oil produced by the recycling technology is greater than the oil necessary for recycling. Thus v functions as a fundamental criterion to measure the efficiency of recycling technology. We shall investigate this point again after the specification of the problems which directly include the recycling sector of waste plastics.

Let a_{n+2} be the input vector of the recycling sector used above, and x_{n+2} be the working level of the sector. x_{n+2} is measured by the amount of oil recycled by the sector. Let p be the n dimension row vector which elements show the amount of waste plastics jointly produced by each industry and p_{n+2} be the amount of the waste plastics required for one unit production of oil. Let d_{m+3} be the amount of waste plastics discharged by the household. Finally let N be the amount of input crude oil outside the economy. Then the problem is specified as follows.

$$Minimize \qquad N$$

$$\text{s.t.}$$

$$\begin{array}{rrrrcl}
(B-A)x & -ex_{n+1} & -a_{n+2}x_{n+2} & & \geq & d \\
-gx & +x_{n+1} & & & \geq & d_{m+1} \\
-cx & & x_{n+2} & +N & \geq & 0 \\
px & & -p_{n+2}x_{n+2} & & \geq & -d_{m+3}
\end{array}$$

$$x \geq 0, \qquad x_{n+1} \geq 0, \qquad x_{n+2} \geq 0$$

The objective is to minimize the input crude oil. The first equation shows the supply and demand balance for domestic products. The second shows the trade balance. The third equation shows that the crude oil cannot be saved more than the amount recycled. Here we assume that the recycled oil is completely substitutable for crude oil. The fourth equation shows the supply and demand condition for waste plastics.

Then we can specify the dual problem as follows.

$$Maximize \qquad vd + v_{m+1}d_{m+1} - v_{m+3}d_{m+3}$$

$$\text{s.t.}$$

$$\begin{array}{lllllr}
v(B-A) & -v_{m+1}g & -v_{m+2}c & +v_{m+3}p & \leq & \phi \\
-ve & +v_{m+1} & & & \leq & 0 \\
-va_{n+2} & & +v_{m+2} & -v_{m+3}p_{n+2} & \leq & 0 \\
 & & v_{m+2} & & \leq & 1
\end{array}$$

$$v \geq 0, \quad v_{m+1} \geq 0, \quad v_{m+2} \geq 0, \quad v_{m+3} \geq 0,$$

where v_{m+2}, v_{m+3} are the value of oil and waste plastics respectively. ϕ is the m dimension vector composed only by 0 elements. Since it is impossible for the economy to be sustained without input of crude oil the minimized N has to be positive. Owing to the duality theorem the last equation in the dual problem holds the strict equality in the optimal solution. This means $v_{m+2} = 1$, that is, the oil value of the oil itself is 1.

As mentioned above let us examine how the value system v and v_{m+1} in the model without the recycling sector works for the evaluation of the recycling technology. Now let us assume the following equation.

$$va_{n+2} \geq 1 \tag{1}$$

In other words the total oil value of the input factors to produce one unit oil in the recycling sector is greater than 1. Let v^* and v^*_{m+i} (i=1,2,3) be the optimal solution in the dual problem inclusive of the recycling sector. Then we can easily show that the following equation can never be satisfied.

$$v^* d + v^*_{m+1} d_{m+1} - v^*_{m+3} d_{m+3} < vd + v_{m+1} d_{m+1} \tag{2}$$

The proof is as follows. Now assume $v_{m+2} = 1, v_{m+3} = 0$ and let us consider v, v_{m+i} (i=1,2,3). If (1) is satisfied then v, v_{m+i} (i=1,2,3) has to be a feasible solution of the dual problem inclusive of the recycling sector. Moreover if (2) is satisfied the problem has the feasible solution which value of the objective function is greater than the optimal solution. This is a contradiction. Therefore (2) can never be satisfied.

The right hand side of (2) expresses the oil necessary without the recycling sector and the left hand side expresses that with the recycling sector. Therefore the fact that the above equation is not satisfied means that we cannot save the oil input by introducing the recycling technology from a macroscopic view.

