ISCTE Business School
Instituto Universitário de Lisboa

SCOPE ECONOMIES BETWEEN INDISCRIMINATE AND SELECTIVE URBAN SOLID WASTE COLLECTION

Limin Jiang

Dissertation submitted as partial requirement for the conferral of

Master in Economics

Supervisor:
Prof. Henrique Monteiro, ISCTE Business School, Department of Economics

September 2017

- Spine -

SCOPE ECONOMIES BETWEEN INDISCRIMINATE AND SELECTIVE URBAN SOLID WASTE COLLECTION

Limin Jiang

ISCTE Business School
Instituto Universitário de Lisboa

Abstract

Recycling is one possible option within municipal solid waste (MSW) management to deal with the growing quantities of MSW produced. Only a few scholars have analysed the costs of this service and asked the question whether municipal solid waste management service utilities benefit from providing waste disposal and recycling services jointly. This dissertation tries to answer this question in the Portuguese context. In other words, it tries to find whether there are economies of scope in the Portuguese municipal solid waste management market between waste collection and disposal and recycling services.

To answer the question, this study estimates a cost function of the municipal solid waste collection and disposal and recycling services in Portugal. Using a panel of 260 Portuguese retail municipal solid waste management service providers observed from 2001 to 2015, a multi-output translog cost function is estimated. The index value for scope economies is -0.27, meaning diseconomies of scope have been found.

Key words: Municipal Solid Waste Management, Cost Analysis, Economies of Scope

JEL Classification System: L25; Q53

Resumo

A reciclagem é uma opção possível na gestão de residuos sólidos urbanos para lidar com a crescente quantidade deste tipo de resíduos que é produzida. Não existem muitos Estudos que tenham analisado este serviço e perguntado se as entidades gestoras de resíduos sólidos urbanos beneficiam do fornecimento simultâneo dos serviços de recolha de lixo e de reciclagem. Esta dissertação procura responder a essa questão no contexto português. Por outras palavras, ela tenta descobrir se existem economias de gama na gestão de residuos sólidos urbanos no mercado português entre a recolha de resíduos e os serviços de reciclagem.

Para responder à questão, este estudo estima uma função de custo para os serviços de recolha de resíduos sólidos urbanos e de reciclagem em Portugal. Usando um painel de 260 entidades gestoras de serviços de gestão de resíduos sólidos urbanos observadas de 2011 a 2015, estima-se uma função de custos multi-produto translog. O índice de economias de gama é de -0.27, significando que existem deseconomias de gama.

Palavras-chave: Gestão Municipal de Resíduos Sólidos, Análise de Custos, Economias de Gama

Sistema de classificação JEL: L25; Q53

Acknowledgements

First of all I would like to express appreciation to my supervisor, Prof. Henrique Monteiro, for his expert and patient guidance. Thanks very much for all the helpful advices and especially the support on data translating and software Stata using. I am very grateful to have such a responsible and inspiring supervisor.

I would also like to thank Prof. Catarina Roseta Palma and my classmates for their valuable suggestions.

Finally, I appreciate all the encouragements and selfless support from my family.

Index

1 Introduction ... 2
2 Literature Review ... 6
2.1 History of Cost Analysis in Municipal Solid Waste Market ... 6
2.2 Econometric Method and Functional Form ... 7
2.3 Dependent Variable Used ... 9
2.4 Independent Variables Used ... 9
2.5 Estimates of Economies of Scope ... 11
3 Overview of Municipal Waste Management Sector ... 13
3.1 Introduction of MWM Sector in Portugal ... 13
3.2 Cost and Revenue Analysis of Portuguese MWM Sector ... 15
3.3 Integration of Portuguese MWM Service and Economic Benefits ... 17
4 Model and Data ... 18
4.1 Model Specification and Methodology ... 18
4.2 Data Specification ... 19
5 Results and Scope Economies Analysis ... 21
5.1 Estimation Results ... 21
5.2 Scope Economies Analysis ... 24
6 Conclusion ... 25
7 Bibliography ... 27

List of Abbreviations

2SLS: Two Steps Least Squares

CS: Composite Specification

DEA: Data Envelopment Analysis

MSW: Municipal Solid Waste

MWM: Municipal Waste Management

NBSC: National Bureau of Statistics of China

NLSUR: Non-linear Seemingly Unrelated Regression

NSW: New South Wales

OLS: Ordinary Least Square

SFA: Stochastic frontier approach

SUR: Seemingly Unrelated Regression

Translog: Transcendental Logarithmic

TS: Transcendental Logarithmic Specification

USA: United States of America

USEPA: United States Environmental Protection Agency

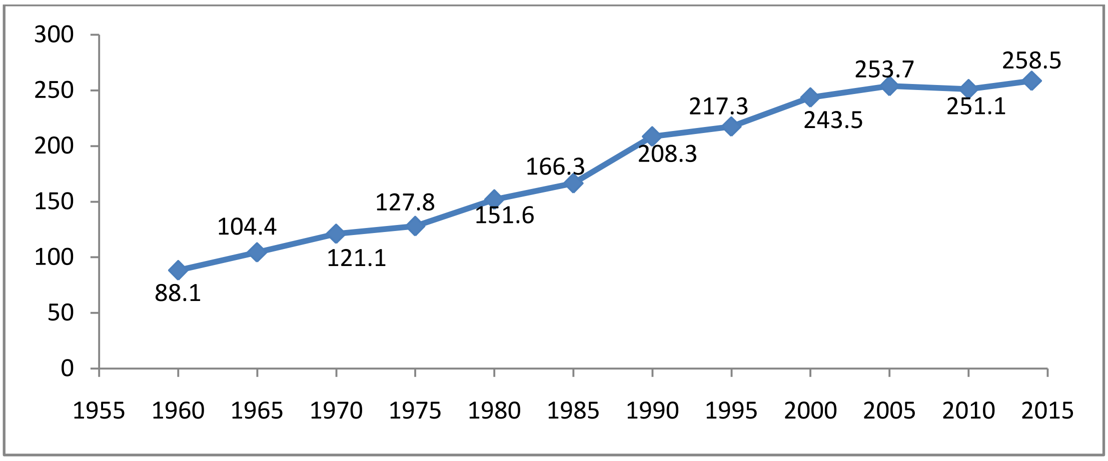
1 Introduction

Municipal solid waste (MSW) is a type of waste that consists of daily waste we make, such as product packaging, bottles, food scraps, newspapers and glass (USEPA 2016a). Municipal waste management (MWM) is a public service including the collection, handling, recovery, recycling, burning for energy production and landfilling of municipal solid waste (ERSAR 2013). MWM service is one of the most significant public service regarding the quality of life of urban residents. Uncollected solid waste will not only occupy public space and affect the appearance of the city (smelly and dirty waste will leave tourists badly impressed) but also aggravate air pollution and spread diseases as a media for bacteria.

However, governments all over the world are facing enormous challenges regarding MWM. More than half of the world's population has no regular access to trash collection (Hoornweg & Bhada-Tata 2012). Moreover, due to the rising incomes as well as the need for a higher living standard, people are more willing to consume and therefore making more waste. The world cities total volume of MSW generation is expected to be 2.2 billion tones by 2025 (Hoornweg & Bhada-Tata 2012). Increasing municipal solid waste generation is becoming a growing challenge for cities especially in low-income regions where MWM service occupied the largest part of its budget (Hoornweg & Bhada-Tata 2012, p.11). USA's MSW generation has increased significantly, from 88.1 billion tons in 1960 to 258.5 billion tons in 2014 (USEPA 2016b), with a yearly growth rate of 2.01% per year. In Figure 1-2, an apparent increasing trend can be noticed, shows that collected and transported MSW has been growing at a yearly growth rate of 3.5 million tons per year for the last 15 years in China. Total MSW generation in China has also increased, "from 31,320 thousand tons in 1980 to 178,602 thousand tons in 2014, (…) with an annual average growth rate of 5.5%" (Gu et al. 2017, p. 59).

