UNIVERSITÀ
DEGLI STUDI
DI TORINO

ALMA UNIVERSITAS
TAURINENSIS

Founded in 1404

DEPARTMENT OF
ECONOMICS AND STATISTICS
WORKING PAPER SERIES

Quaderni del Dipartimento di Scienze
Economico-Sociali e Matematico-Statistiche

ISSN 2279-7114

SIZE AND DENSITY ECONOMIES IN REFUSE COLLECTION

GRAZIANO ABRATE

FABRIZIO ERBETTA

GIOVANNI FRAQUELLI

DAVIDE VANNONI

Working paper No. 9 - July 2012

Size and Density Economies in Refuse Collection

Graziano Abrate

(University of Piemonte Orientale and HERMES)

Fabrizio Erbetta

(University of Piemonte Orientale and HERMES)

Giovanni Fraquelli

(University of Piemonte Orientale and Ceris-CNR)

Davide Vannoni[1]

(University of Torino and Collegio Carlo Alberto)

Abstract

The focus of the paper is to analyze the costs of solid waste collection by applying a well-behaved multi-product cost function model to a sample of more than 500 Italian municipalities. Beyond shedding light on the presence and on the extent of size (or scale) economies, our aim is to investigate in depth the issue of economies of density, which is still an underexplored topic in the literature. Our cost function specification, by being able to estimate several measures of density economies (such as output density economies, vertical density economies and horizontal density economies), allows to capture the impact of different urbanization models on the costs of refuse collection and disposal. The results of the estimates highlight the presence of output density economies as well as horizontal density economies. Conversely, there is significant and robust evidence of the existence of vertical density diseconomies, which suggests that congestion problems in densely populated councils are severely affecting garbage collection costs. Finally, there is evidence of diseconomies of size, which suggests that aggregating the refusal collection operations of several municipalities would not bring savings in the average costs.

Keywords: Solid waste, density economies, cost functions.

JEL codes: D24, H42, L32, L99

[1] *Corresponding Author*: University of Torino, Department of Economics and Statistics, Corso Unione Sovietica 218 bis, 10124 Torino – Italy. Tel: + 39 + 0116706083. E-mail: vannoni@econ.unito.it.

1. Introduction

In the last decades EU directives have promoted an intense liberalization and deregulation program in an attempt to improve the efficiency of local public services across Europe. The attention of policymakers has been directed towards the promotion of competition and cost efficiency through a mixture of divestitures, outsourcing and competitive tendering. The refusal collection industry does not represent an exception to that. Together with prescriptions which are valid for all local public utilities, some sector specific interventions have set ambitious environmental goals, as a consequence of a greater concern for sustainability and environmental protection. In fact, economic and demographic growth, the urbanization process, as well as the change of consumption habits of citizens have all contributed to the sharp increase of solid waste production. To contrast this trend, Directives 2006/12 and 2008/98 oblige EU members to reduce their waste production and to adopt measures to improve recycling programs. In Italy, the reforms introduced by the *Ronchi's decree* (law 22/1997) and by the *Environmental Code* (law 152/2006) are aimed at favouring the integrated management of a too much fragmented production process, as well as at promoting competitive tendering procedures for the management of waste collection. Moreover, they introduced a new tariff system (i.e. the *Environmental Hygiene Tariff*, labelled *TIA*) that, creating a direct connection between the solid waste generated by households and the amount to be paid for the refuse collection service, should induce citizens to adopt a more responsible environmental behaviour, and, thanks to a price-cap system, should push operators to increase their efficiency levels.

An effective reform of the solid waste sector cannot be implemented without undertaking a detailed analysis of the cost structure and the technological characteristics of operators. For example, issues such as the presence of scale economies are crucial to define the optimal size configuration. In order to undertake a comprehensive study of the technology of a network industry, it is important to understand not only how costs vary with output, but also how they change when the extent of the network changes as well. In other terms, the size of the firm depends on the interplay between output and the characteristics of the network served. This implies that the simple computation of scale economies must be integrated by the computation of a set of complementary measures of density economies.

This paper aims to contribute to the literature by analysing the cost structure of a sample of more than 500 Italian municipalities that provided waste collection and disposal services during years 2004-2006. From a methodological point of view, we will use a flexible cost function model that is well equipped to measure scale and density economies at different output levels. The remainder of the paper is organized as follows. In the next section the relevant literature is briefly reviewed. In section 3 we present our empirical cost function model. In section 4 we describe our dataset an we show some first descriptive statistics. Section 5 presents our main results, and section 6 concludes.

2. Literature review

The empirical literature dealing with refusal collection has devoted much more attention to demand-side aspects (i.e., how to discourage land disposal, how to encourage recycling and recovery, how to design and implement an optimal pricing program, and so on) than to supply-side issues such as the cost analysis of the municipal solid waste. This has been recently acknowledged by Bohm et al. (2010):

"*The economics literature is largely silent (with a few important exceptions) on understanding the costs of municipal waste and recycling services. Data limitations may have also hampered investigations into costs*" (Bohm et al., 2010, p. 864).

Starting from the seminal works of Hirsch (1965) and Stevens (1978), scholars have analysed the costs of the refuse collection industry by investigating mainly issues such as the optimal scale of operation and the efficiency comparison between private and publicly owned operators. In a typical study, (average or total) costs are regressed on output (a measure of pick up points or of the quantity of waste collected in a year) and other explanatory variables, among which some measures of population and/or housing density. It is somewhat surprising to observe that, in spite of the fact that the literature on the estimation of density economies in network industries is well developed (see sub-section 2.2. below), none of the studies reported in Table 1 followed the traditional approach, which consists of including some variables accounting for the size of the network (i.e. population, area size, number of homes, number of buildings) in a well-behaved and flexible cost function model.

2.1. The Impact of Density on Average or Total Costs

Hirsch (1965) worked on a sample of 24 cities and municipalities in the St Louis area in 1960, and found that the average cost per pickup was not depending on the number of pickup points, suggesting the absence of scale economies. Moreover, a measure of customer density (residential pickups per squared mile) was found to have no impact on average cost. Contrary to this, evidence of density economies was found by Dubin and Navarro (1988) for disposal and by Carroll (1995) for separated collection. Dubin and Navarro (1988) worked on a sample of 261 US cities observed for the year 1974 and found that the population size had a negative impact on the average cost per yard of waste collected only for relatively small municipalities (with population below 20,000 inhabitants), while the coefficient associated to a measure of housing density (housing units per mile squared) was found to be negative and significantly different from zero, suggesting for the presence of density economies at all municipality sizes. Carroll (1995) focused on recycling costs only and found for a sample of 57 Wisconsin cities observed in 1992 that average recycling costs per household were negatively correlated to a measure of population density (Households per square kilometre). Moreover, scale economies were found to be negligible. More recently, Ohlsson (2003) studied the refusal collection costs of 170 firms in 115 Swedish municipalities observed for year 1989. While the focus of the paper was on comparing public versus private forms of organizing the waste management sector, he included some measures of housing and population density among the explanatory variables of the average cost per ton of waste collected. The positive and significant impact shown by the measure of housing density suggested the presence of diseconomies of density.

While inferring the presence of density economies by investigating the impact of density measures on average costs can be accepted only to some extent and as a preliminary result, the attempt to tackle this issue while estimating total cost functions is much more questionable, as will be argued in more detail below.

Stevens (1978) estimated a Cobb Douglas total cost function on a sample of 340 US public and private firms, and found that economies of scale were exhausted at population sizes above 50,000 inhabitants. A measure of housing density (households per square mile) was not found to be significantly different from zero, while the author was expecting a negative and significant sign. Such an interpretation was shared by Domberger et al. (1986) and Dijkgraaf and Gradus (2003). Domberger et al. (1986) worked on a sample of 610 local authorities in England and Wales observed for year 1984 and found that, consistent with a priori expectations[2], the total costs were negatively correlated to a measure of housing density (units per hectare). Dijkgraaf and Gradus (2003) collected data on a sample of 85 Dutch municipalities observed in 1996 and, by regressing total costs on a set of explanatory variables, could not reject the hypothesis of the presence of constant returns to scale. Moreover, the (inverse) measure of housing density (Km^2 per pickup point) was not found to have a significant impact on refusal collection costs. Finally, Reeves and Barrow (2000) estimated a total cost function on a sample of 44 Irish local authorities observed for years 1993-1995, and found both constant returns to scale and "density economies" (i.e. the coefficients associated to their measure of housing density, units per hectare, turned out to be negative and significant in all regressions).

