Neural, Parallel, and Scientific Computations 19 (2011) 165-180

ESTIMATING FLEXIBLE COST FUNCTIONS ON REFUSE COLLECTION IN ATTICA REGION, GREECE

VASSILIA NINNI[1]

[1]**Department of Business Administration, Athens University of Economics and Business, 76, Patission str., 104 34 Athens, Greece**

Abstract. The purpose of this study is to investigate the existence of economies of scale and other economic parameters influencing the rate of return of the domestic solid waste collection process. To this end, the case of the Attica region in Greece, which includes equal amounts of urban and rural areas, is considered. The investigating approach is performed via the transcendental logarithmic cost function, a member of the family of flexible functions, which was selected as the most suitable for this particular application. Despite the increased complexity of the problem, the results of estimation of the econometric model lead to useful conclusions. A complementary relationship between capital and labour is observed, while strong substitution relationships for the (capital, labour) and (labour, energy) variable pairs are found. Our analysis also indicates absence of economies of scale in refuse collection services.

Keywords - refuse collection, economies of scale, transcendental logarithmic cost function.

1. INTRODUCTION

The large quantities of municipal waste are the visual component of the environmentally-hazardous way we use natural resources. Every year European Union (EU) countries produce very large quantities of solid waste which usually ends up in designated areas of interment – sometimes in unlawful landfills – burnt in incinerating plants, recycled or composted in sorting plants. The Organization for Economic Co-operation and Development (OECD) estimates that solid waste across Europe in the year 2020 will be approximately 45% more than the amount recorded for year 1995. This prediction is reinforced by the emphasis the EU is giving on the proper management of solid waste. In fact, the target figures of Sixth Program for Action for European Union Environment are the 20% reduction of solid waste quantities by year 2010 and by 50% by year 2050. It is widely believed that this goal is going to be reached by applying the appropriate policies regarding the reduction of waste, recycling, safe disposal and cost effective waste management. It is this last point that the present work is focused on, i.e. the identification

Received September 1, 2010

of the existence of economies of scale and other economic factors influencing the efficiency of solid waste management.

In this paper, we will consider the case of Greece that, as a EU member, has to comply with the environmental guidelines set by EU regarding the disposal of solid waste. Specifically, we consider the case of waste management in the Attica region, which includes the wide Athens metropolitan area. The difficult task of waste management – collection and final processing – of solid waste in Greece is the responsibility of local authorities (municipalities and communities). Performance assessment of a service such as refuse collection has attracted the interest of many researchers. This performance measurement in refuse collection and its improvement can be regarded as an optimizing measure of the rate of return for this service. In general, the rate of return can be defined as the output to input ratio. When we are dealing with multiple inputs and outputs this ratio is far more difficult to be measured as several weighing factors need to be calculated first. When these factors are finally determined then the rate of return (denoted as r) can be defined as the ratio of the sum of all weighted outputs by the sum of all weighted inputs.

Therefore, the recognition of the necessity for rate of return improvement for the case we examine reflects the following: (a) the effort that has to be made by a local authority in improving the performance of the particular service, (b) the necessity in establishing a certain procedure in assessing this performance and (c) the exact definition and comprehensive description of all the tasks of the service so that necessary statistical data is collected and is made available. In particular for local authority, performance measurement by using special performance indices offers the following advantages: (a) performance indices are useful in understanding the performance of a service, (b) performance indices are necessary as they can be used to compare the rate of return of services offered by different municipalities. On many occasions, the comparison of the same service across several municipalities can be useful in deducing interesting conclusions. Another advantage is that (c) performance indices offer the possibility of studying time-related trends.

In assessing a performance index, local authorities can investigate the parameters and their interactions in influencing that performance index value and also its expected value. In order to understand the complexity of the statement above we will confine our investigation to the refuse collection service. In this case the rate of return can be defined as:

$$r = \frac{\text{Refuse Collection Cost}}{\text{Total Weight of Refuse (in tons)}}$$

As there are several parameters that influence the rate of return, we group them in the following categories: (a) human resources management of the service, (b) available vehicles and equipment (waste collection vehicles, special equipment and other machinery support), (c) service productivity (weight of refuse per worker in the waste collection vehicles), (d) financial resources of the service (for machinery investment), (e) depositing sites for amassed waste, and (f) organization and scheduling of the service (optimal routes, frequency of collection, size of waste collection vehicles).