Thus the following equation has to be satisfied so that the recycling sector saves the macro input of crude oil.

$$va_{n+2} < 1 \tag{3}$$

Although (3) is a necessary condition it is not a sufficient condition. In other words, even if (3) holds, we cannot exclude the case that the oil necessary with the recycling sector is not different from that without the sector. However, we can say that the case is quite rare as we have investigated in the previous part of this section. Therefore (3) can be the important criterion for assessing new technologies.

It is true that we can directly judge the recycling efficiency by solving the problem inclusive of the recycling sector. Yet to use the criterion (3) takes some advantages. For example, let us consider the case that we have some alternative technologies for recycling. If we use (3) as the criterion it is not necessary to solve each problem for each technology. Since we already have the vector v by solving the linear programming problem without the recycling sector, we simply need to calculate the total value the input coefficient and to compare the value with 1. Moreover we can extend the methods into the assessment of more general technologies. In other words not only for recycling technologies we can assess whether a new technology has oil saving efficiency or not by the same procedure as described above.

3 Specification of the Recycling Technology

First let us simply describe the recycling technology of waste plastics which is working as an experimental plant in Japan. The kinds of waste plastics which can be processed by the plant are polyethylene, polypropylene and polystyreen. The four major plastics include, in addition, polyvinyl chloride, which in this stage of technology cannot be processed, for the plant cannot absorb chlorine gas without damage to the plant. However we assume that the recycling plant can process the waste plastics of polyvinyl chloride with minor change that cannot affect the estimation of the technology. These raw materials have to be broken into pieces before they are taken into the plant. The materials are heated up to about 400 centigrade and transformed into gas, which passes through artificial zeolite as catalyst and is finally transformed into oil. The ratio of the materials and the product is 10:8 measured by weight. The ingredients of the product are gasoline 50%, kerosene 25% and light oil 25%.

Next we shall estimate the input coefficients of the recycling technology except for fixed facilities of the plant. Table-1 shows the components of input and output flow of the technology per 1 t of waste plastics to be processed by the plant. We assume that the fuel oil 200 kg is substitutable by the same amount of recycled oil. Then the recycled oil valued by the price in 1985 amounts to ¥ 32,755. The total cost for electricity amounts to ¥ 36,534.

Then we have to match these components to the classification of the 1985

Wasted Plastics		1	t
Sorting, washing, crushing	Electricity	1,100	kwh
	Other Costs	14,000	¥
Recycling Plant	Fuel Oil	200	kg
	Electricity	400	kwh
	Zeolite	2,000	¥
	Other Costs	2,000	¥
Product	Recycled oil	800	kg

Table 1: Product and Input Flow

Input-Output Table in Japan. Since the electricity is treated as an independent product in the Input-Output Table, we can make it correspond to the product in the table as a cost directly. We make the artificial zeolite correspond to the sector of the other industrial inorganic chemicals in the input-output table. The other costs are distributed among elements using the input vector of the sector of the petrochemical basic products in the Input-Output Table which is normalized to make the sum equal to 1. Before making the normalized vector, we eliminate the elements for the other industrial inorganic chemicals, oil products, products related to petrochemical basic products and electricity from the vector, for these elements are already included. The configuration is listed in the first column of the table in Appendix 1. We finally have the input coefficient vector, i.e. a_{n+2}, vector by these elements divided by the nominal value of recycled oil.

Finally we have to estimate the coefficients related to the supply and demand of waste plastics. Since waste plastics does not have stable evaluation by markets we have to deal with the quantity of waste plastics in physical term. The amount of waste plastics required to produce one unit of recycled oil can easily be calculated by the relationship in Table- 1. The amount of waste plastics discharged by each industry is estimated as follows. As mentioned in the first section, total industrial waste plastics amounts to $282 \times 10^6 t$ in 1985. However we do not have information about how much of the amount is partly attributed to each industry. Therefore we assume that each industry discharged waste plastics in proportion to the input of plastics. We distribute the total $282 \times 10^6 t$ to each industry in proportion to the input of plastics. The output coefficient is obtained by dividing it by the activity level of the industry. We assume that waste plastics discharged by households amount to 10 % of the total waste materials of $4,344.9965 \times 10^6 t$ in 1985.

