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Article

Defining the Organization of Municipal Solid Waste Management Based on Production Costs

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Abstract: A long-lasting dilemma on the efficient provision of services of general economic interest has become increasingly important in the waste management industry: competition or monopoly in municipal solid waste management. Previous literature has primarily examined the economics of scale and scope to provide an adequate response. Here, we contribute by investigating subadditivity in municipal solid waste management service costs. Subadditivity is a critical concept used to justify imperfect competition, which encourages natural monopolies where one producer will function more effectively than more firms. To test the hypothesis that a subadditivity in costs in waste management exists, we design a simulation based on empirical data for Milan, Italy. We compared the total production cost of the incumbent firm with the alternative hypothesis built by dividing the city into four areas and assigning each area to a different hypothetical firm. The results suggest that the existence of subadditivity results in 6% lower production costs, primarily stemming from business synergies, lower transactional costs, and optimization of productive resources and facilities. The evidence justifies, ceteris paribus, that the provision by a single firm is preferable to multiple firms in the analysis case. Implications for policies are straightforward. The one-fit rule approach fails to set the best condition for policymakers to create a level playing field transparently and efficiently for industry operators to perform efficiently.

Keywords: waste management; cost subadditivity; economies of scale; economies of scope; waste management chain; MSW

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1. Introduction

Municipal solid waste management has become a major multidisciplinary topic and has gained even more traction in environmental economics [1,2] due to its prominent role in the transition toward circular cities. No wonder interest in how to identify the most cost-effective organizational forms has increased backed by circular economy targets.

Although it may appear linear, there are stages and coordination complexities that characterize it. A division into two consequential stages that differ technically and economically can be used to simplify understanding. First, at the waste collection stage, the separation of unsorted and sorted waste takes place. Second, the treatment and disposal stages are when recyclable waste is treated and residual waste is disposed of [3].

Concerning coordination complexities, one should note that waste management service contains a multitude of subservices, including waste collection, street sweeping, cleaning, on-demand, or residual waste disposal services; see Appendix A for a taxonomy of those considered in this paper.

The key question is: what is the most efficient industrial setting for this service? Economic theory suggests that competition is the first option, provided that certain conditions are met. A fair, competitive environment is also one of the main targets of European legislation on competition and public procurement; see, for example, the Directive 2014/24/EU on public procurement [4]. However, there may be exceptions to this principle, for example, in the case of benefits arising from the optimal scale of production in a particular industry.

We investigate whether the services of a single firm are socially preferable to those of several firms. We test this idea empirically by focusing on the production efficiency of waste management, considering possible subadditivity in production costs in the city of Milan, Italy. The analysis is developed by comparing a business-as-usual model in which waste management is provided by a single firm with an alternative scenario in which the city is divided into four areas and four firms provide the service in each of these areas.

We add to the literature on industrial production empirical evidence from a sector that is becoming increasingly important due to its relevance to the circular economy, particularly regarding the existence of subadditivity of costs.

The rest of this article is organized as follows: we review the relevant literature on economies of scale, subadditivity of costs, and waste management efficiency in Section 2. After that, in Section 3, some detailed information regarding the theory of cost subadditivity is provided together with the rationale for our hypothesis building and the research design. Section 4 contains the main empirical evidence. Section 5 discusses the main considerations and implications arising from the results obtained. Conclusions follow.

2. Literature Review

Given the convergence of various factors, such as public policies [5] and climate commitments, the need to provide public services in an economic and eco-efficient way is a focus in environmental economics [6,7]. Furthermore, the trend of the global economy is stressing industrial structures, especially in countries that depend on the import of raw materials. Several approaches have been used to investigate this sector. In this paper, we review some studies that have dealt with scale and scope dimensions since, to the best of our knowledge, additional studies are needed on subadditivity of costs—that is the purpose of this paper.

Efficient production size and scope and the environmental impact of firms are important for policy and market organization [8], and the number of relevant studies on the cost of waste management has increased [9–13]. The approaches used to estimate costs of waste management are often based on the unit cost method, benchmarking techniques, and cost estimation models using, for example, cost and production function analysis [14,15] and data envelopment analysis and stochastic frontier analysis [16].

Previous literature provides many insights into different technologies, scale economies, market forms, industries, and countries [17,18]. Scholars have also tried to empirically assess the impact of different regulated business models on waste management efficiency by focusing on the size of the territorial areas and municipalities [19,20]. For example, a recent paper analyzes municipalities that, like other production units, should be large enough to minimize average costs [21]. This is consistent with the fact that a renewed interest in decentralization has affected local public governance around the world [22], as well as at metropolitan scales [23]. Such studies can assess whether the scale of activities can explain performance in waste management [24].

