ARTICLE IN PRESS

Waste Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Cost and efficiency of disaster waste disposal: A case study of the Great East Japan Earthquake

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ARTICLE INFO

Article history:
Received 16 March 2016
Revised 5 September 2016
Accepted 26 September 2016
Available online xxxx

Keywords:
Cost
Efficiency
Disaster waste
Great East Japan Earthquake
Data envelopment analysis

ABSTRACT

This paper analyzes the cost and efficiency of waste disposal associated with the Great East Japan Earthquake. The following two analyses were performed: (1) a popular parametric approach, which is an ordinary least squares (OLS) method to estimate the factors that affect the disposal costs; (2) a non-parametric approach, which is a two-stage data envelopment analysis (DEA) to analyze the efficiency of each municipality and clarify the best performance of the disaster waste management. Our results indicate that a higher recycling rate of disaster waste and a larger amount of tsunami sediments decrease the average disposal costs. Our results also indicate that area-wide management increases the average cost. In addition, the efficiency scores were observed to vary widely by municipality, and more temporary incinerators and secondary waste stocks improve the efficiency scores. However, it is likely that the radioactive contamination from the Fukushima Daiichi nuclear power station influenced the results.

1. Introduction

The major earthquake and tsunami in Japan on March 11, 2011 (Great East Japan Earthquake, hereafter) generated an enormous amount of waste such as the debris and rubble of destroyed houses, buildings, cars, and ships; this waste included tsunami sediments (UNEP, 2012). In Iwate, Miyagi, and Fukushima prefectures, where the damage was particularly extensive, the amount of waste from this disaster was 17,080 thousand tons of debris and rubble, and 10,910 thousand tons of tsunami sediments, amounting up to a total of 28,000 thousand tons (information available from the Ministry of the Environment, Japan, at http://kouikishori.env.go.jp/en/archive/h23_shinsai/). Excluding tsunami sediments, the generated debris was equivalent to the municipal solid waste generated in Iwate Prefecture for 9 years and that generated in Miyagi Prefecture for 14 years (the Tohoku Regional Environmental Office and Japan Environmental Sanitation Center, 2014). Despite this, the municipalities in the prefectures other than Fukushima Prefecture, which has been damaged by radioactive contamination from the Fukushima Daiichi nuclear power station, almost completed their waste disposal within 3 years and on schedule (information available from the Ministry of the Environment, Japan, at the above URL).

On the other hand, the disposal costs for removing the disaster waste and tsunami sediments amounted to approximately 1,150 billion yen (9.5 billion dollars[1]). This amounts to roughly 37,000 yen per ton (information available from the Ministry of the Environment, Japan, at the above URL). However, the disposal costs vary widely by municipality, as presented in the next section. Financial assessment of the waste disposal projects for the Great East Japan Earthquake would provide us with useful suggestions toward more efficient plans with respect to waste management in anticipated future disasters. However, no quantitative estimations have been conducted for financial assessment in the case of the earthquake although there are a few reports based on qualitative expectation (the Miyagi Prefectural Government, 2015). Therefore, this study analyzes the cost efficiency of disaster waste disposal quantitatively in the case of the earthquake. It uses both a parametric approach (ordinary least squares, OLS) and a non-parametric approach (data envelopment analysis, DEA) to clarify the "average" cost function and best performance of the disaster waste management.

2. Background and literature review

Brown et al. (2011) review existing studies of disaster waste disposal and point out the importance of an economic view, such

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[1] The Yen is converted into USD assuming an exchange rate of approximately 100 yen to 0.83 dollars (the average rate in 2015).

http://dx.doi.org/10.1016/j.wasman.2016.09.032
0956-053X/

Please cite this article in press as: Sasao, T. Cost and efficiency of disaster waste disposal: A case study of the Great East Japan Earthquake. Waste Management (2016), http://dx.doi.org/10.1016/j.wasman.2016.09.032

as minimizing disposal costs. In contrast, they note that there is little information about the economic effects of disaster waste management. A few exceptional surveys were conducted by Hsiao et al. (2002) and FEMA (2007). Hsiao et al. (2002) shows that the economic benefit of waste concrete recycling exceeds the cost with respect to the Chi Chi earthquake that occurred in Taiwan in September 1999. FEMA (2007) notes that debris removal operations accounted for 27% of the disaster recovery costs.

Most studies that examine costs and economic efficiency of waste management focus on municipal solid waste (hereafter, MSW) other than disaster waste. For example, Antonioli and Filippini (2002), Bohm et al. (2010), Callan and Thomas (2001), and Stevens (1978) use a parametric approach to examine the cost structure of MSW management. On the other hand, Ichinose et al. (2013), Marques et al. (2012), Nakano and Managi (2012), Rogge and De Jaeger (2012) use DEA to measure the efficiency of MSW management. Table 1 summarizes the literature review.

The advantage of OLS is that it is computationally easy and straightforward, and then it provides the best fit of the "average" cost function (Sarafidis, 2002). In other words, it reflects the "central tendency" behavior of the observations (Cooper et al., 2007).