Figure 1-1 and Figure 1-2 show some statistical facts about MSW status in the United States of America (USA) and China, USA's MSW generation has increased significantly, from 88.1 billion tons in 1960 to 258.5 billion tons in 2014 (USEPA 2016b), with a yearly growth rate of 2.01% per year. In Figure 1-2, an apparent increasing trend can be noticed, shows that collected and transported MSW has been growing at a yearly growth rate of 3.5 million tons per year for the last 15 years in China. Total MSW generation in China has also increased, "from 31,320 thousand tons in 1980 to 178,602 thousand tons in 2014, (…) with an annual average growth rate of 5.5%" (Gu et al. 2017, p. 59).

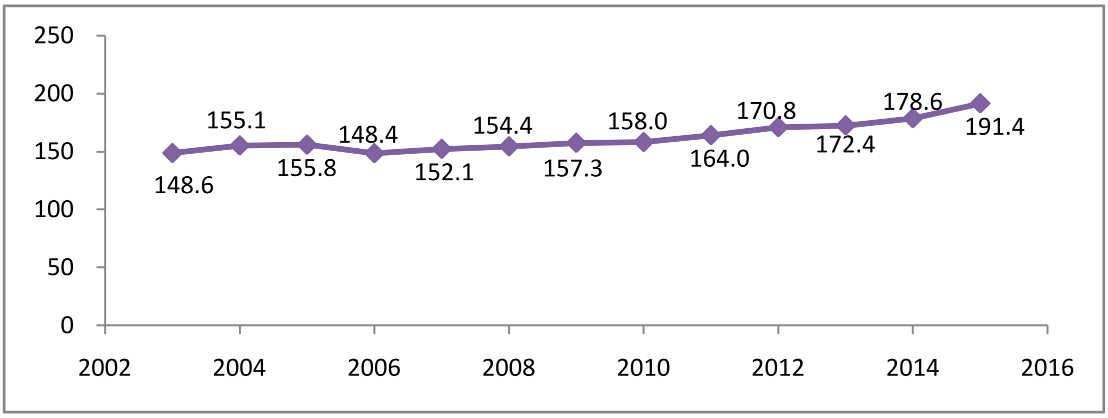
Figure 1-1 Total MSW generation (Billion tons) in the USA



[1]

Source: USEPA (2016b) p. 3.

Figure 1-2 Collected and transported MSW (million tons) in China



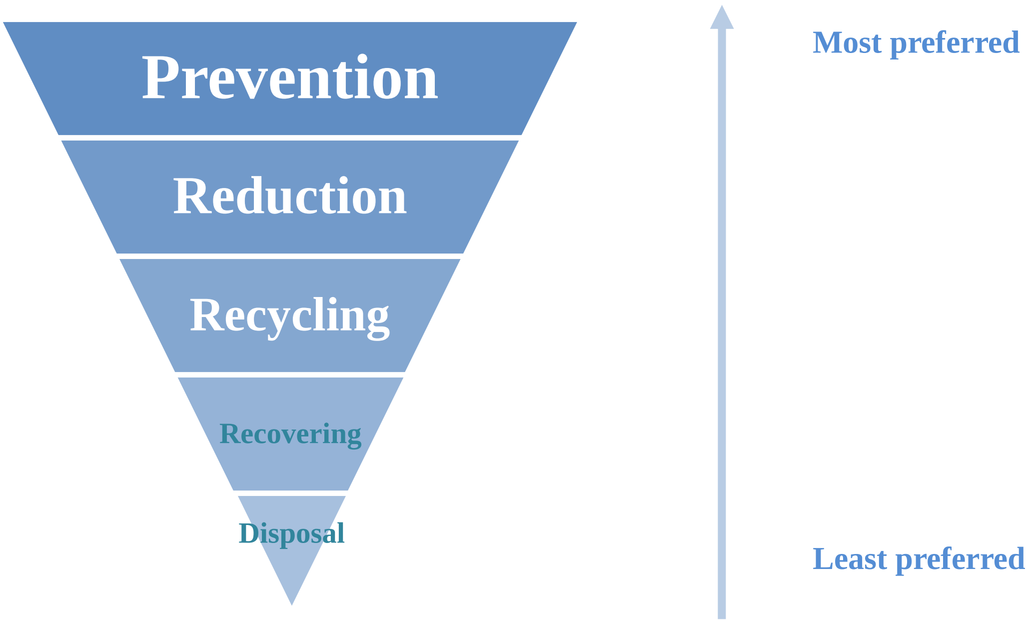
[1] The last data 258.5 is total MSW generation in USA for year 2014.

Source: NBSC (2017). Available at : http://data.stats.gov.cn/index.htm（accessed on 2017-10-21）

Due to the ever-growing quantities of waste generation, governments face increasing costs with the municipal solid waste management service. Globally, solid waste management costs will increase from annual $205.4 in 2012 to about $375.5 billion in 2025, growing at 4.75% per year, according to the Word Bank's prospection (Hoornweg & Bhada-Tata 2012).

Therefore, optimizing the MWM process is a task which brooks no delay. Recycling has always been an encouraged practice in municipal solid waste management policy for its environmental benefits and resource efficiency. It is also a practice that could help reduce the waste as it has a comparatively high position in the waste management hierarchy, which indicates an order of preference for actions to reduce and manage waste (Hyman et al. 2013). Figure 1-3 presents a waste management hierarchy.

Figure 1-3 Waste Management Hierarchy

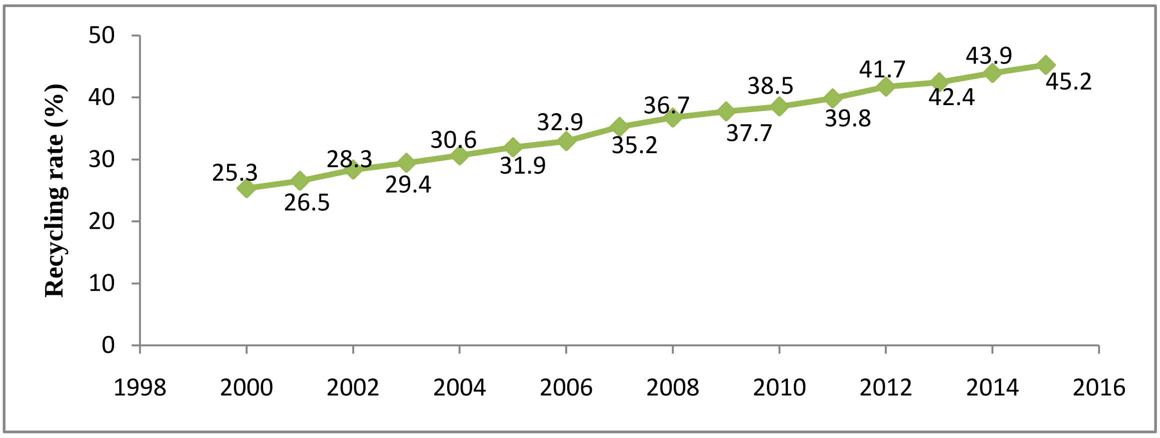


Source: Hyman et al. (2013), p. 20.

Figure 1-4 illustrates the recycling rate for European Union (27 countries), a steady rising trend can be seen. A further increase in the recycling rate to 65% by 2030 was proposed as a target for the Circular Economy Package in 2015 (EC 2015). The Circular Economy Package is adopted by the European Commission and it includes revised legislative proposals on waste. In the proposal, it sets clear targets for reduction of waste and establishes long-term path for waste management and recycling (EU 2015). Not just European countries, USA has also seen a rising recycling rate of municipal solid waste, as it shows in

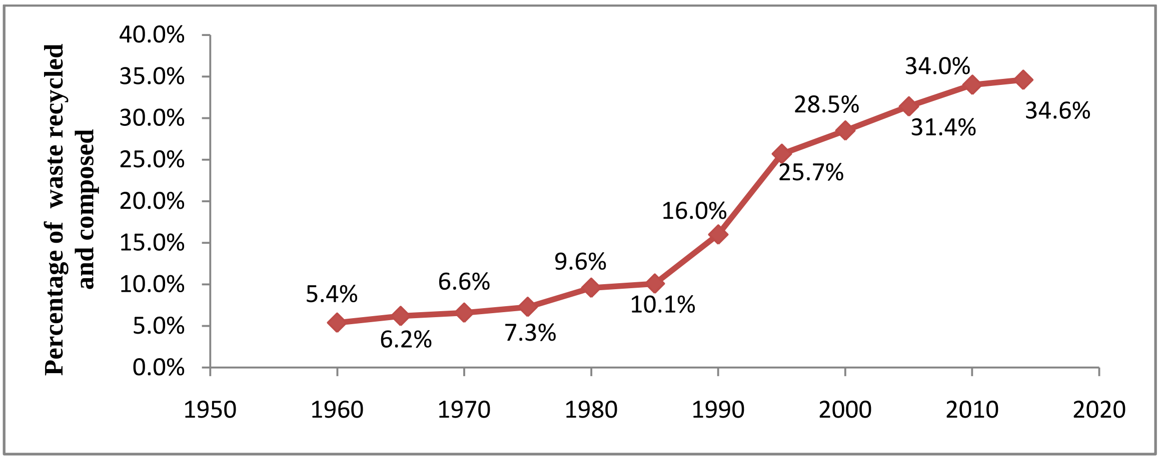
Figure **1-5**.