All these parameters are directly or indirectly linked to the rate of return we have already defined by variable r. One way to investigate the existing relationship of this variable and the dominant parameters will be to estimate a relation of the following form:

$$r = f(\text{parameters})$$

Using this relationship we can easily assess which parameters are statistically important in estimating r (cost per ton of collected waste). It is unfortunate that the estimation of such a relation needs statistical data which is not available as it is not kept by Greek municipalities, at least until present day. Nevertheless, in this study we will attempt to derive a different econometric model (using statistical data we had access to, and despite our numerous efforts it was impossible to find relevant statistical data) which will yield information relating to certain fundamental data, such as economies of scale and substitution elasticities for waste collection services of some municipalities in the Attica region.

2. RELATED WORK

International literature states that, in municipalities with small population, it is possible for scale economies either to exist (Stevens, 1977; Dubin & Navarro, 1988) or not (Hirsch, 1965; Callan & Thomas, 2001). An early study by (Hirsch, 1965) examines the effect of several factors in influencing the cost of the refuse collection service. Using statistical data collected from 22 municipalities in the state of St. Louis, by using the method of multiple regression, the author came to the conclusion that in that particular case there are no economies of scale. Hall and Jones using statistical data from 32 communities in Texas with populations over 3000, have investigated the issue of whether economies of scale exist or not (Hall & Jones, 1973). They have used the multiple regression method as well and have concluded that communities with populations up to 9600 showed economies of scale, as opposed to communities with higher numbers of inhabitants. This particular study has shortcomings as it uses the number of inhabitants as a measure of magnitude of the product, while a more convenient variable would be the refuse quantity. Another issue is the fact that the number of inhabitants is included among the independent variables although it is strongly connected to the population size, while we should note the omission of the sanitation workers' salaries from the study.

Kemper and Quigley investigated the issue by using a sample of 128 communities in Connecticut (Kemper & Quigley, 1976). Their research work estimated the average cost function using the number of households as the product variable. They have concluded that there are no economies of scale although it is possible for economies of scale to exist in communities of up to 2000 inhabitants. In this work as well, the parameters involving costs such as workers' compensation are also ignored. Kitchen examining the statistical data of 48 cities in Canada with populations of over 10,000 inhabitants, derived an average cost function using the number of inhabitants as the product variable (Kitchen, 1976). The empirical results of his work lead to the existence of an inverted U-shaped relationship between average cost and population. That is, the refuse collection cost increases initially with population increase, it reaches a peak and then decreases.

A more dependable investigation is conducted by Stevens who used a 340-community sample (Stevens, 1977). The communities examined had a population ranging from 2500 inhabitants to over 700,000. Total cost functions were estimated separately for communities under 20,000, of 30,000, and 50,000 inhabitants as for communities over 50,000 inhabitants. Assessments were classified according to the nature of refuse collection enterprise, which can be either municipal or private. The deduced function of cost which was derived from the Cobb-Douglas production function incorporates as product variable the quantity of waste expressed in tons. The study concluded that economies of scale exist in communities with up to 20,000 inhabitants, while for communities between 20,000 and 50,000 the indications are mixed.

Collins and Downes performed data analysis on 53 St. Louis communities (Collins & Downes, 1977). The product variable used was the number of collection vehicles. Multiple regression results have shown the existence of an inversely proportional relation between monthly household costs and number of refuse collecting units. This relationship was thought of as an indication of economies of scale existence. According to the aforementioned studies, it seems that economies of scale are present only in communities with rather low populace. Other studies involved in the investigation of economies of scale in public services were conducted by (Walzer, 1972; Ahlbrandt, 1973; Young, 1974; Stevens, 1977; Fox, 1981; Domberger et al., 1986; Tickner & McDavid, 1986; Cubbin et al., 1987; Diewert & Wales, 1987; Gyimah-Brempong, 1987; Deller et al., 1988; Callan & Santerre, 1990; DeBoer, 1992; Duncombe & Yinger, 1993; Szymanski, 1996), while the case of Attica region in Greece has been previously examined by (Panas & Ninni, 1998). Overall, we could state that the relevant literature does not provide concrete evidence that economies of scale can be found in municipal solid waste management.

