An application of statistical methods on sustainable pricing mechanism for waste container recycling in Taiwan

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Abstract. Waste containers generated by households are recycled under 4-in-1 recycling program in Taiwan for more than 20 years. Along with the development of circular economy, waste recycling has become increasingly important. Recycling fund plays an important role in keeping the recycling system running. Developing a sustainable pricing mechanism for the recycling system is an important but sophisticated issue. This study aims to use statistical methods including sampling design, regression model, ratio estimation, and cost estimation model to carry out a sustainable pricing mechanism, which can not only reflect the reality of recycling market but also comply with circular economy. The sustainable pricing mechanism proposed by this study first considers recycling cost, recycling revenue, recycling performance, as well as balance of recycling fund, and then sets differential pricing mechanism based on the product designs and recycling technologies. It is also a floating pricing mechanism that responds to monthly economic changes. This study takes waste container recycling as an example for statistical modelling. The statistical methods used in this study can also be applied for other solid waste recycling items.

1. Introduction

Along with the development of circular economy, waste recycling has become increasingly important. Four categories of waste containers made of different materials, namely, plastics, metals (iron, aluminum), glass, and paper (paper tableware, paper boxes, aluminum foil packages) (Source: https://recycle.epa.gov.tw/en/recycling_materials_01.html) have been regulated to be recycled with 4-in-1 recycling program in Taiwan. The responsible enterprises including the related manufacturers, importers, and vendors are charged with clearance, recycling, and disposal fees to collect recycling funds for subsidizing collecting and recovering discarded containers. The recycling fund plays an important role to keep the recycling program running. How to charge responsible enterprises and how to subsidize recycling enterprises in response to the changing economic environment to make recycling efficiently running is an important but sophisticated issue. Current formula for computing fee rates considers recycling cost, administration cost, recycling revenue and financial balance of the recycling fund, of which, recycling cost and recycling revenue are the major components for calculating recycling fee rates [1].

Recycling system of the 4-in-1 recycling program in Taiwan has been explored in many previous studies [1-6]. Hsu and Kuo explored recycling charge and subsidy for recycling of waste containers in...
Taiwan [1]; estimated amount of waste containers discarded by households [2]; evaluated the recycling performance of household solid waste based on estimating total production values [3]; presented an estimation method of recycling fee rate for recycling waste home appliances in Taiwan [4]. Bor, Chien and Hsu [5] explored a recycling system which could provide market incentive for recycling waste packaging containers. Hsu [6] evaluated the recycling performance based on estimating the production value and employment opportunities of recycling solid waste in Taiwan. Lee and Hsu [7] explored the recycling system of waste container and market price effect on the recycling collection methods.

Many previous researches have been done for exploring the waste recycling. King and Murphy [8] estimated residential solid waste generation using sampling survey with stratification and corresponding estimation. Klein and Robison [9] explored the impact of solid waste disposal costs on product prices by a standard input-output technique. The study results supported that rising waste disposal costs can lead firms to reduce waste volume. Tellus Institute [10] presented that the cost of waste recycling should contain both traditional internal cost and environmental external cost, as well as established the recycling fee rates and product charge for waste recycling.

This study aims to use statistical methods including sampling design, ratio estimation, cost estimation model, and regression model to link pricing mechanism with socioeconomic variables and also comply with circular economy. The fee charges and subsidies calculated by the proposed pricing mechanism could further respond to changing economic environment and recycling market monthly. Therefore, it is also a floating pricing mechanism that responds to monthly economic changes. This study takes waste container recycling as an example to do the statistical modeling. The statistical methods used in this study can also be applied for other solid waste recycling items.

2. A recycling mechanism of solid waste in Taiwan

2.1. Recycling system

The 4-in-1 recycling program (Source: https://recycle.epa.gov.tw/en/recycling_knowledge_01.html) initialized by Environmental Protection Administration (EPA), Taiwan in 1997, which intended to combine strengths of four parties: public community, recycling enterprises, local authorities, and recycling funds into a recycling network to increase efficiency of recycling solid wastes [2]. Under the 4-in-1 recycling program, current recycling system of solid waste in terms of material flow and cash flow is shown in figure 1. The material flow shows that the solid waste generated by households is classified and distributed in three categories: recycled, un-recycled but disposed as garbage, or un-recycled and un-disposed but illegally dumped. The cash flow in figure 1 shows that the responsible enterprises including manufacturers, importers, and vendors of related containers users have responsibilities to pay the recycling fee to build up a recycling fund. The collected recycling fund is further used to subsidize recycling enterprises including collectors, collecting points, and recovery plants to do the recycling work.

