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The Impact of population size and bin structure on the cost of municipal solid waste: evidence from Sweden and Norway

Magnus Söderberg, Vivek Kumar Sundriyal, Jonas Gabrielsson

RATIO Näringslivets forskningsinstitut

Box 3203
103 34 Stockholm

Besöksadress:
Sveavägen 59, 4 tr

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Magnus Söderberg,
magnus.soderberg@ratio.se
Corresponding author. Ratio Institute, Stockholm, SWEDEN.
Centre of Applied Energy Economics and Policy Research, Griffith University, Parklands Drive, Southport QLD 4222, AUSTRALIA. Telephone: +61 (0)7 555 270 84.

Vivek Kumar Sundriyal,
vivek.sundriyal@hh.se
Department of Business, Halmstad University, SWEDEN

Jonas Gabrielsson,
jonas.gabrielsson@hh.se
Department of Business, Halmstad University, SWEDEN

Abstract

Increasing waste levels, combined with ambitious environmental targets, are exerting upward pressures on the cost for municipal solid waste in many countries. The purpose of this study is to investigate what municipalities can do to counteract this development. We collect information about population, cost and waste from 225 Swedish and Norwegian municipalities and empirically investigate how waste bin structure/type of waste collection system and population affect municipalities' waste cost. Results indicate that 4-compartment bins is the most expensive bin structure (+13%) and using the same bin types in detached and multi-family dwellings leads to coordination savings (-18%). The cost minimising population is slightly above 600,000 inhabitants. Several of the surveyed municipalities have substantially fewer inhabitants than that and cost per inhabitant can be reduced by up to 30% in several locations through collaborations with larger neighbours. In Sweden, transferring the responsibility for solid waste from the municipalities (290 in total) to the regions (20 in total) would eliminate almost all scale inefficiencies.

Key words: Waste management, cost, population, bins, Sweden, Norway

JEL Codes: L98, Q53, Q58

1. Introduction

The municipal solid waste (MSW) sector is one of the essential services that make up the bedrock of modern societies (Di Foggia & Beccarello, 2020; Hoornweg & Bhada-Tata, 2012). Essential services are usually required to be affordable to all its customers and supplied in a cost-efficient manner. To support local waste authorities reach those objectives, this study investigates how different types of bin structures/collection systems and scale properties affect the total cost of collecting and handling municipal solid waste. Data is collected from the MSW sectors in Sweden and Norway, two countries with ambitious waste targets.

The MSW sectors in many countries experience increasing waste levels due to rising income and continued urbanization, which have led to a proliferation of consumption opportunities (Halloran, Clement, Kornum, Bucatariu, & Magid, 2014; Hoornweg & Bhada-Tata, 2012). World Bank forecasts suggest that waste generation is likely to continue to increase from the current level of two billion tons per annum, to three and a half billion tons in 2050 – an increase by approximately 70% (Di Foggia & Beccarello, 2020). Additionally, statistics from Eurostat reveal that the amount of MSW per capita in the EU-28 has increased every year since 2013 and in September 2018 an investigation concluded that 14 member countries were at risk of missing the target to reuse/recycle 50% of its waste by 2020 (European Commission, 2018). These developments have led to an experimentation of policies[1], including requirements to collect and handle waste in a cost-efficient manner (Greco, Allegrini, Del Lungo, Savellini, & Gabellini, 2015).

Additional complications in Sweden are two upcoming regulatory changes that will give the municipalities an extended waste collection responsibility. From January 2024, the Swedish municipalities will be fully responsible for the collection of all household waste streams. In addition to general and organic waste, which they have handled for more than a century, they will now also be responsible for newspapers and packaging (plastic, clear and coloured glass, corrugated paper, metal). From January 2027, all these streams must be collected curbside. The regulatory changes are critical steps towards a more sustainable material recycling infrastructure, but they imply added coordinating complexities and costs to the MSW operations.

[1] A large range of polices have been discussed extensively in the popular media, e.g. (i) reduced convenience of waste disposal (The Guardian, 9 Oct 2017), (ii) improved infrastructure capacity and options (The Guardian, 21 Oct 2019), (iii) more relevant information to consumers (Göteborgs-Posten, 4 Aug 2019), (iv) establishment of marketplace for used products (The Guardian, 18 June 2019), (v) legal restrictions about non-recycled products (The New York Times, 16 March 2019), (vi) development of educational programs (extract.se, 5 Feb 2019), (vii) higher product, landfill and incineration taxes (The Times, 18 Feb 2019), (viii) feedback about own and social norm behaviours (LetsRecycle.com, 19 Nov 2019).

