Projecting municipal solid waste

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Title: **Projecting municipal solid waste: the case of Hong Kong SAR**

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ABSTRACT:
Waste projection informs waste policy making and is an indispensable process in waste management planning. Between the two major methodological approaches in forecasting MSW generation, the time-series approach uses past data and their distribution to determine future waste trends. The factor model on the other hand explains and predicts waste arisings with explanatory variables such as socio-economic factors of the waste generators. This latter approach not just aims at making predictions on waste quantities, it also aims at unveiling hypothetical causal relationships between factors for the prediction of waste arisings. Thus, it is more sophisticated and intellectually sound.

In this study, results of previous waste projections conducted by the Hong Kong's environmental authority on domestic, commercial and industrial waste growth are verified against actual waste data for determining the accuracy of these predictions. In addition, using the MSW data from 1979-2007 as the reference paths, two autoregression models, a factor-model based technique, were developed to simulate commercial, industrial and domestic waste disposal for the period 2008 to 2036 for Hong Kong SAR. While the use of multiple factor autoregression model appears to have rectified the over-estimation tendency of classical linear regression model, a number of empirical and data constraints which are also typical of other factor-model based techniques are encountered.
(208 words)

KEYWORDS: municipal solid waste, waste projection, classical linear regression, autoregression, factor models, time series models

1. Introduction

Waste projection is an important process in waste management. Reliable prediction of future waste arisings raises the effectiveness of waste management planning and enhances of the efficiency of waste facilities. Waste projection results are often used to provide justification for specific waste policy measure formulation and in the planning of waste treatment and recycling facilities and collection service. Equipped with an accurate projection of the waste type and their quantities, policy makers are then able to understand the dimension and scale of the problem and make informed decisions. In reality, decision makers often are to make decision based on unverified projection data however. It is because usually the projection covers periods very distant into the future and few waste management decision making bodies would have the luxury to wait for decades to validate a methodology before using it to make planning decisions. Thus, it would be useful if the accuracy of waste projection method can be verified against actual data for informing decision makers the reliability of such a method.

In this study, after a review of two standard methodological approaches in municipal solid waste (MSW) projection, there is a validation of former MSW forecasts conducted for Hong Kong against actual waste disposal data of the corresponding year. The validation serves to illustrate the limitations in one of the waste projection methods. The second part of this paper is a demonstration on the use of autoregression, a factor-model based method, to project MSW arisings for Hong Kong SAR and how some noted limitations can be rectified or overcome. This paper will conclude by discussing the uncertainties of and the lessons learnt from this study in waste projection.

2. Methodological review

2.1 Time series models and their pros and cons

There are two major methodological approaches in forecasting MSW generation. The first one involves the use of past data and their distribution to determine future waste trends. Time series analysis is a typical example of such methodological approach. Specific techniques include various curve estimation techniques (S-, cubic, quadratic, linear curve etc.), exponential smoothing and Auto-Regressive Integrated Moving Average (ARIMA) models. In these techniques, “time” is used as a predictor variable. Annual, monthly or even daily waste data can be used in such analyses. Previous experience in the application of time series analysis on waste arising projection was that seasonal-ARIMA and non-linear technique were found to produce good results in terms of predictive accuracy and cumulative errors (Navarro-Esbrí et al., 2002). Similarly, time-series analyses were noted to generate valid prediction of the seasonal impacts (Matsuto and Tanaka, 1993; Navarro-Esbrí et al., 2002) or weekly waste collection service patterns (Katsamaki et al., 1998) up to two years’ time if daily waste data were used. Using geometric lag time-series analysis Chang et al. (1993) found that a negative relationship existed between average waste generation per capita per day and total population. As a relatively straightforward technique, the S-curve technique is the best method to make waste projection for up to 50 years (Bridgwater, 1986).