2.2. Recycling fund and its performance

Recycling fund is the core of whether the recycling system can operate successfully. The cash flow in figure 1 shows where the funds come from and where the funds go to. The recycling fund consists of two major components: recycling charge and recycling subsidy. There is a formula provided by Fee Rate Review Committee for calculating recycling fee rate under the 4-in-1 recycling program. With current formula the recycling fee rate is a function of seven variables: recycling cost, un-recycling but disposed cost, un-disposed cost, transaction cost, recycling revenue, balance of recycling fund, and production volume (detailed described in [1]). Of which, the un-recycling but disposed cost (measured by garbage disposed fee) was set to zero to avoid double charges because people in Taiwan have paid garbage clearance fee. Moreover, the un-disposed cost is ignored since the amount of un-disposed solid waste is very small, therefore this component also set to zero. That is, the recycling charge only considers the recycling part but not un-recycling part in figure 1. There is no formula for calculating...
subsidy. In general, the recycling subsidy is decided to cover the collection and recycling cost and adjusted with the recycling performance in terms of recycling rate.

![Diagram of recycling system]

**Figure 1.** Current recycling system of solid waste.

**Table 1.** Announced recycling charges and subsidies\(^a\), unit: NT$/kg.

| Waste containers       | Recycling fee charge | Recycling subsidy |
|------------------------|----------------------|-------------------|
|                        | \( F \) \( S \) \( S_c \) | Remarks          |
| Iron                   | 1.64                 | 1.41             | 0.85          | Remarks          |
| Aluminum               | 1.00                 | 1.00             | 0.40          | Remarks          |
| Glass                  | 2.00                 | (A) 2.10         | (A) 1.10      | A: single color  |
|                        | (B) 1.55             | (B) 0.55         |               | B: mixture color |
| Paper                  | 3.32                 | 7.25             | 5.25          | Remarks          |
| Aluminum foiled package| 6.42                 | 7.25             | 5.25          | Remarks          |
| PET                    | (A) 8.50             | (A) 4.50         | (A) 4.50      | Remarks          |
|                        | (B) 9.35             | (B) 4.50         |               | Remarks          |
| PP/PE                  | 7.00                 | 4.50             | 4.50          | Remarks          |
| PVC                    | 87.00                | 14.00            | 4.50          | Remarks          |
| PS                     | 11.64                | 7.63             | 3.815         | Remarks          |
| EPS                    | 69.83                | 31.61            |               | Remarks          |
| PLA                    | 5.96                 | 15.17            |               | Remarks          |

\(^a\) Summarized from https://recycle.epa.gov.tw/epa/ShowPage2.aspx?sn=24.

The fee rates and subsidies have been amended many times since 1997. Current recycling charge per unit \( F \) and recycling subsidy per unit \( S \) for recycling waste containers are listed in table 1. The subsidies for recycling waste containers \( S \) include collecting and recovery subsidies which are integrated and given to recovery plants based on the certified amount. The subsidized recovery plants
are required to purchase waste containers from collectors, collecting points, or local clearing teams with a minimum purchase price ($S_c$).

The recycling funds accumulated until August 2018 and recycling rates for each waste container are listed in Table 2. The total surplus of container funds accumulated to 2018 is about NT$3.82 billion. Most of recycling funds have surplus, of which PET recycling fund has the highest surplus; whereas, funds of PS, EPS, paper, and aluminum foil package present a deficit. Table 2 also shows that these materials with fund deficits have relatively low recycling rates as well.

Table 2. Recycling rate and cumulative balance of recycling fund in 2018.

| Waste containers       | Balance of fund (Million NT$) | Recycling rate (%) |
|------------------------|--------------------------------|--------------------|
| Iron                   | 337                            | 86.25              |
| Aluminum               | 200                            | 80.67              |
| Glass                  | 520                            | 87.47              |
| PET                    | 2,030                          | 92.86              |
| PP/ PE                 | 750                            | 73.11              |
| PVC                    | 311                            | —                  |
| PS                     | -280                           | 36.48              |
| EPS                    | -190                           | 9.78               |
| Paper                  | -100                           | 60.41              |
| Paper meal box         | 540                            | 52.06              |
| Aluminum foiled package| -150                           | 55.34              |

*a Data are not available.

3. Statistical methods used for pricing mechanism

The statistical methods used for pricing mechanism in this study includes: (1) a sampling design for conducting a sampling survey to collect information about the recycling market; (2) a ratio estimation to estimate waste related quantities and obtain its distribution; (3) a regression model for price forecast; (4) a cost estimation model for cost estimation.