---

[2] In the authors' words: "*The density of units is likely to have a negative effect on total costs; the proximity of pick-up points and shorter walking distances in areas of high density would suggest that costs should be lower in these areas*" (p. 75)

Callan and Thomas (2001) estimated, using a sample of 110 municipalities in Massachusetts observed for years 1996-1997, two separate cost functions for disposal and recycling. The results suggested the presence of constant returns to scale for disposal and increasing returns to scale for recycling, as well as the existence of scope economies of the order of 5 percent across the two activities. Turning to the issue of density economies, they found a positive impact of their housing density measure (single-family homes per square mile) on total costs only for waste sent to disposal. However, in striking contrast to the above four mentioned papers which estimated total cost functions, they interpreted this result as evidence of density economies: "*Because this model specifies total cost as the dependent variable, housing density should be a positive influence in the model. However, if economies of density exist, which is expected, the elasticity of total cost with respect to density should be less than unity*" (p. 553).

Bohm et al. (2010) analysed both solid waste disposal and recycling activities on a sample of 428 US communities for year 1996. Two quadratic cost functions (one for disposal, one for recycling) were simultaneously estimated using Zellner's SUR model. While the average cost function for disposal was found to be everywhere decreasing, highlighting the presence of increasing returns to scale, the one for recycling was exhibiting a U shape, suggesting that, after a certain threshold, the costs for recycling were increasing sharply.

The positive coefficient associated to their measure of population density (significantly different from zero only for the regression relative to disposal activities) was not interpreted as straightforward evidence of the presence of diseconomies of density, but simply as evidence that high-density municipalities could have incurred high costs to transport waste due to the inability to operate vehicles in densely populated urban areas,[3] as well as to the need to drive towards remote landfills for disposal.

Bel and Mur (2009) investigated the costs of refusal collection on a sample of 56 Spanish municipalities observed in year 2003. They included a measure of population density among the regressors but, fully aware of the above problems of interpretation experienced in the literature, they stated that the final effect of the variable was a priori undetermined. In their own words: "*As population density increases, the amount of waste collected at each stop grows, in principle, reducing the costs of collection. However, greater population concentration leads to greater problems of traffic congestion, so that over time, transport time can be greater and so, therefore, can costs.*" (p. 2775).

[3] For instance, the presence of narrow streets may reduce the ability to use large, specialized equipment. In addition, the extent of on-street parking may involve difficulties in using some automated machinery, with the consequence that operators are forced to use more manual labor.

Following the above arguments, Simoes and Marques (2011) included both population density and its squared value as regressors in a cost frontier estimation, and obtained, on a sample of 32 Portuguese firms in charge of the waste treatment service observed for the years 2001-2008, a negative coefficient for the former and a positive coefficient for the latter. This suggests that in non congested areas operators could enjoy density economies, but the latter are soon replaced by density diseconomies, which emerge when population density bypasses a certain threshold level.

Sharing the doubts raised by Bohm et. al (2010) and Bel and Mur (2009), we believe that, especially in regressions where total cost is chosen as the dependent variable, the sign and magnitude of the coefficient of a proxy for population or housing density cannot be used to provide evidence in favor or against the existence of economies\diseconomies of density. Indeed, given the high correlation existing between municipality size and degree of urbanization as proxied by a density measure, it is not appropriate to make such an inference. A more promising line of research would require to include directly in the cost function model some characteristics of the networks which are served, and it is towards this methodology that we now turn our attention.

2.2. The Measurement of Density Economies

There is a well established literature that addressed the estimation of density economies together with scale economies in network utilities. For example, Caves et al. (1984), in their analysis of the US airlines industry, introduced in the cost function, together with the traditional output measures (revenue passenger miles, revenues ton-miles), a measure of the size of the network (number of airports served by each airline), so as to be able to have a distinct evaluation of *output density economies* (i.e. the proportional increase in costs due to an increase of output, keeping fixed the size of the network) and scale economies (i.e. the proportional increase in costs due to a simultaneous increase of both output and network size). The same methodology was applied by Roberts (1986) for the electricity industry, by Cambini et al. (2007) for the local public transport industry, by Torres and Morrison (2006) and Filippini et al. (2008) for the water sector, to cite some examples of other network industries. To the best of our knowledge, only Antonioli and Filippini (2002) adopted a similar method in the context of the refusal collection sector. Using data on a sample of 30 Italian waste and disposal collection firms for years 1991-1995, they estimated a system of equations, including a Translog cost function and the associated cost-share equations, by applying the iterative Zellner's (1962) seemingly unrelated regression (SUR) technique. The results of the estimations suggested the presence of output density economies, as well as of scale economies for small and medium-sized firms, while the largest firms in the sample were found to operate in an output region exhibiting diseconomies of scale.

While the measurement of output density economies separated from scale economies allows a better understanding of the costs and in general of the technology properties of network utilities, Roberts (1986) and Torres and Morrison (2006) pushed the analysis a step forward by exploring two dimensions of the network size. In the case of the electricity industry, both the number of customers and the square miles of the service area were included among the regressors, so as to be able to compute a measure of *customer density economies* (i.e. the proportional increase in costs due to the increase of output and the number of customers, keeping fixed the area size) that, together with the other measures of *output density economies* and scale economies (which are labelled by the author *size economies*), allowed to undertake a more complete description of the variability of costs. In the case of the water utility industry, Torres and Morrison (2006) included both area size and the number of customers, and, similarly to Roberts (1986), provided separate estimates of output density economies, customer density economies and scale (or size) economies. However, they were also interested in computing a measure of *spatial density economies*, according to which costs were allowed to vary with output and the area size, keeping fixed the number of customers.[4]

Building on the two above mentioned studies, in this paper we will analyse several aspects of the networks which are served by the operators in charge of the management of solid waste collection, i.e. the population served, the number of buildings, as well as the area size. As illustrated in Figure 1, we will estimate five measures of size and density economies. Other than the usual indices of *output density economies* and *size economies*, we will in fact disentangle *customer density economies* into two measures, which are intended to take into duly account the vertical and the horizontal distribution of demand in a given area, respectively. In fact, moving from an initial situation in which, in a given area, a certain number of citizens live in a given number of buildings and produce a certain amount of garbage (top-left rectangle in Figure 1), the production of solid waste can increase:

- because more people live in the same number of buildings (which are progressively transformed into taller apartment buildings), as it happens in densely populated areas with a vertical urban development (top-right rectangle). In this case, we can measure "vertical density economies": in terms of density indicators, we would have an increase of population density, while the per-capita consumption, as well as the housing density, would not vary;

[4] While this index is interesting in the context of the water utility industry, where it is possible that a specific number of customers can increase water consumption as well as the size of the service area (i.e. by "*living in areas with larger housing acreage or public spaces where customers are more spread out and perhaps also use more water for purposes such as irrigation*" (Torres and Morrison, p. 110), we believe that it is less appropriate in the context of other network utilities such as the solid waste industry.

- because the same population is horizontally spread in a larger number of buildings which insist in the same surface (centre-right rectangle). This allows the measurement of "horizontal density economies", resulting from an increase of housing density together with an increase of per-capita waste consumption;

- because both population and the number of buildings increase, i.e. a mix of the two above reasons (bottom-left rectangle). This leads to the measurement of "overall density economies", where a proportional increase of both population and housing density occurs, while per-capita consumption is kept constant.