Other studies focus on the cost structures of waste management [10], the relation with exogenous factors such as population density [25], the need to develop strategies to achieve sustainability targets [26], compliance with environmental legislation and costs [27], and zero waste management [28]. Similar approaches have been developed for other local environmental services, such as water, where studies suggest substantial cost benefits from the joint production of treated quality water [29] and potential benefits of appropriate scale and scope economies considering vertical and horizontal configurations of water industries [30]. The increasing pressure for cost efficiency has prompted governments to transfer some waste services to private firms [31], giving rise to the question of whether for-profit firms are compatible with outcomes that maximize social welfare [32].

Economic and political factors exert different impacts on waste management by private and public firms [33]. Private waste management operators are not necessarily better performers than public firms [34] because the profit maximization typical of private operators may clash with the social and environmental targets typical of public services. To this end, business models and waste management methods, such as the organization of collection services, have received limited attention [35], even if they have a significant impact [36]. Both controllable and noncontrollable factors can have a significant impact on costs [37].

Broadly speaking, a function is said to have subadditivity when the whole is less than the sum of two or more parts. This attribute is important in economies of scale when the combined operating costs of two enterprises are less than the sum of their individual operating costs [38]. Economies of scale take place when the average cost of production declines as production increases. Such a decline in average production cost can stem from, according to the sector, high fixed costs, lower input prices, or learning economies.

What characterizes economies of scale is that such relations typically operate over a range of output rather than for all possible output levels [39]. When economies of scale pertain to the firm's entire output rather than to a specific product, the cost savings resulting from making these products together include a variety of economies of scope. Concerning economies of scope, subadditivity of costs refers to a situation where the total cost of activities performed in combination is less than the total cost of activities performed separately due to synergies [40]. Indeed, multiple products show scope economies when the combined cost of producing them is lower when their production is organized jointly than when it is separate for each product or produced by more firms [41].

In a public service such as waste management that is made up of many services, it is reasonable to think that, based on economies of scale and scope, a logic of vertical integration is necessary, e.g., for transaction costs and information efficiencies. Economies of scale and scope also affect the public service delivery market structure debate. Specifically, fostering competition incentivizes operators to operate efficiently. However, competition in the market is not always the preferred configuration, as the production technology or the characteristics of the services produced can generate market failures. In some circumstances, existing production technology makes it more efficient to concentrate production on a single subject than a solution in which several firms carry it out. In such cases, the activity is configured as a natural monopoly. It is recognized that municipal waste services have typically been provided through natural or legal monopolies [15]. Indeed, services of general economic interest have general economic utility often subject to public service obligations. Market rules apply to firms responsible for managing such services as long as competition does not prevent them from accomplishing their tasks in the general interest, for example, in cases of imperfect competition [42]. Therefore, such services can be provided either by the state or by the private sector and by more firms that are part of public contracts or in a monopolistic manner.

Subadditivity of costs is a critical concept frequently used to justify imperfect competition, which encourages natural monopolies even if its analysis is challenging due to information asymmetry [43]. We help fill this gap by providing a detailed analysis of the cost production structure by empirically testing our idea using a specific business scenario.

3. Materials and Methods

Arguments for and against monopoly and competition in the provision of services embrace many perspectives [44,45]. Subadditivity assumes that the output level is produced at the lowest cost by a single firm [38]. Economies of scope and economics of scale are constrained types of subadditivity by comparing the costs of more firms that specialize in producing different outputs to one that produces two goods at comparable output levels. Taking an example of firms that produce individually, the production cost equals the sum of the costs incurred by each firm to produce a quantity q of product or service x. Equation (1) formalizes this concept, where Q stands for the quantity and i corresponds to one of the n firms existing in the industry. Equation (1) indicates that the production cost of the total quantity Q is the sum of the costs incurred by each firm to produce the share of Q, i.e., Q/n produced by each.

$$Production\ cost = \begin{cases} c_m(Q_x); one\ firm \\ \sum_{i=1}^{n} c_i\left(\frac{Qx}{n}\right); n\ firms \end{cases} \quad (1)$$

{\displaystyle \sum _{i=1}^{n}c_{i}\;(Q_{i})}The hypothesis underlying the theory of subadditivity is resumed in Equation (2).

$$c_m(Q_x) \leq \sum_{i=1}^{n} c_i\left(\frac{Qx}{n}\right) \tag{2}$$

Natural monopolies stand out because marginal costs are typically small once an investment is made and because average costs decrease with increased output; if only one firm operates in the market, production costs may be lower than if there are competitors.

The standard average cost functions for one or more firms are shown in Figure 1. Subadditivity indicates that it is cheaper to produce the same production level when only firm one is producing. The existence of economies of scale is a sufficient but not required condition for monopolies to be sustainable. However, subadditivity is considered necessary even if there are insufficient conditions for a natural monopoly to be considered efficient.