3.1. Sampling design

Sampling design includes the sampling methods and corresponding estimators used for estimating related parameters. A sampling survey is a basic method to collect market information but it is expensive to conduct sampling survey annually. A strictly designed sampling survey can achieve higher accuracy of estimation subject to cost constraint. A sampling survey was conducted to obtain the information about recycling market, such as amount of waste and its distribution, collecting and recycling cost, and prices of secondary materials in this study. Sampling frame consists of 617 resource collectors and 90 waste recovery plants which include register enterprises and non-register enterprises. Only register enterprises are audited and subsidized by recycling fund. Official statistics in Taiwan show that there are 303 register enterprises including 226 resource collectors and 74 waste recovery plants (Source: https://recycle.epa.gov.tw/epa_search3/Nepa_searchv21.aspx?key=10&sno=24&subno=49).

Stratified PPZ sampling (unequal probability sampling, probability proportional to auxiliary variable $Z$) [1,11] is used in this study to select more representative enterprises in the recycling market. Resource collectors are stratified by county, whereas waste recovery plants are stratified by material type they recycle. PPZ sampling uses recycling quantity in last year as an auxiliary variable for sampling probability.

The unbiased estimators for stratified PPZ sampling are displayed as following equations [11]:

$$\hat{Y}_{h,ppz} = \frac{1}{n_h} \sum_{i=1}^{N_h} \frac{y_{hi}}{z_{hi}}, \quad z_{hi} = \frac{M_{hi}}{\sum_{i=1}^{N_h} M_{hi}} > 0, \quad \sum_{i=1}^{N_h} z_{hi} = 1, \quad \hat{Y}_{ppz} = \sum_{h=1}^{H} \hat{Y}_{h,ppz}$$ (1)
\[
\hat{y}_{h,ppz} = \left(\bar{y}_{h,ppz}/N_h\right) N,
\] where subscript \( h \) denotes the stratum and \( i \) the unit within the stratum; \( z_{hi} \) is the weight of \( i^{th} \) element (i.e. resource collector or waste recovery plant) within the \( h^{th} \) stratum with its economic scale \( M_{hi} \); \( N_h \) is the total number of units in the \( h^{th} \) stratum with its economic scale \( M_{hi} \); \( N \) is the number of units in the sample of the \( h^{th} \) stratum. \( \hat{y}_{h,ppz} \) is an unbiased estimate of subpopulation total \( Y_h \); \( \hat{y}_{st,ppz} \) is an unbiased estimate of subpopulation mean \( \bar{y}_h \); \( \hat{y}_{ppz} \) is an unbiased estimator of population total \( Y \); \( \hat{y}_{st,ppz} \) is an unbiased estimator of population mean \( \bar{Y} \).

3.2. Ratio estimation

Ratio estimation is used to increase precision of estimation by taking advantage of high correlation between auxiliary variable \((X)\) and interest variable \((Y)\) when population total of auxiliary variable is known \([11]\). Therefore, this study uses ratio estimation to estimate total market recycled quantity. The estimator of ratio for total market recycled quantity to audited-certified quantity with stratified PPZ sampling is given by

\[
r_h = \frac{\hat{y}_{h,ppz}}{\bar{x}_{h,ppz}}
\]

where \( \hat{y}_{h,ppz} \) and \( \bar{x}_{h,ppz} \) are respectively sample average market recycled quantity and sample average audited-certified quantity (recovery plant) within the \( h^{th} \) stratum, and \( r_h \) is the estimated ratio for the \( h^{th} \) stratum. The ratio estimator for total market recycled quantity \( Y_h \) is given by \([11]\)

\[
\hat{Y}_h = r_h \bar{X}_h
\]

where \( \bar{X}_h \) is a true total audited-certified quantity of subpopulation for material item \( h \), and \( \hat{Y}_h \) is the estimated total market recycled quantity including certified and un-certified quantity for material item \( h \).

The un-recycled solid waste is classified into (1) un-recycled but disposed and (2) un-recycled and un-disposed. Most of the un-recycled solid waste is collected by local cleaning team and disposed with landfill or incineration. Accordingly, the un-recycled and un-disposed solid wastes are usually ignored, while the un-recycled but disposed is estimated from the component of municipal solid waste. Based on the official statistics of municipal solid waste and the ratio of waste containers to the municipal solid waste, we obtain the estimate of un-recycled waste containers \([2]\). The total generated waste consists of recycled and un-recycled quantity is thus estimated by

\[
\bar{W}_h = \bar{Y}_h + \bar{g}_h
\]

where \( \bar{W}_h \) is an estimator of total generated waste for item \( h \); \( \bar{Y}_h \) is an estimator of total recycled waste for item \( h \); \( \bar{g}_h \) is an estimator of un-recycled waste for item \( h \).

