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An analysis of municipal solid waste discards in Taiwan based on consumption expenditure and policy interventions

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This paper presents a quantitative methodology and an empirical case study in Taiwan on modelling municipal solid waste (MSW) discards based on the consumption and MSW policy effects through a simultaneous equation system (SES) model. The results indicate that per capita consumption expenditures on 'food', 'household appliances' and 'amusement & education' are associated with the changes of the discards of most of the waste streams in Taiwan from 1992 to 2004. The developed model, meanwhile, identifies the effects of several important MSW policy measures. With regard to the model implication, consumers could try to reduce their unnecessary consumption, producers may rethink their responsibility on reducing MSW discards, and municipalities could evaluate the effectiveness of the existing policy measures to improve it upon based on the quantitative analysis. The backcasts and estimates of the discards of MSW streams could enable the planning, designing and executing of MSW system. The findings of this study would facilitate the consumer behaviour and support the policy design towards a low-waste-discard society.

Keywords: lifestyle changes, consumption pattern, policy effect, simultaneous equation system, municipal solid waste management

Introduction

The phenomenon of 'mass production, mass consumption, and mass disposal' has become popular in modern societies. Recent studies have established that unsustainable patterns of production and consumption are the driving factors for global environmental problems (Vitousek *et al*. 1997, Spangenberg & Lorek 2002, Wilk 2002, Rood *et al*. 2003; Schor 2005). Consumer behaviour originating from the contemporary lifestyle has great potential to increase these environmental impacts, particularly with regard to municipal solid waste (MSW) generation and discards (Cooper 2005, Gilg *et al*. 2005). Of the MSW generated by sources such as residential areas, commercial districts, office buildings, institutions, etc., a portion is either recycled or treated by the MSW producers themselves and the rest is collected and managed by the local municipalities. In the present study, the portion that is collected, treated and disposed by the municipalities is referred to as MSW discards and hence the total MSW generated comprises MSW discards and the recycled portion.

A successful MSW management system is one that minimizes the pollution and health risks. To meet this goal, municipalities of most countries take responsibility for the collection and treatment of MSW discards using clean technologies. However, the collection and treatment of MSW are usually insufficient due to a lack of complete information on the amount of MSW discards. Such deficiency leads to a serious decline in environmental quality. Hence, the estimation of MSW discards is particularly important for rational planning and designing of MSW management systems. Further-

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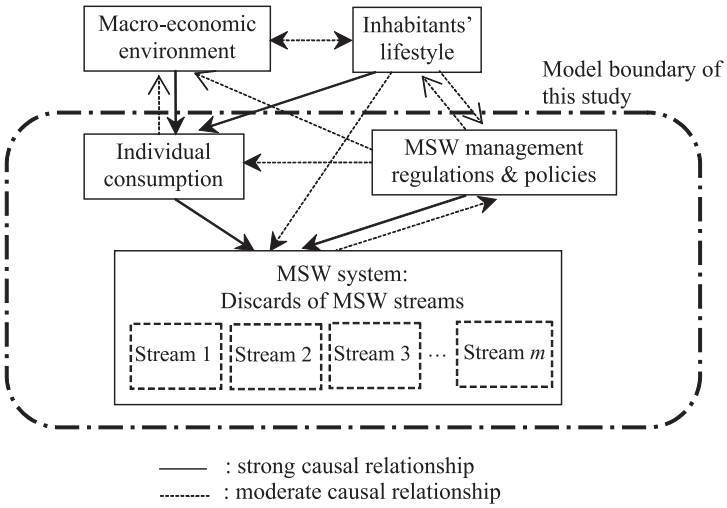

Fig. 1: The potential driving factors of MSW discards and the model boundary in this study.

more, efficient MSW policy measures can not be made unless the impacts of the influencing factors on MSW discards are analysed. In the present paper a quantitative methodology for this purpose is proposed in order to identify the relationship between the driving factors of MSW discards, in terms of both quantity and composition, and to rationally tailor the system in keeping with techno-eco-environmental considerations. Herein, an in-depth perspective of the MSW conversion process during consumption is provided in the next section. The following two sections then present a description of the econometric modelling framework, which has been designed to model MSW discards by waste stream, and the validation of the model by a case study of Taiwan where the economy is growing rapidly and the municipalities are endeavouring to manage MSW problems. The main achievements of this study are summarized in the final section.

The MSW conversion process during consumption

In order to precisely manage MSW problems, it is necessary to explore the relationship among MSW discards and the driving factors during consumption. Several characteristics can be found in the conversion process linking commodities with waste. Firstly, one commodity may become disaggregated into several categories of waste so that simultaneous consideration of the correspondence between the categories of commodities and waste composition is required. Secondly, each commodity has its own lifespan in a household, depending on its characteristics (e.g., durable or non-durable). Thirdly, during the utilization process of any commodity, part of its weight may be lost or increased before final conversion into waste. For example, the quantity of food waste may vary to a significant extent depending on the individual's diet preference. Thus, the discarding of MSW is a highly dynamic and uncertain process. These characteristics create the concept that waste comprises discarded commodities that are broken or useless, and consumer behaviour and lifestyle may play important roles in the MSW conversion process. Furthermore, consumer behaviour is influenced by macroeconomic factors. Many MSW policy measures have been instituted worldwide, and so the effects of these policies need to be considered and analysed when modelling MSW discards. Efficient MSW policy measures may change consumer behaviour and lifestyle, so that waste reduction can be achieved. Based on these observations, the relationship among potential factors of MSW discards is demonstrated in Figure 1, and the present study focuses on the interaction among MSW discards, consumption and the effects of MSW policy measures.