Figure 1-4 Recycling Rate for MWS in European Union (27 countries)



Source: Eurostat. Available at : http://ec.europa.eu/eurostat（accessed on 2017-12-14）

Figure 1-5 Percentage of waste recycled and composed in the USA



[2]

Source: USEPA (2016b), p. 3.

However, establishing a recycling system separate from the usual waste collection and disposal system may increase the cost of the service. Alternatively, to make waste recyclable, firstly you have to separate it from other waste, and this would need extra labor or sorting machines and some contamination of the recyclable materials would occur. Extra storage containers for recycling waste are also necessary for maintaining the properties that allow the waste to be recycled. In this thesis, we estimate a cost function of waste services using Portuguese MWM utilities as observations in order to find which is more efficient (i.e., creates the lowest unit cost): to have separate entities managing each service (waste collection and disposal versus collection and handling of recyclable materials) or to have the same firm doing both.

2 Literature Review

In this section we review the literature regarding the estimation of cost functions in MSW market. Three aspects will be discussed, from the history of cost analysis in MSW market to the function and variables used, as well as the estimation of economies of scope. The appendix provides a summary of selected papers estimating the waste service cost function.

[2] The last data 34.6% is for year 2014.

2.1 History of Cost Analysis in the Municipal Solid Waste Market

The earliest research focusing on the empirical analysis of cost functions of MSW management is Hirsch (1965). Using a data of 24 cities and municipalities in the St. Louis City-County area in 1960, he estimated a log linear cost function, and found that an increase from two to three weekly pickups increases collection costs by about 28 percent on average.

Subsequently, Stevens (1978) used data collected from 340 United States cities to see whether there were economies of scale in MSW market and analyzed the effect of market structures (private monopoly, public monopoly and competitive) on cost. Stevens found evidence of the existence of economies of scale in cities that had more than 50,000 inhabitants and that a private monopolist, on average, enjoyed cost savings. Dubin & Navarro (1988) performed their analysis based on a sample similar to the one used in Stevens (1978). They focused on the effect of market structure as well as on economies of density (service providers may enjoy a lower unit cost where population densities are higher). Departing from Stevens' use of total cost, Dubin and Navarro choose cost per yard of garbage collected as their explained variable. Population density (number of households per square mile) had a negative statistically significant effect on average cost (per yard) of garbage collected in their model. Analogous to Stevens (1978), they found evidence of scale economies.

Bohm et al. (2010) separately analyzed the disposal and recycling costs of 284 municipalities in the United States using two different non-linear log cost functions. They found economies of scale both in waste collection and disposal and curbside recycling, but which disappeared at high levels of recycling.

2.2 Econometric Method and Functional Form

A general form of the cost function is shown in (2.1)

$$(\mathrm{C}) = \mathrm{f}(\mathrm{Y}, \mathrm{P}) \tag{2.1}$$

Where C refers to the total cost of municipal waste management service, Y refers to the output in the MSW market, i.e. the quantity of the waste collected, and P represents the input price.

The econometric methods used in cost efficiency assessment of MSW markets are multiple. Many of them are parametric methods. Analysis based on Ordinary Least Squares (OLS) with a log linear function is widely used for disposal service cost analysis. Equation (2.2) represents the log linear function, where C is the total cost, Y is a vector with the different types of outputs, P includes the input prices and Z represent some other relevant variables. (Stevens, 1978)

$$\ln(C) = \alpha_0 + \alpha_1 \ln(Y) + \alpha_3 \ln(P) + \cdots + \alpha_n \ln(Z) \tag{2.2}$$

Antonioli & Filippini (2002) used a transcendental logarithmic (translog) function, which allows the values for economies of scale and density to vary with output. A translog function is shown in equation (2.3).

$$\begin{aligned} \ln(C) = \alpha_0 + \sum_i \alpha_i \ln(Y_i) + \frac{1}{2}\sum_i \sum_j \alpha_{ij} \ln(Y_i) \ln(Y_j) + \sum_i \sum_r \delta_{ir} \ln(Y_i) \ln(P_r) + \sum_r \beta_r \ln(P_r) \\ + \frac{1}{2}\sum_r \sum_l \beta_{rl} \ln(P_r) \ln(P_l) + \sum_h \gamma_h \ln(Z_h) \end{aligned} \tag{2.3}$$

They firstly introduced input price factors and using seemingly unrelated regression (SUR), first proposed by Zellner (1962), they estimated a cost system including a translog cost function and a factor share equation which is shown in (2.4).

$$S_r = \sum_i \delta_{ir} \ln(Y_i) + \beta_r + \sum_l \beta_{rl} \ln(P_l) \tag{2.4}$$

Carroll (1995), Stevens (1978), Dubin & Navarro (1988) and Sorensen (2007) used OLS to estimate the cost function while Zafra-Gómez et al. (2013) used pooled OLS.

The econometric method based on SUR was used more and more often in cost analysis in the MSW market, especially in studies focusing on the cost of both disposal and recycling service. Callan & Thomas (2001) and Bohm et al. (2010) both used the SUR method. Abrate et al.

(2014) used non-linear generalized least squares estimation (NLSUR) and compared two cost function specifications: TS (translog specification) and CS (Composite specification). The latter is shown in Equation (2.5) below. Since there is no zero output in our data, TS model (translog function) is a more concise choice.

$$
\begin{aligned}
\ln(C) = \ln\Bigg[\alpha_0 &+ \sum_i \alpha_i \ln(Y_i) \\
&+ \frac{1}{2}\sum_i\sum_j \alpha_{ij} \ln(Y_i)\ln(Y_j) + \sum_i\sum_r \delta_{ir} \ln(Y_i)\ln(P_r)\Bigg] \\
&+ \sum_r \beta_r \ln(P_r) \\
&+ \frac{1}{2}\sum_r\sum_l \beta_{rl} \ln(P_r)\ln(P_l) + \sum_h \gamma_h \ln(Z_h)
\end{aligned}
\qquad (2.5)
$$

The non-parametric method Data Envelope Analysis (DEA) was also used in some studies (Rogge & De Jaeger 2012; 2013) to make an assessment of the cost efficiency of the MSW service.

2.3 Dependent Variable Used

The most widely used dependent variable among all cost efficiency analysis for the MSW market is the total cost of MSW service. For instance, Stevens (1978) analyzed the total cost to households served, using a sample of 340 public and private waste collection firms in the United States from 1974 to 1975. Antonioli & Filippini (2002) had a sample of 30 Italian firms that provide waste collection and disposal service at provincial level using total cost. Reeves & Barrow (2000) chose total gross expenditure on refuse collection service including: employees, premises, transport, materials, supply of bins, apportionment of central administration costs based on a survey covering 88 Ireland local authorities.

Before recycling programs were popularized, the MSW service consisted mainly of the waste collection and disposal service, including refuse collection, transportation and disposal. When data for recycling services became available, scholars started analyzing the cost of recycling services to find the potential factors that may affect recycling service costs or evaluate the performance of recycling programs. Carvalho & Marques (2014) analyzed the total cost for recycling (including operating expenses and the capital expenses) based on all the 37 existing recycling utilities in Portugal during the period 2006-2010. Other studies using the total service costs of MSW service (including both disposal and recycling service) were Bel & Fageda (2010), Zafra-Gómez et al. (2013) and Bel et al. (2014). It is worth mentioning that Callan & Thomas (2001) and Abrate et al. (2014) were the only ones to analyze the joint cost of providing both the disposal and the recycling services.