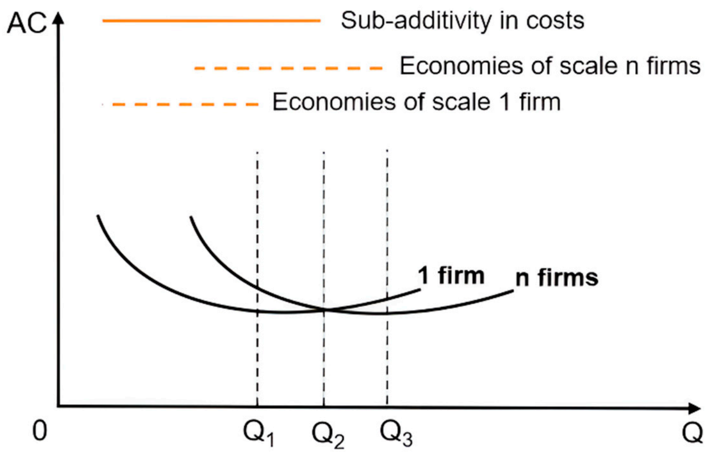

Figure 1. Average costs of one and multiple companies in a monopolistic market; Q = quantity of output; AC average cost.

We empirically tested whether starting from data on costs and waste production, Equation (3) H_0 is verified, i.e., if the service falls between 0 and Q_2 in Figure 1. In such a case, the collection of waste is configured as a natural monopoly due to economies of scale and above all, economies of density, which lead us to believe that the service costs are lower if the service is carried out by a single firm rather than by several firms. Beyond a certain level of output, in the case of Figure Q_2, more firms are able to operate more effectively.

In network services such as municipal solid waste collection, economies of density take on central importance. To ascertain the existence of a market failure, it is necessary to verify the conditions that make the collection phase a natural monopoly that cannot be contested.

A contestable natural monopoly, although not optimal, allows for eliminating the monopoly rents and can reach the most efficient allocation compatible with the cost coverage constraint in the absence of regulation. This result implies that in markets characterized by few irreversible costs and without other barriers to entry, competition in the market can produce results close to second-best efficiency even in the presence of natural monopolies. Furthermore, situations of market failure occur when the goods and services produced are public goods, such as waste management, because the market does not easily allow optimal production, given the difficulty in preventing free-riding behaviors.

Research Design

Our research question consists of testing the subadditivity of costs in waste management production costs in Milan. To contextualize the analysis, Table 1 presents contextual data regarding waste production.

Table 1. Background information regarding waste in the city of Milan.

Year	Inhabitants	Sorted Waste Tons	Waste Generated Tons	Sorted Waste %	Sorted Waste per Capita kg/Inhabitant	Waste per Capita kg/Inhabitant
2020	1,397,715	381,660	608,413	62.7	273.1	435.3
2019	1,406,373	433,404	707,507	61.3	308.2	503.1
2018	1,395,980	407,318	692,228	58.8	291.8	495.9

Source: Italian National Environmental Protection Institute.

The waste management incumbent runs the service both in the Municipality of Milan and in seventeen other towns in the Milan metropolitan area. Table 2 contextualizes the scope of the incumbent to carrying out the case study; indeed, the incumbent firms run the service in the Municipality of Milan and in seventeen other municipalities in the metropolitan area.

Table 2. Scope of analysis.

Variable	Total	Case Study
Number of Municipalities	18	1
Population	1844	1400
Area km^2	383	182
Workforce	3097	2444

Source: Own elaboration based on incumbent website.

Starting from the technical and economic data concerning the municipal waste collection service in Milan, we reclassified the cost of waste management to test our hypothesis. The cost reconstruction path started from information made publicly available by the Municipality of Milan, and the procedure for determining the values attributed to the activities refers to the accounting and technical documentation: the financial statements of the incumbent waste management firm, the indicators referring to the use and cost of personnel, and the indicators relating to the use of capital goods derived based on the service monitoring activity, as well as by analyzing the service contract.

Based on the above information, we estimated the costs classified as follows: collection, sweeping, other services, and on-demand. To verify the existence of subadditivity in the costs, starting from the accounting data, we estimated the overall costs, hypothesizing that four firms ran the service as in Figure 2. Therefore, the business-as-usual hypothesis foresees that the total quantity of the service that corresponds to the waste management service for the entire city of Milan was provided by a single operator, whereas the alternative hypothesis foresees that each of the four firms provide a fraction of the service provided the total quantity is the same.

Milan is divided into nine districts; we did not take into consideration a scenario with more than four firms, as the same organizational measures could not be guaranteed for each one. The hypothesis of mutual use of production inputs by different firms in the same operating area appears incompatible with adequate levels of effectiveness and efficiency. Given the characteristics of the service and the city of Milan, we simulated by assuming four firms corresponding to the four incumbent divisions. Geographically, in Figure 2 firm 1 runs the service in the northeast area of the city that is denoted as area 1, firm 2 runs the service in the southeast area, i.e., area 2, firm 3 runs the service in the southwest area that corresponds to area 3, and firm 4 runs the service in area 4 or the northwest side of the city. This is due to the inevitable duplication of costs deriving from fixed costs and investments necessary for the organization and provision of the service over reduced operating areas—the reduction of the functional area does not correspond to a proportional reduction in costs. Therefore, we assume that each firm independently carried out the service in the assigned areas. Table 3 provides information regarding the city of Milan and how it could be divided to allow multiple firms to run the waste management service.