Increasing collection, transportation and processing costs of the collected waste have become a critical issue and have pushed municipalities to evaluate the drivers of cost at an ever-increasing level of detail (Jacobsen, Buysse, & Gellynck, 2013). Prior research has suggested MSW costs are driven by population size, density, market structure (public versus private operators), type of waste, and quantity of waste collected as crucial factors influencing the costs of waste management (Bel & Fageda, 2010; Guerrini, Carvalho, Romano, Marques, & Leardini, 2017; Tickner & McDavid, 1986). With multiple new waste streams, it will be particularly important for municipalities to understand how different bin choices impact the cost. With an increase in the level of collection and handling complexity, it will also be important to understand the role of economies of scale. Municipalities vary greatly in size, and it is well known that other essential services with network characteristics are subject to substantial economies of scale (e.g., Boscan & Söderberg, 2021; Söderberg, 2008, 2011).

This study focuses on the empirical relationship between population size and bin structure on the total MSW cost in Swedish and Norwegian municipalities. Using an extensive survey to collect unique cost and operational data from municipalities in these two countries, we find that the 4-compartment bins is the most expensive bin structure and that the cost minimizing population size is around 600,000 inhabitants. Several of the surveyed municipalities are substantially smaller than the cost minimizing population size and cost savings up to 30% per inhabitant is possible in several locations through collaborations with larger neighbours. In Sweden, there seems to be a strong case for transferring the responsibility for solid waste from the municipalities (290 in total) to the regions (20 in total) and we encourage policy makers to investigate that further.

The remainder of the paper is organized as follows. Section 2 provides a literature review of related research together with a brief background of the Swedish and Norwegian MSW sectors. Section 3 presents the data – information pertaining to the sample, the research design, the key variables, and the models used for analyses. Analyses are presented in Section 4, which is followed by conclusions in Section 5.

2. Literature Review

In recent years, there has been an increasing interest in understanding the cost drivers of MSW (e.g., Callan & Thomas, 2001; D'Onza, Greco, & Allegrini, 2016; Di Foggia & Beccarello, 2020; Fernández-Aracil, Ortuño-Padilla, & Melgarejo-Moreno, 2018), largely driven by the emphasis on efficient waste management by policy makers across the world (Buclet & Godard, 2001). Broadly, MSW refers to waste from households and commercial establishments such as shops, restaurants, and offices, while excluding waste from private sewers or construction-related waste not produced by professional operations. By managing MSW costs efficiently, and constantly seek cost reducing opportunities, municipals minimize slack and can charge their customers lower prices.

A municipal waste collection system involves the activities and actions required to manage the generated waste, such as pickup, transport and disposal at the treatment location. The MSW costs are commonly divided into collection and treatment. Waste collection systems differ worldwide, and range from no organized collection to sophisticated system consisting of multicompartment bins capable of handling different waste types or underground containers for separate waste types that are accessed by individual tags. Some locations use optical sorting where coloured plastic bags are used for different waste types and as a basis for automatic, factory-level sorting.

The literature on waste management systems tend to focus on either demand, looking into the legislations and public policy implications of waste management (e.g., Buclet & Godard, 2001), or supply challenges, such as organizational or market structures (e.g., Dubin & Navarro, 1988; Ohlsson, 2003; Stevens, 1978) and cost structures (e.g., Callan & Thomas, 2001). For example, focusing on the market or organizational structure, studies have investigated issues such as private, public, or collaborative models of waste collection (e.g., Stevens, 1978; Tickner & McDavid, 1986; Young, 1972). Focusing on the cost structure, studies have investigated issues such as population size and density or the bin structure/collection system (sorted and unsorted) (e.g., De Jaeger et. al., 2011; Greco et al., 2015).

Waste management can differ across countries due to policies or legislations (e.g., Bilitewski, 2008; OECD, 2013) or due to supply-side factors such as collection systems or market structure (e.g., Fernández-Aracil et al., 2018; Greco et al., 2015). However, the Scandinavian countries have several common denominators in their legalization and organization of their MSW sectors (Andersson & Stage, 2018; Kipperberg, 2007). For example, in Norway and Sweden, municipalities are responsible for collecting waste from households and commercial establishments such as restaurants, shops and offices. While municipalities have exclusive collection rights, no exclusive rights exist to treat the collected waste. According to the industry associations in the two countries, municipalities can choose to treat their own waste, send it to another municipality, or contract it out to a private enterprise.[2]

Municipalities in Sweden and Norway are autonomous entities that finance their waste management through fees collected from the residential and business customers with a requirement that the revenues can only cover the sum of collection and treatment expenditures, i.e., regulated according the full cost

[2] Swedish Waste Management, www.avfallsverige.se/in-english/, and Norwegian Waste Management and Recycling Association, www.avfallnorge.no/about-avfall-norge.

recovery principle (Haraldsson, 2016). However, the autonomy of the municipalities allows them to influence their cost structures by considering the direct (e.g., wages) and indirect (e.g., administration) costs needed to collect and treat municipal waste. Additionally, the municipalities must ensure that their fees are fair and reasonable to the residents. A problem with full cost regulation is that municipalities have weak incentives for cost reductions, which can lead to over-investment or gold plating (Averch & Johnson, 1962). This makes cost benchmarking important, and in particular, it pinpoints the importance of studying how municipal choices related to the collection and treatment of waste influence their total cost of supplying waste management services.