The average costs of MSW service were also used in some studies, such as Dubin & Navarro (1988) which analyzes the cost per yard of garbage collected and D'Onza et al. (2016) which uses a sample of 67 Italian municipalities and uses full cost per inhabitant for each type of waste as their explained variable.

2.4 Independent Variables Used

The most important explanatory variable among the cost analysis of MSW market is output, in other words, quantities of solid waste collected for disposal or recycling.

Other important cost determinants are the input prices, which in the MSW market mean wages paid for labor, the price of capital and fuel price, but some studies only use wage as the input price. For example, Stevens (1978) used monthly wages paid to a refuse collector, Bel & Mur (2009) used wage (salary cost per employee) in the private service sector for each municipalities of Aragon, in 2003, to model the total cost paid for MSW services in that region of Spain. Bel & Fageda (2010) used mean wage per employee at the provincial level to estimate total cost of MSW service delivery in Galicia, another Spanish region. Some studies, such as Abrate et al. (2014), Bohm et al. (2010) and Antonioli & Filippini (2002), use all three input prices.

Market structure was also chosen by many scholars. Stevens (1978) considered three forms of market structure: private monopoly, public monopoly and competitive. Public monopoly means “a public agency collects refuse from all residents of a specified geographic area”, while in private monopoly “a private firm collects refuse from all residents of a specified geographic area” and in a competitive “a private firm collects refuse from some but not all households residing in an area” (Stevens, 1978, p. 2). Dubin & Navarro (1988) thought of similar market structure forms: private market, public monopoly and private monopoly (including contract and franchise arrangements). They described private market structure form as “a private firm” will provide the collection service and be paid directly by the customer, contract arrangement as “local government hires a private firm to provide collection services and the firm is the sole provider of the service and is paid by the city”, franchise arrangement as “local government awards a private firm the exclusive right to collect refuse in a specified area” (Dubin & Navarro 1988, p.2)

Market structure variables, or service provider in other words, had simpler forms in later literatures. Bel & Fageda (2010) used a dummy variable with value 1 if the service delivery has been contracted out to a private firm and 0 in all other possible situations to represent the market structure characteristic. Other chosen variables were factors that may affect the service process, such as the frequency of waste collected (Bel & Fageda 2010; Reeves & Barrow 2000), the existence of a landfill (Callan & Thomas 2001), and also features of the service area, such as density (Carvalho & Marques 2014; Callan & Thomas 2001; Abrate et al. 2014a; Bohm et al. 2010) altitude (Greco et al. 2014) or tourist activity (Bel & Fageda 2010).

2.5 Estimates of Economies of Scope

To the author’s knowledge, Callan & Thomas (2001), Abrate et al. (2014) and (Carvalho et al. 2015) are the only studies that jointly analyzed MSW disposal and recycling services and estimated the economies of scope in MSW market.

Callan & Thomas (2001) analyzed the joint annual cost of producing both disposal and recycling services. They were the first to present a multi-product cost structure and test for scope economies in MSW service market. Using the SUR method, they estimated a log cost function on a sample of 110 municipalities observed for the years 1996-1997 in Massachusetts, United States. The quantity of waste, housing density, market structure, waste collection frequency, the existence of a landfill, access to recycling facilities and the existence of a state fund for recycling services were chosen as explanatory variables.

Callan & Thomas (2001) found evidence of the existence of economies of scope, specifically they found an approximate value of 5% cost savings achieved by jointly providing both disposal and recycling service. Product-specific scale economies for recycling services and economies of density for disposal were also found to exist.

Regarding the disposal cost function, quantity of waste disposed, quantity of waste recycled and the interaction term between them, housing density, curbside pickup frequency and the existence of a landfill were found to have significant effects on cost. Regarding the recycling cost function, quantity recycled, quantity disposed, the interaction term between them and curbside pickup frequency were found to be significant determinants. Callon and Thomas (2001) found no significant evidence for existence of economies of density in recycling service. In line with Stevens (1978), Callon and Thomas (2001) found market structure not to be statistically significant in both cost functions.

Abrate et al. (2014) investigated the multi-product cost structure on a panel data of 529 Italian municipalities during 2004-2006. They applied a non-linear generalized least squares estimation (NLSUR) to estimate two forms of cost function: a composite specification (CS) cost function and a translog specification (TS) cost function, using as explanatory variables the quantity of disposed waste, the quantity of waste recycled, the input prices (of capital, labor and fuel).

Besides quantities of disposed and recycled waste, population density and market structure variables, (Abrate et al. 2014) added a time trend t representing technological progress, the size of municipality and geographical dummies in the extended model. In line with Callan & Thomas (2001), Abrate et al. (2014) found existence of scope economies in MSW service market. They also found scope economies to rise with municipality size. For municipalities having more than 300,000 inhabitants, scope economies could be up to 20% higher. Unlike scope economies, the economies of scale disappeared for large municipalities (with more than

100,000 inhabitants). As for the market structure, franchised monopoly was believed to be the best choice for municipalities from a cost saving perspective. Population density and market structure, besides the time trend and geographical variables were all found to be statistical significant in their models.

Carvalho et al. (2015) used a panel data, 184 local utilities in New South Wales (NSW) from year 2000 to 2005, to analyze the economies of scope in NSW municipal solid waste management market. They also used a translog cost function with multiple outputs (household (unsorted) waste collected and recycling waste collected) and calculate the cost complementary between these two outputs to evaluate the economies of scope. The condition of cost complementary is shown as equation (2.6).

$$\frac{d^2\,C}{dU\,dR} < 0 \tag{2.6}$$

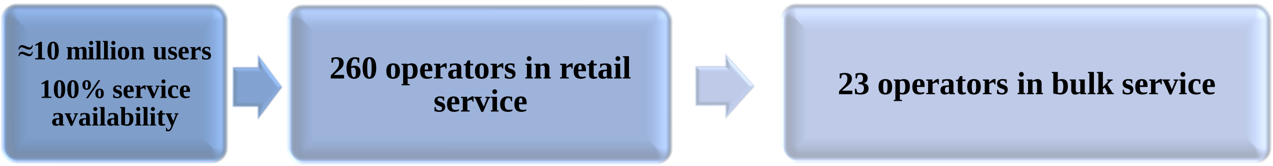
Where C refers to the total cost of MSW service, U and R refer to the outputs, i.e. household (unsorted) waste collected and recycling waste collected respectively. If the cost function satisfies equation (2.6), then there is cost complementary between the two outputs, which means there is economies of scope in NSW municipal solid waste management. They found the index for cost complementary to have negative average values, although not statistically significant from zero at 95 percent confidence level. The index is statistically significant for a 90 percent confidence level, but only for utilities collecting more than approximately 9,000 tons/year of unsorted MSW or serving more than 32,300 inhabitants (Carvalho et al. 2015). Therefore, it is still controversial whether economies of scope exist in NSW municipal solid waste management market, especially for large utilities.