4 Processing of the Input-Output Table

We use the 1985 Input-Output Table of Japan, where one unit is treated as 100 million yen. Although our analysis is primarily based on the 183 sectors integrated table, we utilize the data from the 529×408 basic table when necessary.

The integrated table includes the products, iron scrap and non-ferrous metal scrap, which are not produced as main products by any sector. We assume that these products are produced as joint products by industries. Clearly all sectors have the potential to produce these products.

Since we pay attention to the flow of crude oil in this analysis, we should avoid treating petroleum refinery products as a single kind of products. We assume that the petroleum sector jointly produces gasoline, jet fuel oil, kerosene, light oil, heavy oil A, heavy oil B and C, naphtha, LPG, and other petroleum refinery products. These data are listed in the basic table. Thus the total sector number is 181, and the total product number is 191 in our model.

Except for the petroleum refinery sector, the working level of each sector is measured by the amount of main product. The working level of the petroleum refinery sector is measured by the amount of gasoline produced.

Now let us show how to construct matrices and vectors from the input-output table. First, the input coefficient matrix A is the sum of an intermediate input coefficient matrix A' and a capital service coefficient matrix C, that is, $A = A' + C$. The matrix A is obtained by dividing the input elements by the activity level of each sector. To make the C matrix, we distribute the depreciation of fixed capital by normalized vector which is obtained by the fixed capital formation matrix in 1985. In the fixed capital formation matrix, products are classified into the basic classification employed by the basic table and sectors are classified by an 84 sectors table. It is easy to integrate the basic classification into ours. To disintegrate the sector classification, we assume that similar sectors, which are treated as same sectors when the 183 table is integrated into the 84 table, have the same proportion of various fixed capital. Then we divide the elements by the activity level of each sector.

The column vector of the output coefficient matrix for each sector includes the element 1 for the main products of the sector and non-zero elements for the iron scrap and non-ferrous metal scrap which are joint products divided by the amount of the main product, and all the other elements are zero. As stated above, since the activity level of the petroleum refinery sector is measured by the production level of gasoline, the element for the gasoline is 1 and the other elements of joint products are proportional to this level.

The import row vector g is the sum of the column elements of the import matrix for each sector divided by the activity level. The export column vector e is constructed by normalization of the export vector in the final demand part of the integrated table. The row vector c of crude oil input coefficient is constructed by dividing the crude oil input for each sector by the activity level and by making the element of domestic crude oil sector 1. Moreover, as an exception, the crude oil input is measured by the physical term, Kilo liter kl. Finally the final demand vector for domestic products d can be obtained directly from the table and the final demand for imported products d_{m+1} is the sum of imported products.

5 Solution without the Recycling Sector

First we solved the problem in which the recycling sector of waste plastics was not implemented. As discussed in the theoretical analysis, we can evaluate the recycling technology with the value vector of crude oil which can be obtained from the model without the recycling technology.

The calculation was performed by the revised simplex method of linear programming. The value of the objective function in the optimal solution amounts $195{,}695 \times 10^3 kl$. This means that in order to produce the final demand basket in 1985, this amount of crude oil has to be input to the economy at the minimum. On the other hand, the actual amount of crude oil input to the Japanese economy in this year is about $219{,}300 \times 10^3 kl$. The difference between the two numbers suggests that the Japanese economy have the potential to save crude oil input.

Let us investigate the optimal solution vectors. The table in Appendix 2 shows the structure of the solution. The first column shows the optimal production configuration. The second column shows the amount of excessive production for each sector in the optimal solution. The third column shows the dual solution vector, elements of which mean the crude oil value for each products and are measured by physical term kl.