3. THE RATE OF RETURN IN LOCAL GOVERNMENT

The rate of return of an organization or service owned and managed by local government is undoubtedly connected to the existing relationship between the products (outputs) of a particular service and the inputs it utilizes. The public sector and organizations belonging to local government are responsible for offering and producing large number of services. These services cannot normally be valued under regular market prices. Therefore, under these circumstances, these organizations have to develop their own internal mechanisms such as zero-base budget, assessment of their investments, and other similar procedures that would function as substitutes in a way similar to how the market operates.

Issues related to the efficient use of financial resources are very important to the public sector. A publicly owned organization or service will be optimal when it manages to produce the largest possible product using the minimal level of input. This concept is derived by optimizing producer function, since production function is defined in such a way as to deliver the maximum possible product level that can be actually produced utilizing a given sum of inputs. Hence the production function sets a limit to a wide range of possible cases. These cases can be below or above the frontier production function.

In measuring the rate of return or efficiency we need to follow a three stage procedure. At first we need to define all inputs and outputs, as in the public sector we encounter issues normally absent in the private sector. Secondly, we have to define what is attainable, i.e. results that can be achieved or set of outputs that can be delivered when a given set of inputs is used. Finally, we will try to estimate an efficiency index. The efficiency analysis is entirely based on the theory of production and cost functions. We can, therefore, write these functions as follows:

$$y = f(x_1,...,x_n) \text{ (production function)}$$

$$c = g(p_1,...,p_n, y) \text{ (cost function)}$$

where y is the product, $x_1,\ldots, x_n$ are the inputs to the production mechanism, c is the total cost and $p_1,\ldots, p_n$ are the input values. It is possible for the observed product to be under the curve defined by the production function, as Figure 1 shows. Point B on the curve is a point that corresponds to efficiency. Conversely, point A is a point which is in the non-efficiency region, since it is located under the production function curve.

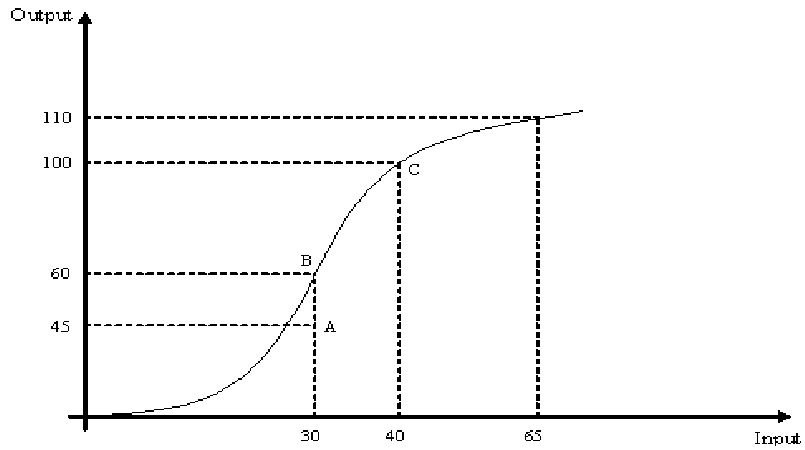

Figure 1. A production function example.

Let us assume that the refuse collection service has the shape of the curve above, with the sole input to be labour (measured in man-hours) and the sole output refuse to be collected (measured in tons). If we now assume that by proper tuning of the service we can move point A to point B and this can be solely achieved by improving labour resources then the efficiency level which at point A was standing at 1.5 tons per man-hour is now increased to 2 tons per man-hour. This means that one way of improving the refuse collection service could be by improving its efficiency.

