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Productive efficiency of public and private solid waste logistics and its implications for waste management policy ☆

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ABSTRACT

This paper measures the productive efficiency of municipal solid waste (MSW) logistics by applying data envelopment analysis (DEA) to cross-sectional data of prefectures in Japan. Either through public operations or by outsourcing to private waste collection operators, prefectural governments possess the fundamental authority over waste processing operations in Japan. Therefore, we estimate a multi-input multi-output production efficiency at the prefectural level via DEA, employing several different model settings. Our data classify the MSW into household solid waste (HSW) and business solid waste (BSW) collected by both private and public operators as separate outputs, while the numbers of trucks and workers used by private and public operators are used as inputs. The results consistently show that geographical characteristics, such as the number of inhabited remote islands, are relatively more dominant factors for determining inefficiency. While the implication that a minimum efficient scale is not achieved in these small islands is in line with the literature suggesting that waste logistics has increasing returns at the municipal level, our results indicate that waste collection efficiency in Japan is well described by CRS technology at the prefectural level. The results also show that prefectures with higher private-sector participation, measured in terms of HSW collection, are more efficient, whereas a higher private–labor ratio negatively affects efficiency. We also provide evidence that prefectures with inefficient MSW logistics have a higher tendency of suffering from the illegal dumping of industrial waste.

1. Introduction

History has shown that the inevitable consequence of economic growth is increasing waste. Waste, often dubbed as the “third pollution,” requires attention similar to air or water pollution.[2] However, the waste processing industry, as well as households' decision-making processes regarding waste creation, appears to be subject to market distortions, such as hidden subsidies, ad-hoc regulations and inefficient public operations.[3] When the market fails to discipline the industry, benchmarking and measuring efficiency of behaviors by decision-making units in the industry become important. In terms of cost, waste collection is the major component of municipal solid waste processing. For example, 74.7% of the total cost is due to waste collection in the metropolitan area of Tokyo.[4]

Nonetheless, it appears that not many economists have realized the importance of waste collection because the literature on this issue is very limited. Hirsh [7] was one of the first empirical studies to concentrate on the cost of waste collection, focusing on 25 cities near Saint Louis in the US. Following Hirsh's seminal work, Stevens [6] and Dubin and Navarro [13] studied larger samples in the US and showed empirical evidence of economies of scale [13] and economies of density

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1 Tel.: +81 76 445 6455.
2 Small [11] was probably the first to dub the waste as the third pollution.

3 See Porter [10] for further discussion.
4 Ministry of the Environment of Japan (http://www.env.go.jp/recycle/waste_tech/ippan/h21/data/shori/total/05.xls). The national average of the cost share of municipal solid waste collection in Japan is 47.5%. See Banker et al. [2] for further evidence outside of Japan.

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[6]; Yamamoto [15] mostly confirmed similar cost structures for Japanese data.

While these previous papers are based on parametric analysis, this paper measures the productive efficiency of solid waste logistics in Japan by applying various data envelopment analysis (DEA) models to cross-sectional data at the prefecture level. DEA, pioneered by Farrel [4], is one of the primary methodologies in estimating multi-output multi-input production efficiency. DEA nonparametrically identifies the production possibility frontier and then measures the inefficiency of each DMU as the distance to the frontier.[5] A number of studies have adopted DEA in measuring efficiency for various industries, such as banking and transportation.[6] However, the literature on efficiency measurements in the reverse-logistics industry is limited.

The results consistently show that the set of underperforming prefectures is similar among different model settings, with Ehime being the most inefficient prefecture, closely followed by Nagasaki. Our list of underperforming prefectures indicates that small inhabited islands are overrepresented; therefore, geographical characteristics appear to be a major factor determining the efficiency of these underperforming prefectures. Ehime, for example, has 33 islands in its jurisdiction, with an average population of 525 and an average area of 2.71 km^2 per island. This production size is too small to achieve the minimum efficient scale in waste collection because, as shown by the literature, increasing-return technology is implemented at the municipal level.[7] At the same time, our results indicate that the production technology has constant returns to scale at the prefecture level.

In addition to geographic influences, our results show that prefectures with a higher private sector participation, measured in terms of household solid waste collection, are more efficient, even though the labor ratio of the private sector negatively affects the efficiency. Through a spatial econometric analysis, we also provide evidence that prefectures with inefficient MSW logistics have a higher correlation with the volume of illegal dumping of industrial waste.