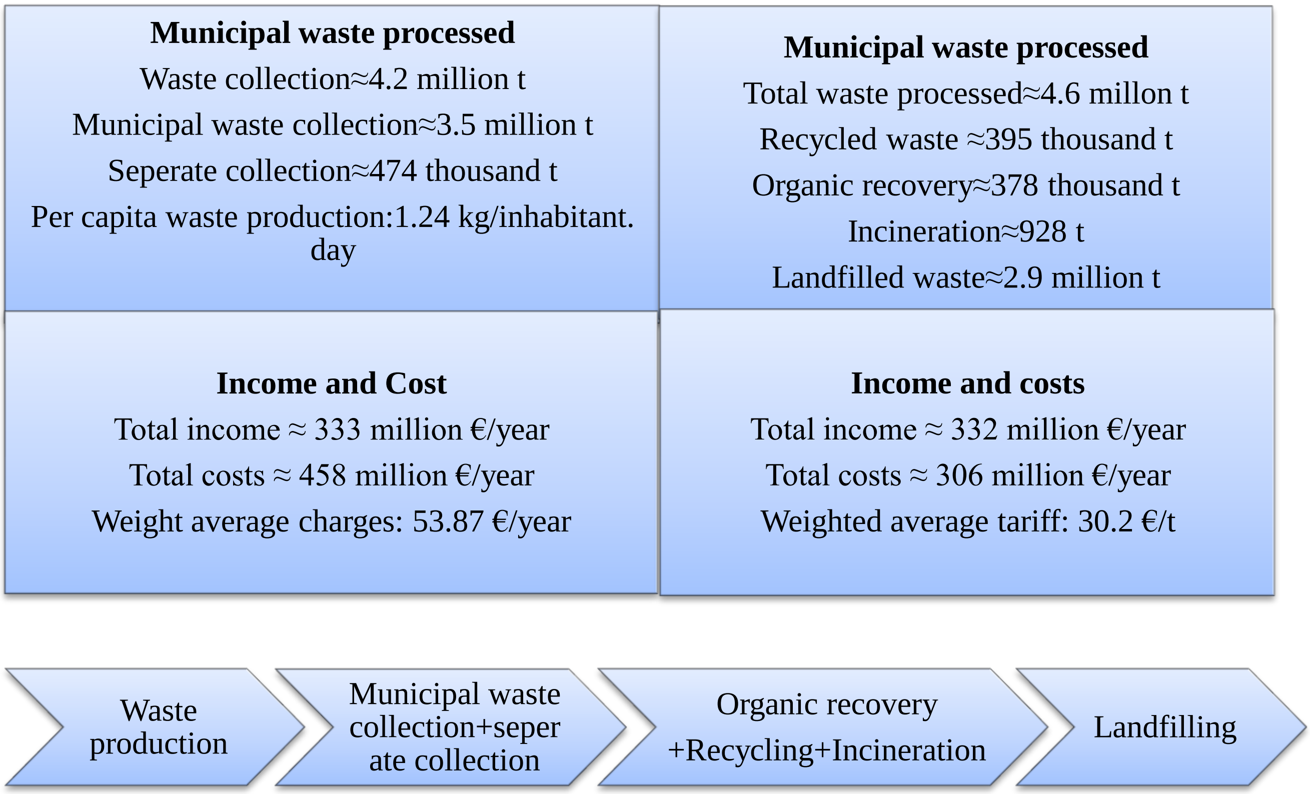
3 Overview of Municipal Waste Management Sector

3.1 The Portuguese MWM Sector

The municipal solid waste management service, which contains the collection, transport, temporary storage, sorting, recovering and disposal of domestic waste, can be classified into retail, which contains waste collection and transport provided primarily by municipal systems, and bulk, which carries out all the remaining process (ERSAR 2013). Over 80% of Portuguese population is covered by bulk services. Retail and bulk activities can be managed by different operators. There are 283 operators in mainland of Portugal, providing municipal waste management service for over 10 million users. Figure 3-1 gives information on some main figures and processes of MWM service in mainland Portugal in 2012.

Figure 3-1 Main figures of MWM service in mainland Portugal





Source: (ERSAR 2013) p.34

Three management models are possible: direct management, delegation and concession. Direct management means that the municipalities or autonomous municipal services operate the service. In delegation and concession management models, the participation of private companies is possible. These three models can also be divided into some sub-categories. Table 3-1 shows the overview of operators of MWM service by management models and sub-models.

Table 3-1 Overview of operators of MWM service

Management Model	Sub-Model	Bulk Service	Retail Service	Total[3]
Concessions	Multi-municipal concessions	12	0	12
	Municipal concessions	0	1	1
Delegations	State-owned companies	0	0	0
	State/municipalities partnerships	0	0	0
	Municipal and inter-municipal companies	8	20	27
Direct Management	Association of municipalities	3	2	5
	Municipalized and inter-municipalized services	0	6	6
	Municipalities	0	231	231
Total		**23**	**260**	**282**

Source: (ERSAR 2013) p.35

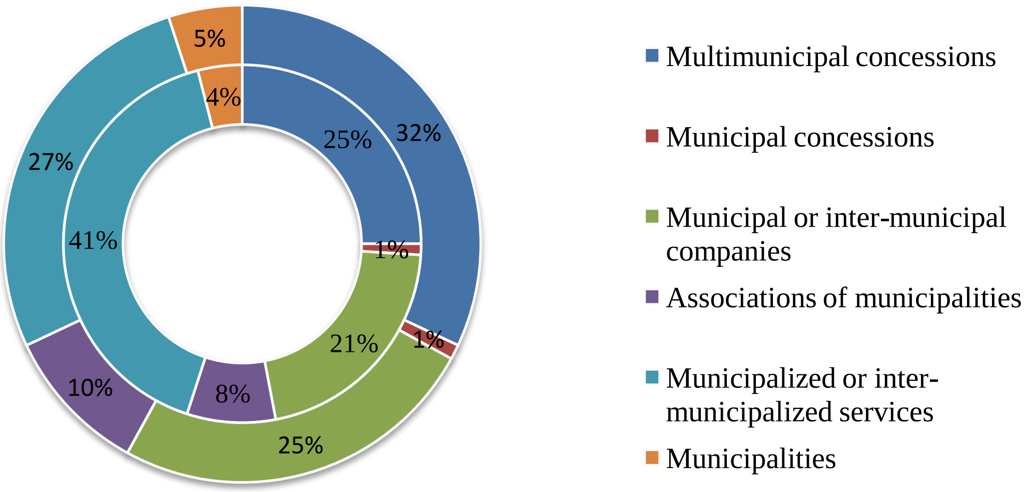
3.2 Cost and Revenue Analysis of Portuguese MWM Sector

The total cost and total revenue for MWM service are about 764 million € and 665 million € per year, respectively. The cost comes from providing and maintaining infrastructures, such as waste containers, waste collection vehicles, from human resources and energy consumption, mainly fuel consumption. 55% of the revenue comes from the bulk service, and the majority of these are generated by concessions.

Figure 3-2 illustrates the total cost and total revenue of municipal waste management service of different management sub-models.

[3] Note that there are operators which in some regions belong to the bulk sector and in others to the retail sector (e.g. EPAL). Therefore the total column isn't strictly the sum of bulk and retail components.

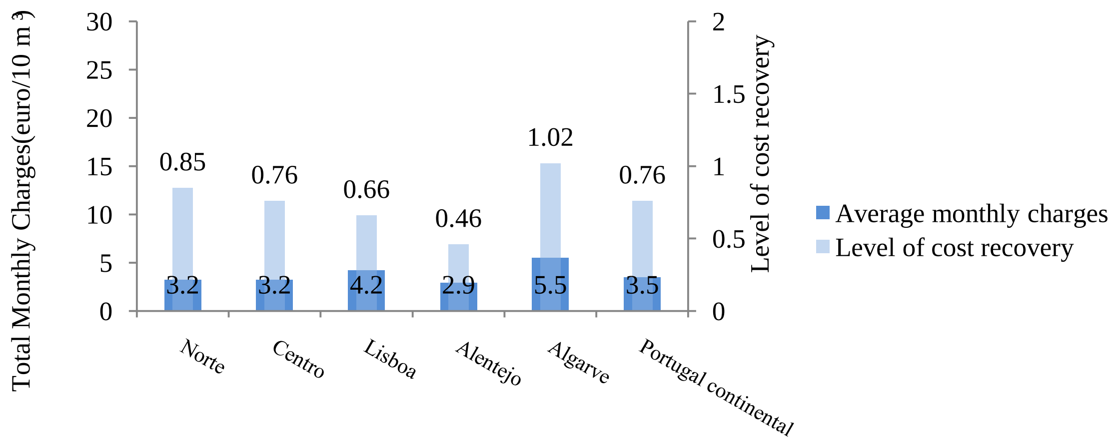
Figure 3-2 Total revenues (outside circle) and total expenditure of MWM activity, by management sub-model



Source: (ERSAR 2013) p.53-55

The Portuguese Water and Waste Services Regulation Authority (ERSAR) states that "tariff charges should allow a growing recovery of economic and financial costs accruing from the provision of services as well as boost cost efficiency and assure quality standards of services, economic sustainability and use of the services at reasonable prices to the overall population" (ERSAR 2013). Figure 3-3 shows the average monthly tariff charges for MWM service (considering a benchmark consumption level of $10m^3$) and the level of cost recovery by regions, using the data in 2012. We can see most of the regions don't have full cost recovery of this service. Thus, there is huge potential to improve the management strategy and gain more economic benefits from cost recovery.