3.3. Regression model

Regression model is used to establish relationships among related prices and macroeconomic indices in recycling market, such as raw material price, secondary material price, import price index, export price index, and whole price index. The multiple regression model used in this study is shown as the following equation

\[
Y = \beta_0 + \beta_1 X_1 + \cdots + \beta_p X_p + \epsilon, \quad \epsilon \sim N(0, \sigma^2)
\]

where \( Y \) is dependent variable; \( X_1, \ldots, X_p \) are independent variables; \( \beta_0, \beta_1, \ldots, \beta_p \) are regression coefficients; \( \epsilon \) is an error term assumed to be normally distributed with zero mean and constant variance \( \sigma^2 \). Two major prices, purchasing price of waste container and price of secondary material recovered from waste container, are needed to be estimated with pricing mechanism in recycling system. It is without a doubt that purchase prices of waste containers paid by collectors or recovery
plants depends on the minimum purchase price ($S$) officially announced and related with prices of corresponding raw materials, while prices of secondary materials are related to prices of corresponding raw materials and economic indices. Using relative prices of recycling market and macroeconomic indices as independent variables in equation (6), the estimated regression equations can be used to for price forecast of recycling system.

3.4. Cost estimation model
Most of previous studies associated with the recycling cost rely on sampling survey to capture the complex nature of the cost and to comply with the reality. However, it is expensive to do a large-scale of sample survey annually. Therefore, this study intends to develop a cost estimation model for waste recycling, which is not only in response to the reality of recycling market, but also in compliance with economic theory. Many studies have developed models with production function for cost analysis, such as Cobb-Douglas cost function, CES cost function [12-14]. Moreover, Stone price index has been widely used with price modeling in related studies, such as Alston etc. [15] and Pashardes [16].

Recycling enterprises conduct recycling work will incur four major costs, namely labor cost ($PC_L$), depreciation cost of equipment ($CE_E$), storage cost ($CS_S$) and administration cost ($CA_M$). The recycling costs are assumed to be changed along with the input prices of labor, equipment, storage, and administration as follows:

$$C = f(P_L, P_E, P_S, P_M).$$

(7)

where subscripts $L$, $E$, $S$ and $M$ denote labor, equipment, storage, and administration input, respectively; $P_L$, $P_E$, $P_S$, and $P_M$ denote prices of labor input, equipment input, storage input, and administration input, respectively. The change rate for recycling cost is thus derived as

$$\frac{\partial C}{C} = \beta_L \left( \frac{\partial P_L}{P_L} \right) + \beta_E \left( \frac{\partial P_E}{P_E} \right) + \beta_S \left( \frac{\partial P_S}{P_S} \right) + \beta_M \left( \frac{\partial P_M}{P_M} \right), \sum_{i=L,E,S,M} \beta_i = 1$$

(8)

where $\beta_L$, $\beta_E$, $\beta_S$ and $\beta_M$ represent the weights of labor input, equipment input, storage input, and administration input on total cost, respectively. The cost for period $t$ ($C_t$) based on the cost in base period ($C_0$) and change rate from base period to period $t$ ($R_{0t}$) is estimated by the cost estimation model expressed as follows:

$$C_t = (1 + R_{0t})C_0$$

(9)

4. Empirical results on waste container recycling

4.1. The distribution of waste containers
The distribution and quantity of waste containers for each material are estimated with the estimators in equations (1)-(5) based upon the data collected by sampling survey in 2018. The estimation results are shown in tables 3 and 4. Table 3 show that nearly 100% of waste containers in 2018 are collected through audited-certified recycling system (about 96% of total recycled quantity) with subsidies except that of discarded iron containers and aluminum containers. Table 4 summarizes the estimates of recycled quantity in table 3 and un-recycled quantity to display the distribution of waste containers for each material item and estimate total quantity of waste containers in 2018 as well. Total generated waste containers in 2018 is estimated around 638,801 tons. Table 4 also indicates that in terms of absolute quantity, waste glass containers, waste PP/PE containers and waste paper meal boxes account have relatively high un-recycled quantities; while in terms of proportion, waste PS and EPS containers have relatively high un-recycled rate. The whole recycled rate is estimated about 78.30% in 2018 for waste containers, which is slightly higher than that of in 2017 (74.24%). In general, except waste aluminum containers most of the recycling waste containers are recycled through 4-in-1 system which has been certified and subsidized. Due to the high market value of aluminum, waste aluminum containers can be collected and recovered without subsidies.
### Table 3. Estimated total recycled amount in 2018.