3. Model and Estimation

Our proposed research strategy will start with the estimation of a Translog cost function:

$$\begin{aligned}\ln(C/P_F) = \alpha_0 + \sum_i \alpha_i \ln i + \frac{1}{2}\sum_i\sum_j \alpha_{ij} \ln i \ln j + \sum_i\sum_r \delta_{ir} \ln i \ln(P_r/P_F) \\ + \sum_r \beta_r \ln(P_r/P_F) + \frac{1}{2}\sum_r\sum_l \beta_{rl} \ln(P_r/P_F)\ln(P_l/P_F) + \psi_C\end{aligned} \qquad [1]$$

where C refers to the total cost of production, i and j refer to the outputs and to the network size measures (i.e. i, j = Waste sent to disposal sites (Y_D), Waste sent for recycling (Y_R), Population (P), Buildings (B), Area Size (A)), P indicates factor prices (in our three-input case F stands for fuel, while the subscript r, l = Labor (L) and Capital (K)), and ψ_C is a random noise having appropriate distributional properties to reflect the stochastic structure of the cost model.

Cost-shares are computed as $S_r = (X_r P_r)/C$. By Shephard's Lemma $X_r = \partial C/\partial P_r$, where X_r is the input demand for the rth input, so that $S_r = \partial \ln C/\partial \ln P_r$. Therefore, the associated input cost-share equations are obtained by applying the *Shephard's Lemma* to expression [1]

$$S_r = \sum_i \delta_{ir} \ln i + \beta_r + \sum_l \beta_{rl} \ln(P_l/P_F) + \psi_r \qquad [2]$$

where ψ_r is the error term relating to the cost-share r.

Given the regularity conditions ensuring duality between the production function and the cost function, the Translog specification is a flexible form in the sense of Diewert (1974), i.e. it does not impose a priori restrictions on the characteristics of the underlying technology. To be consistent with cost minimization, the system [1]-[2] must satisfy symmetry ($\alpha_{ij} = \alpha_{ji}$ and $\beta_{rl} = \beta_{lr}$ for all couples i, j and r, l) as well as the following properties: *a*) non-negative fitted costs; *b*) non-negative fitted marginal costs with respect to outputs; *c*) homogeneity of degree one of the cost function in input prices ($\Sigma_r\beta_r = 1$ and $\Sigma_l\beta_{rl} = 0$ for all r, and $\Sigma_r\delta_{ir} = 0$ for all i); *d*) non-decreasing fitted costs in input prices; *e*) concavity of the cost function in input prices. Symmetry and linear homogeneity in input prices are imposed *a priori* during estimation. In a similar vein, in order to ensure that the cost functions are linearly homogeneous in input prices, we normalize total cost and input prices by the price of fuel. The other regularity conditions are checked ex-post.

The cost function is estimated jointly with their associated input cost-share equations, so as to improve the efficiency of the estimation of parameters. Because the three share equations sum to unity, to avoid singularity of the covariance matrix only the labor and capital equations (S_L and S_K, respectively) are included in the system [1]-[2]. Before the estimation, all the right-hand side variables were standardized on their respective sample average values. This allows the interpretation of first-order parameters as cost elasticities evaluated at the sample means, and makes the analysis of scale and density economies more straightforward. Parameter estimates were obtained by applying Zellner's iterated seemingly unrelated regression technique, a well-known procedure which ensures estimated coefficients to be invariant with respect to the omitted share equation (Zellner, 1962).[5]

4. Data Description

Our dataset refers to a balanced panel of 529 Italian municipalities providing waste disposal and recycling services over the period 2004-2006, for a total of 1587 *pooled* observations. The sample can be considered as fairly representative of the entire population of municipalities.

As to the sample composition by geographical area, 39 percent of observations refer to municipalities localized in Northern and Southern Italy, respectively, while the remaining 22 percent are localized in the central regions of the country. The share of the total waste volume designated for recycling is 20 percent. However, in Northern regions of the country recycling accounts for 37 percent of the total, while in the Centre and in the South separated collection is much more limited (13 percent and 7 percent of the total, respectively).

Data on costs and output quantities are obtained from annual MUDs (i.e. annual declarations concerning municipal solid waste collection) which have been provided by Ecocerved. Input prices have been computed by integrating the information available in the MUDs with additional information drawn from questionnaires sent to the firms (or organizational structures) managing the service in the municipalities. Total cost (C) is the sum of labor, capital, and fuel costs of the municipalities. The two output categories are tons of MSW disposed (Y_D) and tons of MSW recycled (Y_R). The demand and network characteristics are the number of citizens who reside in the

[5] To be more precise, we performed a maximum likelihood estimation of the constrained linear SURE system, following the procedure described by LIMDEP's manual. The restricted estimator turns out to be a hybrid between generalized least squares (GLS) and maximum likelihood estimators. The results of simple GLS estimates as well as the ones coming from non linear SUR estimates (NLSUR) are virtually unchanged and are available upon request.

municipality (P), the number of buildings (B), the number of homes (H), and the area size measured in km^2 (A). Productive factors are labor, capital and fuel. The price of labor (P_L) is given by the ratio of total salary expenses to the number of employees. Capital price (P_K) is obtained by dividing depreciation costs by the capital stock. The price of diesel fuel (P_F) has been gathered, for each province, from data released by the local Chambers of Commerce.

Summary statistics on outputs, demand and network characteristics, input prices and shares as well as other demographic and urban variables are provided in Table 2. The average amounts of waste disposed and waste sent for recycling are respectively Y_D=17,125 tons and Y_R=3,770 tons, while the average number of inhabitants, buildings and homes are respectively P=41,093, B=4,960 and H=17,970. The average municipality occupies an area size of about 83 Km^2, and is endowed with about 1,900 beds which are available for tourism activity. As to the other variables of interests, the average value of *Tariff* highlights that 25 percent of councils have introduced the new waste tariff (*TIA*, i.e. Environmental Hygiene Tariff) in substitution of the preceding waste tax (*TARSU*, i.e. Tax on Urban Solid Waste).[6] Finally, the last two columns of Table 2 show that, on average, 74 percent (16 percent) of the waste collected in the Province where the municipality is located goes to disposal sites (incinerators) which are localized in the same Province.

5. Results

As we have argued in Section 2, the issue of the measurement of density economies in the waste collection industry is rather underdeveloped. Since the empirical papers investigating on the existence of density economies in other network industries used different measures of network size and demand, in this section we will present the results stemming from the estimation of 22 different specifications of the Translog cost system [1]-[2]. Other than representing a useful robustness check, this procedure can be helpful for those scholars who want to compare our results with the ones emerged in the literature. The results of the SUR estimations for the Translog model are presented in Tables 3a and 3b. The eleven models listed in Table 3a include a single output for refusal collection (i.e. Y=Y_D+Y_R, the sum of waste collected and sent to disposal sites and waste sent for recycling), while the eleven models listed in Table 3b consider a multi-product approach in which disposal and recycling are seen as two potentially separable outputs. We first included one network variable (population, buildings, homes, area size, respectively) in models (2) through (5) and (13) through (16), and, progressively, two and three network variables. For ease of comparison, Cambini et al. (2007) estimated model (5), while Roberts (1986) and Torres and Morrison (2006)

[6] While the *TARSU* was computed on the basis of the size of the home, the *TIA* takes into account, together with the size of the household living spaces, the family size and the amount of waste produced too.

relied on model (17) and Filippini et al. (2008) in model (6). As to the few papers available for the refuse collection industry, Antonioli and Filippini (2002) estimated model (5), while Abrate et al. (2012) relied on model (12). The original contribution of our paper to the above literature is the estimation of models (9) through (11) and (20) to (22), in which all the three network variables are included into the analysis. As illustrated in Figure 1, the inclusion of population, buildings and area size allows to compute different measures of density economies, such as output density economies ($ODE = 1/(\varepsilon_{CY})$) and overall customer density economies $CDE = 1/(\varepsilon_{CY} + \varepsilon_{CP} + \varepsilon_{CB})$, which can be separated in two distinct components: vertical population density economies $PDE^{V} = 1/(\varepsilon_{CY} + \varepsilon_{CP})$ and horizontal housing density economies ($HDE^{H} = 1/(\varepsilon_{CY} + \varepsilon_{CB})$). Finally, size economies are computed by using all output elasticities ($SE = 1/(\varepsilon_{CY} + \varepsilon_{CP} + \varepsilon_{CB} + \varepsilon_{CA})$).[7] For all indicators, there are (density or size) economies if they take on values greater than one and diseconomies if they take on values lower than one.