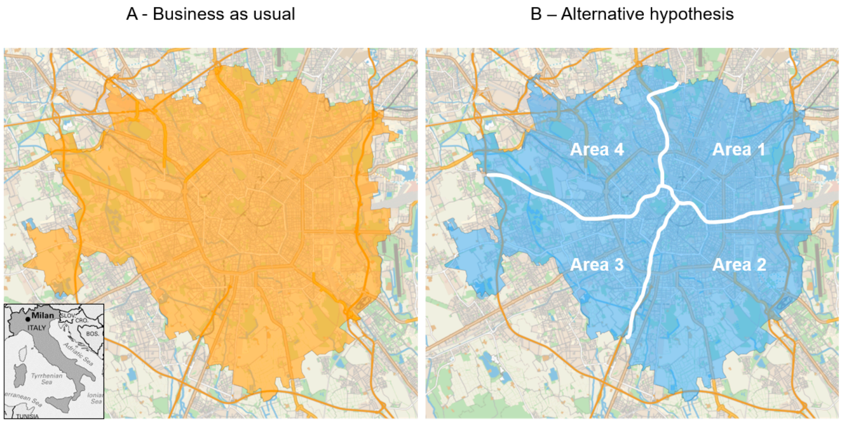

Figure 2. Approach for the alternative scenario. City of Milan, Italy. Inhabitants 2020: ~1.4 million, (metropolitan ~2.9 million). Elevation: 130 m above sea level. Area: 181.76 km^2. Subfigure; localization of the City of Milan.

Table 3. Reclassification of the city of Milan according to our scenario.

Administrative Units			Area 1		Area 2		Area 3		Area 4	
	km^2	Pop	km^2	Pop	km^2	Pop	km^2	Pop	km^2	Pop
District 1	9.7	98,679			4.8	49,339	4.8	49,340		
District 2	12.6	163,335	12.6	163,335						
District 3	14.2	145,328	14.2	145,328						
District 4	21	162,795			21	162,795				
District 5	29.9	127,280			29.9	127,280				
District 6	18.3	152,519					18.3	152,519		
District 7	31.3	177,731					20.4	115,525	11	62,206
District 8	23.7	188,650							23.7	188,650
District 9	21.1	190,058	10.6	95,029					10.6	95,028
Areas 1, 2, 3, 4 *			37.4	403,692	55.7	339,413	43.5	317,384	45.2	345,884
Milan	181.8	1,406,373								

Source: Elaboration based on data available online for the Municipality of Milan. * Our estimation. See Figure 3 for a map showing overlapping between municipalities and areas.

Figure 3 overlaps districts and business units that correspond to the areas used in the alternative hypothesis.

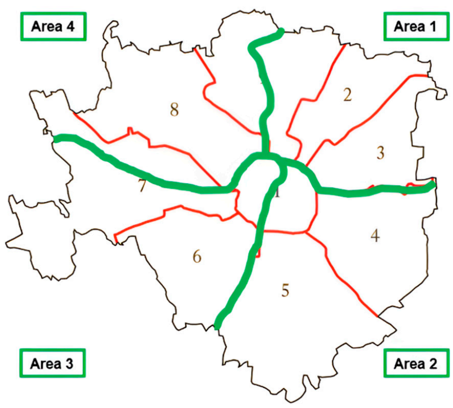

Figure 3. Districts and the four areas. In red nine districts, in green four areas.

From Table 3, the population of the four identified areas ranges from 0.31 to 0.4 million inhabitants, whereas the areas range from approximately 37 km^2 to slightly less than 56 km^2, from which we can derive population densities from 6 to 10 thousand inhabitants per km^2. We were able to divide the costs between the four firms considering the minimum organizational information for the performance of the service, inferable from the information in the documents used by the agency of the city of Milan. Appendix A summarizes the four types of services: collection, sweeping, other, and on-demand—more than fifty different subservices constitute the waste management service.

We define our hypotheses as follows:

$$Hypotheses : \begin{cases} H_0 = c_m(Q) \leq \sum_{i=1}^{4} c_i\left(\frac{Q}{4}\right) \\ H_1 = c_m(Q) > \sum_{i=1}^{4} c_i\left(\frac{Q}{4}\right) \end{cases} \quad (3)$$

Considering the hypothesis formalized in Equation (3), we developed our research question to verify H_o. In this paper, we focus on the production cost structure.