In the table we can confirm that the values of the products excessively supplied are zero. This fact is derived from the duality theorem of linear programming. Actually among the products jointly produced by the petroleum refinery sector, All values of the products except for naphtha are zero because of excessive production. This means that naphtha is the most scarce product among the petroleum refinery products for the Japanese economy in 1985. Of course, for the actual production, since these joint products are slightly substitutable, the economy can avoid this rigid situation.

The other excessive production appears for the sector of two wheel motor vehicle and the sector of watches and clocks. This result is related to the joint production of scrap. The sector of two wheel motor vehicle produces iron scrap with high proportion, on the other hand, the sector of watches and clocks produces the non-ferrous scrap with high proportion too. Since the scarcity of these kinds of scrap is rather high for the production of the final demand, these sectors are actually transformed into those of the scrap production as main products in our model. This shows the inefficiency of the actual economy from the view point of the saving of crude oil.

Now let us evaluate the recycling technology by means of the dual solution as theoretically examined in the previous section. We employ the following notations.

s : Recycled oil per ton of waste plastics

r : Intermediate input vector per ton of waste plastics

t : Depreciation of fixed capital per ton of waste plastics

k : Proportion vector of fixed capital, normalized as $|k| = 1$

v : Crude oil value vector

s, r, and k are already given in the section for technology specification. v is gven as the dual solution of the model without the recycling technology. However p is not specified explicitly yet. First let us investigate the t which satisfies the following equation.

$$s = rv + tkv \tag{4}$$

Let t^* be t which satisfies the above equation[6]. This equation means that the amount of produced recycled oil is just equal to the total crude oil value of the technology which can produce it. As suggested in the theoretical part, in this case the recycling technology can save the input of crude oil. On the other

[6]The variables can be related to the input coefficient vector a_{n+1}, i.e., $r + tk = a_{n+2}/p_{n+2}$ and also $s = 1/p_{n+2}$. Since we need the variable t the new notations are introduced.

Depreciation ¥ $/t$	Input of crude oil $\times 10^3 kl$	Rate of saving %	Activity level of recycling sector 10^6¥	Value of waste plastics kl/t
0	187,920	3.973	378,854	0.673264
20,000	188,126	3.868	379,193	0.655553
100,000	188,947	3.448	380,556	0.584393
300,000	191,028	2.385	384,005	0.404235
500,000	193,146	1.303	387,517	0.220781
700,000	195,303	0.200	391,095	0.033940
800,000	195,695	0	0	0

Table 2: Summary of calculation

hand, if the depreciation of fixed capital of this technology is less than t^*, the technology is efficient, for it can save the input of crude oil. We can easily calculate t^* and,

$$t^* = 735,939.$$

In other words, if the depreciation of fixed capital for recycling $1t$ of waste plastics is less than ¥ 735,939, then the technology is efficient. The rational depreciation is now estimated to be about ¥ 20,000 for $1t$ of waste plastics and this t^* is very large. Therefore, we can expect high level of saving efficiency of crude oil by this technology.

6 Estimation of the Oil Saving Efficiency

Let us investigate how much we can save crude oil with the recycling technology for waste plastics. Although we have to make the model include the recycling technology, we have not specified the depreciation of fixed capital for the technology which is denoted as t in the previous chapter. We try to catch how the efficiency of the technology would change by making the depreciation shift to different levels. The alternatives of the depreciation are 0, 20,000, 100,000, 300,000, 500,000, 700,000, and 800,000 per $1t$ of waste plastics. The summary of calculation is shown in Table- 2. We can confirm that the depreciation exceeding the critical level $t^* = 735,939$ make it impossible to save crude oil. Since the normally expected level of the depreciation is 20,000, at that level the amount of saving of crude oil is about $7.569 \times 10^6 kl$[7], which is 3.9% for the total input of crude oil to the Japanese economy.