The waste management sectors in Sweden and Norway are considered successful in many ways, with a large share of food waste being converted into renewable energy and non-food waste being recycled. However, both countries have recently witnessed increasing amounts of waste collected from households, largely driven by increased consumption resulting from economic growth. For example, in 2020, the Swedish Waste Management reported that the amount of food and residual waste collected in Sweden was 202 kg/person – an increase of about 3% compared to the previous year. The increasing waste levels in both countries pose significant challenges for developing cost-effective solutions for waste collection and treatment, while operating in a policy landscape with increasing municipal responsibility for curbside collection of MSW close to household properties to meet ambitious recycling targets.

Swedish and Norwegian municipalities have a great deal of freedom to choose how to collect and process MSW by engaging in collaborations with other entities and designing their collection systems. In the following paragraphs, we discuss two central factors influencing the total cost of managing household waste: population size and bin structure.

2.1 Population size

Prior studies have investigated the influence of population size and density on municipal waste cost, but results have been mixed. Some studies have suggested that waste is subject to economies of scale (e.g., Dijkgraaf & Gradus, 2003), whereas others have suggested the opposite (e.g., Ohlsson, 2003). Municipalities vary in size, and collaborations can be a way for small municipalities to benefit from potential economies of scale (Pérez-López, Prior, Zafra-Gómez, & Plata-Díaz, 2016). However, caution is required since the cost curve can increase steeply at large populations due to increasing coordination costs driven by growth, development and scope complexity (Brown & Potoski, 2003).

In both Sweden and Norway, the constitution allows local government autonomy to choose the organizational structure for waste management. In this regard, municipalities can be responsible for their waste management through their own organization, through an external vendor (private contractors) or through collaboration with other municipalities. The waste sectors in both countries have a long history of inter-municipality collaborations. However, as mentioned above, it is not undisputed that waste management collaborations lead to economic benefits – at least not for larger municipalities.

2.2 Bin structure

Waste bin structure is one of the critical characterizing features of a waste management system, and it has been claimed to be a key cost driver (D'Onza et al., 2016). In both Sweden and Norway, there are several different systems in use for collecting and transporting municipal waste from households and commercial establishments. Broadly, food and residual waste can be collected as unsorted fractions in a single bin, a practice that was common a few decades ago but that most municipalities have discontinued. The most common structure today is to use separate bins for different waste types. The bins, which can be of different sizes and have interior compartments, are placed at households or drop-off points and the waste from the bin is collected and transported to the treatment centres or landfills (Dahlén & Lagerkvist, 2010).

More specifically, Sweden and Norway differ in their bin structures in the following way. The bin structures used in Sweden are: (i) separate bins (often two bins, one for general/residual waste and the other for organic waste), (ii) 4-compartment bins, i.e., four different waste streams in each bin, (iii) one bin with different waste types disposed of in different coloured plastic bags for subsequent optical sorting, and (iv) one bin for all waste types, i.e., no sorting. In Norway, the different bin structures used are: (i) separate containers, municipalities have up to five bins, each dedicated to a unique waste stream, (ii) 2-compartment bins and (iii) one bin with different waste types disposed of in different coloured plastic bags for subsequent optical sorting. While there has been a general interest in studying bin structure/collection system in past research (e.g., De Jaeger, Eyckmans, Rogge, & Van Puyenbroeck, 2011; Greco et al., 2015), the extent to which different bin structures influences the total cost of managing MSW in Sweden and Norway has not been investigated in the empirical literature.

3. Data

We collect primary data directly from the Swedish and Norwegian municipalities through an electronic survey. The data are cross-sectional and represent the year 2020. The first step of the collection process was to determine the organization responsible for the municipal waste in each municipality. In most situations, each municipality takes care of its own waste. Still, it is not unusual for municipalities to collaborate and be part of inter-municipality organisations that serve two or more municipalities. In Sweden, there are 290 municipalities, and there are a total of 262 organizations that are responsible for waste management. In Norway, there are 356 municipalities and about 200 organizations accountable for waste management.[3]

3.1 Variable definitions

The key objectives of our study are to empirically identify (i) the scale properties of waste management, and (ii) how cost is affected by municipals' choice of the bin structure. The electronic survey asks each organization responsible for MSW in Sweden and Norway for the following information: (1) the total cost incurred for the collection and handling of MSW and (2) the bin structure for each property type.