4. Results

Based on the above assumptions, a reasonable approximation of the total industrial cost of the individual activities that make up the waste management service was reconstructed. It should be noted that the total cost includes both the activities of collection and waste treatment and disposal. Table 4 shows the distribution and total cost according to the simulation designed to test our hypothesis.

Table 4. Business-as-usual and simulation.

	Costs and Resources	Workforce	Means	Production Cost
	Business-as-usual: incumbent			
c(Q)		2444	761	314,879,379
	Collection	999	248	157,821,729
	Sweeping	1378	498	141,086,581
	Other services	36	15	13,077,784
	On-demand	31	0	2,893,285
	Alternative hypothesis: firm 1/4			
$c_i\left(\frac{Qi}{n}\right)$	Collection	285	70	45,323,303
	Sweeping	390	141	40,399,649
	Other services	16	6	3,981,982
	On-demand	17	0	1,328,732
	Alternative hypothesis: firm 2/4			
$c_i\left(\frac{Qi}{n}\right)$	Collection	260	66	41,894,035
	Sweeping	348	128	36,385,046
	Other services	16	6	3,352,230
	On-demand	17	0	1,310,193
	Alternative hypothesis: firm 3/4			
$c_i\left(\frac{Qi}{n}\right)$	Collection	230	59	39,019,567
	Sweeping	328	128	35,136,937
	Other services	16	6	3,197,337
	On-demand	17	0	1,306,381
	Alternative hypothesis: firm 4/4			
$c_i\left(\frac{Qi}{n}\right)$	Collection	239	61	38,432,266
	Sweeping	343	118	34,649,655
	Other services	16	6	5,249,366
	On-demand	17	0	1,289,739
	Ttoal alternative hypothesis: Firms 1, 2, 3, 4			
$\sum_{i=1}^{4} c_i\left(\frac{Q}{4}\right)$		2555	795	332,256,419
	Collection	1014	256	164,669,171
	Sweeping	1409	515	146,571,287
	Other services	64	24	15,780,915
	On-demand	68	0	5,235,045

Note: reconstruction of costs to predict the total cost of service under the two hypotheses was possible by accessing information contained in the service contract between the Municipality of Milan and the incumbent, see Appendix B for parameters.

For each service contained in the service contract, all the production inputs, including staff, were allocated to one of the four actual business units. Differences in costs primarily derived from the fact that both staff and other production inputs would duplicate by dividing the service. This consideration is often omitted in economies of scale studies although it is of prominence.

Table 4 shows that the output level is produced at the lowest cost by a single firm providing imperfect competition, which encourages one producer since it probably functions more effectively than more firms. This can be examined by comparing workforce and production means. Regarding the workforce, our results suggest that a monopolist produced the same output as four firms, employing 4% fewer employees and requiring 9.5% fewer means of production.

Figure 4 compares the total production cost of waste management following our research design hypothesis. The production of a single firm is socially preferable in terms of production costs.

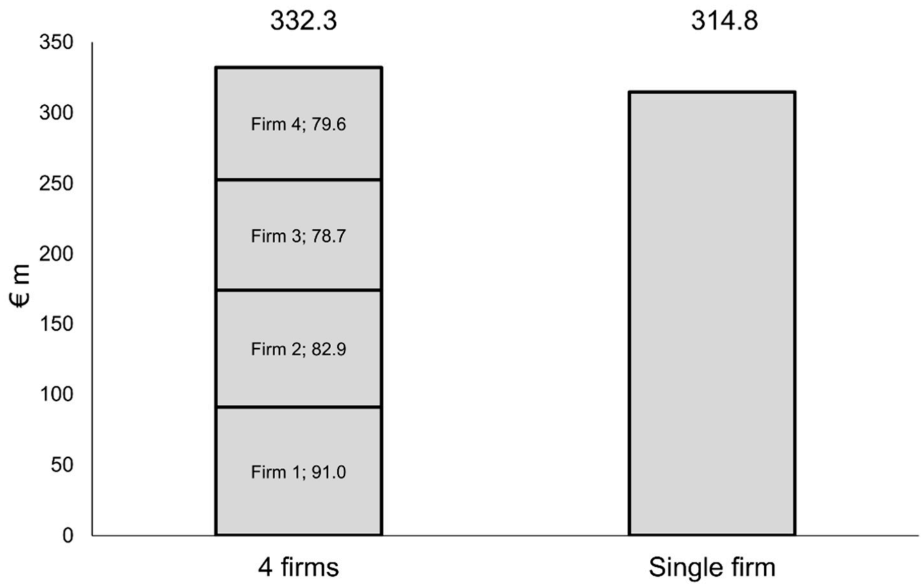

Figure 4. Simulation output of production costs.

We did not perform our simulation on more, smaller areas because the same organizational measures, such as the availability of operational areas functional to the service, could not be guaranteed in each area. The idea that different service managers share the same operational area seems incompatible with adequate levels of effectiveness and efficiency because of the duplication of costs deriving from the fixed costs and investments necessary for the organization and delivery of the service in reduced operational areas. The reduction in the operating area does not correspond to a proportional reduction in the costs. The simulation assumed that the firm that manages the waste management service provides the same services in each area.