It is beneficial to use physical quantities of commodities to estimate MSW discards, but the relevant data is rarely available. Alternatively, monetary data could be used as a substitutive indicator. Some studies have used the income level, for example, the gross domestic product (GDP), to estimate MSW generation (Dyson & Chang 2005, Beigl *et al*. 2008), but a proportion of an individual's income may be deposited or invested. Thus, consumption expenditure may be regarded as a relatively direct indicator – a similar concept is suggested by Daskalopoulos *et al*. (1998) and UNEP (2006). Next, it is necessary to develop a quantitative model to reflect the MSW conversion process.

Model development

Many quantitative approaches have been established to model MSW generation for different purposes; for example, to identify the relationships among the influencing factors by regression analysis (Daskalopoulos *et al*. 1998, Chen & Chang 2000, Bandara *et al*. 2007, Beigl *et al*. 2008), and to analyse the behaviour of MSW generation by time series analysis and system dynamics (Chang & Lin 1997, Navarro-Esbrí *et al*. 2002, Dyson & Chang 2005, Chao 2008). Although these studies attempted to correlate waste quantity with logically relevant factors, the MSW conversion process during consumption could not be well presented in the models, without simultaneously considering consumption and policy effects for the respective waste stream. Although some models have been developed for MSW streams by multi-equation regression

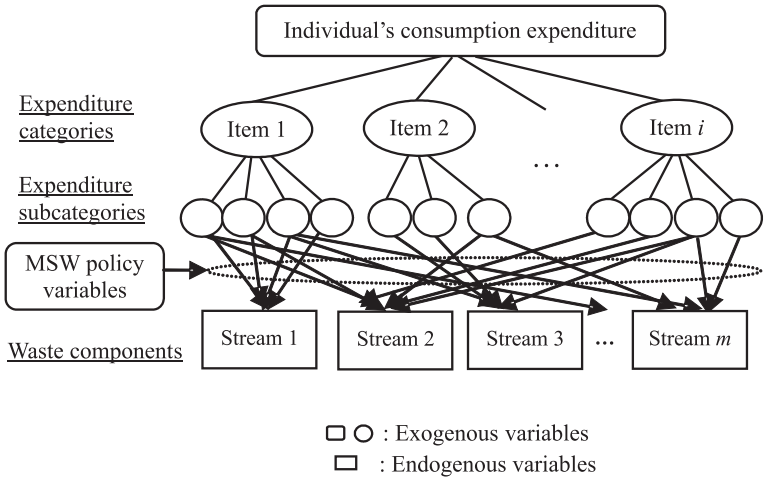

Fig. 2: The model diagram of MSW discards.

(Daskalopoulos *et al*. 1998, Bandara *et al*. 2007) the established single-equation models do nor readily account for the potential cross-equation correlations, namely the endogeneity among waste streams, and so bias might exist in their estimations. Hence, this study introduced the simultaneous equation system (SES) approach to account for the potential endogeneity among MSW streams, so that ultimately the phenomenon of MSW discards could be described precisely and accurately.

Model formulation

The SES model can be constructed by two types of model structure, namely the recursive equation system (RES) and the seemingly unrelated regression (SUR) system. With a structural formulation, the RES allows one explained variable of one equation to be an explanatory variable in other equations in order to represent the endogeneity among the explained variables. However, the SUR represents the endogeneity among the equations by linking the error terms.

In this study, a SES model was constructed based on the SUR system because in the SUR, specific explanatory variables could be selected in each equation according to the respective waste conversion process. Thus, the SUR system provides a more reasonable and flexible model structure than the RES for the MSW conversion process. Using the SUR system, a model diagram of the SES model describing the MSW conversion process is presented in Figure 2.

Equations to represent the waste streams form the equation system, which is represented as follows:

$$WE_{m,t} = \omega(x_{c,t}, z_{k,t}) \quad \forall\, m, c, k \tag{1}$$

where $WE_{m,t}$ is the row vector of the amounts of MSW discards by fraction in year t; $x_{c,t}$ is the column vector composed of an individual's related consumption expenditure on a category or subcategory c in year t with regard to the waste conversion process; $z_{k,t}$ is the column vector of policy variables, including dummy or continuous variables; ω is the corresponding MSW conversion function.

In order to make the model implications straightforward and explicit, the equations adopt the linear form and are formulated as follows:

$$WE_{m,t} = \alpha_m + x_{c,t}{}^{\mathrm{T}}\delta_c + z_{k,t}{}^{\mathrm{T}}\zeta_k + \varepsilon_{m,t} \quad \forall\, m, c, k \tag{2}$$

where α_m, δ_c, and ζ_k are the column vectors of the parameters; $\varepsilon_{m,t}$ is the row vector of the error terms.