| Waste containers       | $r_h$ (%) | $\hat{Y}_h$ (metric ton) |
|------------------------|-----------|-------------------------|
| Iron                   | 106.94    | 34,931                  |
| Aluminum               | -         | 16,357                  |
| Glass                  | 100.00    | 205,997                 |
| PET                    | 100.00    | 104,611                 |
| PVC                    | -         | -                       |
| PP/PE                  | 100.00    | 82,444                  |
| PS                     | 100.00    | 4,147                   |
| EPS                    | 100.00    | 783                     |
| Aluminum foil package  | 100.00    | 10,224                  |
| Paper                  | 100.00    | 9,758                   |
| Paper meal boxes       | 100.00    | 30,911                  |
| Total                  | 103.87    | 500,163                 |

* Data are not available.

### Table 4. The distribution of waste containers in 2018, unit: metric ton.

| Waste containers       | Total ($\hat{W}_h$) | Certified ($\hat{Y}_h$) | Un-certified ($\hat{G}_h$) |
|------------------------|----------------------|-------------------------|----------------------------|
| Iron                   | 40,501               | 32,665                  | 2,266                      |
| Aluminum               | 20,277               | 0                       | 16,357                     |
| Glass                  | 235,499              | 205,988                 | 9                          |
| PET                    | 112,657              | 104,611                 | 0                          |
| PVC                    | 1,238                | -                       | -                          |
| PP/PE                  | 112,771              | 82,444                  | 0                          |
| PS                     | 11,368               | 4,147                   | 0                          |
| EPS                    | 8,004                | 783                     | 0                          |
| Aluminum foil package  | 18,476               | 10,224                  | 0                          |
| Paper                  | 16,153               | 9,758                   | 0                          |
| Paper meal boxes       | 59,381               | 30,911                  | 0                          |
| Total                  | 638,801              | 481,531                 | 18,632                     |

* Data are not available.

#### 4.2. Estimates of recycling cost

The survey conducted in 2018 did not collect recycling cost information, so the cost has to be estimated by cost estimation model based on previous survey. The latest cost survey was conducted in 2013. The estimates of recycling cost in 2018 are based on 2013 sampling survey and reflect changes from 2013 to 2018. Table 5 displays the changes of related price indices from 2013 to 2018. Price changes in table 5 present corresponding input price changes for recycling waste containers.

Changes in wage indices of various industries reflect their cost changes of labor inputs. For waste recovery cost, considering the difference in wage rates across industries, each recycling item adopts the change of the wage rate of its corresponding material industry as the basis for the cost change of labor input. That is, waste recovery of iron/aluminum, glass, plastic, and paper containers adopts wage rate of metal, mining, plastic, and paper industries, respectively. For waste collecting cost, because of collection or sorting work related to service industry, the change of wage rate in service industry is thus used to reflect the change of its labor input. Besides, for both of collection and recovery cost, change in whole sale price index of energy is used to reflect the cost change of administration input; change in price index of land use for industrial area is used to reflect the cost change of storage input;
change in interest rate of loan is used to reflect the cost change of equipment input. Most of price indices in table 5 are increased except whole sale price index of energy and interest rate of loan. This implies that equipment investment and management costs for waste recycling are declining, while storage and labor costs are rising.

Based upon equations (8) and (9), the changes of related price indices from 2013 to 2018 in table 5 are used to obtain changing rates and recycling costs in 2018 shown in table 6. The change rates and recycling costs from 2013 to 2018 did not show significant changes due to offsetting results among price indices.

Table 5. Changes of related price indices from 2013 to 2018, unit: %.

| Price indices                     | 2013   | 2018   | Change of price indices |
|-----------------------------------|--------|--------|-------------------------|
| Indices of wage rate             |        |        |                         |
| Metal industry                    | 102.92 | 105.46 | 2.47                    |
| Mining industry                   | 101.65 | 104.31 | 2.62                    |
| Plastic industry                  | 101.38 | 108.35 | 6.88                    |
| Paper industry                    | 95.97  | 101.30 | 5.55                    |
| Service industry                  | 99.97  | 109.46 | 9.49                    |
| Whole sale price index of energy  | 123.31 | 102.12 | -17.18                  |
| Price index of land use for industrial area | 97.93 | 102.15 | 4.31                    |
| Interest rate of loan             | 2.22   | 1.90   | -14.41                  |