One of the advantages of time-series analysis is its flexibility - that it admits waste data measured at any kind of meaningful intervals. Another advantage is that it requires only few types of data. In many cases, only data for two variables are needed: time and the past pattern of the key variable to be predicted. However, it is essentially because of the dispensability (or actually inability to include) of other potentially influential explanatory variables that even if a particular curve (and thus trend) is found to explain well the past behaviour of a variable, there is no convincing reasons why the future trend of the variable to be predicted will assume that shape. Such deficiency persists even in more sophisticated models where a leading indicator is used. A leading indicator is a series (of data) that helps predict the value of another series one or more time periods later (SPSS Inc., 1999). The lack of empirical justification in the predicted future waste trend is a major deficiency of using time series analysis in public policy making because the credential of the decision made based on those results are hampered. From the waste management perspective, the prediction made with time-series analysis also lacks power of generalization and intellectual values. Furthermore, a relatively large number of observations are required for the more sophisticated time-series models. For instance, 50-100 equally spaced observations are required for ARIMA (Box and Jenkins, 1976; Box et al., 1994; Granger, 1989). However, the greater the availability of data for formulating the waste trend and for validating the predicted trend, the more accurate the results will be for the ARIMA method. Thus, if only annual waste data are available, then data availability may limit the application of time-series analysis.

2.2 Factor models and their pros and cons

The second approach uses factors such as socio-economic and other explanatory variables to explain and predict waste arisings. This approach does not just aim at making predictions on waste quantities, it also aims at unveiling hypothetical causal relationships between factors for the prediction of waste generation. Thus, it is more sophisticated and intellectually sound than the time series approach. Informed by published literature, explanatory variables for forecasting MSW generation rate include household size, residency type, age groups, employment, electricity consumption, tipping fees, consumer price index (CPI), gross domestic product (GDP), education, culture, geography and climate. Among these, factors more relevant to this study include GDP, age distribution of the population, CPI, population, accommodation type, household size, and weather. Population has been considered as one of the most important variables affecting total waste arisings (McBean and Fortin, 1993; USEPA, 1997). Yet, Chang et al. (1993) found that population threw little light on the prediction of average waste generation rate. Income, including GDP, was considered an influential factor on waste generation in some cases only (Ali Khan and Burney, 1989; Buenrostro, et al., 2001; Chang et al., 1993; Hockett, et al., 1995; Wang and Nie, 2001). USEPA (1997) on the other hand found that employment and taxable transactions (involving the use of CPI) were strongest predictors of waste generation in California. Bagby et al. (2001) found that average household size and trends in the housing market stabilized waste generation rate in Seattle in their forecasted period. Employment by sector was found to be a good predictor of the percentage of commercial waste (Bach et al., 2004; Gay et al., 1993; Hockett et al., 1995) and building demolition areas, construction areas, population, construction investment and monetary values of the activities are commonly used to predict the quantities of concrete debris (Bergsdal et al., 2007; Shi and Xu, 2006; Yost and Halstead, 1996). The stocks-and-flows model deployed by Bergsdal et al. (2007) could be considered as a specific form of factor models and were appropriate for the prediction of construction waste and with suitable modifications to commercial and industrial waste of specific trade sectors too.

Certainly, there is no guarantee that valid explanatory variables can be identified. Grossman et al. (1974) tested a number of independent variables and none was found to adequately explain or forecast waste generation. This may due to the difficulties in including theoretically valid but hard-to-measure variables, such as the level of environmental awareness of the population, waste management literacy of the population and forms of waste policies deployed, e.g. MSW charging, PRS control, level of recycling activities (Hockett et al., 1995; Jenkins, 1993). In other cases, the data at appropriate levels for potentially valid explanatory variables are simply hard to collect. Joutz (1996) remarked that while the models he developed were theoretically sound, there was no good source of data for two of the factors in his models, namely MSW tipping fees and avoided costs of electric utility industry. Similarly, as a legitimate candidate to explain household waste generation or disposal rates, the income level of individual waste generators is also a variable that generally has no good source of data. To obtain income data specific to household or individual levels, it will inevitably infringe personal privacy. Thus, obtaining the permission to collect these data is generally difficult. As a result, more often than not in actual modelling, proxies for the best factors are used instead. For instance, Joutz (1996) used the ratio of two national level economic indices to approximate real tipping fees.