Total cost follows the definition used by the Swedish waste management association.[4] Specifically, each municipality is informed that total cost follows the Environmental Code EK21 (excluding sludge and other liquid waste), which includes:

1) Administration costs (EK8)
2) Service costs (e.g., mobile collection of waste from recycling centres) (EK1)
3) Operating costs, including personnel (EK12)
4) Costs for Incineration of residual waste including long-distance transport (EK13)
5) Costs incurred for treatment of biological waste including long distance transport (EK15)
6) Other costs that are included in the basis for the collection of waste tariffs for waste from households (EK18).

3.2 Survey

In the next step, the survey was designed and sent out to the authorized individuals of the waste management department within organizations that were responsible for waste management. Examples include the Manager or the Director of the waste management department within the organization. To obtain information about the total cost of waste management and the type of bin structure through the survey, we formulated the two questions shown below.[5]

> *Question 1: In 2020, what was the total cost (EK21)* for the municipality's waste management according to the Environmental Code excluding sludge and other liquid waste?*[6]

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[3] For further details, see Norwegian Waste Management and Recycling Association https://avfallnorge.no/about-avfall-norge.

[4] The association consists of around 400 stakeholder and trade associations in the field of waste management and recycling, e.g., municipalities, municipal corporations, and private waste management corporations. Further info: avfallsverige.se/in-english/.

[5] The questionnaire was in Swedish and Norwegian. We present here the English translation of the questionnaire.

[6] The respondents in Sweden have the prior knowledge of the environmental codes since they provide this information to Avfall Sverige on a regular basis. For Norway we use the Swedish definition when asking about cost by clearly communicating the definition. In some instances, the municipalities asked clarifying questions before they provided their financial data.

(EK21 Constitutes the sum of EK1, EK8, EK12, EK13, EK15 and EK18).
Please write the total amount in SEK:[7]

Similarly, to obtain the information on the collection system we asked the following question:

Question 2: In 2020, which bin structure did the municipality use for its collection of kerbside waste (organic and residual)? If several structures were used in parallel, write the most common one, i.e., the structure most households used. Please indicate one bin structure for each residence/business type. Use the following notation: 1) Separate bin, 2) Two bins, 3) Four-compartment bin, 4) Optical sorting, 5) Grinder to drain, 6) Other, 7) No sorting.
Choose one of the seven options above for each of the following customer types:

Detached house: ____________
Block of apartments: ____________
Restaurants: ____________
Grocery stores: ____________

Bin structure was collected per customer/property. Additionally, although the survey asked the respondents for the bin structure of Restaurants and Grocery stores, the final analysis only included information based on detached and apartment customers. We elaborate on this in the section below where the construction of the independent variables is described in detail.

3.3 The dependent and independent variables.

The dependent variable used the subsequent econometric analyses is *Cost per inhabitant*. This variable is constructed by dividing the total cost of waste management (EK21) obtained from the survey questionnaire, with the population of each municipality obtained from Statistics Sweden and Statistics Norway. Since the respondents reply to the total cost in their respective currencies, i.e., SEK for Sweden and NOK for Norway, monetary values in NOK are converted into SEK values by using the conversion 100 NOK = 97.8465 SEK.[8]

The independent variables include (1) the various bin structures used by the municipalities and (2) the population of each municipality. To perform the regression analysis, we construct the first independent variable in the following manner. From the seven types of collection systems as shown in Question 2, we arrive at five bin structures: (1) Separate bins, (2) One bin with different waste types disposed of in different coloured plastic bags (optical sorting), (3) 2-compartment bins, (4) 4-compartment bins, and

[7] When sent to municipalities in Norway, the currency was instead NOK.
[8] This was the average daily exchange rate between the two currencies in 2020.

(5) One bin, i.e. no sorting. We create one variable for each collection system. Each of the above variables take the value 0 if the municipality does not use that particular bin structure and the value 1 if the majority of customers use that bin structure. For example, if the bin structure for detached houses and apartment buildings is one bin with coloured plastic bags, then the variable for optical sorting takes the value 1 while variables for the other bin structures all take the value 0. However, in case different property types use different collection systems (e.g., 4-compartment bin for detached houses and 2-compartment bin for apartment buildings) the variables take the value that equals the ratio of the total number of residential property types (detached houses and apartment buildings) for each municipality, to the number of the specific property type. For example, the municipality of Bjuv in Sweden that has a total of 6,301 residential properties, with 4,579 detached houses (all of which have 4-compartment bins) and 1,722 residential apartments (all of which have separate bins). The variable for the separate bin for Bjuv takes the value 0.27 (1,722/6,301), the variable for the 4-compartment bin takes the value 0.72 (4,579/6,301)[9] and the variables for the other bin structures take the value 0.