5. Discussion

Starting from the fact that services of general economic interest can be provided either by the state or by the private sector and by more firms or by a monopolist, it is important to refer to the extent of imperfect competition and the structure of production costs to identify the best service provision industrial organization. Indeed, it is worth noting that economic theory foresees competition as the best option, provided that specific conditions are satisfied. Furthermore, a fair, competitive environment is also among the main targets of European legislation. As mentioned in the Introduction, however, we need to consider that such a principle can be derogated, e.g., following gains deriving from the optimal production size. A monopolistic structure in the municipal waste management service should be evaluated based on economies of scale, economies of scope, economies of density, morphological characteristics of the territory, relevant policies, and barriers to entry. The provision of the municipal solid waste management service must follow the technical and economic efficiency of the service, which, from the results, appears achievable through a single operator.

A single provider in a city like Milan is not in contrast with market principles. Indeed, competition is restricted when there is an intention to unduly favor or disadvantage certain economic operators; it follows that competition is not restricted by subadditivity of costs and other peculiarities of the sectors outside of public interest regulatory targets [46]. It seems that managing the entire municipal area by a single economic operator could positively affect the community, given the potential savings on the costs of managing the service. Considering the information in this study as a whole, we can verify that there are no substantial differences between the two management hypotheses regarding the activities of separate collection, separate collection of the organic fraction, separate collection of paper and cardboard, separate collection of glass, separate collection of plastic and metal packaging, street sweeping activities in general, and activities of emptying the bins—given that the quantity of the production factors, employed personnel, vehicles, and containers are proportional in the two scenarios analyzed in this article.

Furthermore, the results show that the activities that incur the highest costs are those related to collection, in particular, the sorting of bulky waste, durable goods, batteries, pharmaceuticals, exhausted toner cartridges, residual and sorted waste collection with dedicated containers, residual and sorted waste collection in cemeteries, the cleaning of markets, the collection and disposal of small items containing asbestos, the separate collection of used clothing, the separate collection of used oil and some sweeping activities such as cleaning the banks of watercourses, collecting leaves, cleaning tree rows and related areas, mowing and weeding sidewalks, washing tunnels, arcades, and underpasses of value. This is primarily due to the increase in personnel and vehicles to ensure service under the alternative scenario.

The contribution to the literature in the field of efficiency in the management of public services and in waste management consists of shedding light on concepts that are sometimes considered synonyms in studies aimed at evaluating the efficiency of public services: economies of scale and the subadditivity of costs, even if what emerged from the simulation may have some interpretative limitations. We start from the incumbent's financial and industrial data; therefore, some might object that it is impossible to calculate the costs of potential competitors based on the incumbent's costs. However, although this consideration might be worth noting, it does not override our hypothesis. The municipal waste management industry has a relatively rigid cost structure. Therefore, it is not wrong to assume that the cost structure of potential new entrants to the market may be similar to the cost structure of the incumbent, given that there are constraints concerning the quality of the service that imply a series of rigidities that the flexibility of the companies cannot overcome since this is, as mentioned, a market structure characterized by structural rigidity.

Based on the empirical evidence that emerged, we can deduce some implications for industrial policy and the governance of waste management services.

It is necessary to prepare regulatory measures and incentives to favor the aggregation of companies that do not reach a minimum efficient size. This concept is also critical considering the provisions of European legislation on public procurement, which is aimed at encouraging the participation of small and medium-sized enterprises. However, differently from other sectors where legislation is being more and more harmonized across countries, the number of non-harmonized laws in force across countries as well as their constant updates are prominent problems that make it difficult to obtain comparable information [47].

The results of this paper demonstrate that a market configuration that allows more companies to provide part of the municipal waste management service could worsen social well-being due to the increase in total production costs. However it should be noted that this consideration is not extendable in cities of different size or other organizational forms; for example, another study found that social welfare would increase if tenders' scope were reduced in terms of size [19]. Instead, another study based in Finland reported that switching from laissez-faire production to public procurement reduces the number of active firms on the local market, but results in a statistically significant and substantial decrease in prices [48], whereas an analysis of the city of Barcelona, where the city is divided in four areas, found that firms strategically manage quality performance and tend to deliver higher quality where they anticipate easier monitoring by the regulator [49], which can be thought of as a non-optimal condition given that quality of the service is not the same for citizens.