By such formulation, the coefficient of one explanatory variable designates its marginal impact on the explained variable in the equation; that is, how much the explained variable would change if the explanatory variable was varied by one unit.

Model estimation and statistical diagnosis

Kiviet & Phillips (1996) have argued that the estimators in the equation system would be biased by the ordinary least squares (OLS) method if the cross-equation correlations exist. Even with a small number of datasets, similar conclusions have also been suggested in recent studies (Weng & Chang 2001, Hanna 2007, Chang 2008). In the present study, the equation system is initially estimated by the OLS method, and then estimated with the SUR method. The SUR estimation which involves the generalized least-squares (GLS) estimation gives consistent and efficient estimators for the SES model which is formulated in the SUR (Pindyck & Rubinfeld, 1998). Comparing the results from the OLS and SUR estimation, the endogeneity among the MSW streams would be confirmed.

The *t*-test is used to judge the significance of the estimator of the respective parameters. The adjusted coefficient of determination (adjusted R^2) is used as the measurement of the 'goodness of fit' for each equation. The mean absolute percentage error (MAPE) is used to evaluate the variance between the estimates and the true values of the endogenous variables. MAPE is calculated as follows:

$$\mathrm{MAPE} = \left(\frac{1}{N} \sum_{s=1}^{N} \frac{|\hat{Y}_s - Y_s|}{Y_s} \right) \times 100\%$$

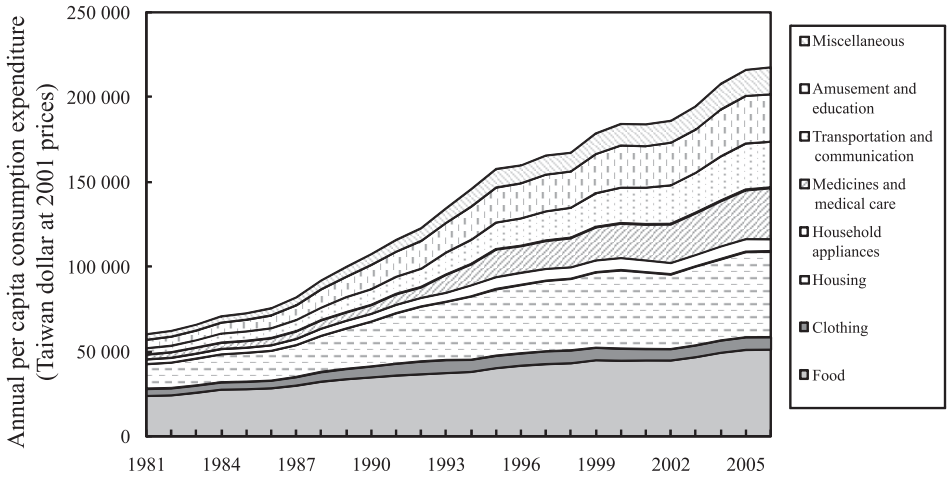

Fig. 3: The structure of the individual's consumption expenditure in Taiwan: 1981 to 2006.

where Y_s and $\hat{Y}_s$ are the original series and the model fitting values, respectively; N is the length of the series.

The model credibility is confirmed by a higher value of adjusted R^2, a lower value of MAPE, and significant t values of the parameters. Further, some statistical tests are used to diagnose the validity of the regression results in terms of the best linear unbiased (BLU) estimators (Bronwyn & Clint 2005). The Lagrange multiplier (LM) test is to diagnose the heteroscedasticity within the error terms, and the smaller values of LM statistics confirm the normality of the error terms. The potential multicollinearity among the explanatory variables is evaluated by examining the significances of the parameters. Multicollinearuty problem may arise if most of the parameters are insignificant but a high adjusted R^2 value is fitted simultaneously in an equation. The Dubin–Waston (DW) statistics are used to evaluate the degree of serial correlation among the error terms (e.g., close to 2).

Case study

Background of the case study area

Taiwan is a small island with limited natural resources, but with one of the densest population in the world, namely 637 persons per km^2 (TDGBAS 2009a), imposing high pressures on the environment. The rapidly progressing industrialization and urbanization in Taiwan have caused dramatic changes in all perspectives of life, including people's lifestyle, consumer behaviour and MSW discards. The official per capita consumption expenditure data in Taiwan (TDGBAS, 2009b) were analysed during model development. Figure 3 presents the time series plots of the major expenditure categories from 1981 to 2006, and the increasing trends of the expenditure categories can be observed.

The Taiwan Environmental Protection Administration (TEPA) has issued fundamental laws and supportive regulations to manage the MSW problems, and policy measures using economic instruments such as deposit, green-label, charges and fees, etc., have been launched to control the rapidly growing amount of MSW (Bor *et al*. 2004, Lu *et al*. 2006, TEPA 2009a). Furthermore, non-governmental groups have played an important role in local recycling programmes. Waste composition data is reported from 1992 to 2004 on a dry basis whereas per capita overall MSW discards data are available from 1988 to 2006 (TEPA 2009b). Figure 4 illustrates the official records of the composition structure of MSW discards in Taiwan, and the overall MSW discards started to decrease in the last decade. The definition of MSW in Taiwan is based on a collection process, consisting of general waste from the households, commercial shops, office buildings, institutions, etc. In the present study, MSW is classified into eight categories based on the physical properties, for example, paper, metal, plastics, etc.