3.4 Descriptive statistics.

Table 1 presents the descriptive statistics for the variables used in the analysis. From the 290 municipalities in Sweden, we obtained survey responses from 143 municipalities. From these responses, we merged information of those municipalities that collaborate with other municipalities leading to a total of 109 observations for Sweden. Similarly, for Norway, of the 356 municipalities in total, we obtained responses from 82 municipalities. From these responses, we merged information for those municipalities that collaborate with other municipalities leading to a total of 37 observations. Thus, our regression analyses presented below contain 146 observations, comprising of 109 observations from Sweden and 37 from Norway. Overall, we see a higher cost per inhabitant in Norway. We also note for Sweden, none of the municipalities that responded to our survey questionnaire used the 2-compartment bins, while for Norway, none of the municipalities that responded used the 4-compartment bin structure. However, other bin structures are rather similar in the two countries.

[9] The values are rounded to the nearest second decimal.

Table 1. Descriptive Statistics

	Mean	Std. Dev.	Min	Max
Sweden (109 Obs.)				
Cost per Inhabitant	1,092	396	453	2 685
Inhabitants	72,944	128,025	2,841	1,032,370
Ratio of separate containers	0.678	0.416	0	1
Ratio of Optical sorting	0.081	0.267	0	1
Ratio of 2-compartment container	0	0	0	0
Ratio of 4-compartment container	0.100	0.229	0	0.831
No sorting	0.101	0.303	0	1
Norway (37 Obs.)				
Cost per Inhabitant	1 602	605	980	3 793
Inhabitants	54 991	116 727	461	693 494
Ratio of separate containers	0.811	0.397	0	1
Ratio of Optical sorting	0.162	0.374	0	1
Ratio of 2-compartment container	0.135	0.347	0	1
Ratio of 4-compartment container	0	0	0	0
No sorting	0.081	0.277	0	1

In Figure 1 we present the distribution of the cost per inhabitant in the two countries. It is evident that the average cost is higher in Norway and that the right-hand tail of the cost distribution is both longer and thicker in Norway.

Figure 1. Total cost comparison between Sweden and Norway

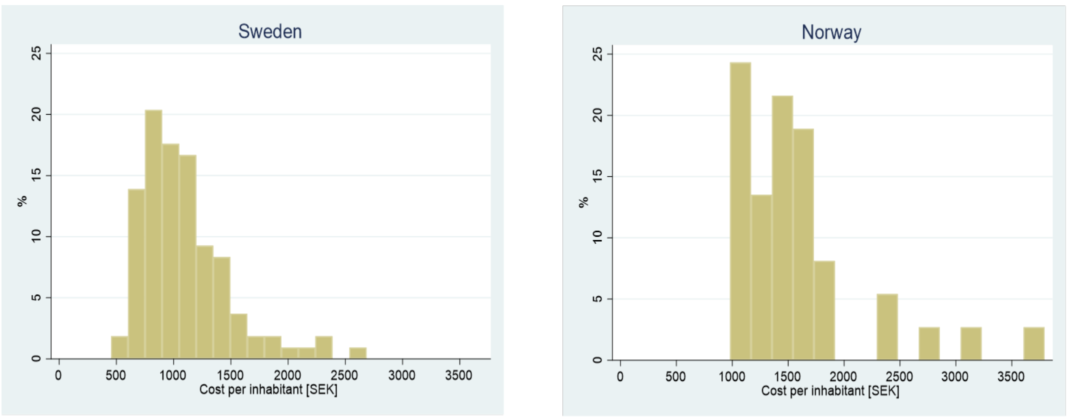
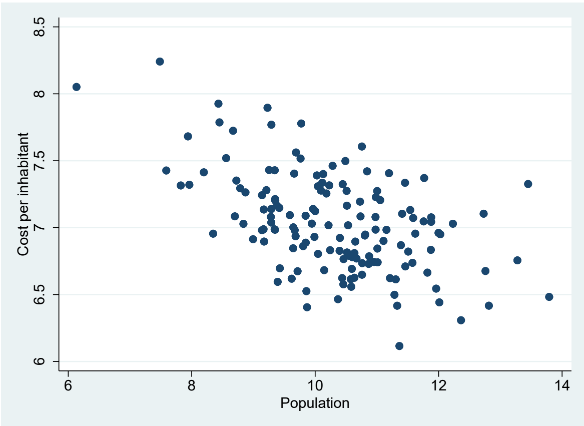


Figure 2 displays the relationship between cost per inhabitant and population (both variables are transformed by the natural logarithm). The cost seems to be higher for smaller municipalities. It also seems that the relationship is non-linear as the downward slope levels off around a population of 12. If this is the true relationship between cost and population (it can change when other factors are controlled for in the econometric estimation), then waste management is subject to diminishing economies of scale. To test the hypothesis that the scale effect is diminishing, and possibly has an optimal point that is smaller than the largest municipality, the model specification must be flexible enough to test for these aspects.