Even if empirically and theoretically valid variables can be identified and good source of data is available, in order to perform the prediction, these exogenous explanatory variables need to be forecasted as well. Yet, very often projected data for these other explanatory variables are not available and therefore researchers have to find their way to generate the projected values of the explanatory variables first before prediction of the waste quantities can be performed. Obviously, the validity of the projection on waste quantities hinges largely on the accuracy of the predictions on these exogenous determinants.

In most noted studies, researchers are making the fundamental assumption that the supply of waste disposal and treatment facilities are to meet the generation capacity of the society, ie., the demand for waste facilities. An alternative approach is adopted by Joutz (1996) who attempted to determine the market equilibrium situation instead, i.e., the situation where quantity supplied equals quantity demanded for waste (handling, treatment or recycling) facilities.

It should be noted that neither the factor model nor the time series model is capable of making projection of waste composition which is typically measured by the relative percentage of each waste component. It is because both models can only be used to project one dependent variable at a time. To project the composition of a waste stream with any of the two approaches mentioned, each waste component has to be made a dependent variable on its own. Even if the projection for each waste component is conducted accordingly, there is no guarantee that the aggregated percentage of all waste components would be exactly 100%, a required condition for waste composition measurement. Thus, to analysis waste composition, some other methods are needed. The most commonly used method in this regard is cluster analysis as it is capable of analysing more than two characteristics of a parameter simultaneously. However, cluster analysis cannot be used to project the future trend of each individual characteristic.

3. A review on waste composition and waste generation rate in Hong Kong SAR

Figure 1 shows the trends of averaged daily MSW, domestic and C&I waste disposed in Hong Kong from 1979 – 2007 which is also the data series used in this paper to estimate future MSW disposal needs for Hong Kong. In addition, the Environmental Protection

Department (EPD) of Hong Kong has also been conducting waste composition analysis on an annual basis. Figure 2 states the compositions of MSW (i.e, domestic, commercial and industrial waste) from 1989 – 2007. From Figure 1, actual domestic waste disposal rates started to decline from 2003 onwards as a result of the expansion of formal source separation of domestic waste scheme while C&I waste still assume a continuous growth trend despite some fluctuations in the early 1990 in Hong Kong. The combined results of the two are a stabilization of MSW disposal rate. It is also evident from Figure 1 that no curve estimation technique on its own will be able to take into consideration the influence of source separation of waste measure on waste disposal needs (see s.5.1). Therefore, factor models remain the only rational choice.

[insert figures 1 and 2 here]

Table 1 lists the MSW generation/disposal rates per head and per unit of GDP of Hong Kong and three other selected areas. There are a number of constraints in obtaining appropriate data for making such comparison. The major reason is that not all official waste figures available from public domain have it clearly stated whether they are disposed or generated quantities. In Hong Kong, only waste disposal figures can be accurately estimated and only waste disposal rates were used in all previous waste projections. As a result, when the author selects data for making this comparison, priority is given to cities whose waste authorities are able to give separate figures for the amount of waste generated and disposed. In the end, data for Taipei, Singapore and New York city data (for one year only) were selected for this very reason.