Due to the normalization of the dependent and the explanatory variables, the cost elasticities with respect to the output, to the measures of the network size and to factor prices for the 'average municipality' are very easy to recover. As documented in Table 2, the *average* municipality corresponds to an hypothetical council of an average area size (about 83 Km^2), collecting an average level of production (i.e. 17,125 tons of Y_D and 3,770 tons of Y_R), serving an average population (about 41,093 inhabitants) which lives in an average number of buildings (4,960) and homes (17,970), and facing average values of productive factors' prices.

At the above point of normalization, $\partial \ln C / \partial \ln i = \varepsilon_{C\,i} = \alpha_i$. The cost elasticity with respect to Y (ε_{CY}) measures how much costs increase when garbage production becomes bigger, keeping constant all the rest (i.e. population, buildings, homes and area size). Obviously, this turns out to be the most important cost component, with estimated elasticities which range from 0.65 to 1.12. In the multi-output models, a percentage increase in disposal has a much higher impact than recycling (ε_{CY_D} ranges from 0.55 to 0.87 while ε_{CY_R} ranges from 0.09 to 0.23), reflecting the low recycling share of the average Italian municipality.[8] Analogously, the cost elasticity with respect to population (buildings, homes, area size, respectively) measures how much costs increase when only

[7] In the two-output case, ε_{CY} is the sum of the cost output elasticities for disposal and recycling: $\varepsilon_{CY} = \varepsilon_{CY_D} + \varepsilon_{CY_R}$. Our baseline models are (20) and (9), while in models (10) and (21) we used homes as (an imperfect) substitute for buildings and in models (11) and (22) we used homes as a substitute for population.

[8] Clearly, this does not mean that recycling is less costly than disposal. To simulate an increase of the recycling share, one should compute the effect on costs of substituting disposal with recycling, while keeping constant the total amount of waste (Abrate et al., 2012).

the number of citizens (buildings, homes, area size, respectively) increases, keeping fixed the amount of waste (both disposal and recycling) collected and the other network and demand variables. As shown in tables 3a and 3b, population is the second most important determinant of costs. In particular, considering models (9)-(11) and (20)-(22), the estimates of the cost elasticity ε_{CP} range from 0.23 to 0.48, suggesting that the costs to collect a specified amount of garbage increase between 23 percent and 48 percent if the population who lives in the same number of buildings (or homes) doubles in a given area. A similar interpretation can be given to the cost elasticity with respect to the number of homes. Both the area size and the number of buildings exhibit a negative sign, even if in the latter case the coefficient is not always statistically different from zero. The negative cost elasticity found for area size ε_{CA} is not new in the literature (see, for example, Roberts, 1986) and is not surprising. In our context, in fact, the area size can be interpreted as a fixed factor acting as a constraint, in terms of land availability, for each municipality. Therefore, the fact that garbage collection costs are slightly reducing if the area size increases can be due to the reduction of traffic congestion problems. This interpretation is supported by the fact that, by running separate regressions for municipalities with population density (D_P = Population/Area size) above and below the median value, we get estimates of ε_{CA} equal to -0.08 and 0.06, respectively, suggesting that in less densely populated areas the territorial constraint is less of a problem.

By combining the above cost elasticities to obtain estimates of density and size economies, we get results which are very robust across models, especially for the specifications which include three network variables. Firstly, there is statistically significant evidence of the presence of output density economies. Keeping constant the number of buildings (or homes) as well as the population and the area size, costs increase less then proportionally with the amount of waste collected. This result, which is commonly found in the literature (see, for example, Antonioli and Filippini, 2002), has been traditionally interpreted in the sense that franchised monopolies are the best way to organize the service in a given area, while promoting side by side competition, i.e. by allowing for the presence of several waste management operators in the same territory, appears to be a more costly alternative. However, while this finding rules out the possibility that the same individual is served by two utilities, we cannot exclude the possibility to divide the service area of a town in two or more districts, allowing a competitive bidding between different operators in each of them.

More interestingly, there is an extraordinarily robust support for rejecting the hypothesis that overall customer density economies are constant or increasing. In fact, when output is allowed to increase together with population and buildings (or homes), within a given area size, i.e. when output growth is accompanied with increases in both population density (D_P) and housing density (D_{HB} = Buildings/Area Size or D_{HH} = Homes/Area Size), costs increase more than proportionally.[9] This result can be explained by distinguishing the vertical and the horizontal aspects of urbanization. Models (9)-(11) and (20)-(22) point towards the presence of vertical density diseconomies which are partially counterbalanced by the existence horizontal density economies. In a situation in which outputs increase together with the number of buildings, but the number of citizens and the area size are kept constant (which can be interpreted as an horizontal spreading of buildings in a given area), refusal collection costs would increase less than proportionally (i.e. HDE^H is greater than one). Conversely, in a context in which the output increases together with population, but the number of buildings and the area size remain the same, costs would increase more than proportionally (i.e. PDE^V is lower than one). This scenario corresponds to the diffusion of a vertical urbanization model, where tall buildings substitute flatter ones. In other terms, it would be detrimental for the efficiency of waste collection services if the existing service areas of municipalities were to become more densely populated. As commented above, the combined effect of PDE^V and HDE^H generates overall customer density diseconomies (i.e. *CDE* is lower than one), suggesting that congestion problems in densely populated areas are seriously affecting refusal collection costs. Finally, by including into the analysis also an increase in the area size, there is evidence of the presence of weak diseconomies of size. This suggests that it could not be rational for the average municipality to expand its service area or to merge with adjacent councils, for example by forming consortia or by adhering to multi-municipality agreements.

While the results shown above are robust across models, we concentrate on models (9) through (11) and (20) through (22), and in particular in model (20), which has to be considered as our best choice. The estimates of model (20), which are presented in Table 4, suggest that the cost function is performing quite well, with most of the regressors exhibiting coefficients which are significantly different from zero. Noticing that, taking the average municipality as a reference point, S_r is simply the estimate of β_r, it turns out that the estimates of labour (S_L) and capital (S_K) price elasticities are around 0.44 and 0.06, which practically coincide with the actual sample averages.

Fully exploiting the potential of our Translog flexible cost function model, we can evaluate if and how size and density economies are changing when the size of the municipality changes. The estimates of the cost output elasticities become now:

$$\partial \ln C/\partial \ln i = \varepsilon_{C\,i} = \alpha_i + \alpha_{ii} \ln i + \sum_{j \neq i} \alpha_{ij} \ln j \qquad [3]$$

[9] Notice the difference of our approach with respect to the studies cited in section 2.1, that directly included population density and housing density among the regressors.

where outputs and network variables are allowed to vary. In Table 5, the parameter λ is used to scale up and down the size of the average municipality. Moving along each row it is possible to simulate how much waste costs vary following a proportional increase of all different output and network variables (Y_D, Y_R, P, B, and A). The results shown in Tables 3a and 3b for the average municipality are confirmed also for the five alternative simulated municipalities' sizes. In particular, output density economies, horizontal density economies and vertical density diseconomies are all confirmed as technological characteristics of both small and large councils. Similarly, overall customer density diseconomies and size diseconomies are confirmed, but turn out not to be significant for large councils.

However, all the figures reported in Table 5 refer to hypothetical municipalities, i.e. to municipalities which are scaled up and down by taking as a reference point an hypothetical "average municipality". For the sake of completeness, we have estimated also size and density economies for all 1587 observations in our sample, and the results are again extraordinarily robust. Table 6 reports the average, minimum and maximum values of our measures of density and size economies for the whole sample, as well as some detailed information for five selected municipalities (Florence, Milan, Palermo, Rome and Turin). Notice the high variability of both area size and the number of buildings across municipalities. For example, small municipalities such as Comacchio and Acri have much more extended service areas than bigger cities such as Florence and Turin. To take another example, Palermo has a number of citizens which is half of the population of Milan, but the number of buildings is similar between the two cities.