So, monopoly may be more efficient than competition when it comes to local service delivery, according to a study that found that municipalities that adopt an industrial organization strategy and create hybrid ownership firms benefit from market engagement and economies of scale due to monopoly production [50]. The above also impacts governance at the local level and, in particular, companies' organization and ownership structure. Typically, local authorities can entrust the management of local public services through three procedures: the first procedure consists of entrusting to third parties through public procedures following the provisions on contracts and service concessions, the second procedure involves the establishment of a mixed public–private company, and the third procedure consists of in-house management. EU jurisprudence also allows the so-called in-house provision of public services by the local authority under specific conditions, for which we refer to Article 106 of the TFEU. The optimal forms shall be selected considering reaching circular economy targets as the goal, given the positive impact on the economy [51,52].

6. Conclusions

As a service of general economic interest to which market rules apply, except where competition is contrary to the general interest, as in certain cases of imperfect competition, municipal waste management can be provided by several companies or by a single firm. As waste management is a strategic pillar of the circular economy, municipal waste management services must be organized to maximize the cost-effectiveness of their provision. Despite a remarkable body of economic literature, the results are heterogeneous due to different contexts, scholars' specializations, types of waste, and research approaches. Our results suggest the existence of subadditivity of costs, estimated at 6% lower production costs in the case of a single firm against a hypothetical market setting in which four firms separately provide a share of the service. Therefore, a municipal solid waste configuration with more companies simultaneously running the service in geographically divided areas could worsen social well-being due to the increase in total production costs.

Such efficiency gains come from synergies, lower transaction costs, and optimization of productive inputs and facilities. It must be taken into consideration that the results refer to a case study and similar conclusions can be drawn for cities with similar characteristics in terms of geographic, urbanistic, societal, and socio-economic conditions.

In addition, within the same framework, it is important to better understand the role of synergies in business models, particularly the implications of the size and scope of waste management firms given environmental targets. However, given that economies of scope favor large utilities, it is important to study the role of participation of small and medium-sized enterprises in the public procurement market due to the barriers that sometimes make it difficult for them to participate in tenders. We highlight that the 'one size fits all' approach is not the best way for policymakers to create a level playing field for businesses. The combination and trade-offs between economic efficiency targets and the implications of circular economy targets need to be clarified to better understand the main development drivers for generating growth opportunities for the benefit of society and the environment.

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Data Availability Statement: Publicly available datasets were analyzed in this study. Data on waste production and costs can be found at: https://www.catasto-rifiuti.isprambiente.it/index.php?pg=ru (accessed on 7 January 2023). Parameters are listed in Appendix B.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

- Collection
    - Residual fraction of separate collection, separate collection of plastic and metal
    - Separate collection of organic fractions, separate collection of cardboard, separate collection of glass
    - Separate collection of bulky waste, waste collection and market cleaning, separate collection of used clothing
    - Separate collection of durable goods
    - Separate collection of batteries, separate collection of pharmaceuticals, separate collection of used toner cartridges
    - Recycling
    - Collection with dedicated containers
    - Collection in cemeteries
    - Asbestos collection and disposal
    - Separate collection of used vegetable oil
- Sweeping
    - Fine sweeping, global sweeping
    - Emergency response on public land
    - Hazardous waste collection
    - Roadside litter removal operations
    - Illegal dumping, cleaning of degraded areas
    - Massive sweeping
    - Sensitive areas—manual sweeping
    - Sensitive areas—mechanized sweeping
    - Sensitive areas—emptying litter bins
    - Area sweeping
    - Cleanup of municipal stream banks
    - Leaf collection
    - Cleaning tree rows and related areas
    - Mowing and weeding of sidewalks, parks: cleaning, dog areas, draining sumps
    - Galleries, porches, valuable areas
    - Emptying trash cans
- Other
    - Services at travel camps
    - City fairs, public events
    - Snow service
    - Purging and unclogging manholes
    - Cleaning of streambanks and embankments
    - Garbage collection service at municipal facilities
    - Cleaning of settling tanks
    - Bus toilets
    - Inspection of construction

- On-demand
    - Snow service
    - Pest and rodent control, installation of mobile signs, cleaning of weekly markets, after-events cleaning, cemetery waste disposal, miscellaneous emergencies, fountain cleaning, litter removal in public areas