The second factor to be considered in interpreting the data in Table 3 is that the definitions of MSW are not the same for the cities mentioned. In Hong Kong, MSW includes domestic, commercial and non-hazardous industrial solid waste only. However, the closest equivalent to MSW in New York city is what is called “Department of Sanitation New York (DSNY)-managed waste”. DSNY-managed waste include “putrescible and non-putrescible waste that DSNY collects, recycles or disposes of from all residences in the City, not-for-profit institutions, other City, state and federal agencies, as well as waste from special DSNY operations such as lot cleaning, street cleaning and other operations.” (City of New York and Department of Sanitation, 2006). It is not immediately clear to the users of the data if DSNY-managed waste include non-hazardous industrial waste of the city. In Taipei, MSW includes all solid waste from domestic activities and waste from non-industrial activities (Environmental Protection Administration, 2007). So, non-hazardous industrial waste has been excluded from the MSW figures of Taipei. In addition, waste from large commercial establishments is also excluded. This is because large commercial establishments are required by law to dispose of their solid waste and the environmental authority of Taipei city has no data on total commercial waste generated or disposed from these large commercial establishments (Lu, S.C., 2007, personal communication with officer of the Fourth Division, Environmental Protection Administration of Taipei on 10th September, 2nd, 5th and 22nd October Taipei). Singapore’s waste disposal data, on the other hand, include all the solid waste incinerated and landfilled which covers also construction and demolition waste (Ministry of the Environment and Water Resources, 2009), a waste stream that is excluded from Hong Kong’s MSW data. Thus, on the whole, the coverage of Singapore’s waste data is the most extensive among all the four cities compared and that Taipei and New York city’s waste data cover less waste streams than those covered by the MSW in Hong Kong.

[insert Table 1 here]

Notwithstanding all the uncertainties in the accuracy and difference in the coverage of the data, it appears that a large range exists in per capita MSW generation and disposal rates between cities. Taipei has the lowest per capita MSW generation and disposal rates in the three years compared and Singapore the highest. In terms of waste disposed for each dollar of GDP (converted into Hong Kong dollar equivalent), Singapore is slightly more waste-intensive than Hong Kong. Yet, it should be reiterated that the coverage of Singapore's waste statistics is the widest among all cities compared. Thus, strictly speaking they are not directly comparable figures.

4. A Review on Territorial MSW forecast for Hong Kong SAR

In this section, the accuracy of EPD's previous domestic and commercial and industrial (C&I) waste projection studies will be validated by the actual waste arising figures of the corresponding years (whenever available) to throw light on the prediction accuracy and constraints of forecasting waste by the factor model based classical linear regression method.

A series of city-wide MSW projections using classical linear regression have been published in *Monitoring of Solid Waste* reports from 1988-1999 (EPD, 1988-1999). They are also the only systematic waste projection exercise noted for Hong Kong SAR. In all EPD's waste projection[1], GDP in current year value or constant 1990 prices were used as the only explanatory variable in the regression models. All along, current year GDP was found to have a linear relationship with waste disposal rates. It was also mentioned that domestic waste disposal was closely related to population and C&I waste to economic activities (EPD, 1999). Since the reporting formats of the results of these former waste projection exercises were not standardized, the author decided that only the projected results of the following 3 years, 1996, 2001 and 2006 would be collated for comparison as far as possible. Actual waste arisings of the relevant years are also stated to contrast with the projected results (see Table 2).

[insert table 2 here]

It is apparent that the projection obtained by using linear projection from the value of GDP and time has consistently overestimated the actual quantities of MSW requiring disposal. Amidst the tendency of overestimation[2], the projected results of domestic waste for 2001 from the 1998 Study although was slightly less than the actual quantities of domestic waste disposed, was reasonably accurate. More significant underestimation however can be found with the 1999 Study which forecasted that in 2006, C&I waste requiring disposal would be 2,140 tpd (EPD, 2000). However, as it turned out, there were 2,643 tpd of C&I waste disposed in 2006 (EPD, 2007). This underestimation can be attributed to the exceptionally small value projected for the daily per capita C&I waste requiring disposal for that very year (at 0.55 kg/employee/day) (EPD, 2000).