Table 6. Estimates of recycling costs in 2018.

| Waste containers    | Collection | Recovery | Total recycling cost (NT$/Kg) |
|---------------------|------------|----------|-------------------------------|
|                     | Change rate (%) | Cost (NT$/Kg) | Change rate (%) | Cost (NT$/Kg) |                          |
| Iron                | 1.00       | 3.97     | 0.89                         | 4.38          | 8.35                      |
| Aluminum            | 1.00       | 3.71     | 0.88                         | 7.44          | 11.15                     |
| Glass               | 0.96       | 2.73     | 0.92                         | 2.62          | 5.35                      |
| PET                 | 0.98       | 4.51     | 0.92                         | 9.53          | 14.05                     |
| PVC                 | 0.98       | 4.72     | 0.89                         | 9.72          | 14.43                     |
| PP/PE               | 0.96       | 3.93     | 0.92                         | 8.55          | 12.48                     |
| PS                  | 0.97       | 3.77     | 0.88                         | 9.71          | 13.48                     |
| EPS                 | 0.98       | 7.98     | 0.93                         | 8.83          | 16.81                     |
| Paper               | 0.99       | 4.15     | 0.92                         | 3.96          | 8.11                      |
| Paper meal boxes    | 0.99       | 4.15     | 0.92                         | 3.96          | 8.11                      |
| Aluminum foiled package | 0.99   | 4.03     | 0.92                         | 3.96          | 7.99                      |

*Change rate represents the growth rate from 2013 to 2018.

4.3. Estimated regression equations and related prices of recycling market

In this study, the prices of raw material are collected from market survey, purchase prices paid by collectors to purchase waste containers and prices of secondary materials recovered by recovery plants are estimated from sampling survey conduct in May 2019. Estimated prices are shown in table 7. Basically, prices of raw materials are much higher than that of the corresponding purchase prices and secondary material prices. Moreover, the purchase prices are higher than secondary material prices. Some of the purchase prices remain the same as minimum purchase price (S_c) in table 1, such as glass and paper. Basically, the price of the secondary material varies with the economy and the price of the raw materials. However, recently the price of secondary PVC has dropped to zero because the material
is not environmentally friendly. Most of the glass secondary materials are used in the glass bottle processes, so the price remains NT$1.00/kg for years.

**Table 7.** Estimated prices of purchase, raw materials, and secondary materials\(^a\), unit: NT$/kg.

| Waste containers | Raw material | Purchase | Secondary material |
|------------------|--------------|----------|--------------------|
| Iron             | 18.18        | 7.76     | 9.44               |
| Aluminum         | 70.02        | 36.67    | 60.25              |
| Glass            | —\(^b\)      | 0.55     | 1.00               |
| PET              | 34.67        | 11.70    | 25.70              |
| PVC              | 26.35        | 0.00     | 0.00               |
| PP               | 34.16        | 13.60    | 20.10              |
| PE               | 31.71        | 20.20    | 25.40              |
| PS               | 40.15        | 7.60     | 10.90              |
| EPS              | 40.15        | 24.00    | 25.00              |
| Paper            | 26.08        | 5.25     | 2.11               |

\(^a\) Raw material prices are collected from market survey, while purchase prices and secondary material prices are estimates from sampling survey in May 2019.

\(^b\) Data are not available.

The relationships between secondary material prices with raw material prices, purchase prices, and macro-economic price indices are carried out by multiple regression analysis based on monthly data from January 2017 to May 2019 for further price forecast. The estimated regression equations with the corresponding \(p\)-values of their independent variables, \(R^2\), and adjusted \(R^2\) for each recovery material except glass and PVC materials are presented in the following equations:

\[
Iron: \hat{y}_1 = 2.406 + 0.908 p w_1 \quad R^2 = 0.981, \quad \overline{R^2} = 0.980
\] (10)

\[
Aluminum: \hat{y}_2 = 28.217 + 1.009 r p_2 + 0.278 t - 0.414 w p i \quad R^2 = 0.959, \quad \overline{R^2} = 0.954
\] (11)

\[
PET: \hat{y}_3 = 41.415 + 1.870 p w_3 - 0.374 w p i \quad R^2 = 0.788, \quad \overline{R^2} = 0.772
\] (12)

\[
PE: \hat{y}_4 = -21.612 + 0.825 p w_4 + 0.300 w p i \quad R^2 = 0.801, \quad \overline{R^2} = 0.785
\] (13)