In the case of the ¥ 20,000/t depreciation, the activity level of the recycling

[7] The amount is derived by $195,695 - 188,126$.

sector for waste plastics is ¥ 379,193$\times 10^6$, which equivalents to 8.683$\times 10^6 kl$ in terms of crude oil. This means that if the depreciation could possibly be zero, then we could save 8.683$\times 10^6 kl$. However, in actual we can only save 7.569$\times 10^6 kl$. The difference 1.114$\times 10^6 kl$ is consumed directly or indirectly by the recycling process of waste plastics. The difference is unexpectedly small.

The activity level of the recycling sector for waste plastics increases as the depreciation increases. This means that the increase in depreciation causes the increase in activity levels of the other sectors and the increase in waste plastics jointly produced. Therefore the recycling sector has to increase the activity level to recover from technological inefficiency as much as it can.

Finally, the value of waste plastics decreases as the depreciation increases. This shows directly the deterioration of the technology. At the point of zero activity level of recycling sector, since waste plastics is excessively produced, the value of waste plastics becomes zero too.

7 Concluding Remarks

Our empirical study for the recycling technology for waste plastics shows that this technology has high efficiency in saving the total input of crude oil for the Japanese economy. On the other hand, the technology still does not have the ability to produce value added. In this stage of progress, the technology has to be in the area of increasing returns to scale. Therefore the economic policies to use the recycling technology for waste plastics in many fields of the economy are required.

References

[1] Pearce,D.W. and R.K.Turner (1990), *Economics of Natural Resources and the Environment* (Harvester Wheatsheaf: London)

[2] Washida,T. (1992), *Kankyou to energy no keizai bunseki (Economic Analysis of the Environment and Energy)* (Hakuto Syobo: Tokyo)

[3] Dorfman,R., P.A.Samuelson and R.M.Solow (1958), *Linear Programming and Economic Analysis* (McGraw-Hill Book Company, Inc.: New York)

[4] Gale,D. (1960), *The Theory of Linear Economic Models* (The Univ. of Chicago Press: Chicago)

Appendix 1

The list is for the products which are inputs to the recycling sector as intermediate products or fixed capital.

Intermediate Input	Proportion of Fixed Capital	Dual Solution	Sector
44.937	0.00000	0.6186	Coal and Lignite
63.773	0.00000	0.4576	Natural gas
0.000	0.00013	1.4515	Other textile products
5.436	0.00000	0.7985	Wearing apparel
1.399	0.00000	0.6433	Apparel accessories
25.832	0.00576	1.0041	Wooden furniture and accessories
87.399	0.00000	0.4443	Printing and publishing
112.101	0.00000	0.9358	Industrial soda chemical
2000.000	0.00000	2.5515	Other industrial inorganic Chemicals
436.080	0.00000	0.9597	Coal products
57.746	0.00000	1.9325	Other rubber products
7.534	0.00000	0.7022	Leather footwear
0.054	0.00000	1.0091	Miscellaneous leather products
0.538	0.00000	0.5212	Other glass products
4.844	0.00000	0.6495	Ceramic, stone and clay products
0.000	0.00012	1.9539	Metal products for construction
0.000	0.00077	1.2116	Heating and cooking apparatus
13.723	0.00000	0.0841	Other metal products
0.000	0.01598	1.2493	Engine and boilers
0.000	0.00391	1.3060	Conveyors
0.000	0.00291	2.0079	Refrigerators and air conditioning
0.000	0.01021	1.1483	Other general industrial machinery
0.000	0.00007	0.9604	Mining and construction machinery
0.000	0.41238	0.9363	Chemical machinery
0.000	0.00058	0.7810	Industrial robots
0.000	0.06844	0.8210	Other special industrial machinery
0.000	0.00345	1.5670	Other general machines and parts
819.581	0.00000	0.6166	Repair of general machinery
0.000	0.00220	0.4704	Office machines
0.000	0.00217	1.4154	Household electric appliance
0.000	0.02398	0.9737	Computer and accessory device
0.000	0.00444	1.1231	Communication equipment
0.000	0.00094	0.8910	Applied electronic equipment
0.000	0.02449	1.5684	Heavy electrical equipment
0.000	0.04219	1.5007	Other electrical equipment
204.882	0.00000	0.7129	Repair of electric machinery
0.000	0.00396	1.2514	Passenger cars
0.000	0.00365	1.4267	Trucks, buses and other cars