5. MSW forecast to 2036

In this section, a different factor model-based technique - multiple factor autoregression method, is used to forecast MSW up to 2036 for Hong Kong SAR. The reasons for using autoregression instead of classical linear regression method and its constraints will be discussed in subsequent sections. All computations for waste quantity projection in this study were conducted with SPSS v.14.

5.1 Forecasting domestic waste arisings with the factor model

Although classical linear regression was used in EPD's previous studies, when the author replicates calculation with daily domestic waste disposed in Hong Kong (1979-2007) on one hand and population, GDP and the number of housing estates participating in domestic source separation of waste programmes (SSP) on the other, the classical linear regression model suffers from both the autocorrelation[3] and multicollinearity problems. With the presence of autocorrelation, the coefficients found may show to be significant even though it is not actually the case (Gujarati, 1992). A more appropriate technique for predicting the trends of time series data is the maximum–likelihood method in the autoregression procedure. This procedure uses the same algorithm that the ARIMA procedure uses for estimating autocorrelation and it gives better results among the 3 procedures available in SPSS v.14. The autoregression procedure estimates true regression coefficients from time series with first-order autocorrelated errors and thus is best suited for time-series data where the influence of previous data on latter data is strong.

The best autoregression model (Model A) and the coefficients are:

<u>Model A</u>

		Coefficient
	Constant	-4199.634
Dependent variable:	Daily domestic waste disposed	
Independent variables:	GDP per capita (in current values)	0.01*
	Population (mid-year)	0.001**
	SSP (number of housing estates participated)	-2.159**

* - significant at 0.05 level

** - significant at 0.01 level

Figure 3 shows the amount of domestic waste disposed predicted by Model A and the upper and lower confidence limits. The model tracks well the trend of domestic waste disposed in Hong Kong and the actual domestic waste arisings stays within the 95% upper and lower confidence limits throughout the period.

[insert Figure 3 here]

In order to predict domestic waste disposed through to 2036 with model A, future values for mid-year population, per capita GDP and SSP participation from 2008 to 2036 have to be obtained first. At the time of writing, the population, GDP and SSP participation values of Hong Kong for 2008 and the interim value for SSP for 2009 are already available. In addition, the SSP target for 2010 is used as the assumed number of housing estates participating in SSP for that year. Furthermore, population projection up to 2036 and medium term GDP projection for Hong Kong SAR has been conducted by the Hong Kong Government (see below) and they will be used in the autoregression projection. Thus, only the values for per capita GDP (from 2009-2036) and SSP participation (2011-2036) need to be computed. Simple curve extension procedures supplemented by latest economic forecast and expert judgement are deployed to compute the future values for the explanatory variables.

Thus, the accuracy of Model A in predicting domestic disposal quantities through to 2036 depends also on the accuracy of these curves to forecast the future situations of our economy and SSP participation. Table 3 states the computed and assumed values for SSP and per capita GDP for projecting domestic waste disposal with the autoregression model.

[insert table 3 here]

The author is of the view that it is more appropriate to impose a ceiling on SSP housing estates for the future. The ceiling value for SSP participating housing estate is arbitrarily freezed at 1,921 housing estates for 2012 and subsequent years. In 2007, there were only 388 public (and government involved) housing estates in Hong Kong (Hong Kong Housing Authority, 2007). Thus, to achieve all future SSP targets, the government needs to enlist the support from private residential housing. Since there are considerable uncertainties in soliciting private housing management bodies to implement SSP, the author does not rule out the possibility that even the arbitrary ceiling of 1,921 housing estates may still be too optimistic. In addition, even if there are enough numbers of private residential buildings/estates to participate, it is reasonable to assume that their waste recovery potential is smaller than that in public housing estates owing to the much smaller dweller numbers per building or per estate in private housing. As a result, the coefficient of -2.159 is possibly an overestimation on the waste reduction potential of SSP.