Continuing with the example, let us examine the relationship between productivity and service size. We assume that the collection service increases in size. This change is depicted by moving point B to point C, where the number of man-hours is increased from 30 to 40. We now observe that at point C, the productivity level from 2 tons per man-hour (point B), has now reached 2.5 tons per man-hour, the man-hours have increased from point B to point C by 33% and the weight of the collected refuse has correspondingly increased from point B to point C by 66.6%. At the same time, we observe that the percentage increase in man-hours (33%) from point B to point C is less than the percentage increase in refuse collection, a fact that justifies the productivity increase (25%). Thus, we observe that in this case, productivity increase is due to the effects of economies of scale.

The fundamental concept of the economies of scale is based on the fact that production facilities of a given size have a cost advantage when compared to other facilities or organizations of different size and scale. The most common and acceptable method of assessing economies of scale is the one which utilizes functions of production and cost or even estimation of the frontier production and cost functions (Stochastic Frontier Analysis, also referred to as SFA). In the course of this investigation we could attempt, using SFA, to assess different economic parameters, but the quality and availability of the necessary statistical data unfortunately dictate the choice of methodology.

4. THE MODEL

The assessment of economies of scale is based on the economic theory of production. In order to study the substitution possibilities and the economies of scale for the case of refuse collection by the Attica region municipalities, we start by assuming that technology is described by a production function which relates the product y (tons of waste) to capital (K), labour (L) and energy (fuel) (E), hence:

$$y = f(K, L, E) \tag{1}$$

We assume that the refuse collection services minimize production costs and according to the theory of production, the production structure as described by equation (1) can, under certain conditions, be expressed by the cost function as follows:

$$c = g(y, P_K, P_L, P_E) \tag{2}$$

where c is the total cost, y is the product quantity and P_K, P_L, P_E are the input values of K,L,E correspondingly.

For the purpose of applied research, it is necessary to select the appropriate function g in equation (2). It is furthermore necessary to select a suitable expression which imposes the minimum set of limitations to the characteristics of the production function and especially to the economies of scale and to the substitution elasticities. There are a number of functions with these characteristics available today, such as the transcendental logarithmic function (TLF), the Leontief generalized function, the generalized quadratic function and others. A common characteristic of all these functions is that they can provide a certain approach to the formulation of a cost function.

The purpose of this study is not the investigation of the applied analysis for various functional expressions but the selection of the most convenient function to tackle the issue in hand. In our case we have selected to use the transcendental logarithmic cost function, as we believe to be the most suitable for the application under consideration. Christensen and colleagues first propose the TLF to be a convenient tool for a second degree approach to an arbitrary cost function (Christensen et al., 1971; 1973). The transcendental logarithmic cost function (TLCF) we intend to use for the present task can be written as follows:

$$\log c = \alpha_0 + \alpha_y \log y + \frac{1}{2}\alpha_{yy}(\log y)^2 + \alpha_1 \log P_K + \alpha_2 \log P_L + \alpha_3 \log P_E + \frac{1}{2}\gamma_{11}(\log P_K)^2 +$$
$$+ \gamma_{12} \log P_K \log P_L + \frac{1}{2}\gamma_{22}(\log P_L)^2 + \gamma_{23} \log P_L \log P_E + \frac{1}{2}\gamma_{33}(\log P_E)^2 + \gamma_{1y} \log P_K \log y + \qquad (3)$$
$$+ \gamma_{2y} \log P_L \log y + \gamma_{3y} \log P_E \log y$$

where $\gamma_{ij}=\gamma_{ji}$ (i,j=1,2,3).

To ensure that the production function is adequately determined it must be homogeneous to a first degree with regards to the values. That is, for a given product level a proportional increase in all values should result in a proportional increase in all costs. This leads to the following restrictions on the parameters of the cost function:

$$\begin{gathered} \alpha_1+\alpha_2+\alpha_3=1 \\ \gamma_{11}+\gamma_{12}+\gamma_{13}=0 \\ \gamma_{12}+\gamma_{22}+\gamma_{23}=0 \\ \gamma_{13}+\gamma_{23}+\gamma_{33}=0 \\ \gamma_{1y}+\gamma_{2y}+\gamma_{3y}=0 \end{gathered} \qquad (4)$$