Figure 2. Relationship between cost per inhabitant and population in Sweden and Norway (n=146)



Note. Cost per inhabitant and Population are both transformed using the natural logarithm.

4. Analysis and Econometric Results

The analysis is performed in two steps. First, we identify the relationship between population and cost per inhabitant. In the second step we perform simulations to assess what the effects would be if neighbouring municipalities decide to merge their waste management services.

The first step focuses on OLS regressions where the key independent variables are linear population, squared population and share variables of bin structure. Also, an indicator variable is included to control for country effects since the two countries have different regulations, cultures, and to some extent, geography. This implies that the model of interest can be specified as:

$$\ln C_i = \beta_1 + \beta_2 \ln Pop_i + \beta_3 \ln Pop_i^2 + \beta_4 Sep_i + \beta_5 Opt_i + \beta_6 2comp_i + \beta_7 4comp_i + \beta_8 NoSort_i + \beta_8 Nor_i + \varepsilon_i \quad (1)$$

where i is municipality, C_i is cost per inhabitant as defined by EK21 cost definition, Pop is the population, Sep is ratio of households with separate bins, Opt is the ratio of households with single bin and different coloured plastic bags for different waste types, $2comp$ is the ratio of households with 2-compartment bins, $4comp$ is the ratio of households with 4-compartment bins, $NoSort$ is the ratio of households with no sorting, i.e. a single bin for all waste types. ε is the random noise and *Nor* is an indicator variable that takes the value 1 if the municipality is in Norway and 0 otherwise. Table 2 presents the coefficient estimates for the effects of the population and the bin structure on the total cost. The results are split into two groups. The first group, which consists of models (1), (2) and (3), presents estimates based on the inhabitants residing in the municipality. The second group, i.e., model (4), (5) and (6), presents estimates where population is adjusted to control for temporary visitors and individuals that commute to and from neighbouring municipalities. Models (1) and (4) include all observations, Models (2) and (5) exclude the three largest municipalities (Stockholm, Gothenburg and Oslo), and models (3) and (6) exclude the three largest municipalities and also controls for how cost is affected when all customer types have the same bin structure (*All same bin*).

Table 2. Main Results

	(1)	(2)	(3)	(4)	(5)	(6)
	Cost per inhabitant			Cost per adjusted inhabitant		
Pop	-0.64*** (0.18)	-0.64** (0.21)	-0.61** (0.22)			
Pop^2	0.02*** (0.01)	0.02** (0.01)	0.02** (0.01)			
Adj. Pop				-0.55*** (0.16)	-0.60*** (0.20)	-0.57*** (0.21)
$Adj.Pop^2$				0.02*** (0.01)	0.02** (0.01)	0.02** (0.01)
Ratio of Separate bins	0.03 (0.07)	0.02 (0.07)	0.04 (0.07)	0.11* (0.06)	0.10* (0.06)	0.11** (0.06)
Ratio of Optical bins	0.06 (0.10)	0.03 (0.10)	0.05 (0.10)	0.11 (0.08)	0.09 (0.08)	0.10 (0.08)
Ratio of 2-bins	0.19** (0.09)	0.21** (0.09)	0.21** (0.09)	0.17* (0.09)	0.18* (0.09)	0.19* (0.09)
Ratio of 4-bins	0.05 (0.13)	0.04 (0.13)	-0.17 (0.15)	0.17 (0.12)	0.15 (0.12)	-0.04 (0.16)
Norway	0.26*** (0.05)	0.25*** (0.05)	0.26*** (0.06)	0.32*** (0.05)	0.32*** (0.05)	0.32*** (0.05)
All same bin			-0.16* (0.09)			-0.14 (0.10)
Constant	10.91*** (0.91)	10.92*** (1.08)	10.97*** (1.11)	10.26*** (0.82)	10.52*** (1.01)	10.54*** (1.03)
Observations	146	143	143	142	139	139
R-squared	0.440	0.434	0.443	0.500	0.492	0.500

Standard errors in parentheses. * p<0.10; ** p<0.05; *** p<0.01

4.1 Effect of bin structure

Using model (1) as the baseline, it can be noted that the only coefficient that is significant at the 5% level is the structure that uses 2-compartment bins. The estimates suggest that compared to an unsorted system, a 2-compartment bin structure is $e^{7.12309} - e^{6.9288} \approx 219$ SEK/inhabitant more expensive.