Model development for Taiwan

The SES model was developed in four steps. The first step was to design a reasonable equation system for the MSW streams. The related consumption expenditures on the respective MSW streams were used as the consumption variables, and both discrete and continuous types of indicators reflecting policy interventions or the citizens' environmental consciousness were considered as the policy variables. Table 1 presents descriptions of the candidate variables in the model development. Three important policy measures were used as dummy variables to analyse their impacts on MSW discards. In addition, a continuous variable, the recycling rate of MSW generation for all the waste streams ($Recy_t$), was considered as a policy variable because it is a policy target of MSW management and an indicator for public environmental consciousness. The incineration rate of MSW discards for all the waste streams, $Inci_t$, was also used as a policy variable. The higher incineration rate would imply the extent to which the local municipalities endeavoured to manage the recycling programmes to achieve stable operation of incinerators. Trends in the recycling rate and the incineration rate are reported in Figure 5 (TEPA 2009b). As important policy targets, both the indices have been promoted rapidly in the past two decades. However, some influencing local measures, for exam-

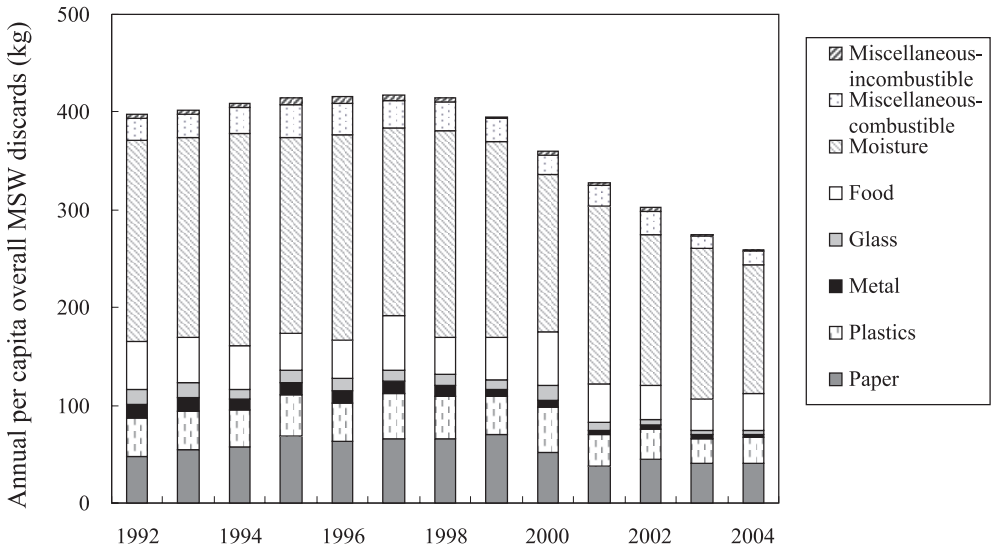

Fig. 4: The structure of per capita MSW discards in Taiwan: 1992 to 2004 (on a dry-basis).

Table 1: Descriptions of variables for the model development.

Variable	Description	Unit
$WE_{m,t}$	Annual per capita MSW discards by eight categories in year t. m = paper, plastics, food, moisture content, miscellaneous combustible items (abbreviated as 'mis-c'), metal, glass and miscellaneous incombustible items (abbreviated as 'mis-inc').	kg
$Cons_t$	Annual overall per capita consumption expenditure in year t.	10^4 Taiwan dollar (NT$) at 2001 prices
Fd_t , AE_t	Annual per capita consumption expenditure on 'food' and 'amusement & education', respectively, in year t.	10^4 NT$ at 2001 prices
FAE_t	The summation of Fd_t ('food') and AE_t ('amusement & education') in year t.	10^4 NT$ at 2001 prices
Mis_t	The summation of annual per capita consumption expenditure on the subcategories of 'miscellaneous food commodity', 'beverages', 'furniture' and 'household durable equipment' in year t.	10^4 NT$ at 2001 prices
Dum_1	Dummy variable for the 'Resource Recycling Four-in-One Project' action; before 1997, the value is zero and 1 otherwise.[a]	none
Dum_2	Dummy variable for the 'Restrictions on the Use of Plastic Bags' action; before 2001, the value is zero and 1 otherwise.[a]	none
Dum_3	Dummy variable for the 'Mandatory Household Classification and Food Waste Recycling' action imposed in Taipei city; before 2003, the value is zero and 1 otherwise.[a]	none
$Recy_t$	The recycling rate of MSW generation: the ratio of recycled MSW in MSW generation in year t, a continuous variable.[b,c]	%
$Inci_t$	The incineration rate of MSW discards: the ratio of MSW discards treated by incineration in MSW discards in year t, a continuous variable.	%

[a]Considering policy measures would be executed one year previously for some example area, the setting of activating the dummy variables are one-year ahead of the formally bulletined year.
[b]Several types of materials are officially bulletined as mandatory recycle waste in Taiwan, including: (a) containers or materials that are bulletined by the municipalities except for the lubricant; (b) paper products; (c) iron products; (d) aluminium products; (e) glass products; (f) plastics (products made of PET, PE, PVC, PP, and PS except for plastic bags); (g) disc; (h) mobile phone; (i) recharger of the mobile phone.
[c]In this study, MSW generation is the summation of MSW discards and MSW recycled.

ple, 'Keep Trash off the Ground', 'MSW Treatment Fee Charged by Collection Bags' and 'Decrease of MSW Collection Frequency', are not considered in this country-wide model.