On the projection of GDP for Hong Kong, it was confirmed with the Economic Analysis and Business Facilitation Unit that Hong Kong Government did not make GDP projection through to 2036. The medium term outlook (up to 2013) for the economy of Hong Kong was that a 3.5% GDP annual growth trend in real terms and a 2% annual increase in consumer price index were expected (Hong Kong Government, 2009). Curve estimation will be used to project per capita GDP growth for Hong Kong from 2014-2036. Curve estimation is also the method used by Shi and Xu (2006) to forecast the GDP of China for predicting cement production. An exploration of the best-fitted curve function for the historical record of current value of GDP for Hong Kong showed that the quadratic function is the best-fit model for annual GDP growth projection of Hong Kong and it predicted a growth between 1.7%-

2.8% until 2036. The GDP values projected by the quadratic function will then be divided by the projected population of the respective year to obtain the per capita current value of GDP (see Table 3).

Figure 4 shows the projected results. Using model A, the projected population for Hong Kong SAR, and by applying the assumptions on GDP and SSP growth made by the author, it is forecasted that domestic waste will decline from now on until 2014 to about 4,897 tonnes per day (tpd). After that, it will continue to rise with growth in population and per capita GDP to 7,690 tpd (equivalent to 0.9kg per capita per day) in 2036 with a 95% chance of falling between 5,951 and 9,428 tpd.

[insert Figure 4 here]

The eventual increase in domestic waste disposal rate however can be arrested if one of the following occurs:

- waste recovery potential of the SSP is raised (ie., an increase in the coefficient of SSP)
- less waste is disposed by each averaged person (ie., a decrease in the coefficient of population)
- the waste generating potential of per capita GDP declines (ie., a decrease in the coefficient of per capita GDP).

5.2 Forecasting C&I waste with factor model

Actual amount of C&I waste disposed from 1979-2007 was shown previously in Figure 1. EPD’s former waste projections involve standardizing C&I waste disposed by the size of workforce. City-wide labour force data are available from the public domain from 1981 onwards only. To obtain the size of labour force in the private sectors, the numbers of civil servants for the respective year were discounted. In this regard, daily C&I waste disposed per employee from 1981 – 2007 was worked out and shown in Figure 5. It appears that while total C&I waste disposed has been increasing, per capita C&I waste disposal rates have been fluctuating between an upper bound of 0.92 kg/day and a lower bound of 0.5 kg/day.

[insert figure 5 here]

While former literature has found that C&I waste arisings is related to a number of factors, including but not limiting to employment size and floor areas of an establishment (Yu, 1994), the type of industry/ business (DeGeare and Ongerth, 1971; Yu, 1994), and the number of hours/days open per week of an establishment (DeGeare and Ongerth, 1971), many of these factors cannot be applied to explain city-wide C&I waste arisings. An initial assessment on the influence of available factors, namely, GDP, per capita GDP and size of private labour force, on C&I waste disposal rates of Hong Kong shows that the size of labour force bears no relation with C&I waste disposal whether analyzed by linear regression or autoregression methods. Based on the historical waste data published by EPD, neither current GDP nor per capita GDP can be used to explain per capita daily C&I waste disposal quantities in the linear regression or the autoregression method. It is however found that GDP or per capita GDP is a valid explanatory variable for daily city-wide C&I waste disposal quantities. In order to avoid the autocorrelation problem[4], autoregression method is applied to work out the influence of GDP on daily city-wide C&I waste disposal rates. Figure 6 shows the autoregression plots for C&I waste arisings by using GDP and per capita GDP separately as an explanatory variable. The estimates given by the two autoregression functions are actually very close to each other. However, it seems that the plot obtained from using per capita GDP as an explanatory variable tracks the trend of actual observation slightly better and thus GDP per capita is used as the variable for the final model, Model B.