0.000	0.00451	1.5267	Other trans. equipment and repair
1.023	0.00000	0.0000	Watches and clocks
0.753	0.04265	1.1878	Other precision instruments
0.000	0.15855	0.8119	New residential construction
312.785	0.00000	0.6298	Repair of construction
0.000	0.06794	0.9734	Other civil engineering
36534.000	0.00000	1.8287	Electric power
9.956	0.00000	2.1624	Gas supply
306.919	0.00000	0.8347	Water supply
238.356	0.00000	0.1900	Other sanitary services
955.308	0.08389	0.1862	Wholesale trade
27.770	0.00148	0.2192	Retail trade
6507.731	0.00000	0.1244	Financial service
141.055	0.00000	0.1542	Insurance
858.814	0.00000	0.1390	Real estate agencies and rent
42.677	0.00003	0.5459	National railway transport 1
2.099	0.00000	0.4726	National railway transport 2
23.518	0.00000	0.3621	Local railway and tramway
69.316	0.00000	0.1856	Road passengers transport
458.038	0.00720	0.1768	Road freight transport
104.298	0.00000	0.3377	Private self-passenger transport
65.980	0.00000	0.3524	Private self-freight transport
168.340	0.00010	0.3562	Coastal and inland water transport
12.055	0.00016	0.1793	Transport service in harbor
116.837	0.00002	0.4752	Air transport
71.577	0.00056	0.3102	Storage facility service
6.512	0.00000	0.4012	Packing
41.009	0.00000	0.1199	Postal service
104.997	0.00000	0.3979	Telecommunication
0.269	0.00000	0.1809	School education and research
7.158	0.00000	0.5163	Self-education
44.130	0.00000	0.2484	Social and other education
155.962	0.00000	0.2807	Research institute
809.302	0.00000	0.8206	Self-research
431.936	0.00000	0.2018	Other public service
25.025	0.00000	0.3284	Advertising agency
167.371	0.00000	0.1767	Information services
100.530	0.00000	0.5359	Office machines renting and leasing
631.975	0.00000	0.2012	Other business services
11.894	0.00000	0.9299	Office supply
1080.864	0.00000	1.3633	Activities not elsewhere classified

Appendix 2

Optimal Output Configuration $\times 10^4$	Excess Supply	Dual Solution	Sector
436.945	—	0.4566	Cereals
35.865	—	0.5730	Potatoes and pulses
220.520	—	0.4553	Vegetables
105.641	—	0.3797	Fruits
28.925	—	0.6396	Other edible crops
118.961	—	0.5987	Inedible crops
384.329	—	0.6856	Livestock-raising
25.028	—	0.7735	Sericulture
61.807	—	0.5046	Agricultural services
86.061	—	0.2864	Silviculture
125.262	—	0.2270	Logs
24.801	—	0.3425	Minor forest products
303.891	—	0.3843	Maine fisheries
19.083	—	0.6704	Inland water fisheries
0.467	—	0.6668	Iron and ore mining
22.169	—	0.4988	Non-ferrous metal ores
37.912	—	0.5037	Material ceramics
180.447	—	0.3435	Gravel and quarry
2.221	—	0.5476	Other non-metal ores
49.808	—	0.6186	Coal and lignite
9.760	—	23.3240	Crude petroleum
18.432	—	0.4576	Natural gas
220.480	—	0.6411	Slaughtering and meat processing
275.838	—	0.7170	Meat foods
480.083	—	0.5945	Sea foods
466.677	—	0.5816	Grain milling
686.315	—	0.6502	Vegetable and fruit products
618.279	—	0.5801	Other foods
388.994	—	0.3137	Liquor
268.161	—	0.5720	Other beverages
174.761	—	0.9719	Feeds and organic fertilizer
271.852	—	0.2523	Tobacco
213.883	—	1.7753	Raw silk and fiber yarns
449.212	—	1.4256	Fabrics
160.217	—	0.9872	Knit fabrics
177.173	—	0.8298	Yarn and fabric dyeing
186.654	—	1.4515	Other fabricated textile
508.258	—	0.7985	Wearing apparel
26.918	—	0.6433	Apparel accessories
104.678	—	0.8375	Other ready-made textile products
455.028	—	0.7631	Timber, plywood and wooden chips