Although equation (3) can be estimated given the restrictions of equation (4) above, the number of parameters is large enough and an issue of multicollinearity may occur and this may in turn lead to vague parameter estimation. Available literature on this point follows the practice of estimating the TLCF in conjunction with the functions of input demand. These functions are derived by applying Shephard's lemma:

$$\frac{\partial(\log c)}{\partial(\log P_i)} = \frac{P_i}{c} \cdot \frac{\partial c}{\partial P_i} = \frac{P_i \cdot x_i}{c} = S_i \qquad (5)$$

where i=K,L,E denoting the i-input share to the total cost. Hence from equation (3) the following equations are derived:

$$\begin{gathered} S_K=\alpha_1+\gamma_{11}\log P_K+\gamma_{12}\log P_L+\gamma_{13}\log P_E+\gamma_{1y}\log y \\ S_L=\alpha_2+\gamma_{12}\log P_K+\gamma_{22}\log P_L+\gamma_{23}\log P_E+\gamma_{2y}\log y \\ S_E=\alpha_3+\gamma_{13}\log P_K+\gamma_{23}\log P_L+\gamma_{33}\log P_E+\gamma_{3y}\log y \end{gathered} \qquad (6)$$

In evaluating equations (3) and (6), we need to take into account the restrictions of equation (4). Before we can proceed with the estimation, we need to point out that our interest is focused on the economies of scale and elasticities of substitution.

For the elasticities of substitution we make use of Allen's partial substitution of elasticities, which for two inputs i and j is defined as follows:

$$\sigma_{ij} = \frac{c \cdot \dfrac{\partial^2 c}{\partial P_i \partial P_j}}{\dfrac{\partial c}{\partial P_i} \cdot \dfrac{\partial c}{\partial P_j}} \qquad (7)$$

and in the case of the TLCF are expressed as:

$$\sigma_{ij} = \frac{\hat{\gamma}_{ij} + \hat{s}_i \hat{s}_j}{\hat{s}_i \hat{s}_j}, i \neq j \tag{8}$$

$$\sigma_{ii} = \frac{\hat{\gamma}_{ii} + \hat{s}_i^2 - \hat{s}_i}{\hat{s}_i^2}, i = K, L, E \tag{9}$$

The substitution elasticities as shown by (Allen, 1959) are related to the values of elasticities according to the following equation:

$$n_{ij} = \sigma_{ij} \cdot \hat{s}_j \tag{10}$$

Finally, according to (Caves et al., 1984), the economies of scale are defined as the percentage increase of total cost resulting from the percentage increase of the product y, while keeping the input values constant, that is:

$$R = \frac{1}{\frac{\partial \log c}{\partial \log y}} = \frac{1}{\alpha_y + \alpha_{yy} \log y + \gamma_{1y} \log P_K + \gamma_{2y} \log P_L + \gamma_{3y} \log P_E} \tag{11}$$

This equation reveals that when R>1, economies of scale are present, while when R<1 economies of scale are absent. The TLCF offers several advantages (Nadiri & Schankerman, 1981), some of which follow:

- The cost function expresses the minimum overall cost in terms of input values and product quantity.
- The cost function methodology assumes the values and the product as extraneous variables while inputs and total cost as intrinsic variables.
- The TLCF yields directly the estimation of Allen's elasticities of substitution.
- The TLCF also directly yields the estimates of economies of scale without any parameter restrictions.

We define product as the quantity in tons of the refuse at every collection point. Due to the lack of a central service collecting statistical data from all municipal refuse collection services, the data used in this study were collected by the questionnaire method in some representative municipalities.

5. ESTIMATION OF THE TRANSCENDENTAL LOGARITHMIC COST FUNCTION (TLCF)

The analysis of the economies of scale and the elasticities of substitution is derived from the estimation of the TLCF factors, which is performed in this section. The statistical data referred to the municipalities of the Attica region for a 1 year time horizon. The stochastic approach incorporates in cost function cumulatively the stochastic term as well as in the functions of labour and energy shares. These stochastic terms can be interpreted as the random errors during the cost minimization process. The estimation process used is Zellner's SURE method (Zellner, 1962). This method is equivalent to the Maximum Likelihood Method, which yields the same results regardless of the fact that one of the three initial components is neglected in the estimation process. The results are presented in Table 1 below:

Table 1. Parameters' estimation of the transcendental logarithmic cost function

Parameters	**Values**
α_0	-30.44 (2.5)
α_y	0.8852 (2.4)
α_2	0.3447 (1.6)
α_3	0.13631 (2.1)
γ_{11}	-0.02 (4.1)
γ_{12}	0.02376 (4.9)
γ_{22}	-0.021 (1.89)
γ_{2y}	0.03354 (1.6)
γ_{3y}	-0.01674 (2.3)
γ_{23}	-0.0265 (3.2)
γ_{33}	0.0292 (3.4)

Note: The numbers in parentheses are the t-statistic absolute values.