Finally, in Figure 2 our estimates of vertical and horizontal density economies are plotted against two measures of population density (D_P = population/area size) and housing density (D_{HH} = homes/area size). While horizontal density economies do not show any discernible pattern when D_P and D_{HH} are allowed to change, vertical density diseconomies, instead, are found to increase with both population and housing density, highlighting once again that congestion is probably the most important factor to be taken into consideration when studying refusal collection costs.

5.1 Extended model

In order to test the robustness of the above results, we have enriched our baseline specification by adding other explanatory variables that have been usually considered in the literature. Table 7 shows the results of the estimates of our extended model [20], where a time trend *t*, size dummies, geographical dummies, and other cost shifters have been included among the regressors. In particular, *small* and *medium* are dummy variables which identify municipalities where inhabitants are less than 20,000 or included in the 20,000-50,000 range, respectively. *Tariff* is a dummy that takes on the value of one if the municipality has introduced the new waste tariff (*TIA*). *Tourism* is an index of the existing supply of beds in the municipality, while *Landfill* and *Incinerator* are proxies for the presence of nearby disposal facilities.[10]

The first observation is that the extended model exhibits estimates of cost elasticities with respect to outputs, network variables, and factor prices, which are very similar to the ones reported in Table 4, corroborating our previously commented findings about density and size economies. Moreover, the newly added variable can offer a better understanding of the drivers of total costs and improve the overall explanatory power of the model. The coefficient of *t* is negative and statistically significant, highlighting that, in the three year period under investigation, there has been a significant technological progress. Medium sized cities appear to be characterized by lower collection costs as compared to municipalities that serve more than 50,000 citizens (the omitted category). Moreover, the costs are estimated to be lower in the Northern and Central regions of the country. While the variable *Tariff* does not seem to have a discernible impact on total costs,[11] the coefficient associated to *Tourism* is positive and significant, suggesting that in municipalities where the tourism activity is more pronounced the costs of waste collection increase. Finally, consistently with our *a priori* expectations, both *Landfill* and *Incinerator* show a reducing effect on total disposal costs, probably due the lower costs to transport the garbage from the drop-off or collection points to the waste treatment facilities.

6. Summary and conclusions

In this paper we have undertaken a detailed study of the costs of waste disposal and recycling services by applying a well-behaved multi-product cost function model to a sample of more than 500 Italian municipalities observed in years 2004-2006. Our main goal is to shed light on an underexplored topic such as the estimation of density economies, which is particularly important for a full understanding of the technology of network industries such as the refusal collection sector. Rather than adding some proxies for population or housing density as right hand side variables in total costs or average costs regressions, we include several measures of the network, such as the area size, the number of inhabitants living in the municipality, the number of buildings, and the number of homes. This allows the computation of several measures of density economies, such as output density economies (i.e. how much costs increase if the volume of refuse collection increases,

[10] In particular, *Landfill* is the ratio between the waste treated by the existing disposal sites in the Province and the waste produced in the Province, while *Incinerator* is the ratio between the waste incinerated in the Province and the waste collected in the Province. Large shares indicate that the municipality can take benefit from the presence of nearby disposal facilities.

[11] The above result is not surprising. In fact, the *TIA* has been implemented only in a small share of municipalities and, from 2013, as stated in Legislative Decree 201/2001, it will be in turn replaced again with a new municipal tax on waste and services (*TARES*, i.e. Tax on waste and services).

keeping fixed the population, the number of buildings and the area size), horizontal density economies (i.e. how much costs increase when both the volume of refuse collection and the number of buildings increase, keeping fixed the number of inhabitants and the area size), and vertical density economies (i.e. how much costs increase if both the volume of refuse collection and the number of inhabitants increase, keeping fixed the number of buildings and the area size).

The results of our estimates, which are robust across several specifications, show that, for a municipality of an area size of about 83 km^2, in which 41,000 inhabitants live in about 5,000 buildings, the refuse collection costs increase less then proportionally if there is an increase in garbage collection, i.e. there are economies of output density. This suggests that the most efficient way to organize the industry is to rely on a single provider within each council or part of it (i.e. franchised monopoly). If the volume of waste collected increases with the number of inhabitants (given the same number of buildings and the area size), however, costs increase more than proportionally. Therefore, there are vertical density diseconomies, which are due to traffic congestion problems that occur with urbanization models implying vertical developments of buildings insisting on given surfaces. On the contrary, if waste collection increases with the number of buildings (given the same number of citizens and the area size), costs increase less than proportionally. The existence of horizontal density economies reveals that congestion problems are less severe when the population is spread over several buildings with fewer floors.

If, in a given council, the increase of waste collection is accompanied by the increase of both the number of buildings and the population size, costs increase more than proportionally. Therefore, the impact of vertical density economies is only partially counterbalanced by the presence of horizontal density economies. In a similar vein, when also the area size is allowed to increase, costs increase less than proportionally, so that the refusal collection technology exhibits diseconomies of size, suggesting that the aggregation of refusal collection operations across several municipalities would not bring savings in the average cost of collection.

While the above results are all confirmed also for different simulated municipalities' sizes, vertical density diseconomies appear to be higher when population density or housing density increase, which is suggestive of the fact that the congestion plague in densely populated councils is indeed the most important factor that severely affects garbage collection costs.

References

Abrate G., Erbetta, F., Fraquelli G., Vannoni D. (2012) "The Costs of Disposal and Recycling: An Application to Italian Municipal Solid Waste Services", *Regional Studies*, forthcoming.

Antonioli, B. and Filippini, M. (2002) "Optimal Size in the Waste Collection Sector", *Review of Industrial Organization*, 20, 239-252.

Bel, G. and Mur M. (2009) "Intermunicipal Cooperation, Privatization and Waste Management Costs: Evidence from Rural Municipalities", *Waste Management*, 29 (10): 2772-2778.

Bohm, R. A., Folz D. H., Kinnaman T. C., Podolsky M. J. (2010) "The Costs of Municipal Waste and Recycling Programs", *Resources, Conservation and Recycling*, 54, 864-871.

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

Cambini C., Piacenza M., Vannoni D. (2007) "Restructuring Public Transit Systems: Evidence on Cost Properties from Medium and Large-Sized Companies", *Review of Industrial Organization*, 31, 183-203.

Carroll W. (1995) "The Organization and Efficiency of Residential Recycling Services", *Eastern Economic Journal*, 21, 2, 215-225.

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*, 15, 4, 471-489.

Diewert W. E. (1974), "Applications of Duality Theory', in M. D. Intriligator and D.A. Kendrick (eds.), *Frontiers in Quantitative Economics*, Vol II, 106-71, Amsterdam: North-Holland

Dijkgraaf, E. and Gradus R. H. J. M. (2003) "Cost Savings of Contracting Out Refuse Collection", *Empirica*, 30 (2), 149-161.

Domberger S., Meadowcroft, S.A. and Thompson D.J. (1986) "Competitive Tendering and Efficiency: The Case of Refuse Collection", *Fiscal Studies*, 7, 4, 69-87.

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

Filippini, M., Hrovatin N., Zoric, J. (2008) "Cost Efficiency of Slovenian Water Distribution Utilities: An Application to Stochastic Frontier Methods", *Journal of Productivity Analysis*, 19, 169-182.

Hirsch W. (1965) "Cost Functions of Urban Government Service. Refuse Collection", *Review of Economics and Statistics*, 47, 87-92.

Ohlsson, H. (2003) "Ownership and Production Costs. Choosing between Public Production and Contracting-out in the Case of Swedish Refuse Collection", *Fiscal Studies*, 24 (4), 451-476.

Reeves, E. and 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), 129-150.

Roberts M. J. (1986) "Economies of Density and Size in the Production and Delivery of Electric Power", *Land Economics*, 62, 4, 378-387.