In formulating the equation of paper waste discards, the individual's consumption expenditure on 'amusement and education' (AE_t) could be considered to increase the amount of paper waste discards. Meanwhile, the dummy variable representing 'Resource Recycling Four-in-One Project', Dum_1, may have a reducing impact on paper waste discards because this measure promotes recycling activities on paper waste and improves the citizens' environmental awareness. Similarly, the overall recycling rate ($Recy_t$) has a reducing impact on paper waste discards. Hence, the above variables were

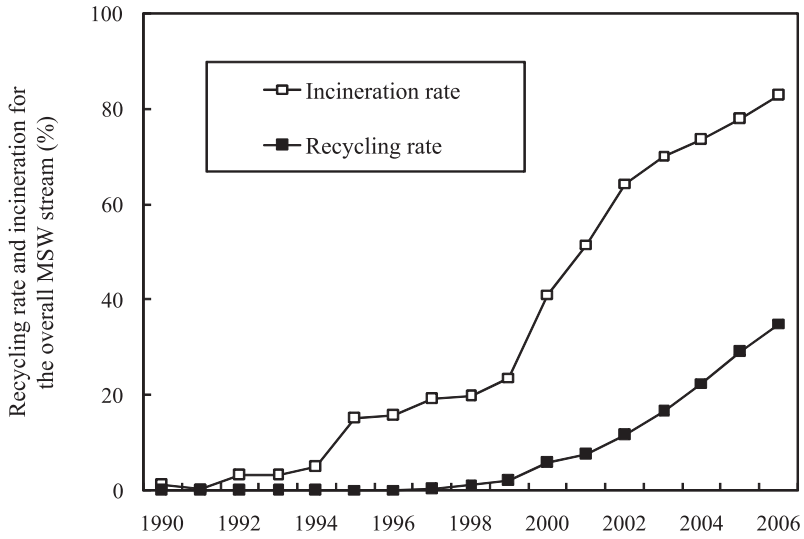

Fig. 5: Historical trends of the recycling rate of MSW generation and the incineration rate of MSW discards in Taiwan: 1990–2006.
Note: Both the recycling rate of MSW generation and the incineration rate of MSW discards are for the overall MSW stream since data for respective waste stream is not available.

Table 2: Explanatory variables selected in the equations for MSW streams.

Equation for MSW streams	Explanatory variable	
	Consumption variable	Policy variable
Paper	AE_t	$Recy_t$ and Dum_1
Plastics	FAE_t	$Inci_t$ and Dum_2
Food	Fd_t	$Inci_t$ and Dum_3
Moisture	Fd_t	$Inci_t$ and $Recy_t$
Metal	Mis_t	$Inci_t$
Glass	Mis_t	$Inci_t$
Miscellaneous combustibles	$Cons_t$	$Recy_t$ and Dum_1
Miscellaneous incombustibles	Mis_t	$Recy_t$ and Dum_1

considered when developing the equation of paper waste discards. Subsequently, the equation of the respective waste stream was formulated considering its influencing variables. Table 2 reports the specific explanatory variables selected for each MSW stream.

The second step was to divide the datasets into three periods: during the estimation period (1992–2004), the relationships among the variables were to be defined; during the ex-post forecast period (2005–2006), the prediction performance of the model was tested; during the backcast period (1981–1991), the historical data of the explanatory variable was used to model the past quantities of the discards of MSW streams.

The third step was to choose an appropriate modelling approach to solve the equation system by using the dataset during the estimation period. The estimation was performed with the statistical software TSP® 5.0. The equations were initially estimated by the OLS method, respectively, in the context of the single-equation models. Some expenditure items were merged rationally to avoid any multicollinearity problems in the fitting process. Table 3 reports the OLS estimators and regression diagnosis. Considering the potential cross-equation correlations, the equations were solved by the SUR method through the SES approach. The results are shown in Table 4.

In Tables 3 and 4, most of the parameters have significant estimators at 5% confidence level or better with rational signs in both single-equation models and the SES model. Both models generate estimates of MSW streams with acceptable variances. The LM statistics and the DW statistics from the OLS and SUR estimation certified the BLU properties of the estimators. By examining the *t* statistics, more convincing estimators of the parameters were obtained from the SUR estimation than the OLS outcomes. Moreover, the adjusted R^2 values were greatly improved in the SUR estimation for all the equations. Based on these observations, the endogeneity among MSW streams was confirmed by the SES approach, and the SES model was used for further analysis.