The majority of parameters, albeit without strict economic meaning, are statistically important. Observing the values of parameters α_2 and α_3, the following comments can be made. Firstly, the economic meaning of these parameters is that they tend to reflect the components of labour and energy shares. Secondly, the values of parameters α_2 and α_3 (0.3447 and 0.13631 respectively) are not significantly different from the component means of our data.

One of TLF advantages is the information revealed by Allen's elasticities of substitution. We are interested, at first, at the inputs elasticities which are given by the following relation:

$$\sigma_{ii} = 1 + \frac{\gamma_{ii}}{S_i^2} - \frac{1}{S_i}, i = K, L, E \tag{12}$$

One condition that must be fulfilled for the cost function to be adequately determined is:

$$\sigma_{ii} < 0, \forall i \tag{13}$$

For this particular cost function we have obtained the following values for the sample mean:

$$\hat{\sigma}_{11} = -4.893$$
$$\hat{\sigma}_{22} = -0.1482$$
$$\hat{\sigma}_{33} = -3.6355$$

The σ_{ii} (i=K, L, E) values obtained confirm the assumption that the cost function must be concave. A more rigorous condition that has to satisfy the cost function is that the second derivative matrix of the cost function or Hessian matrix $\left[\frac{\partial^2 c}{\partial P_i \partial P_j}\right]$ is negatively determined for every observation. Binswanger has shown that this condition is expressed through the elasticities of substitution $[\sigma_{ij}]$ and this matrix is negatively determined (Binswanger, 1974). This condition was applied to the sample mean and it was confirmed.

Let us now return to the examination of the substitution possibilities among inputs K, L and E. For every input pair, the elasticity of substitution according to Allen measures the percentage variation of the input ratio which is due to a variation of 1% of the relative input values. A negative value for σ_{ij} ($i \neq j$) means that inputs are complementary, i.e. a relative input value increase leads to the reduction of the other input value. A positive value for σ_{ij} ($i \neq j$) means substitution of inputs and this practically means that an increase in the value of an input leads to the relative increase of the other input value. The elasticities' values of the sample mean are:

$$\sigma_{12}=1.5255$$
$$\sigma_{13}=-0.43642$$
$$\sigma_{23}=0.56641$$

Observing these values we can make the following observations:

- Capital and labour can be substituted. We observe that the elasticity value is greater than one, which means that the capabilities of substitution between capital and labour are important.

- Regarding the relationship between capital and energy we note that the elasticity of substitution value is negative which means in terms that these two inputs are complimentary. The complementary structure for this particular service means that small variations in energy costs lead to greater reductions in the use of capital.
- The relationship between labour and energy is positive and indicates that these inputs can be substituted.

Allen's elasticities of substitution are useful not only when we wish to establish whether the cost function is adequately determined or to investigate the structural relationship of inputs, but also when we need to calculate the elasticities of demand. These elasticities for this particular case have the following values:

$$n_{12}=1.33043$$
$$n_{13}=-0.02259$$
$$n_{23}=0.4207$$

We observe that on two occasions the input values are small (inelastic) and that the highest value appears for input n_{12}, appearing to be elastic. Concerning economies of scale - see equation (11) – we note that when R is less than 1 decreased performance is observed while when greater than 1 economies of scale are achieved. Estimation of scale economies obtained for every municipality is tabulated below.

Observing estimation values as they appear in Table 2, we conclude that all municipalities under consideration show decreased or non-existent economies of scale. These results lead us to the doubt of whether these reimbursable services can function under the principle of an economy of scale.