Simoes P. and Marques R. C. (2011) "How does the Operational Environment Affect Utility Performance? A Parametric Study on the Waste Sector", *Resources, Conservation and Recycling*, 55, 7, 695-702.

Stevens B. J. (1978) "Scale, Market Structure, and the Cost of Refuse Collection", *Review of Economics and Statistics*, 6 (3), 438-448.

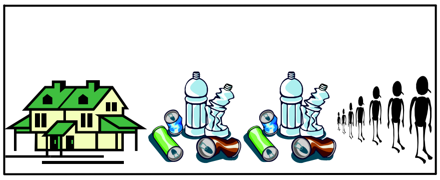
Torres M., Morrison Paul C. J. (2006) "Driving Forces for Consolidation or Fragmentation of the US Water Utility Industry: A Cost Function Approach with Endogenous Output", *Journal of Urban Economics*, 59, 104-120.

Zellner, A. (1962) "An Efficient Method of Estimating Seemingly Unrelated Regression and Test for Aggregation Bias" *Journal of the American Statistical Association*, 58, 348-68.

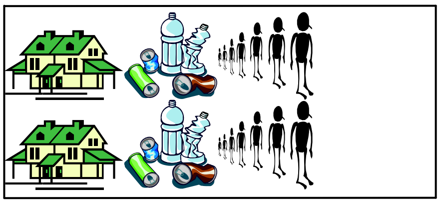
Table 1. Available Evidence on the Impact of Density on Solid Waste Costs

	Independent Variable	Density Measure	Results
	Average Cost		
Hirsch (1965)	Average Cost per Pickup	Residential Pickups per Mile^2	Not Significant
Dubin and Navarro (1988)	Average Cost per Yard collected	Housing Units per Mile^2	Negative Impact
Carroll (1995)	Average Cost per Household	Households per Km^2	Negative Impact (Recycling Activities)
Ohlsson (2003)	Average Cost per Ton	Inhabitants/Km^2, Housing Units/Km^2	Positive Impact
	Total Cost		
Stevens (1978)	Total Costs	Households per Mile^2	Not Significant
Domberger et al. (1986)	Total Costs	Units per Hectare	Negative Impact
Reeves and Barrow (2000)	Total Costs	Units per Hectare	Negative Impact
Callan and Thomas (2001)	Total Costs Disposal/Recycling	Single-Family Homes per Mile^2	Positive Impact (only for Disposal)
Dijkgraaf and Gradus (2003)	Total Costs	Km^2 per Pickup point	Not Significant
Bel and Mur (2009)	Total Costs	Inhabitants per Km^2	Not Significant
Bohm et al. (2010)	Total Costs	Persons per Mile^2	Positive Impact (only for Disposal)
Simoes and Marques (2011)	Total Costs	Inhabitants per Km^2	Negative Impact up to a Threshold

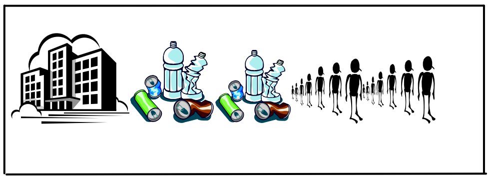
Figure 1. Density and Size Economies



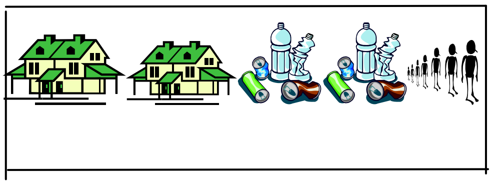
Output Density Economies: $ODE = 1/(\varepsilon_{CY})$



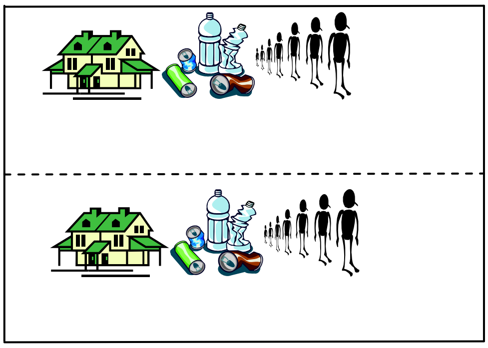
Customer Density Economies:
$CDE = 1/(\varepsilon_{CY} + \varepsilon_{CP} + \varepsilon_{CB})$



Vertical Population Density Economies: $PDE^{V} = 1/(\varepsilon_{CY} + \varepsilon_{CP})$



Horizontal Housing Density Economies: $HDE^{H} = 1/(\varepsilon_{CY} + \varepsilon_{CB})$



Economies of Size: $SE = 1/(\varepsilon_{CY} + \varepsilon_{CP} + \varepsilon_{CB} + \varepsilon_{CA})$

Table 2. Summary Statistics

	Mean	Std. dev.	Min	Max
Total Cost (10^3 euro)	5,436	23,965	46	48,065
Output and Network Variables				
Waste Disposed (tons): Y_D	17,125	71,196	118.44	1,462,128
Waste Sent for Recycling (tons): Y_R	3,770	13,044	8.86	210,211
Total Waste (tons): Y	20,895	82,800	155.14	1,670,424
Population: P	41,093	142,264	993	2,711,491
Number of buildings: B	4,960	7,309	353	127,713
Number of homes: H	17,970	62,348	430	1,150,547
Area Size (km^2): A	83.44	106.17	2.00	1,285
Population Density: D_P = P/A	903.31	1,240.94	21.82	9,441
Housing Density: D_{HH} =H/A	373.48	496.10	14.57	3,476
D_{HB} =B/A	107.18	101.62	4.82	784
Input prices				
Price of capital (euro): P_K	0.102	0.021	0.040	0.160
Price of labor (euro): P_L	36,607	5,735	22,663	62,613
Price of fuel (euro): P_F	1.023	0.122	0.780	1.370
Cost shares				
Capital share (%): S_K	5.71	3.90	1.00	17.90
Labor share (%): S_L	44.90	12.01	18.91	73.02
Other variables				
Tariff (% of municipalities)	0.249	0.433	0	1
Tourism (number of beds)	1,938.91	7,127.47	0	127,983
Landfill (%)[a]	0.74	0.57	0	5.88
Incinerator (%)[a]	0.16	0.28	0	1.40

[a] Ratio between waste treated by disposal sites (incinerators) in the Province and waste produced in the Province.

Table 3a. Size and Density Economies: Models with a Single Output ($Y=Y_D+Y_R$)

	Single Output	Single Output-One Network Variable				Single Output-Two Network Variables			Single Output-Three Network Variables		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Waste Collected : ε_{CY}	1.03***	0.65***	1.12***	0.79***	1.06***	0.70***	1.09***	0.84***	0.66***	0.68***	0.74***
Output Density Economies: $1/\varepsilon_{CY}$	-	*1.50****	*0.89****	*1.26****	*0.94****	*1.42****	*0.91****	*1.19****	*1.51****	*1.48****	*1.35****
Population : ε_{CP}		0.44***				0.40***			0.48***	0.28***	
Buildings: ε_{CB}			-0.12***				-0.03		-0.06**		-0.11***
Homes: ε_{CH}				0.29***				0.27***		0.16***	0.43***
Vertical Density Economies: $1/(\varepsilon_{CY}+\varepsilon_{Ci})$ [a]	-	-	-	-	-	-	-	-	*0.88****	*1.04*	*0.85****
Horizontal Density Economies: $1/(\varepsilon_{CY}+\varepsilon_{Cj})$ [a]	-	-	-	-	-	-	-	-	*1.66****	*1.20***	*1.59****
Overall Density Economies: $1/(\varepsilon_{CY}+\varepsilon_{Ci}+\varepsilon_{Cj})$ [a]	-	-	-	-	-	*0.90****	*0.94****	*0.90****	*0.93****	*0.89****	*0.94****
Area Size: ε_{CA}					-0.05***	-0.04***	-0.06***	-0.06***	-0.02*	-0.05***	-0.03**
Size Economies: $1/(\varepsilon_{CY}+\varepsilon_{Ci}+\varepsilon_{Cj}+\varepsilon_{CA})$ [a]	*0.97****	*0.92****	*1.00*	*0.93****	*1.00*	*0.93****	*0.99*	*0.95****	*0.94****	*0.93****	*0.97****

[a] *i =P,H; j=B,H*

*** Significant at 1 percent, ** Significant at 5 percent, *Significant at 10 percent. For density and size economies, the null hypothesis is that $1/\sum \varepsilon_{Ci}$ is not different from one.