Figure 3-3 Average tariff charges and cost recovery level by regions



Source: (ERSAR 2013) p.65

3.3 Integration of Portuguese MWM Service and Economic Benefits

There are three types of integration in MWM service: horizontal integration, vertical integration and integration of service. Horizontal integration means several municipalities integrate into one single operator, and make use of scale economies to increase efficiency and to reduce the tariffs charged to costumers (ERSAR 2013). Vertical integration "translates the level of incorporation, in the same operator, of multiple, integrated and sequential parts of the supply chain of a service, in order to enable the use of economies of process and, thus, maximized market opportunities" (ERSAR 2013, p. 61). The integration of the service is the focus of this dissertation. Operators managing different but related services may potentially enjoy economies of scope, which can also improve the efficiency and reduce cost. For instance, the operator that has both municipal waste disposal and recycling service could reduce the unit cost by providing and maintaining the same containers, establishing the same collection routes traveled by the same trucks, comparing to separately providing these two services. In mainland Portugal, 88% of the municipalities have integration of municipal waste management service. In the following sections we analyze potential economies of scope and economies of density in the Portuguese waste sector.

4 Model and Data

4.1 Model Specification and Methodology

In this section, two cost functions: a translog function and a loglinear function are presented, as well as the econometric methods that have been used to estimate them. A comparison between these two models will also be made in the next part.

As mentioned in the literature review, the translog function is used by most of the researchers to estimate the multi-output model due to its flexibility. The model is shown in (4.1).

$$\ln(C) = \alpha_0 + \sum_i \alpha_i \ln(Y_i) + \frac{1}{2}\sum_i\sum_j \alpha_{ij} \ln(Y_i)\ln(Y_j) + \sum_i\sum_r \delta_{ir} \ln(Y_i)\ln(P_r) + \sum_r \beta_r \ln(P_r) + \frac{1}{2}\sum_r\sum_l \beta_{rl} \ln(P_r)\ln(P_l) + \sum_h \gamma_h \ln(Z_h) \qquad (4.1)$$

Where the C is the total cost of the solid waste collection, Y refers to the output and i,j ∈（D, R）are indices of two outputs: waste disposal and recycling. P is the input price, and r, l∈（L, F, K）are indices of three input prices: labor, fuel and capital. Z refers to some other relevant variables that have influence on cost (population density, altitude differences, dummy variable for certification), which will be explained specifically in the next section. The equation (4.1) assume $\alpha_{ij} = \alpha_{ji}$ for all i,j.

A loglinear function is also used to estimate the total cost. The function is shown in equation (4.2)

$$\ln(C) = \alpha_0 + \alpha_1 \ln(D) + \alpha_2 \ln(R) + \alpha_3 \ln(L) + \alpha_4 \ln(F) + \alpha_5 \ln(K) + \alpha_6 \ln(P) + \alpha_7 \ln(A) + \alpha_8 \ln(T) + \varepsilon \tag{4.2}$$

Where the C is the total cost of the solid waste collection, D and R refers to the quantities of two outputs: disposal and recycling, L, F, K represents three input price: labor price, fuel price and capital price. P refers to the population density. A represents the altitude differences. T is a dummy variable identifying if the utility has at least one quality or environmental certification. ε is the disturbance term.

All variables have been divided by their respective sample mean before logarithmic transformation, so that the results can all be interpreted as cost elasticities evaluated at the sample mean (Monteiro, 2009). And the econometric method used in this paper is simple OLS (ordinary least square).

The aim of this empirical analysis is to answer the question "can municipal solid waste management service providers save cost from providing waste disposal and recycling service jointly?" To do so, an index for the economies of scope is given by equation (4.3).

$$SP = \frac{C(Y_D, 0) + C(0, Y_R)}{C(Y_D, Y_R)} - 1 \tag{4.3}$$

If the value of index SP is bigger than 0, then it means there is economies of scope in municipal waste management, in other words, service providers will save cost from providing waste disposal and recycling service jointly. While when SP is less than 0, there is diseconomies of scope in MWS market.

4.2 Data Specification

We use an unbalanced dataset of 260 Portuguese retail municipal solid waste management service providers from 2011 to 2015. Data are collected from the annual report on Water and Waste industry in Portugal. Table 4-1 and Table 4-2 show the definition of the variables used in cost function and some summary statistics.

Table 4-1 Definition of the variables

Variable	Definition
C	Total cost of municipal solid waste management (€/year)
D	Total waste collected excluding the recycling waste (t/year)
R	Recycling volume (t/year)
L	Average monthly wage (€)
F	Average price of diesel (€/liter)
K	Interest rate of 10-year Portuguese Government Bonds
P	Population density (N.° /km^2)
A	Altitude difference (m)
T	If the utility has at least one quality or environmental certification

Total cost (C) covers all the cost caused by municipal solid waste management activities, including labor, capital and fuel cost. Two outputs are Y, quantities of disposed waste per year and R, recycling volume per year. Regarding to the three productive factors, we use the monthly wage as a proxy of labor price (L), and the average price of diesel for fuel price (F), interest rate of Portuguese Government Bonds for capital price (K). P refers to the population density. According to the results of (Antonioli & Filippini 2002), there is economies of density in municipal solid waste management market. Population density is expected to have a negative effect on total cost. A means the altitude difference between the max altitude and the minimum altitude in the area. The garbage vehicles will use more fuel when going up and down mountains than if the area they serve is a plane land. Therefore, the expected sign for the coefficient of variable altitude difference is positive. T is a dummy variable identifying if the utility has at least one quality or environmental certification. Getting a quality or an environmental certification will also increase the cost of the utility. Variable T is supposed to have a positive effect on total cost too.

Table 4-2 Summary statistics of the variables

Variables	Obs	Mean	Std. Dev.	Min	Max
C	1230	2792699	6504021	45298.11	5.68e+07
D	1398	31759.01	77818.04	643	829747
R	1396	4810.837	16255.3	29	265796
L	1405	1044.288	95.74243	952.86	1362.55
F	1410	1.341355	0.0841829	1.20062	1.4477
K	1410	6.6505	3.301292	2.423333	10.5475
P	1280	320.0637	837.8659	4.9	7388.7
A	1280	533.5078	361.9072	17	1818
T	1818	0.1714286	0.3770286	0	1

5 Results and Scope Economies Analysis

5.1 Estimation Results

Software Stata has been used to estimate the model and the results are shown in Figure 5-1 and Figure 5-2.

Figure 5-1 Translog parameter estimates for the cost function in MWM market

```
. reg lntcms lnwdms lnwrms lnplms lnpfms lnpcms ///
> lnwdms_2 lnwrms_2 lnplms_2 lnpfms_2 lnpcms_2 ///
> lnwdms_lnwrms lnwdms_lnplms lnwdms_lnpfms lnwdms_lnpcms ///
> lnwrms_lnplms lnwrms_lnpfms lnwrms_lnpcms ///
> lnplms_lnpfms lnplms_lnpcms lnpfms_lnpcms ///
> lnpopdms lnaltdms certif if type == "Retail", robust
note: lnpfms_2 omitted because of collinearity

Linear regression                                      Number of obs =    1105
                                                       F( 22,  1082) =  841.43
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9237
                                                       Root MSE      =  .32327
```