\[
PP: \hat{y}_5 = -11.949 + 0.089 p w_5 + 0.234 w p i \quad R^2 = 0.864, \quad \overline{R^2} = 0.854
\] (14)

\[
PS: \hat{y}_6 = 3.473 + 0.153 t + 0.075 r p_6 \quad R^2 = 0.802, \quad \overline{R^2} = 0.787
\] (15)

\[
Paper: \hat{y}_7 = -4.12 + 0.036 t + 0.056 w p i \quad R^2 = 0.870, \quad \overline{R^2} = 0.860
\] (16)
where $pw$, $rp$, $wpi$, $epi$, and $t$ represent variables of purchase price of waste container, raw material price, whole sale price index, export price index, and time, respectively; the subscripts 1 to 7 denote material items: iron, aluminum, PET, PE, PP, PS, and Paper, respectively.

The estimation results show that most of secondary materials have significant relationships with purchase price ($pw$) and whole sale price index ($wpi$). The prices of iron and plastic secondary materials increase as the corresponding purchase prices increase. In general, the prices of plastic secondary material are usually positively related with the whole sale price index, but the aluminum and PET with high market values show negative relationships. In addition, the prices of secondary aluminum, PS, and paper increase with time $t$.

5. Sustainable pricing mechanism

The sustainable pricing mechanism proposed by this study first considers recycling cost, recycling revenue, recycling performance in terms of recycling rates, as well as balance of recycling fund, and then sets differential recycling charges and recycling subsidies based on green design and resource recovery rates, respectively. Based on the estimated cost and recycling revenue, basic recycling charge and subsidies are calculated. The calculated recycling charges per unit proposed in this study have reflected the reality of recycling market.

The financial balance of fund and recycling rate for each recycling item in table 2 show that PET container has high recycling performance with the highest surplus of fund and the highest recycling rate. All of the un-recycled waste PVC containers are disposed by landfill or incineration. Waste containers of PS, EPS, paper, and aluminum foiled package have relatively low recycling rates and fund deficits as well. For those recycling items with recycling rate less than 60% and deficit of fund, increasing both of recycling charge and subsidy is suggested to balance budget deficit and also stimulate the recycling rate as well. Besides, PVC container is not environmentally friendly and its secondary material has no market value. Increasing recycling charge could lead manufactures to use environmentally friendly materials instead of PVC; whereas increasing subsidy could also give incentive to recyclers to collect and recover the waste PVC containers.

Taking into account recycling performance and balance of recycling fund for each recycling item, for those items with low recycling rates and high negative balance of fund, such as PS, EPS, and paper containers, the recycling charges have been increased by adding three-year amortization of fund balances; whereas for those items with high recycling rates and high positive balance of fund, such as PET, aluminum, iron, and glass containers, the recycling charges have been reduced by subtracting five-year amortization of fund balances. In addition, the recycling charges of EPS and PVC are calculated by five times of their basic recycling charges. The suggested reasonable recycling charges are displayed in table 8. Relatively high recycling charge and subsidy on EPS containers intend to balance its fund deficit of recycling waste EPS containers and also increase the recycling performance as well; whereas the high recycling charge for PVC containers intends to reduce the use of PVC material and to lead manufacturers to use environmentally friendly materials to replace PVC. The negative recycling charge in table 8 and 100% uncertified recycling in table 4 on waste aluminum containers indicate that it should be removed from recycling list.

The basic recovery subsidies are calculated based on the estimated recycling cost and adjusted by relevant economic indices described in previous section. Moreover, for those recycling items with relatively low recycling rates, such as PS, EPS, and PVC containers, the subsidies are calculated by 1.5 times of their basic recovery subsidies. The reasonable recovery subsidies are displayed in table 8. As mentioned earlier, relatively high subsidies on PVC, PS, and EPS containers intends to give incentives to enhance their recycling performances.

In order to comply with the global trend of the circular economy, the sustainable pricing mechanism uses green design of products and resource recovery rate of recycling as the basis for differential pricing. The preferential rate is calculated by adding or subtracting 10% of the general rate. The suggested recycling pricing of fee charges and subsidies for the sustainable recycling system is listed in table 8. For those manufacturers or importers with green designs, such as containers with easy
tearing of the label film, or containers containing a certain proportion of secondary materials, preferential rates can be applied. Recovery plants that use environmentally friendly technologies can apply preferential subsidies, such as recovery processes using waste reduction or pollution prevention facilities or a certain percentage of resource recovery.