Table 3b. Size and Density Economies: Models with Two Outputs (Y_D,Y_R)

	Two Outputs	Two Outputs-One Network Variable				Two Outputs-Two Network Variables			Two Outputs-Three Network Variables		
	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)
Waste Collected : ε_{CY_D}	0.78***	0.56***	0.84***	0.59***	0.83***	0.62***	0.87***	0.62***	0.59***	0.55***	0.59***
Waste Sent for Recycling: ε_{CY_R}	0.23***	0.10***	0.23***	0.14***	0.21***	0.10***	0.18***	0.13***	0.09***	0.10***	0.12***
Output Density Economies: $1/(\varepsilon_{CY_D}+\varepsilon_{CY_R})$	-	*1.51****	*0.93****	*1.37****	*0.96****	*1.40****	*0.95****	*1.34****	*1.45****	*1.54****	*1.43****
Population : ε_{CP}		0.41***				0.38***			0.43***	0.23***	
Buildings: ε_{CB}			-0.07***				0.03		-0.03		-0.09***
Homes: ε_{CH}				0.35***				0.35***		0.23***	0.46***
Vertical Density Economies: $1/(\varepsilon_{CY_D}+\varepsilon_{CY_R}+\varepsilon_{Ci})$ [a]	-	-	-	-	-	-	-	-	*0.90****	*1.14**	*0.86****
Horizontal Density Economies: $1/(\varepsilon_{CY_D}+\varepsilon_{CY_R}+\varepsilon_{Cj})$ [a]	-	-	-	-	-	-	-	-	*1.52****	*1.14**	*1.63****
Overall Density Economies: $1/(\varepsilon_{CY_D}+\varepsilon_{CY_R}+\varepsilon_{Ci}+\varepsilon_{Cj})$ [a]	-	-	-	-	-	*0.91****	*0.92****	*0.91****	*0.92****	*0.90****	*0.94****
Area Size: ε_{CA}					-0.06***	-0.05***	-0.08***	-0.06***	-0.04***	-0.06***	-0.04***
Size Economies: $1/(\varepsilon_{CY}+\varepsilon_{Ci}+\varepsilon_{Cj}+\varepsilon_{CA})$ [a]	*0.99*	*0.93****	*1.00*	*0.93****	*1.03***	*0.96****	*1.00*	*0.96****	*0.96****	*0.95****	*0.97***

[a] *i =P,H; j=B,H*

*** Significant at 1 percent, ** Significant at 5 percent,* Significant at 10 percent. For density and size economies, the null hypothesis is that $1/\sum\varepsilon_{Ci}$ is not different from one.

Table 4. Translog Estimates of Model [20]

Regressors	Estimates	s.e.	*Regressors*	Estimates	s.e.
Constant	15.353***	(0.013)	$\ln(P_L/P_F)$	0.421***	(0.004)
$\ln Y_D$	0.594***	(0.037)	$\ln(P_K/P_F)$	0.069***	(0.001)
$\ln Y_R$	0.093***	(0.013)	$\ln(P_L/P_F)^2$	-0.135***	(0.015)
$\ln P$	0.428***	(0.044)	$\ln(P_K/P_F)^2$	0.028***	(0.004)
$\ln B$	-0.031	(0.027)	$\ln(P_L/P_F)\ln(P_K/P_F)$	0.028***	(0.005)
$\ln A$	-0.040***	(0.013)	$\ln Y_D \ln(P_L/P_F)$	0.014**	(0.007)
$\ln Y_D{}^2$	0.503***	(0.055)	$\ln Y_R \ln(P_L/P_F)$	-0.039***	(0.003)
$\ln Y_R{}^2$	0.027***	(0.009)	$\ln P \ln(P_L/P_F)$	0.011	(0.010)
$\ln P^2$	0.787***	(0.143)	$\ln B \ln(P_L/P_F)$	0.023***	(0.007)
$\ln B^2$	0.065	(0.058)	$\ln A \ln(P_L/P_F)$	-0.007**	(0.003)
$\ln A^2$	0.035**	(0.015)	$\ln Y_D \ln(P_K/P_F)$	0.008***	(0.002)
$\ln Y_D \ln Y_R$	0.020	(0.021)	$\ln Y_R \ln(P_K/P_F)$	0.004***	(0.001)
$\ln Y_D \ln P$	-0.565***	(0.085)	$\ln P \ln(P_K/P_F)$	-0.016***	(0.003)
$\ln Y_D \ln B$	0.082*	(0.053)	$\ln B \ln(P_K/P_F)$	-0.004*	(0.002)
$\ln Y_D \ln A$	-0.047**	(0.023)	$\ln A \ln(P_K/P_F)$	0.011***	(0.001)
$\ln Y_R \ln P$	-0.078**	(0.031)			
$\ln Y_R \ln B$	0.038*	(0.020)			
$\ln Y_R \ln A$	-0.016**	(0.008)			
$\ln P \ln B$	-0.183***	(0.070)			
$\ln P \ln A$	0.038	(0.030)			
$\ln B \ln A$	-0.002	(0.023)			
Observations	1587				
System Log-Lik.	4420.87				

Estimated asymptotic standard errors in parentheses. *** Significant at 1 percent level in a two-tailed test. ** Significant at 5 percent level in a two-tailed test. * Significant at 10 percent level in a two-tailed test. All regressors have been normalized on their respective sample mean values.

Table 5. Size and Density Economies at Different Simulated Output and Network Variable Levels

	Scaled outputs and network variables [a]					
	$\lambda = 0.25$ Y_D=4,281 Y_R =942.5 P= 10,273 B=1,240 A=20.86	$\lambda = 0.5$ Y_D=8,561 Y_R =1,885 P= 20,546 B=2,480 A=41.72	$\lambda = 1$ Y_D=17,122 Y_R =3,770 P= 41,093 B=4,960 A=83.44	$\lambda = 2$ Y_D=34,244 Y_R =7,540 P= 82,186 B=9,920 A=166,88	$\lambda = 4$ Y_D=68,488 Y_R =15,080 P= 164,372 B=19,840 A=333.76	$\lambda = 8$ Y_D=136,976 Y_R =30,160 P= 328,744 B=39,680 A=667.52
Output Density Economies	1.41*** (0.09)	1.43*** (0.08)	1.45*** (0.09)	1.48*** (0.12)	1.50*** (0.17)	1.53** (0.22)
Vertical Density Economies	0.88*** (0.02)	0.89*** (0.02)	0.90*** (0.02)	0.91*** (0.02)	0.92*** (0.03)	0.93** (0.02)
Horizontal Density Economies	1.47*** (0.10)	1.50*** (0.09)	1.52*** (0.11)	1.55*** (0.16)	1.58*** (0.22)	1.61** (0.29)
Overall Density Economies	0.90*** (0.02)	0.91*** (0.02)	0.92*** (0.01)	0.93*** (0.02)	0.94** (0.03)	0.95 (0.02)
Size Economies	0.95** (0.02)	0.95*** (0.01)	0.96*** (0.01)	0.96** (0.02)	0.97 (0.03)	0.98 (0.04)

[a] λ =1 indicates a municipality of an average area size that collects average quantities of Y_D and Y_R for an average population living in an average number of buildings. The parameter λ is used to scale up and down the outputs of the "average municipality". Standard errors in parenthesis.*** Significant at 1 percent level in a two-tailed test. ** Significant at 5 percent level.
* Significant at 10 percent level. For density and size economies, the null hypothesis is that the figures are not statistically different from one.