The fourth step was to validate the SES model during the ex-post forecast period (2005–2006). MAPE was measured for per capita overall MSW discards, and the results are shown in Table 5. The small values of MAPE implied that the SES model was credible. It should be noted that the MAPE of the overall MSW discards was possibly smaller than that of the respective MSW stream. As both overestimates and underestimates might be generated for MSW streams, there would be a counterbalance for the overall MSW discards.

Interpretation of results

After statistically validating the SES model, the outcomes were important for the MSW management system. The SES model not only quantified the MSW conversion process but also served as an estimation tool.

Table 3: Results of the single-equation models for MSW streams by the OLS method.

Explanatory variables		Explained variables (MSW streams)							
		$WE_{paper,t}$	$WE_{plastics,t}$	$WE_{food,t}$	$WE_{moisture,t}$	$WE_{metal,t}$	$WE_{glass,t}$	$WE_{mis\text{-}c,t}$	$WE_{mis\text{-}inc,t}$
Consumption variable	AE_t	30.805 (17.35**)	–	–	–	–	–	–	–
	FAE_t	–	7.130 (22.43**)	–	–	–	–	–	–
	Fd_t	–	–	11.965 (13.79**)	55.193 (24.39**)	–	–	–	–
	Mis_t	–	–	–	–	25.101 (15.51**)	24.206 (10.40**)	–	10.336 (10.55**)
	$Cons_t$	–	–	–	–	–	–	1.914 (18.17**)	–
Policy variable	Dum_1	–4.729 (–0.84)	–	–	–	–	–	–5.321 (–2.09)	–1.991 (–2.40*)
	Dum_2	–	–11.438 (–2.39*)	–	–	–	–	–	–
	Dum_3	–	–	–3.743 (–0.50)	–	–	–	–	–
	$Inci_t$	–	–0.171 (–1.78)	–0.254 (–2.15)	–1.359 (–2.38*)	–0.167 (–7.22**)	–0.121 (–3.63**)	–	–
	$Recy_t$	–2.126 (–5.85*)	–	–	–1.225 (–0.79)	–	–	–0.973 (–5.96**)	–0.134 (–2.39*)
LM heter.		0.002	0.54	2.86	1.16	1.19	0.08	0.42	3.16
DW statistic		1.20	2.09	2.45	1.82	1.67	1.65	1.79	1.78
MAPE (%)		10.50	6.81	11.22	5.75	16.27	17.20	11.82	25.98
Adjusted R^2		0.582	0.763	0.087	0.768	0.788	0.399	0.700	0.676

Values in the parentheses denote the *t* value.
* and ** denote significance at the 5 and 1% levels, respectively.
LM heter. denotes the LM statistic for heteroscedasticity.

Evaluation of the influencing factors

Based on the estimators of the parameters of the explanatory variables, the quantitative effects of specific consumption expenditure on the discards of the corresponding MSW streams could be clearly seen in the equation system.

Statistically significant and positive signs of the consumption variables indicate that consumption drives the quantities of the discards for all waste streams. From Table 4, the individual's consumption expenditures on 'food', 'household appliances' and 'amusement & education' increased the amount of discards for most of the MSW streams. Thus, efficient waste reduction could be achieved if potential excess consumption was eliminated. Based on the estimators in Table 4, a decrease of individual expenditure by 10^4 NT$ (at 2001 prices) on AE_t would result in a decrease of annual per capita paper waste discards by 30.75 kg. Similar implications could be obtained from each equation. Using the above information, policy-makers could propose policy incentives or impose regulations to promote environmental awareness among citizens and to modify the unsustainable consumption and production. Furthermore, consumers could find suggestions to help them to evaluate their expenditure on specific categories, which yield large MSW discards, and producers may try to reduce waste within the production and transportation of the goods, for example, by reducing excess packaging materials. In addition, the life spans of the products could be prolonged by considering the concepts of 'dematerialization' and 'slower consumption' (Ayres & van den Burgh 2005, Cooper 2005).

Based on the parameters of policy variables, substantial policy implications could be found for the municipalities. Statistically significant and negative signs in the policy variables in Table 4 imply that MSW policy interventions improve the reduction of the discards of MSW streams, particularly on plastic waste and the moisture content of waste. The policy effects of the measures are successfully identified in the SES model. The outcomes indicate that the recycling activities have been increased, and citizens have gradually changed their habits during consumption. However, policy-makers may propose adequate substitutes for plastic packaging materials and supply sufficient administrative budgets to local municipalities for the enforcement of relevant regulations. In addition, policy measures promoting the recycling activities would benefit waste reduction by increasing the environmental consciousness of society. As the promotion of recycling rate is an important policy target in Taiwan, eco-

Table 4: Results of the SES model for MSW streams by the SUR method.