This paper is organized as follows. Section 2 presents our data. Section 3 provides various DEA productive efficiency measurement results. In Section 4, we analyze the obtained results for the reverse-logistics industry in Japan. Finally, Section 5 concludes.

2. Data

In this paper, we classify solid waste into four categories. Data provided by the Ministry of the Environment of Japan categorizes municipal solid waste (MSW) into two types: namely household solid waste (HSW) and business solid waste (BSW). In addition, there are two types of operators, public and private, to collect the waste. The municipalities in Japan are responsible for taking the necessary actions to properly manage their municipal solid waste, as stipulated by Article 4 of the Waste Management and Public Cleansing Law.[8] However, a notification by the Ministry of Environment to prefectural governments states that each prefecture is responsible for supervising the entire waste-processing plan by providing adequate advice and instructions to its municipalities and ensuring that they submit solid waste processing plans and revisions when they impose or revise their plans.[9] Thus, while private waste collection operators are consigned, contracted, or licensed by a local government, they must, for example, notify the prefectural governments about waste-processing operations or obtain permission from them. Given that the prefectural government is in charge of monitoring the entire solid waste processing operation, we measure the productive efficiency of solid waste collection at the prefectural level.

Table 1
Summary statistics for original data.
Source: Ministry of Environment.

Variable	Mean	(Std. dev.)	Min.	Max.	N
Household waste (public)	229,074.4043	(440,209.5879)	1909	2,495,407	47
Household waste (private)	386,883.5319	(310,810.5789)	36,961	1,410,292	47
Business waste (public)	1310.234	(2460.9322)	0	13,260	47
Business waste (private)	225,617.1489	(253,175.9074)	35,168	1,309,818	47
Numbers of trucks (public)	290.6383	(372.0159)	19	1773	47
Numbers of trucks (private)	3483.4255	(2726.7394)	550	13,067	47
Numbers of workers (public)	608.7447	(1060.5821)	17	5319	47
Numbers of workers (private)	4617.4468	(3220.6792)	1100	14,920	47

Unit for waste: tons.

It is safe to assume that these public and private operators deal with different production technologies. For example, while private operators collect both HSW and BSW, public operators tend to concentrate on the collection of HSW. Thus, in our analysis we treat waste differently, not only according to the type of waste but also according to the type of operators who collect the waste. Our data set contains the number of trucks used as capital input and the number of workers as labor input for each public and private operator separately; the data were made available by the Ministry of the Environment of Japan. Thus, we have four outputs and four inputs to characterize the production technology of waste collection.

Our data set is a cross section of the fiscal year 2009 data made available by the Ministry of the Environment of Japan. It contains eight variables, four of which are outputs and four are inputs, as mentioned above, for all 47 prefectures in Japan.[10] Table 1 presents the summary statistics for the data.

The outputs are the volumes of HSW and BSW collected. Figs. 1 and 2 display these output data on the map of Japan. As shown on the maps, more waste is generated in more populated areas. This tendency is much more obvious for BSW in Fig. 2 because BSW mostly consists of waste from restaurants, schools and business offices, which are usually agglomerated in metropolitan areas, such as Tokyo.

The inputs are capital and labor, in terms of numbers of trucks and workers employed, measured separately for public and private operators. Fig. 3 provides two partial-factor productivity measures, namely volumes of waste processed per truck and per worker. It is clear that public and private operations use quite different production technology with stark contrasts in their partial-factor productivity. The average and standard deviations of partial-factor productivity for public and private operations are presented in Table 2, which rejects the null hypothesis of equal means for both volume per truck and volume per worker.[11] Our separate treatment of the public and private sectors stems from this observation.

As indicated by Yamamoto [15], reverse logistics production technology exhibits increasing return to scale at the municipal level but does not necessarily at the prefectural level. Subsequently, we will therefore conduct two separate DEA analyses for both cases of IRS and CRS production technology; namely, first by assuming that the production possibility set is convex without any normalization of the original data, and second, by preparing the original data to consider potential non-convexity due to increasing-return production technology.

[5] For details, see for example, Yamaguchi and Yoshida [1].
[6] Oum et al. [9] provide a comprehensive overview of the efficiency measurement literature in the transportation sector.
[7] See Yamamoto [15].
[8] See http://www.env.go.jp/en/laws/recycle/01.pdf.
[9] Published in 1977, revised in 1990. See http://www.env.go.jp/hourei/syousai.php?id=11000014.
[10] Fiscal year 2009 starts in April 2009 and ends in 2010 March.
[11] The z score is 7.67 for the volume per truck and 11.18 for the volume per worker.