Table 6. Size and Density Economies for all Sample Municipalities

	Output Density Economies	Vertical Density Economies	Horizontal Density Economies	Overall Density Economies	Size Economies
Mean	1.57	0.89	1.69	0.92	0.95
Min	1.04	0.82	1.01	0.89	0.93
	Leporano[a] Y_D =6,850; Y_R =557.86 P=7,322; A=15.1 km^2; B=3,997	S. Seb. Vesuvio[a] Y_D =4,816;Y_R =11.25 P=9,851; A=2 km^2 B=977	Leporano[a]	S. Seb.Vesuvio[a]	Circello[a] Y_D =487;Y_R =23.31 P=2,673; A=45 km^2 B=984
Max	3.11	0.95	4.17	0.95	0.98
	Valdagno[b] Y_D =2,152; Y_R =2,588 P=29,453; A=50 km^2; B=5,555	Comacchio[b] Y_D =24,764; Y_R =2,901; P=22,825 A=283km^2; B=7,021	Valdagno[b]	Acri[b] Y_D =6,147; Y_R =36 P=26,295; A=202 km^2; B=6,071	Florence[b]
Florence Y_D =184858	1.31 Y_R =62,979	0.89 P=366,074;	1.35 B=30,945	0.91	0.98 A=102 km^2
Milan Y_D =464385	1.57 Y_R =173,851	0.87 P=1,297,244	1.75 B=39,398	0.92	0.98 A=182 km^2
Palermo Y_D =349325	1.38 Y_R=18,225	0.87 P=662,046	1.50 B=43,884	0.92	0.97 A=159 km^2
Rome Y_D =1462128	1.42 Y_R =182,143	0.89 P=2,711,491	1.54 B=127,713	0.93	0.98 A=1,285 km^2
Turin Y_D =348475	1.51 Y_R =91,618	0.87 P=910,437	1.67 B=34,729	0.92	0.98 A=130 km^2

[a] Municipalities that record the minimum values of *ODE*, PDE^V, HDE^H , *CDE, SE*, respectively.
[b] Municipalities that record the maximum values of *ODE*, PDE^V, HDE^H , *CDE, SE*, respectively.

Figure 2. Density Economies at Different Density Levels

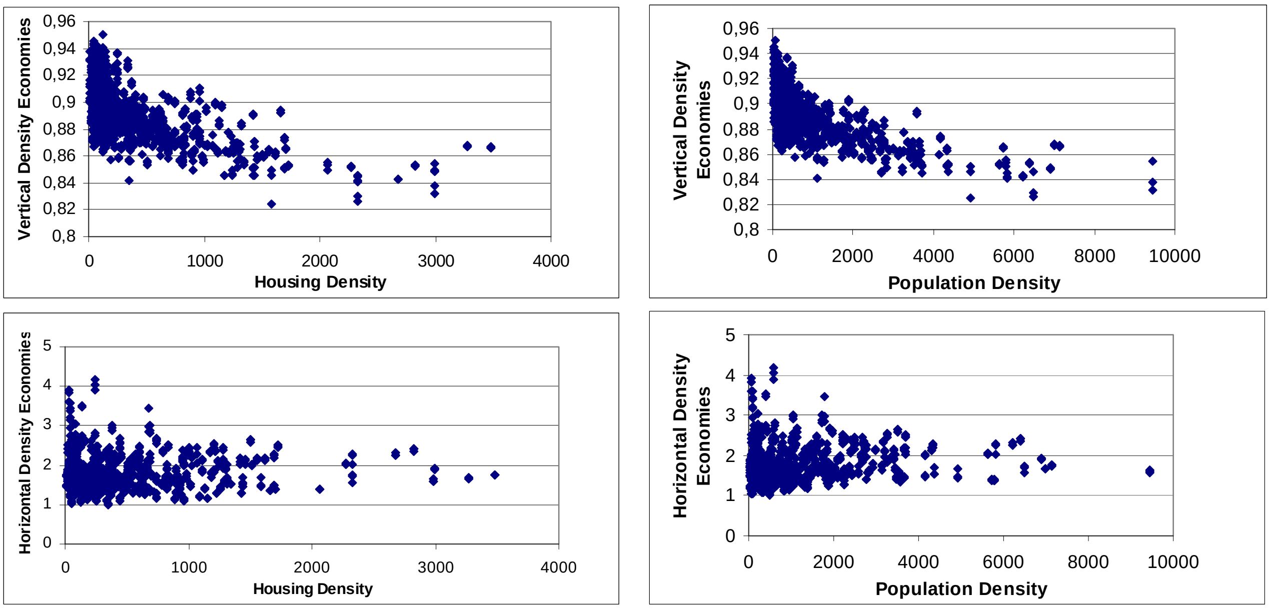


Table 7. Translog Estimates of Extended Model [20]

Regressors	Estimates	s.e.	*Regressors*	Estimates	s.e.
Constant	15.524***	(0.036)	$\ln(P_L/P_F)^2$	-0.137***	(0.015)
$\ln Y_D$	0.538***	(0.041)	$\ln(P_K/P_F)^2$	0.027***	(0.004)
$\ln Y_R$	0.114***	(0.016)	$\ln(P_L/P_F)\ln(P_K/P_F)$	0.028***	(0.005)
$\ln P$	0.457***	(0.046)	$\ln Y_D \ln(P_L/P_F)$	0.014**	(0.007)
$\ln B$	-0.040	(0.027)	$\ln Y_R \ln(P_L/P_F)$	-0.039***	(0.003)
$\ln A$	-0.055***	(0.014)	$\ln P \ln(P_L/P_F)$	0.011	(0.010)
$\ln Y_D^2$	0.452***	(0.057)	$\ln B \ln(P_L/P_F)$	0.023***	(0.007)
$\ln Y_R^2$	0.035***	(0.009)	$\ln A \ln(P_L/P_F)$	-0.008**	(0.003)
$\ln P^2$	0.741***	(0.143)	$\ln Y_D \ln(P_K/P_F)$	0.008***	(0.002)
$\ln B^2$	0.049	(0.057)	$\ln Y_R \ln(P_K/P_F)$	0.005***	(0.001)
$\ln A^2$	0.025*	(0.015)	$\ln P \ln(P_K/P_F)$	-0.016***	(0.003)
$\ln Y_D \ln Y_R$	0.010	(0.021)	$\ln B \ln(P_K/P_F)$	-0.004*	(0.002)
$\ln Y_D \ln P$	-0.527***	(0.085)	$\ln A \ln(P_K/P_F)$	0.011***	(0.001)
$\ln Y_D \ln B$	0.100*	(0.053)	t	- 0.032***	(0.008)
$\ln Y_D \ln A$	-0.047**	(0.023)	*North*	-0.051*	(0.027)
$\ln Y_R \ln P$	-0.076**	(0.031)	*Centre*	-0.046**	(0.020)
$\ln Y_R \ln B$	0.037*	(0.020)	*Medium*	-0.053*	(0.031)
$\ln Y_R \ln A$	-0.020***	(0.008)	*Small*	-0.014	(0.040)
$\ln P \ln B$	-0.181***	(0.069)	*Tariff*	-0.005	(0.004)
$\ln P \ln A$	0.032	(0.030)	*Tourism*	0.008***	(0.003)
$\ln B \ln A$	-0.002	(0.023)	*Landfill*	-0.026***	(0.009)
$\ln(P_L/P_F)$	0.421***	(0.004)	*Incinerator*	-0.020***	(0.005)
$\ln(P_K/P_F)$	0.070***	(0.001)			
Observations	1587				
System Log-Lik.	4450.45				

Estimated asymptotic standard errors in parentheses. *** Significant at 1 percent level in a two-tailed test. ** Significant at 5 percent level in a two-tailed test. * Significant at 10 percent level in a two-tailed test. All regressors have been normalized on their respective sample mean values.

DEPARTMENT OF ECONOMICS AND STATISTICS
UNIVERSITY OF TORINO
Corso Unione Sovietica 218 bis - 10134 Torino (ITALY)
Web page: http://esomas.econ.unito.it/