Model B

		Coefficient
	Constant	1171.65
Dependent variable:	Daily C&I waste disposed	
Independent variable:	GDP per capita (in current values)	0.06**

** - significant at 0.01 level

[insert figure 6 here]

Figure 7 shows the plots of the projected C&I values made by Model B based on the assumed per capita GDP values stated in Table 3. The only year that the actual amount of C&I waste disposed falls out of the 95% prediction range of the model is 1995. This means that Model B is not able to explain why C&I waste drops so dramatically in that year. Yet, in view of the lack of better models, Model B is still adopted. It predicts that C&I waste disposed will increase gradually until 2036. By then, it will reach 3,353 tpd if the assumed mild continuous growth in per capita GDP is also materialized. There is also a 95% chance that the daily disposal rate for C&I waste in Hong Kong will fall somewhere between 2,209 and 4,497 tpd. In sum, Model B is not as able to track the past trends of C&I waste as well as Model A can for domestic waste.

[insert table 4 and figure 7 here]

6. Discussion

6.1 The performance of autoregression models

Table 4 summarizes the results of the two projections for the signposted years from this study and those from EPD's studies. With longer series of data, more explanatory variables and the use of better methods, the projections from this study are all lower than those estimated by EPD with the exception of C&I waste projected made in the EPD's 1999 Study. Not only is the use of multiple factor autoregression model appears to rectify the over-estimation tendency noted in EPD's studies, the predicted per capita MSW disposal rate (ranging from 1.08 kg to 1.29 kg) are all within the probable range (see Table 1).

6.2 The effect of policy change on future waste trends

Policy change will affect the certainty of the predictions. In relation to MSW, two current policy measures are relevant, namely, a plastic bag levy and the promotion of domestic waste separation programme. Implemented since July 2009 (Environment Bureau, 2009), the levy only covers plastic bags issued from supermarket and chain stores in Hong Kong. It is unlikely that the levy will have any noticeable effect on future domestic waste disposal rates in Hong Kong because plastic bag waste accounts for only 1.8% of all solid waste in Hong Kong before the levy was introduced (Hong Kong Economic Journal, 2009) and only a fraction of all plastic bags used and therefore disposed in Hong Kong is covered by the levy.

On the other hand, evident from current study, the total number of housing estates participating in domestic waste separation programme is going to affect future domestic waste disposal rates in Hong Kong. The effectiveness of this programme in diverting domestic waste from disposal is strongly influenced by, among others, the publicity of the programme, the maintenance of the waste recovery facilities and the reputation of the programme. Yet, a very important factor behind all these is Hong Kong Government's political will to promote waste recycling and reduction. Should there be paucity in the promotion of domestic waste separation programme (such as not being able to achieve the 1,921 housing estates target set in the Model A), it is expected that the amount of domestic waste disposed (total and per capita figures alike) in Hong Kong in the future will approach or may even exceed the 95% upper confidence limit. Yet, it is the future development of this last factor that is impossible to be predicted with any degree of certainty by mathematical means. Thus, the projections on domestic waste disposal rates stated in this study will be valid only if there is no significant change in the political will of Hong Kong's environmental authority to promote waste recycling and reduction and that the assumed maximum number of housing estates participating in waste separation programme will be attained.

7. Conclusions

In conclusion, several lessons regarding waste projection can be learnt from this study. First, since factors positively correlated with waste growth are generally more readily available, it is essential that factors negatively affecting waste growth, such as implementation of waste recycling schemes are also included in the forecast model to guard against gross overestimation. Noted from this study is that specific knowledge on factors that will negatively affect waste growth is usually hard to obtain. As a result, expert judgment should be meticulously exercised to artificially adjust the projection if it is indeed impossible to quantify these factors and put them in the projection model. Indeed, accurate waste projection sometimes cannot be made not because of the lack of techniques but the lack of good source of data. Thus, it is recommended that government or waste authorities are to devote more resources in collecting data and statistics on waste recycling, waste reduction as well as other factors that are able to reduce waste generation.