184.898	—	0.6139	Other wooden products
512.405	—	1.0041	Furniture and accessory
157.246	—	0.8595	Pulp
364.928	—	0.9766	Foreign and Japanese paper
374.392	—	0.7571	Other paper
383.280	—	0.6855	Paper container
185.042	—	0.9466	Other converted paper products
1398.771	—	0.4443	Printing and publishing
82.257	—	3.1711	Chemical fertilizer
99.506	—	0.9358	Industrial soda chemicals
303.529	—	2.5515	Other industrial inorganic products
479.170	—	50.2104	Petrochemical basic products
601.509	—	20.8996	Organic chemical intermediate
110.670	—	16.6761	Synthetic rubber
292.766	—	4.4318	other organic chemical products
728.954	—	15.7629	Resin
186.461	—	6.9272	Chemical fiber
425.787	—	0.9948	Medicaments
220.246	—	1.7649	Soap, synthetic detergent
296.401	—	7.1465	Paint varnish and printing ink
144.108	—	1.1782	Photographic sensitive materials
319.180	—	3.9673	Other final chemical products
1007.096	438.375	0.0000	Gasoline
	5.493	0.0000	Jet fuel oil
	101.860	0.0000	Kerosene
	128.204	0.0000	Light oil
	65.630	0.0000	Heavy oil A
	85.552	0.0000	Heavy oil B and C
	—	203.0812	Naphtha
	31.874	0.0000	LPG
	64.673	0.0000	Other petroleum refinery products
485.183	—	0.9597	Coal products
1924.153	—	4.2691	Plastic products
260.775	—	3.8723	Tires and inner tubes
422.096	—	1.9325	Other rubber products
43.609	—	0.7022	Leather footwear
257.686	—	1.0091	Miscellaneous leather products
157.750	—	0.5651	Sheet glass and safety glass
42.464	—	0.5456	Glass fiber and glass products
222.192	—	0.5212	Other glass products
123.868	—	0.7542	Cement
273.303	—	0.4065	Ready mixed concrete

203.952	—	0.5489	Cement products
157.121	—	0.4132	Pottery, China and earthenware
402.770	—	0.6495	Ceramic, stone and clay products
2054.164	—	10.5713	Pig iron and crude stone
	—	185.3276	Iron scrap
1898.799	—	5.7606	Hot rolled steel
395.481	—	2.3157	Steel pipes and tubes
1304.684	—	1.4882	Cold-finished and coated steel
1112.768	—	9.0666	Cast, fogged and other steel
508.952	—	7.0315	Non-ferrous metals
	—	141.6316	Non-ferrous metal scrap
288.127	—	7.1367	Electric wires and cables
1025.639	—	13.5915	Other non-ferrous metal products
390.046	—	1.9539	Metal products for construction
334.120	—	3.2396	Metal products for architecture
154.089	—	1.2116	Heating and cooking apparatus
1466.635	—	0.0841	Other metal products
354.187	—	1.2493	Engines and boilers
292.100	—	1.3060	Conveyors
163.791	—	2.0079	Refrigerators and air-conditioners
999.088	—	1.1483	Other general industrial machines
469.248	—	0.9604	Mining and construction machinery
267.290	—	0.9363	Chemical machinery
81.915	—	0.7810	Industrial robots
856.168	—	0.5149	Metal processing machinery
741.744	—	0.8210	other special industrial machinery
971.922	—	1.5670	Other general machines and parts
627.658	—	0.6166	Repair of general machine
501.835	—	0.4704	Official machines
115.127	—	1.0019	Machinery for service industry
1882.719	—	1.4154	Household electric machinery
1053.280	—	0.9737	Computer and accessory device
514.697	—	1.1231	Communication equipment
369.260	—	0.8910	Applied electronic equipment
1285.511	—	0.9213	Semiconductor and IC
1064.891	—	1.5684	Heavy electrical equipment
1479.873	—	1.5007	Other electrical equipment
1900.266	—	1.0195	Parts and accessory of electrical
266.573	—	0.7129	Repair of electric machinery
1645.065	—	1.2514	Passenger cars
907.248	—	1.4267	Trucks, buses and other cars
3436.517	3301.457	0.0000	Two wheel motor vehicle