Exogenous variables		Endogenous variables (MSW streams)							
		$WE_{paper,t}$	$WE_{plastics,t}$	$WE_{food,t}$	$WE_{moisture,t}$	$WE_{metal,t}$	$WE_{glass,t}$	$WE_{mis\text{-}c,t}$	$WE_{mis\text{-}inc,t}$
Consumption variable	AE_t	30.751 (23.70**)	–	–	–	–	–	–	–
	FAE_t	–	7.228 (32.45**)	–	–	–	–	–	–
	Fd_t	–	–	12.100 (17.24**)	55.255 (41.37**)	–	–	–	–
	Mis_t	–	–	–	–	25.414 (17.36**)	24.830 (11.87**)	–	10.725 (15.31**)
	$Cons_t$	–	–	–	–	–	–	1.923 (25.72**)	–
Policy variable	Dum_1	–3.689 (–1.26)	–	–	–	–	–	–5.888 (–5.29**)	–2.679 (–5.96**)
	Dum_2	–	–10.517 (–6.26**)	–	–	–	–	–	–
	Dum_3	–	–	–1.556 (–0.43)	–	–	–	–	–
	$Inci_t$	–	–0.201 (–4.36**)	–0.287 (–3.53**)	–1.358 (–6.02**)	–0.173 (–8.27**)	–0.132 (–4.42**)	–	–
	$Recy_t$	–2.205 (–7.79**)	–	–	–1.255 (–1.67)	–	–	–0.932 (–8.15**)	–0.096 (–2.41*)
LM heter.		0.01	0.80	2.06	0.23	1.28	0.24	1.05	1.68
DW statistic		1.20	2.17	2.44	1.85	1.68	1.66	1.91	1.61
MAPE (%)		10.59	6.76	10.70	5.73	16.58	17.42	11.69	31.53
Adjusted R^2		0.679	0.817	0.300	0.814	0.823	0.504	0.768	0.732

Values in the parentheses denote the *t* value.
* and ** denote significance at the 5 and 1% levels, respectively.
LM heter. denotes the LM statistic for heteroscedasticity.

Table 5: Model verification for the SES model for per capita overall MSW discards.

Per capita overall MSW discards	MAPE (%)
Estimation period (1992–2004)	2.48
Ex-post forecast period (2005–2006)	3.04

nomically efficient recycling industries and markets for recycled and reused materials may be promoted in the next stage.

Estimation of MSW discards and remarks

By using the established SES model, estimating per capita MSW discards by fraction was possible at every point of time. Moreover, by adding up the discards of MSW streams, per capita overall MSW discards could be estimated. With the historical records of the explanatory variables, both the estimation for annual per capita MSW discards by waste stream and the overall MSW discards were calculated and the results are presented in Figures 6 and 7, respectively. The major trends of MSW streams are modelled in the figures, and the backcasts of MSW discards could help decision-makers to understand the past situation when no records were available.

In terms of future application, the estimation of MSW discards is important for rational planning and designing of the MSW management system; for example, the capacity planning of treatment and disposal facilities and the estimation of potential environmental impacts on the MSW management system. Even, future projections of MSW discards could be achieved with the projections of the explanatory variables. In addition, the current waste estimation model could be coupled with other models of consumer behaviour, so that the impact of the changes of consumption on MSW discards could be evaluated. Furthermore, potential quantities of resources in waste could be evaluated using the estimates of relevant MSW streams, and specific recycling programmes could be further proposed. However, the effects of prospective policy measures on the reduction of MSW discards could not be precisely accounted for in the established SES model until updated data is available.

Conclusion

This paper presents a methodology and a case study of Taiwan to quantify the relationships between consumption, policy measures and MSW discards. Precise estimates of per capita MSW discards were obtained through the SES approach. The analysis results suggest that as individual's consumption