lntcms	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnwdms	.8253384	.0507521	16.26	0.000	.7257547	.9249221
lnwrms	.2378184	.0440466	5.40	0.000	.1513921	.3242448
lnplms	.3403234	.3163541	1.08	0.282	-.2804137	.9610604
lnpfms	-.8739393	1.159324	-0.75	0.451	-3.148717	1.400838
lnpcms	-.0445073	.0925338	-0.48	0.631	-.2260734	.1370588
lnwdms_2	.0585101	.0448315	1.31	0.192	-.0294564	.1464765
lnwrms_2	.0906254	.0284684	3.18	0.001	.034766	.1464849
lnplms_2	-3.282014	1.424378	-2.30	0.021	-6.07687	-.4871575
lnpfms_2	0	(omitted)				
lnpcms_2	-.6014846	.2932811	-2.05	0.041	-1.176949	-.0260206
lnwdms_lnwrms	-.10759	.0700356	-1.54	0.125	-.2450109	.0298308
lnwdms_lnplms	.9337185	.4369651	2.14	0.033	.0763235	1.791114
lnwdms_lnpfms	.5673077	1.282975	0.44	0.658	-1.950093	3.084708
lnwdms_lnpcms	-.0555597	.1497032	-0.37	0.711	-.3493011	.2381817
lnwrms_lnplms	-.9164673	.3447088	-2.66	0.008	-1.592841	-.2400939
lnwrms_lnpfms	-.6132248	1.107556	-0.55	0.580	-2.786426	1.559977
lnwrms_lnpcms	.0549704	.1293695	0.42	0.671	-.198873	.3088139
lnplms_lnpfms	-1.770942	5.986806	-0.30	0.767	-13.51801	9.976122
lnplms_lnpcms	.1326158	.7256511	0.18	0.855	-1.291227	1.556458
lnpfms_lnpcms	3.672712	1.732292	2.12	0.034	.273681	7.071743
lnpopdms	-.0029286	.0148853	-0.20	0.844	-.0321358	.0262787
lnaltdms	.0546808	.0164022	3.33	0.001	.0224971	.0868646
certif	.0154376	.0270739	0.57	0.569	-.0376856	.0685608

Figure 5-2 loglinear parameter estimates for the cost function in MWM market

```
. xi: reg lntcms lnwdms lnwrms lnplms lnpfms lnpcms lnpopdms lnaltdms certif if type == "Retail", robust

Linear regression                                      Number of obs =    1105
                                                       F(  8,  1096) = 1518.39
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.9172
                                                       Root MSE      =  .33458
```

lntcms	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
lnwdms	.8522217	.0303805	28.05	0.000	.7926112	.9118322
lnwrms	.0640799	.0266686	2.40	0.016	.0117526	.1164072
lnplms	.5321914	.1359245	3.92	0.000	.2654898	.798893
lnpfms	.928725	.4704007	1.97	0.049	.0057373	1.851713
lnpcms	-.1038612	.0566482	-1.83	0.067	-.2150123	.0072899
lnpopdms	-.001498	.0113126	-0.13	0.895	-.0236948	.0206988
lnaltdms	.0473123	.0143269	3.30	0.001	.0192011	.0754234
certif	.0338305	.0286179	1.18	0.237	-.0223215	.0899826
_cons	-.0324148	.0241219	-1.34	0.179	-.0797451	.0149154

To make the comparison between these two models we do an F-test. The translog includes the loglinear plus additional variables (the squares of variables and the cross products). We make the F-test of the joint validity of the additional variables in the translog. The null hypothesis is that the coefficients of the additional variables are null. The result for the F-test is:

F (14, 1082) = 9.21

Prob > F = 0.0000

Therefore, the translog is chosen as our model.

As Figure 5-1 shows, the coefficient of variable D has a positive value, and it is statistically significant at a confidence level of 95 percent, which means the quantity of disposal waste has a positive effect on the total cost. The coefficient of variable R also has a positive value too, but it is not statistically significant in this model. Carvalho & Marques (2014) found that collecting larger amounts of recycling waste could save recycling costs for all utilities, especially for those provide less than 420,000 inhabitants. Callan & Thomas (2001) found that a 10 percent increase in recycled waste, should increase a town's annual recycling costs by 2.72 percent or approximately $ 4,553. The coefficient input price for labor, fuel and capital are all insignificant. The population density has a negative effect on the cost, but the coefficient is insignificant. The altitude differences show a positive effect on the cost, this is coherence with our expectation, and it is statistical significant. This means bigger altitude differences will increase the total cost of municipal solid waste management.

5.2 Scope Economies Analysis

As mentioned, the scope economies is calculated by comparing the costs of specialized production with the costs of jointly providing waste disposal and recycling service. Recall the equation here:

$$SP = \frac{C(Y_D, 0) + C(0, Y_R)}{C(Y_D, Y_R)} - 1 \tag{5.1}$$

If the index of economies of scope (SP) > 0, then the economies of scope could be achieved in Portuguese MSM market. Otherwise, there are diseconomies of scope. And the result of our estimation for economies of scope is shown in Figure 5-3.

Figure 5-3 Results for Economies of Scope

```
. di scope_economies
-.27215519
```

As we can see, the index value is -0.27215519, and it is less than zero, which means that we found diseconomies of scope by jointly providing waste disposal and waste recycling service in Portugal. This results is converse with Callan & Thomas (2001), they found that combined services of disposal and recycling can save cost and economies of scope are present in both services, and cost of providing services separately is 5% higher than providing jointly. Economies of scope is also found by Abrate et al. (2014), they used a balanced panel data of

529 Italian municipalities that provided waste collection and disposal services during years 2004–2006 to analyze the cost function of Italian MSM market. They found that the scope of economies increase with the size of municipalities. Their index for economies of scope value is 0.026. We have used a similar method to estimate the cost function and the index for economies of scope, this result is opposite. Compare to Italian, Portuguese municipal solid waste management utilities may not save more cost from providing waste disposal and waste recycling jointly.

6 Conclusion and Suggestions

6.1 Conclusion

Given the data from Waste and Water Management sector, we build a translog cost function of Portuguese municipal solid waste service provider and an index for economies of scope is estimated. By estimating the index, this paper analyzed the scope economies in the MSW market. The index value is -0.27215519, this means that there is no scope economies in Portuguese municipal solid waste management market. Portuguese municipal solid waste management utilities can not benefit from providing waste disposal and recycling service jointly.

6.2 Suggestion

According to the results we got, some suggestions regarding the municipal solid waste management policy could be given. Providing waste disposal and recycling service jointly may not be a good choice for Portuguese municipal solid waste management service providers. Economies of density is found. Utilities could make the most of the economies of density and increase the costumers they serve within a certain area. Altitude differences is also proved to have a statistical significant positive effect on total cost.

However, due to the lack of data and time, the model used in this paper could be improved in further research. Some other relevant variables regarding the cost could also be added into the model, for instance the collection frequency (collection times for a week), the geographic location (in the centre of the country or otherwise) and so on. And more questions could be answered, like the effect of recycling rate on the cost, the relationship between the municipal size and the scope economy.

7 Bibliography

Abrate, G., Erbetta, F., Fraquelli, G. & Vannoni D., 2014. The Costs of Disposal and Recycling: An Application to Italian Municipal Solid Waste Services. Regional Studies, 48(5), pp. 896–909.

Antonioli, B. & Filippini, M., 2002. Optimal size in the waste collection sector. Review of Industrial Organization, 20(3), pp. 239–252.

Bel, G. & Fageda, X., 2010. Empirical analysis of solid management waste costs: Some evidence from Galicia, Spain. Resources, Conservation and Recycling, 54(3), pp. 187–193.

Bel, G. & Mur, M., 2009. Intermunicipal cooperation, privatization and waste management costs: Evidence from rural municipalities. Waste Management, 29(10), pp. 2772–2778.

Bohm, R.A., Folz, D.A., Kinnaman, T.C. & Podolsky, M.J., 2010. The costs of municipal waste and recycling programs. Resources, Conservation and Recycling, 54(11), pp. 864–871.

Callan, S.J. & Thomas, J.M., 2001. Economies of Scale and Scope: A Cost Analysis of Municipal Solid Waste Services. Land Economics, 77(4), pp. 548–560.

Carroll, W., 1995. The organization and efficiency of residential recycling services. Eastern Economic Journal, 21(2), p. 215-225.

Carvalho, P. & Marques, R.C., 2014. Economies of size and density in municipal solid waste recycling in Portugal. Waste Management, 34(1), pp. 12–20.

Carvalho, P., Marques, R.C. & Dollery, B., 2015. Is bigger better? An empirical analysis of waste management in New South Wales. Waste Management, 39, pp. 277–286.

D'Onza, G., Greco, G. & Allegrini, M., 2016. Full cost accounting in the analysis of separated waste collection efficiency: A methodological proposal. Journal of Environmental Management, 167(1), pp. 59–65.

Dubin, J.A. & Navarro, P., 1988. How Markets for Impure Public Goods Organize: The Case of Household Refuse Collection. Journal of Law, Economics & Organization, 4(2), pp. 217–241.