Since all other coefficiencts are positive, the unsorted system is the cheapest, reflecting the intuitive understanding that the simplest, least environmentally friendly, structure is also the cheapest. Separate bins, optical sorting and 4-compartment bins are all similar in cost. The increase in cost that is incurred when going from an unsorted system to one of these three is around 50 kr/inhabitant.

A remark, although without obvious policy implication, is that it cost more to provide the same type of service in Norway. The effect is $e^{7.2179} - e^{7.0263} \approx 238$ SEK/inhabitant. In the table with descriptive statistics we observed that the cost in Norway was about 514 kr higher than in Sweden but in the regression we control for confounding factors, such that Norwegian municipalities are smaller on average, and that the two countries vary in their propensity to use different collection systems. This illustrates the danger of using descriptive statistics for policy analysis.

To determine the cost differential between different bin structures, we begin by selecting a preferred model in Tabel 2. Given that Models (4)-(6) have higher R2, we conclude that the adjusted population values are more appropriate. There is no noticeable different between (4)-(6) and we therefore select (4), that includes the most observations. Next, we calculate the predicted cost for an unsorted bin structure (896 SEK per inhabitant). We repeat for all the other bin structures and finally we calculate all relevant cost differentials. These results are summarized in Table 3.

Table 3 displays that moving from an unsorted collection system to a single bin with coloured plastic bags for optical sorting increases the cost by 108 SEK per inhabitant, if instead moving to separate bins, the cost increases by 104 SEK per inhabitant and moving to 4-compartment bins increases the cost by 165 SEK per inhabitant.

Similarly, the cost effect of moving from a bin structure where customers have different bin structures within a municipality, to one where all customers have the same structure is calculated. This change results in a drop by 149 SEK per inhabitant. Finally, the model (4) estimates suggest that an average inhabitant pays 344 SEK more in Norway than in Sweden.

Table 3. Change in Bin Structure on Cost

Change in Bin Structure	Change in Cost [SEK per inhabitant]
Unsorted to optical system	+ 108
Unsorted to separate bins	+ 104
Unsorted to 4-compartment bins [a]	+ 165
Same bin/collection structure for detached houses and block of apartments	- 149

Notes. [a] There is no noticeable difference between 2- and 4-compartment bins, which is why we only report result for the 4-compartment bin.

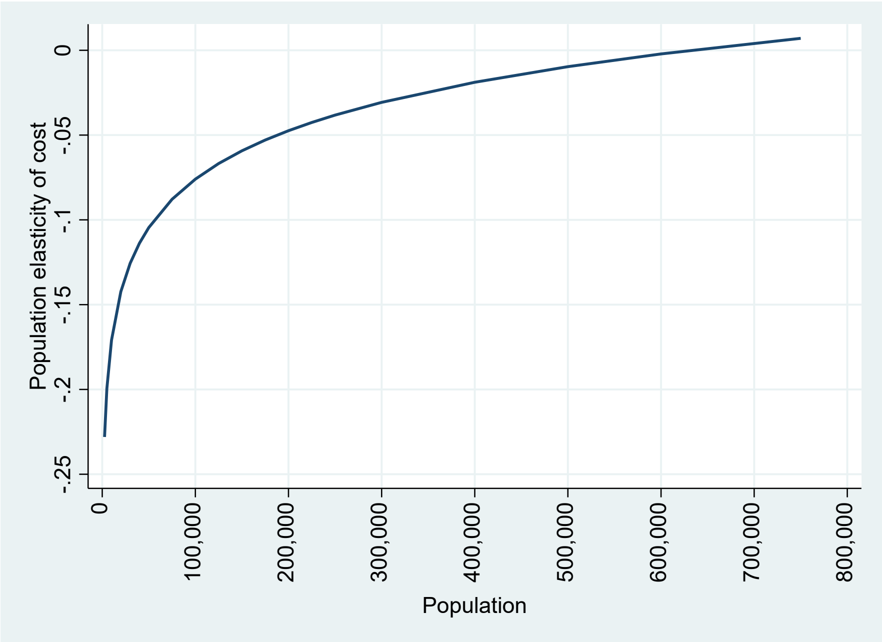
4.2 The effect of population

Comparing the effect of population across the models in Table 2 we conclude that models have similar coefficients and standard errors, at least when the dependent variable is held constant. Thus, results are not sensitive to the exclusion of the largest municipalities or the control of bin structures within municipalities. However, since $\beta_2 < 0$ and $\beta_3 > 0$ and both are significantly different from 0, it follows that waste management services in Sweden and Norway are indeed subject to economies of scale, possibly with diseconomies of scale for the municipalities in the right-hand tail of the population distribution. This is consistent with the pattern that is visible in Figure 2. Because population has a non-linear effect on cost, we calculate the population elasticity at all different levels of population by taking the first derivate of equation (1), using the estimates from model (4) in Table 3. This can be written as:

$$\frac{\partial C}{\partial Pop} = -0.550485 + 2 \times 0.020607 \times Pop$$

Based on the elasticity function, the analysis suggests that the cost per inhabitant is minimised when the number of inhabitants is somewhat above 600,000 (see Figure 3). Thus, the cost per inhabitant decreases if (1) the municipality cooperates with a neighbouring municipality, and (2) the two municipalities together have a population < 600,000. The population elasticity is less than -0.1 when the municipality has fewer than 60,000 inhabitants and less than -0.15 when the municipality has fewer than 20,000 inhabitants, indicating that the smallest municipalities can experience relatively large cost reductions if they collaborate with one or more neighbours. Thus, small municipalities can make substantial cost reductions if they collaborate with larger neighbours.

Figure 3. Population elasticity for different levels of population



4.3 Effect of municipality collaboarations

To provide an understanding of the effect of collaboration on the cost per inhabitant , three scenarios are considered, where each represent collaboration between different types of municipalities. Table 4 summarizes these results. In Scenario 1, two small municipalities in a rural region collaborate. In Scenario 2, a medium-sized city collaborates with a smaller rural municipality. In Scenario 3, a residential, suburban municipality collaborates with a large urban city. As displayed in Table 4, Scenario 1 is illustrated by estimating the savings when the municipalities Färgelanda and Munkedal collaborate. The analysis shows that when both the municipalities collaborate, the relatively smaller municipality (Färgelanda), achieves a saving of about 17% (relative to no collaboration). Similarly, in Scenario 2, the smaller rural municipality of Hylte achieves a saving of about 27% when it collaborates with the medium sized city Halmstad. Finally, in Scenario 3, the residential suburb Kungälv achieves a savings of 14% when it collaborates with the large urban city Gothenburg.

Table 4. Effect of collaborations on total cost

	Population	Cost (SEK per inhabitant)*	Savings from collaboration
Scenario 1: Two small rural municipalities			
Munkedal	10,582	1,219	8.8%
Färgelanda	6,658	1,339	17.1%
Färgelanda + Munkedal	17,240	1,110	
Scenario 2: A medium-sized city and a smaller, rural municipality			
Halmstad	102,767	893	0.8%
Hylte	10,815	1,217	27.2%
Halmstad + Hylte	113,582	886	
Scenario 3: One large and one suburban municipality:			
Göteborg	583,056	834	0%
Kungälv	47,050	967	13.7%
Göteborg + Kungälv	630,106	835	

** The cost per inhabitant is obtained from the margins for the population of the focal municipality.*

5. Discussion and Conclusions

This study investigates the impact of population size and bin structure/collection systems on municipal solid waste cost in Norway and Sweden. Data were obtained from Statistics Norway, Statistics Sweden, and through a survey, which was sent to all municipalities in the two countries. The empirical analysis shows that the waste cost per inhabitant decreasing at a diminishing rate as the population grows, with the minimum cost slightly above 600,000 inhabitants. The measure of population that is used, which controls for visitors (an increase in the relevant population) and commuters (a decrease in the relevant population), is statistically as well as economically significant. The fact that smaller municipalities have higher waste cost per inhabitant can be addressed through collaborations with neighbouring municipalities. Specifically, we find that smaller municipalities achieve the highest savings when they collaborate with medium-sized municipalities. In Sweden, policy-makers can eliminate almost all scale inefficiencies by transferring the responsibility for solid waste from the municipalities (290 in total) to the regions (20 in total).

We also find that the cost in Norway is substantially higher than in Sweden. Further research is needed to understand what is driving that cost differential. In investigating how bin structure/collection system affect cost, we find that the total cost is lowest when municipalities use unsorted bins. This is also the least sustainable option, which is why municipalities are abandoning that bin structure in favour of other structures, with the 4-compartment bin structure being particularly popular. This is important since we find that the 4-compartment bin structure tends to be the most expensive of all the bin structures. Thus, we urge the municipalities to consider separate bins and optical sorting instead.

As a final remark, this study adds a small but growing literature that investigates the drivers of municipal solid waste costs (e.g., Callan & Thomas, 2001; Dijkgraaf & Gradus, 2003; Greco et al., 2015; Lombrano, 2009; Pérez-López et al., 2016; Stevens, 1978).

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