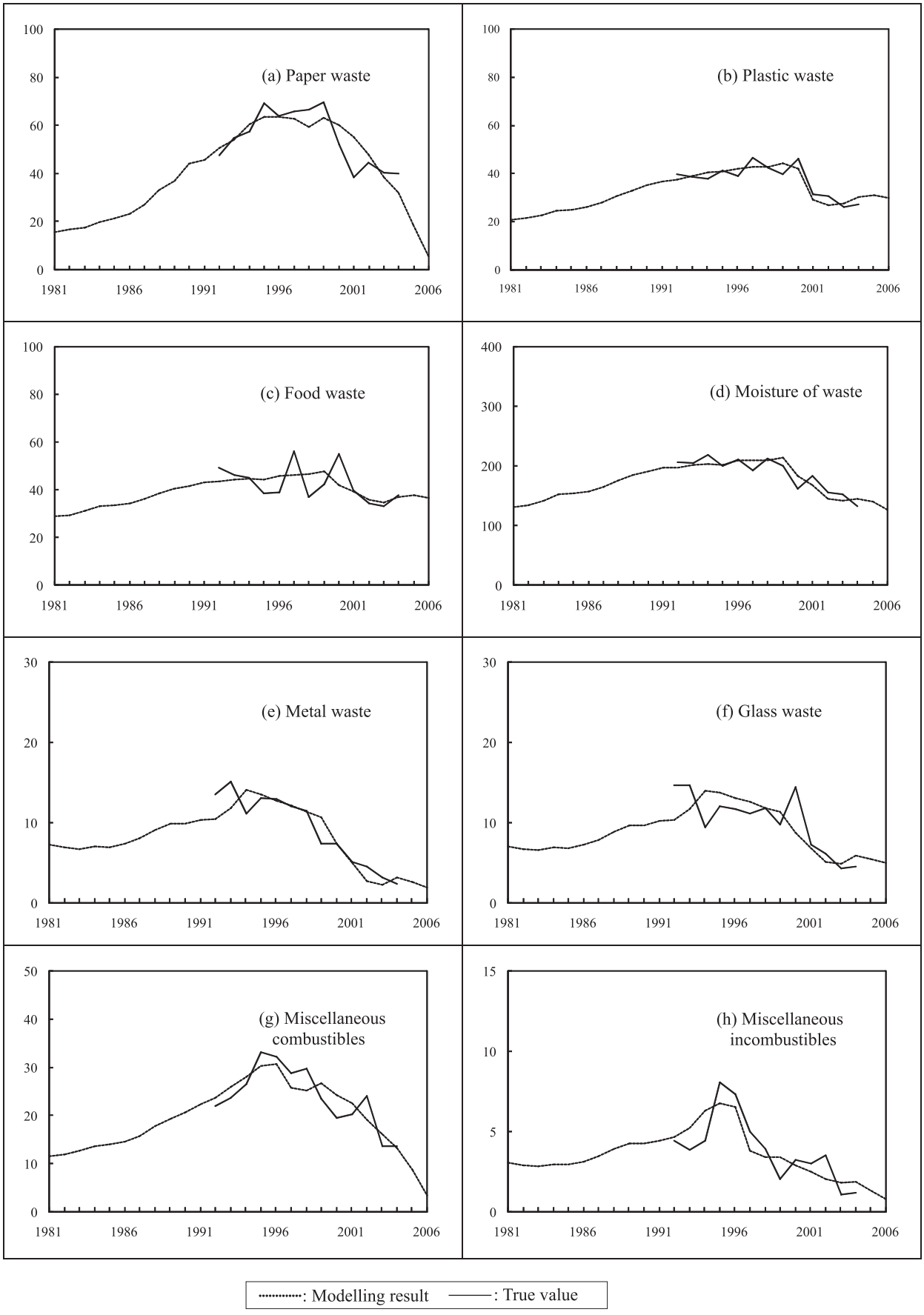

Fig. 6: Model fitting results of the SES model for MSW discards by waste stream: the horizontal axis denotes time (year); the vertical axis is the annual per capita MSW discards (kg).
Notes: (a) The backcast period, estimation period and ex-post forecast period denote the period of 1981–1991, 1992–2004, and 2005–2006, respectively. (b) Since the method of MSW composition analysis changed based on a wet basis from 2005, there are no official records for dry-basis MSW composition data during the ex-post forecast period.

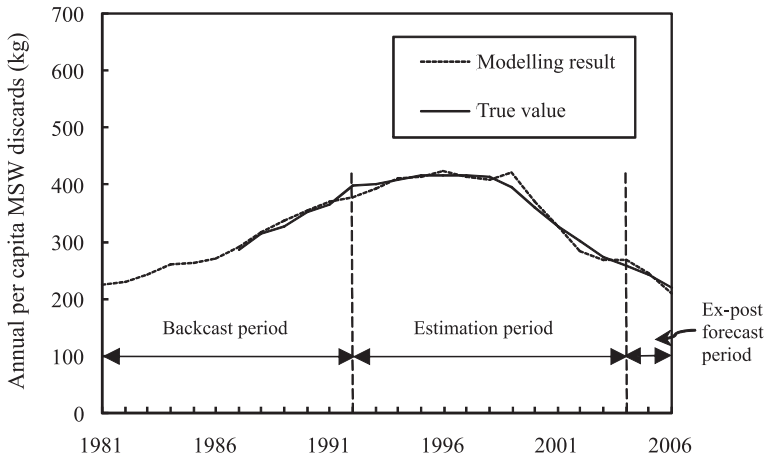

Fig. 7: Model fitting results of annual per capita overall MSW discards by the SES model.

expenditures on 'food', 'household appliances' and 'amusement & education' are associated with the changes of MSW discards in Taiwan over the period. The results also identify the effects of the important MSW policy measures aimed at reducing the discards for waste streams. Based on the model outcomes, consumers should try to eliminate unnecessary consumption by considering waste reduction so that a sustainable consumption behaviour or lifestyle can be developed, and policy makers should evaluate the effectiveness of existing policy measures and improve upon them.

The findings of this study can contribute to the promotion of a low-waste-discard society by: (1) creating strategies to facilitate consumer behaviour based on the quantitative relationship between individual consumption and MSW discards with regard to achieving a more sustainable consumption and lifestyle; (2) planning of the MSW management system for (a) capacity planning of MSW treatment facilities, (b) evaluation of the environmental impacts, such as greenhouse gas emission, from MSW management system, and (c) the estimation of potential resources of waste within MSW discards. However, insufficient data limited the capability of the model to describe the characteristics of the MSW conversion process. A detailed database for the consumption process is required. In addition, such a country-wide model does not readily account for the effects of local MSW policy measures, but this could be achieved by using the established methodology to develop local-scale models. The effects of some prospective policy measures could also be evaluated by using the proposed methodology.

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