5297.700	—	1.6537	Parts of motor vehicle
592.044	—	0.9633	Repair of motor vehicle
627.373	—	1.2382	Ships and its repair
141.776	—	0.5507	Railway cars and its repair
110.699	—	1.1997	Aircraft and its repair
248.494	—	1.5267	Other transportation equipment
269.605	—	0.9337	Optical instruments
11229.882	8534.679	0.0000	Watches and clocks
463.756	—	1.1878	Other precision instruments
156.438	—	1.4621	Toy and sporting goods
878.634	—	1.2412	Other manufacturing products
2261.725	—	0.7761	New residential construction
2928.321	—	0.8119	New non-residential construction
748.234	—	0.6298	Repair of construction
1375.572	—	0.6179	Public utility construction
1493.425	—	0.9734	Other civil engineering
2383.849	—	1.8287	Electric power
224.605	—	2.1624	Gas supply
5.355	—	0.8587	Steam and hot water supply
354.368	—	0.8347	Water supply
298.525	—	0.1900	Other sanitary service
6299.191	—	0.1862	Wholesale trade
3169.599	—	0.2192	Retail trade
3370.751	—	0.1244	Financial service
844.244	—	0.1542	Insurance
1396.257	—	0.1390	Real estate agencies and rent
2733.049	—	0.3075	House rent
367.861	—	0.5459	National railway transport 1
73.738	—	0.4726	National railway transport 2
226.003	—	0.3621	Local railway transport
534.862	—	0.1856	Road passenger transport
1313.971	—	0.1768	Road freight transport
577.131	—	0.3377	Self-passenger transport
604.554	—	0.3524	Self-freight transport
695.555	—	0.9607	Ocean transport
168.800	—	0.3562	Coastal transport
251.819	—	0.1793	Transport service in harbor
277.670	—	0.4752	Air transport
168.887	—	0.3102	Storage facility service
340.639	—	0.4012	Packing

419.218	—	0.2378	Other transport service
195.731	—	0.1199	Postal service
796.163	—	0.3979	Telecommunication
10.318	—	0.3473	Other services for communication
216.876	—	0.2786	Broadcasting
628.336	—	0.3622	Public administration (central)
1113.921	—	0.1481	Public administration (local)
1306.440	—	0.1809	School education and research
49.140	—	0.5163	Self education
190.276	—	0.2484	Social and other education
168.491	—	0.2807	Research institute
731.037	—	0.8206	Self-research
1922.764	—	0.4199	Medical service
261.313	—	0.2873	Social insurance
691.255	—	0.2018	Other public service
589.809	—	0.3284	Advertising agencies
714.650	—	0.1767	Information service
258.461	—	0.5359	Office machines renting
47.269	—	0.4185	Car renting
1889.949	—	0.2012	Other business service
959.084	—	0.2852	Amusement service
1526.646	—	0.3151	Eating and drinking places
401.720	—	0.3404	Hotel and other lodging places
695.456	—	0.2712	Other personal service
280.885	—	0.9299	Office supplies
1339.841	—	1.3633	Activities not classified
7325.840	—	1.7589	Export