Appendix B. Allocation of Resources on Services

Description	*N*	Area 1	Area 2	Area 3	Area 4
Residual fraction of separate collection, separate collection of plastic and metal	Staff	Scheme	Scheme	Scheme	Scheme
	Truck	Scheme	Scheme	Scheme	Scheme
Separate collection of organic fractions, separate collection of cardboard, separate collection of glass	Staff	Scheme	Scheme	Scheme	Scheme
	Truck	Scheme	Scheme	Scheme	Scheme
	Bins	∂ points	∂ points	∂ points	∂ points
Separate collection of bulky waste, waste collection and market cleaning, separate collection of used clothing	Staff	25%	25%	25%	25%
	Truck	25%	25%	25%	25%
Separate collection of durable goods	Staff	1dr-1wo	1dr-1wo	1dr-1wo	1dr-1wo
	Truck	1	1	1	1
Separate collection of batteries, separate collection of pharmaceuticals, separate collection of used toner cartridges	Staff	1 serv	1 serv	1 serv	1 serv
	Truck	1 serv	1 serv	1 serv	1 serv
Recycling	Staff	25%	25%	25%	25%
	Truck	1	1	1	1
Collection with dedicated containers	Staff	25%	25%	25%	25%
	Truck	25%	25%	25%	25%
	Bins	25%	25%	25%	25%
Collection in cemeteries	Staff	2	1	1	4
	Truck	2	1	1	4
	Bins	2	1	1	4
Asbestos collection and disposal	Staff	1dr-1wo	1dr-1wo	1dr-1wo	1dr-1wo
	Truck	1	1	1	1
Separate collection of used vegetable oil	Staff	1 driver	1 driver	1 driver	1 driver
	Truck	1	1	1	1
Fine sweeping, global sweeping	Staff	Scheme	Scheme	Scheme	Scheme
	Truck	Scheme	Scheme	Scheme	Scheme
Emergency response on public land	Staff	1dr-1wo	1dr-1wo	1dr-1wo	1dr-1wo
	Truck	1	1	1	1
Hazardous waste collection	Staff	1dr-1wo	1dr-1wo	1dr-1wo	1dr-1wo
	Truck	1	1	1	1
Roadside litter removal operations	Staff	1 driver	1 driver	1 driver	1 driver
	Truck	1	1	1	1
Illegal dumping, cleaning of degraded areas	Staff	1dr-1wo	1dr-1wo	1dr-1wo	1dr-1wo
	Truck	1	1	1	1
Massive sweeping	Staff	Scheme	Scheme	Scheme	Scheme
	Truck	Scheme	Scheme	Scheme	Scheme
Sensitive areas—manual sweeping	Staff	Scheme	Scheme	Scheme	Scheme

Description	N	Area 1	Area 2	Area 3	Area 4
Sensitive areas—mechanized sweeping	Staff	Scheme	Scheme	Scheme	Scheme
	Truck	Scheme	Scheme	Scheme	Scheme
Sensitive areas—emptying litter bins	Staff	Scheme	Scheme	Scheme	Scheme
	Truck	Scheme	Scheme	Scheme	Scheme
	Bins	∂ w/m	∂ w/m	∂ w/m	∂ w/m
Area sweeping	Staff	Scheme	Scheme	Scheme	Scheme
Cleanup of municipal stream banks	Staff	1dr-1wo	1dr-1wo	1dr-1wo	1dr-1wo
	Truck	1	1	1	1
Leaf collection	Staff	25%	25%	25%	25%
	Truck	25%	25%	25%	25%
Cleaning tree rows and related areas	Staff	1dr-2wo	1dr-2wo	1dr-2wo	1dr-2wo
	Truck	1	1	1	1
Mowing and weeding of sidewalks, parks: cleaning, dog areas, draining sumps	Staff	25% serv	25% serv	25% serv	25% serv
	Truck	25% serv	25% serv	25% serv	25% serv
Galleries, porches, valuable areas	Staff	1dr-1wo	1dr-1wo	1dr-1wo	1dr-1wo
	Truck	1	1	1	1
Emptying trash cans	Staff	Scheme	Scheme	Scheme	Scheme
	Truck	Scheme	Scheme	Scheme	Scheme
	Bins	∂ w/m	∂ w/m	∂ w/m	∂ w/m
Services at travel camps	Staff	1	1	1	1
	Truck	25%	25%	25%	25%
	Bins	25%	25%	25%	25%
City fairs, public events	Staff	1dr-1wo	1dr-1wo	1dr-1wo	1dr-1wo
	Truck	1	1	1	1
Snow service	Staff	m. sweeping	m. sweeping	m. sweeping	m. sweeping
	Truck	m. sweeping	m. sweeping	m. sweeping	m. sweeping
Purging and unclogging manholes	Staff	25%	25%	25%	25%
	Truck	25%	25%	25%	25%
Cleaning of stream banks and embankments	Staff	1dr-1wo	1dr-1wo	1dr-1wo	1dr-1wo
	Truck	1	1	1	1
Garbage collection service at municipal facilities	Staff	1 driver	1 driver	1 driver	1 driver
	Truck	1	1	1	1
Cleaning of settling tanks	Staff	1dr-1wo			
	Truck	1	1	1	1
Bus toilets	Staff	1dr-1wo	-	-	1dr-1wo
	Truck	1	-	-	1
Inspection of construction	Staff	25%	25%	25%	25%
On-demand					
Snow service	Staff	2	2	2	2
Pest and rodent control, installation of mobile signs, cleaning of weekly markets, after-events cleaning, cemetery waste disposal, miscellaneous emergencies, fountain cleaning, litter removal in public areas	Staff	1 serv	1 serv	1 serv	1 serv

Note: serv: for each of the services listed in the description cell, dr: driver, wr: worker, ∂ w/m: workers on means.

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