Table 8. Suggested recycling pricing of fee charges and subsidies, NT$/kg.

| Waste containers | Recycling charges | Recovery subsidies |
|------------------|-------------------|---------------------|
|                  | General rates     | Preferential rates  | General rates | Preferential rates |
| Iron             | 1.60              | 1.44                | 1.41          | 1.55              |
| Aluminum         | -2.87             | 1.00                | 1.10          |
| Glass            | 1.66              | 1.49                | 2.02          | 2.22              |
| PET              | 7.80              | 7.02                | 4.41          | 4.85              |
| PP/PE            | 6.46              | 5.81                | 4.32          | 4.75              |
| PVC              | 86.58             | 77.92               | 23.60         | 25.96             |
| PS               | 14.40             | 12.96               | 11.45         | 12.60             |
| EPS              | 71.56             | 64.40               | 31.92         | 35.11             |
| Paper            | 4.56              | 4.10                | 7.18          | 7.90              |

* Data are not available.

6. Summary and conclusions

This study intends to propose a sustainable pricing mechanism for waste recycling by adopting statistical methods, which can not only link with changing economy and recycling market, but also comply with the global trend of circular economy. The sustainable pricing mechanism proposed by this study first considers recycling cost estimated by the cost estimation model, recycling revenue estimated by the estimated regression equation, recycling performance in terms of recycling rates estimated by ratio estimation, as well as balance of recycling fund, and then sets differential pricing mechanism based on green design and resource recovery rates. The suggested recycling charges and subsidies in this study include general rates and preferential rates to encourage responsible enterprises to produce green-designed products and also to encourage recovery plants to use environmentally friendly technologies for waste recycling. Study results not only propose a pricing mechanism for amending recycling charges and subsidies, but also suggest fee rates and subsidies of waste container recycling. Study results indicate that waste aluminum containers should be removed from the announced listing; recycling charge of PS, EPS and paper containers have to be increased; while the recycling charge of PET can be reduced. In addition, study results also suggest that subsidies for PS and PVC have to be increased to stimulate their recycling rate and recycling performance.

The pricing mechanism proposed by this study can also be used to calculate floating fee rates and subsidies by taking monthly relevant economic indicators into the estimated statistical models (cost estimation model and estimated regression equations) to reflect monthly economic changes. The statistical methods used in this study can also be used for other solid waste recycling items. In order to comply with circular economy and also lead recycling system to be more sustainable, differential pricing mechanism of recycling system based on the product designs and recycling technologies are suggested in this study. However, this study does not explore how to identify green-designed products and environmentally friendly recycling technologies in practice. The implementation details of differential rates are suggested for further study.

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References
[1] Hsu E and Kuo C-M 2011 TMS 2011 Annual Meeting & Exhibition (San Diego) EPD Congress 2011 (Warrendale, PA: TMS) p 1021
[2] Hsu E and Kuo C-M 2014 TMS 2014 Annual Meeting & Exhibition (San Diego) EPD Congress 2014 (Warrendale, PA: TMS) p 595
[3] Hsu E and Kuo C-M 2002 J. Minerals Mater. Char. Eng. 1 121
[4] Hsu E and Kuo C-M 2005 Waste Manage. 25 53
[5] Bor Y J, Chien Y-L and Hsu E 2004 Environ. Sci. Policy 7 509
[6] Hsu E 1999 An Analysis on Production Value and Employment Opportunities of Solid Waste Recycling Taipei Taiwan Environmental Protection Administration Technical report (EPA-044-880-129)
[7] Lee M-C and Hsu E 2009 A Life-Cycle Analysis of Waste Container Recycling System and Market Price Effect on the Recycling Collection Methods Taipei Taiwan Environmental Protection Administration Technical report (EPA-98-HA14-03-A120)
[8] King B F and Murphy R C 1996 J. Environ. Eng. 122 897
[9] Klein Y L and Robinson H D 1993 Atlantic Economic J. 21 56
[10] Tellus Institute 1991 Disposal Cost Fee Study Final Report Boston Tellus Institute
[11] Cochran W 1977 Sampling Techniques third edition (Singapore: John Wiley & Sons)
[12] Intriligator M D, Bodkin R G and Hsiao C 1996 Econometric Models, Techniques, and Applications second edition (New Jersey: Prentice-Hall)
[13] Lin C P 2002 Review of Pacific Basin Financial Markets and Policies 5 111
[14] Hassani A 2012 Applications of Cobb-Douglas Production Function in Construction Time-Cost Analysis (Lincoln, Nebraska: University of Nebraska-Lincoln) MS Thesis
[15] Alston J M, Chalfant J A and Piggott N E 2002 Appl. Econo. 34 1177
[16] Pashardes P 1993 The Economic J. 103 908