Second, even if a valid model has been developed, the certainty of the prediction decreases progressively with time. This is particularly the case with Model A. The 95% confidence of Model A ranges between 1,165 tpd and 2,290 tpd for the first three years of the projected period and grows considerably to 3,477 tpd in 2036. Thus, it is the decision makers' own choice whether or not the projected values for the more distant future will be taken seriously.

Third, even when valid explanatory variables are identified, the future values of these factors may not be available or cannot be accurately predicted. In this study, expert judgment and curve estimation techniques are used to generate the future values of the explanatory variables (per capita GDP and SSP participation) as substitutes. Thus, the validity of projected waste values very much hinges on the validity of the assumed future values of the explanatory variables. This is another reason why the accuracy and creditability of waste projection may be hampered. As a result, despite the availability of more sophisticated and presumably more accurate factor-based models, their reliance (and the general lack of) on accurate projections of the explanatory variables is another major obstacle to its predictive power and popularity.

Fourth, the fact that C&I waste disposal is unrelated to the size of private sector workforce show that C&I waste disposal rate tends to be trade specific and is too heterogeneous to be predicted by macro level statistics on an aggregated level. Moreover, many eligible candidates or the methodology to explain C&I waste disposal rates are valid only at establishment or sectoral level. For instance, Bruvoll and Ibenholt (1997) have shown that their factor-model based macroeconomic model is able to project industrial waste from the manufacturing sector satisfactorily. Thus, it may mean that prediction of aggregated C&I waste disposal rate for the entire economy using factor models may not be accurate or feasible for many cases. As a result, time-series models remain the only feasible choice. In this regard, with a minimum reference path of over 50 observations for the more sophisticated time-series models, it would mean that unless the waste authorities have incessant long term commitment to collect relevant data, accurate projection of C&I waste will be difficult to achieve.

Fifth, waste authorities should caution that they should be aware of the limitations of various waste projection techniques and deploy only methodologies that are empirically correct. A case in point is Hong Kong EPD's approach to project per employee C&I waste figures and multiply this with the projected workforce to obtain the territorial C&I waste disposal quantities. This was not a legitimate practice because the extrapolation of the city-wide figure from per employee figure was not preceded by analyzing the correlation between city-wide C&I waste disposal rate and the size of the workforce. As a result, inconsistent and unstable projection results are generated (see EPD's 1998 & 1999 C&I waste projections in Table 3).

Last but not the least, despite the predicted rising trend of MSW, one should not treat this as an inevitable destiny of future waste disposal trend. Arresting waste growth is not mission-impossible for Hong Kong (and similarly other cities as well) as shown by the decline of domestic waste disposal rate at the onset of the turn of the century. The predicted values generated by the study's models merely show what it will be like if the interaction effects noted between various factors in the past continue into the future. The prediction models do not determine the future however. Raising public environmental awareness, improving the waste management literacy of the community and adoption of waste reduction policy measures can all lower the waste generation coefficients of the population and GDP, ie., less waste is disposed in association with each average person in the economy and each dollar of GDP earned. As a result, despite the grim outlook, it is more advisable to interpret the rising waste trend as an indication of how far Hong Kong is from reversing the growing trend, rather than being frustrated by the projection results. In this regard, the conclusion from this study is not at all surprising - that there is still room for curbing the two waste disposal coefficients.

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[1] These EPD waste projection studies will be identified by the year of the Statistics. For instance, in Table 2, the 1988 Study will mean the waste projection study documented in the *Monitoring of Solid Waste 1988* (EPD, 1989).

[2] EPD was well aware of the general tendency to overestimate future waste disposal needs in its waste projection exercise and remarked that the projected waste quantities should only be considered as the upper limits (EPD, 1989).

[3] Durbin-Watson statistics of the linear regression run by the author is 0.633. With a sample size of 29 and 3 explanatory variables in the model, positive autocorrelation is highly likely.

[4] Durbin-Watson statistics for this linear regression model is 0.608. Positive autocorrelation is therefore highly likely.