A fundamental issue in assessing a municipal policy on cost and management is the existence or not of economies of scale. That is, when economies of scale are present, we can achieve a higher rate of return in direct proportion to the population of each municipality, which means that as the number of inhabitants of the municipality increases the overhead costs are distributed to a greater number of inhabitants leading to a reduction of the cost per capita.

In our case, although the economies of scale indicator values vary between 0.81605 and 0.87266, we could safely assume that they do not significantly differ from the standard scale efficiency values. Although the values are not significantly less than 1 we cannot assume that municipalities operate under economies of scale conditions.

Table 2. Estimations of scale economies in Attica municipalities

Municipalities	R-Value
1	0.839971
2	0.871298
3	0.857621
4	0.845430
5	0.871809
6	0.864363
7	0.862942
8	0.846923
9	0.844911
10	0.841616
11	0.840705
12	0.857362
13	0.853248
14	0.872667
15	0.854511
16	0.850274
17	0.845439
18	0.851268
19	0.854156
20	0.854834
21	0.871392
22	0.851243
23	0.849683
24	0.845578
25	0.843857
26	0.847679
27	0.851308
28	0.849992
29	0.850471
30	0.845453
31	0.816052
32	0.850562
33	0.843216
34	0.855934

6. CONCLUSIONS

In this study, two cases have been examined. According to the first one, refuse collection services utilize three inputs: capital (e.g. refuse collection vehicles, utility vehicles, trucks and other machinery), labour and energy. Therefore it is reasonable to seek whether substitutions exist or not among these inputs. In the second case, we assume that investigating the existence or not of economies of scale in municipal services are useful in the local government decision making process. These two cases are examined for the refuse collection service of Attica municipalities, which are confronted with serious problems regarding domestic solid waste management.

In our investigation we have made extensive use of the TLCF which belongs to the family of flexible functions. The TLCF along with the input equations were used in conjunction with Zellner’s method. Our findings indicate that: a) there is a complementary relation between capital and energy, b) there is strong substitution between capital and labour, c) there is substitution between labour and energy, and d) there are no economies of scale in refuse collection services.

Although this study has shed some light in the complex relations that exist between the inputs present in municipal services, we have to note the severe difficulties we encountered during the data collection phase. Unfortunately, these limitations in particular data quality and the selection of a single year cannot offer a complete picture on the manner the refuse management services operate. This lack of necessary data has prevented us from considering more complex models in order to examine issues related to the productivity of municipal operations.

Furthermore, in a future study, it would be useful to incorporate data sorting out the product in separate categories (e.g. paper, aluminum) as well as data on the total number of refuse collection vehicles, the number of workers involved in refuse collection and the energy, labour and total costs.

7. ACKNOWLEDGEMENTS

This study was funded by the Research Centre of Athens University of Economics and Business (RC-AUEB) as part of the project “Estimation of Flexible Cost Functions in Refuse Collection”, code EP-0779-01.

REFERENCES

1. Ahlbrandt, R. (1973). Efficiency in the provision of fire services, *Public Choice*, v. 18, pp. 1-11.
2. Allen, R.G.D. (1959). Mathematical Economics, Macmillan: London.