On the other hand, the advantage of DEA compared with the parametric approach is that DEA indicates a frontier or "benchmark" corresponding to the theoretical notion of a cost function (Sarafidis, 2002). It deals with best performance and evaluates all performances by deviations from the frontier line (Cooper et al., 2007). Another advantage is that we do not have to assume a functional form of the production or cost function (Cooper et al., 2007). This enables the measurement of productivity in various fields. For example, the measurement using DEA clarifies the pros and cons of business activity and indicates the improvements for more efficient activity. Disaster waste management is no exception. It is necessary to immediately and efficiently dispose of unsorted wastes generated in large quantities, subject to limited budgets, human resources, and time. Therefore, it is very useful to apply the DEA approach to measure the efficiency of disaster waste management. However, no such studies for disaster waste have been conducted until now although some existing studies have applied the DEA approach to the waste management of municipal solid waste other than disaster waste. In addition, few studies have applied the two-stage DEA in the field of waste management (with the exception of Ichinose et al., 2013).

As for the Great East Japan Earthquake, the disposal costs vary by prefecture or municipality. For example, the average costs in Iwate and Miyagi Prefectures are 45,035 yen and 36,189 yen, respectively (per ton in both calculation by the author using data of total disposal amount and total subsidies and finance by the central government) (the Tohoku Regional Environmental Office and Japan Environmental Sanitation Center, 2014).[2] This difference seems to result in different treatment options between the prefectures as follows. In Iwate Prefecture, some burnable wastes were transported to a cement factory located in the prefecture and were utilized as a resource in cement production. In addition, it was difficult to build temporary incinerators because of the geographical characteristics of the region (less flat spaces). Therefore, the prefectural government requested other prefectures to dispose of waste, especially waste that is difficult to dispose of in their own prefecture. In contrast, Miyagi Prefecture promoted the building temporary incinerators because the amount of disaster waste was very large and it had relatively more flat spaces. Actually, the total number of temporary incinerators built in Miyagi Prefecture was 29—much larger than the two that were built in Iwate Prefecture (the Tohoku Regional Environmental Office and Japan Environmental Sanitation Center, 2014). Conversely, the rates of waste incinerated in other prefectures on the basis of the amount of burnable waste were 25% and 8% in Iwate and Miyagi Prefectures, respectively. The rates of waste landfilled in other prefectures on the basis of the amount of non-burnable waste were 57% and 33%, respectively.

In addition, the disposal costs vary widely by municipality. For example, the average costs range from 17,000 to 64,000 yen per ton for the 15 coastal municipalities in Miyagi Prefecture. According to the Miyagi Prefectural Government (2015), the reasons for varying costs among municipalities included the types of waste, the amount of waste, the demolished houses and buildings, the condition of the temporary space for waste, and the geological conditions. The report also indicated that the higher the share of incinerated waste and the lower the share of tsunami sediments, the higher the disposal costs.

Although these factors can affect the costs, the report is not based on any quantitative estimation. Moreover, no studies have examined the determinants of costs and efficiency of the disaster waste management quantitatively.

3. Methodology

3.1. Procedure of the two approaches

This paper performs the following two analyses: (1) a popular parametric approach, OLS, to estimate the factors that affect disposal costs and (2) a non-parametric approach, a two-stage DEA to analyze the efficiency of each municipality. First, for (2), the efficiency scores of each municipality were calculated by DEA. Second, tobit and OLS regressions were used to estimate the factors that affect the efficiency scores calculated by DEA.

These two approaches would clarify both the "average" cost function and best performance of the disaster waste management conducted. Fig. 1 shows the research framework.

3.2. OLS models of average cost

First, this study uses the parametric approach or OLS method to estimate the factors that affect disposal costs. The dependent variable is the average cost for disaster waste disposal. Referring to Brown et al. (2011), this study focuses on the following three factors as determinants: (1) amount; (2) composition; (3) treatment options of disaster waste. The simple regression is as follows:

$$AC_i = \alpha + \beta X_i + \gamma Y_i + \delta Z_i + e_i \quad i = 1, \ldots, N, \tag{1}$$

where AC_i is the average cost of waste disposal, X_i is the vector of the amount of disaster waste and tsunami sediments, Y_i is the vector of the composition of waste, and Z_i is the vector of the treatment options of waste in i th municipality. The components of each vector are presented in Section 4.1. β, γ, δ are estimated parameters, and e_i is the error term that includes all unobserved influences.

3.3. Two-stage DEA models

3.3.1. First stage (DEA)

In the DEA approach, we do not have to assume a functional form of the production or cost function, as in the parametric approaches. DEA models have two orientations: input oriented and output oriented (Cooper et al., 2007; Cook and Zhu, 2013). Input-oriented models minimize the inputs, while keeping the outputs at constant levels. Output-oriented models maximize the outputs, while keeping the inputs at constant levels. In the case

[2] Considering the severity and extensiveness of the damage caused by the Great East Japan Earthquake, the central government supports the prefectures and municipalities in the disaster-hit area financially (almost 100%) using subsidies and special bonds. Please refer to the following website for details: http://kouikishori.env.go.jp/en/archive/h23_shinsai/.

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