EC, 2015. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste [Waste Framework Directive].

ERSAR, 2013. Annual Report on Water and Waste Services in Portugal - 2013. Executive Summary. Lisbon: ERSAR - The Water and Waste Services Regulation Authority.

Greco, G., Allegrini, M., Del Lungo, C. & Savellini, P.G. et al., 2014. Drivers of solid waste collection costs. Empirical evidence from Italy. Journal of Cleaner Production, 106, pp. 364–371.

Gu, B., Jiang, S., Wang, H., Wang, Z., Jia, R., Yang, J., He, S. & Cheng, R., 2017. Characterization, quantification and management of China's municipal solid waste in spatiotemporal distributions: A review. Waste Management, 61, pp. 67–77.

Hirsch, W.Z., 1965. Cost Functions of an Urban Government Service: Refuse Collection. The Review of Economics and Statistics, 47(1), pp. 87–92.

Hoornweg, Daniel; Bhada-Tata, Perinaz. 2012. What a Waste : A Global Review of Solid Waste Management. Urban Development Series Knowledge Papers no. 15. World Bank, Washington, DC.

Hyman, M., Turner, B. & Carpintero, A., 2013. Guidelines for National Waste Management Strategies: Moving from Challenges to Opportunities, United Nations Environment Programme.

Monteiro, H., 2009. Water Tariffs Methods for an Efficient Cost Recovery and for the Implementation of the Water Framework Directive in Portugal. PhD thesis. Lisboa, Portugal: Technical University of Lisbon, School of Economics and Management.

Reeves, E. & Barrow, M., 2000. The impact of contracting out on the costs of refuse collection services: The case of Ireland. Economic and Social Review, 31(2), pp. 129–150.

Rogge, N. & De Jaeger, S., 2012. Evaluating the efficiency of municipalities in collecting and processing municipal solid waste: A shared input DEA-model. Waste Management, 32(10), pp. 1968–1978.

Sorensen, R.J., 2007. Does Dispersed Public Ownership Impair Efficiency? the Case of Refuse Collection in Norway. Public Administration, 85(4), pp. 1045–1058.

Stevens, B.J., 1978. Scale, Market Structure, and the Cost of Refuse Collection. The Review of Economics and Statistics, 60(3), pp. 438–448.

USEPA, 2016a. Municipal Solid Waste. United States Environment Protection Agency.

Available at https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/ (acessed on 2017-10-16).

USEPA, 2016b. Advancing sustainable materials management: 2014 fact sheet. United States Environmental Protection Agency, Office of Land and Emergency Management, Washington, DC.

Zafra-Gómez, J.L. et al., 2013. Reducing costs in times of crisis: Delivery forms in small and medium sized local governments' waste management services. Public Administration, 91(1), pp. 51–68.

Zellner, A., 1962. An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias. Journal of the American Statistical Association, 57(298), pp. 348–368.

Appendix

Summary of the literatures

Article	**Explained Variable**	**Main Explanatory Variables**	**Model**	**Estimation Method**	**Main Conclusion**
(Abrate et al. 2014)	Total cost	Quantity(Disposal and Recycling tons), Factor Price(Labour, Capital, Fuel), Density, Population, time trend t, size dummies, geographical dummies, density and organizational form dummies	composite specification of translog function	Non-linear SUR	1. municipality of a size of about 42500 inhabitants, exhibits aggregate constant returns to scale moderate 2.economies of scope exist, and increase with the size of the council.
(Antonioli & Filippini 2002)	Total cost	Quantity (total of tonnes of waste collected), Prices for labour, fuel, capital; frequency of collection per week is higher than 3/otherwise	Translog cost function	SUR	1. Results indicate the existence of economies of density and economies of scale for most output levels. 2. The consolidation of adjacent service territories in small provinces is likely to reduce costs. 3. An increase in the frequency of collection per week has a strong impact on costs.

Article	Explained Variable	Main Explanatory Variables	Model	Estimation Method	Main Conclusion
(Bohm et al. 2010)	Disposal Cost and Recycling Cost	Factor Price(wage(average hourly earnings of production workers), interest, fuel(price of regular gas), tip fee (cost of waste disposal $ per ton)), pickup frequency(number of curb side recycling collections per month), Density(persons per square mile)	Two Log nonlinear cost function for disposal and recycling	SUR	The costs to collect, separate, process, market, and transport recyclable house-hold materials exceed the costs to collect and dispose the material as waste. Economies of scale are estimated across all observed waste quantities. But for recycling, economies of scale are estimated for only low quantities—the marginal and average cost curves for recycling take on the common U-shaped appearance.
(Callan & Thomas 2001)	Total cost of producing both disposal and recycling services	Quantity of Waste, Housing Density(numbers of single-family homes per square mile), Market Structure, Frequency, Exist of Landfill, Access to Recycling Facility, State Fund	Log linear cost function	SUR	1. Find economies of density for disposal 2.combined services of disposal and recycling can save cost. 3. Economies of scope are present in both services, and cost of providing services separately is 5% higher than providing jointly. 4. Find economies of density for disposal.

Article	Explained Variable	Main Explanatory Variables	Model	Estimation Method	Main Conclusion
(Carvalho&Marques2014)	Total cost for recycling(includes the operating expenses and the capital expenses)	Quantity of recycling, GDP, number of drop off containers per thousand inhabitants, type of management (dummy: public / private), regulation(dummy: if the utilities are regulated),if utilities do the composting process(dummy),whether use incineration(dummy),the ratio between amount of paper and glass collected and the ratio between amount of plastic and glass	Translog cost function	SFA(Stochastic frontier approach)	there are EOD in the recycling activity, the results further demonstrate that a 1% increase in the ratio between the amount of paper and glass collected for recycling (by weight) tends to increase the costs by 0.04%. Private management and incineration tend to reduce costs by about 9% and 15%, respectively, especially for small utilities, recycling in Portugal presents slight ESize in small and median utilities, utilities with dimensions between the 70th percentile and 3rd quartile are with constant returns to size,A1% increase in the ratio between the amount of paper and glass collected for recycling (by weight) tends to increase the costs by 0.04%.
(Dubin & Navarro 1988)	cost per yard of garbage collected	Collection frequency(pickups per week), Density(number of houses per square mile), market structure(private, municipal, franchise), pick up location (curb side or backyard)	linear cost function	OLS	An increase in density by 100 housing units per squqre mile leads to a $1.62 decrease in the annual per housing unit refuse bill.

Article	Explained Variable	Main Explanatory Variables	Model	Estimation Method	Main Conclusion
(Hirsch 1965)	Average annual residential refuse collection cost per ton	Collection frequency(pickups per week), pick up location, pick up density	log linear cost function	OLS	An increase from two weekly pickups to three increased cost by about 28 percent. Moving pickup location from curb to rear double the cost
(Reeves & Barrow 2000)	Total gross expenditure on refuse collection services	Number of domestic and commercial units, Density of units per hectare, privately contracted more than 10%(dummy); Percentage of units collected from more than once a week, Percentage of units collected from less than once a week, Percentage of total costs expended on recycling.	log linear cost function	OLS	Irish local authorities have accrued substantial cost savings by contracting out refuse collection services through competitive tendering.
(Stevens 1978)	Total cost to house holds served(TCHS)	Quantity of refuse collected per year, Market Structure: private monopoly, public monopoly, competitive, Density(the number of households per square mile)	log linear cost function	OLS	1. Small cost savings may be achieved for further increases in scale up to about 50,000 individuals. 2. TCHS is on average less when the collector is a private monopolist than when the collector is a public monopolist. This difference increases with city size, becoming statistically significant for cities with population over 50,000.

Article	Explained Variable	Main Explanatory Variables	Model	Estimation Method	Main Conclusion
(Zafra-Gómez et al. 2013)	Total cost	Quantity of waste collected per year, pickup frequency, service provider, governing party; right wing/left wing; coalition/absolute majority government	Log cost function	OLS	1. Two management forms that reflect a form of privatization, MUC and MCC, are the ones producing the smallest cost reduction. 2. Political parties that enjoy an absolute majority in local government tend to have lower costs.3. Existence of economies of scale.