3. Binswanger, H.P. (1974). A cost function approach to the measurement of elasticities of factor demand and elasticities of substitution, *American Journal of Agricultural Economics*, pp. 377-386.
4. Callan, S.J. & Thomas, J.M. (2001). Economies of scale and scope: A cost analysis of municipal solid waste services, *Land Economics*, v. 77, pp. 548-560.
5. Callan, S.J. & Santerre, R.E. (1990). The Production Characteristics of Local Public Education: A Multiple Product and Input Analysis, *Southern Economic Journal*, v. 57, pp. 468-480.
6. Caves, D.W., Christensen, L.R. & Tretheway, M.W. (1984). Economies of Density versus Economies of Scale: why Trunk and Local Service Airline Costs Differ, *RAND Journal of Economics*, v. 15, pp. 471-489.
7. Christensen, L.R., Jorgensen, D.W. & Lau, L.J. (1971). Conjugate Duality and the Transcendental Logarithmic Production Function, *Econometrica*, v. 39, pp. 255-256.
8. Christensen, L.R., Jorgensen, D.W. & Lau, L.J. (1973). Transcendental Logarithmic Production Frontiers, *Review of Economics and Statistics*, v. 55, pp. 28-45.
9. Collins, J.N. & Downes, B.T. (1977). The Effects of Size on the Provision of Public Services: the Cost of Solid Waste Collection in Smaller Cities, *Urban Affairs Quarterly*, v. 12, pp. 333-347.
10. Cubbin, J., Domberger, S. & Meadowcroft, S. (1987). Competitive tendering and refuse collection: identifying the sources of efficiency gains, *Fiscal Studies*, v. 8, pp. 49-58.
11. DeBoer, L. (1992). Economies of Scale and Input Substitution in Public Libraries, *Journal of Urban Economics*, v. 32, pp. 257-268.
12. Deller, S.C., Chicoine, D.L. & Walzer, N. (1988). Economics of Size and Scope in Rural Low-Volume Roads, *Review of Economics and Statistics*, v. 70, pp. 459-465.
13. Diewert, W.E. & Wales, T.J. (1987). Flexible Functional Forms and Global Curvature Conditions, *Econometrica*, v. 55, pp. 43-68.
14. Domberger, S., Meadowcroft, S. & Thompson, D.J. (1986). Competitive tendering and efficiency: the case of refuse collection, *Fiscal Studies*, v. 7, pp. 69-87.
15. Dubin, J.A. & Navarro, P. (1988). How markets for impure public goods organize: the case of household refuse collection, *Journal of Law, Economics and Organization*, v. 4, pp. 217-241.
16. Duncombe, W. & Yinger, J. (1993). An Analysis of Returns to Scale in Public Production, with an Application to Fire Protection, *Journal of Public Economics*, v. 52, pp. 49-72.
17. Fox, W. (1981). Reviewing Economies of Size in Education, *Journal of Education Finance*, v. 6, pp. 273-296.
18. Gyimah-Brempong, K. (1987). Economies of Scale in Municipal Police Departments: The Case of Florida, *Review of Economics and Statistics*, v. 69, pp. 352-356.
19. Hall, J.P. & Jones, L.L. (1973). Costs of solid waste management in rural Texas communities, *Southern Journal of Agricultural Economics*, v. 5, pp. 115-119.
20. Hirsch, W. (1965). Cost Functions of an Urban Government Service: Refuse Collection, *Review of Economics and Statistics*, v. 47, pp. 87-92.
21. Kemper, P. & Quigley, J.M. (1976). The Economics of Refuse Collection, Ballinger Publications: Cambridge, Mass.
22. Kitchen, H. (1976). A Statistical Estimation of an Operating Cost Function for Municipal Refuse Collection, *Public Finance Quarterly*, v. 4, pp. 56-76.
23. Nadiri, M.I. & Schankerman, M. (1981). The Structure of Production, Technological Change, and Total Factor Productivity Growth in the Bell System, in Productivity Measurement in Regulated Industries, Academic Press, New York, pp. 219-247.

24. Panas E. & Ninni V. (1998). Scale Economies: The Case of Refuse Collection in the Attica Region, *Spoudai*, v. 48, pp. 119-139.
25. Stevens, B.J. (1977). Scale, market structure, and the cost of refuse collection, *Review of Economics and Statistics*, v. 60, pp. 438-448.
26. Szymanski, S. (1996). The Impact of Compulsory Competitive Tendering on Refuse Collection Services, *Fiscal Studies*, v. 17, pp. 1-19.
27. Tickner, G. & McDavid, J. (1986). Effects of scale and market structure on the costs of residential solid waste collection in Canadian cities, *Public Finance Quarterly*, v. 14, pp. 371-393.
28. Walzer, N. (1972). Economies of Scale and Municipal Police Services: The Illinois Experience, *Review of Economics and Statistics*, v. 54, pp. 431-438.
29. Young, D.R. (1974). The economic organization of refuse collection, *Public Finance Quarterly*, pp. 43-72.
30. Zellner, A. (1962). An Efficient Method of Estimated Seemingly Unrelated Regressions and Test of Aggregation Bias, *Journal of the American Statistical Association*, v. 57, pp. 348-368.