Accident Analysis and Prevention 78 (2015) 39–50

Contents lists available at ScienceDirect

Accident Analysis and Prevention

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

Evaluating the efficiency of local municipalities in providing traffic safety using the Data Envelopment Analysis

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ARTICLE INFO

Article history:
Received 12 June 2012
Received in revised form 17 February 2015
Accepted 18 February 2015
Available online 2 March 2015

Keywords:
Traffic safety
Data Envelopment Analysis
Local municipalities
Efficiency
Demographic parameters
Two-stage DEA
Undesirable outputs

ABSTRACT

The purpose of this study was to estimate the relative efficiency of 197 local municipalities in traffic safety in Israel during 2004–2009, using Data Envelopment Analysis (DEA). DEA efficiency is based on multiple inputs and multiple outputs, when their weights are unknown. We used here inputs reflecting the resources allocated to the local municipalities (such as funding), outputs include measures that reflect reductions in accidents (such as accidents per population), and intermediate variables known as safety performance indicators (SPI): measures that are theoretically linked to crash and injury reductions (such as use of safety belts). Some of the outputs are undesirable. Using DEA, the local municipalities were rank-scaled from the most efficient to the least efficient and required improvements for inefficient municipalities were calculated. We found that most of the improvements were required in two intermediate variables related to citations for traffic violations. Several DEA versions were used including a two-stage model where in the first stage the intermediate variables are the outputs, and in the second stage they are the inputs. Further analyses utilizing multiple regressions were performed to verify the effect of various demographic parameters on the efficiency of the municipalities. The demographic parameters tested for each local municipality were related to the size, age, and socio-economic level of the population. The most significant environmental variable affecting the efficiency of local municipalities in preventing road accidents is the population size of the local authority; the size has a negative effect on the efficiency. As far as we could determine, this is the first time that the DEA is used to measure the efficiency of local municipalities in improving traffic safety.

1. Introduction

This study assesses local municipalities in Israel, in terms of traffic safety performance via Data Envelopment Analysis (DEA, Charnes et al., 1978). The objective of our study was to promote efficiency in the field of traffic safety based on inputs and outputs; to identify local municipalities that have to improve their performance, to identify the improvements needed in each municipality, to rank the municipalities, and to identify the demographic factors that affect the municipalities' efficiency.

In current practices of measuring performance of local municipalities (MATAT, 2008) there is no account for the inputs of the municipalities. Thus, the efficiency scores in terms of traffic safety are typically based only on outputs, such as fatalities and accidents. The purpose of DEA is to account for both inputs and outputs in (1) measuring the efficiency of each municipality, and (2) ranking local municipalities relative to each other.

The DEA measures relative efficiency of Decision Making Units (DMUs, in our case: local municipalities), when multiple outputs are sharing multiple inputs, and their price values or weights are not given. DEA is a nonparametric approach, and its advantage in relation to the parametric approach in different contexts is well-documented (Emrouznejad et al., 2008). Basically, DEA utilizes the ratio between the weighted output and the weighted input. For each DMU, DEA finds the ideal weights that maximize its efficiency ratio. A DMU that achieves the maximal possible efficiency ratio 1 (100%) is considered as efficient, the others are considered as inefficient. Basically, DEA dichotomizes the set of DMUs into two sets – efficient and inefficient. We advocate that using DEA scores for rank-scaling DMUs is wrong, since the weights of the inputs and outputs vary from one DMU to another DMU. Thus DEA scores are not comparable to each other. Instead we use here the Cross Efficiency (CE) scores which are based on the cross evaluations that are derived from the weights of all DMUs (Doyle and Green, 1994).

Over the past two decades, DEA has become an acceptable tool for measuring the performance of non-profit institutions. The DEA model was previously implemented to evaluate the productivity of

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http://dx.doi.org/10.1016/j.aap.2015.02.014
0001-4575/

many organizations: hospitals; schools; universities; local municipalities; police forces; prisons; power companies; banks etc. However, in the field of traffic safety we were unable to find any studies that used DEA and only a few studies involving transportation (see a summary of studies in Table 1). DEA has been used to investigate target achievements of the operational units of the Norwegian Public Roads Administration (NPRA), whose responsibilities include traffic safety (Odeck, 2006), and to analyze efficiency and productivity of the Norwegian Motor Vehicle Inspection Agencies (Odeck, 2000). Another example is a practical application of DEA to the Flemish road transportation sector in Belgium (Cruijssen et al., 2006) and to EU countries (Hermans et al., 2008, 2009; Shen et al., 2012). However, none of these studies looked at the efficiency of local municipalities in improving traffic safety.

None of the studies that we could find that have compared units (local municipalities) in terms of traffic safety used DEA. Each study used a different type of Index, including for example, the Overall Safety Index (the ratio between the accident cost for one person in a municipality and the average accident cost in all the municipalities studied (MATAT, 2008), and the Safety Performance Index (Gitelman et al., 2009; Wegman et al., 2008). Another group of measures is based on rates. Because the absolute number of crashes is expected to increase over time (with increasing motorization and population), trends in road fatalities are typically measured and tracked in terms of rates of crashes and injuries. When rates are used, the number of crashes or injuries is divided by some measure of exposure, such as the size of the population. This measure gives the average risk per person (Shinar, 2007). Previous studies, have utilized the DEA to compare local municipalities in Israel but have not focused on their highway safety as performance measures (Dor, 2008; Sinuany-Stern and Friedman, 1998; Tzibel, 2009). Thus, this is the first time that DEA is used to measure the efficiency of local municipalities in improving traffic safety.

In this study, we also hypothesized that there are demographic differences among the various local municipalities, which may affect their efficiencies, invalidating the comparability among them. The factors we could consider were population size, and type of population (median age, socio-economic level etc.). Thus, in the last stage, multiple regressions were preformed to verify the effect of various demographic parameters on the efficiency. We have used CE score as the dependent variable, which is normally distributed, while traditional DEA efficiency scores are not (due to the large concentration of 1 values indicating 100% efficiency).

In our study, we used the 2004–2009 data on 2 inputs, 6 outputs and 8 intermediate variables, for 197 municipalities. We considered 4 models:

1. A Full model that includes 2 inputs and 14 outputs (including the 8 intermediate variables). This is our lead model.
2. A 2-stage DEA model – Stage 1: an Intermediate model – which contains two inputs and 8 intermediate outputs.
3. A Secondary model – Stage 2: that contains the 8 intermediate variables as inputs to the 6 final (main) outputs.
4. A Main model that only contains the two inputs and the main 6 outputs.

The intermediate variables were used in the first two models as outputs, and as inputs in the other models. In the public sector it is known that the outputs are fuzzy. Therefore, we used several versions of DEA including two stage DEA in various ways as listed above. Undesirable outputs (such as fatalities and accidents) were replaced by their reciprocals. The correlations among the various models were used as indicators of the validity of our results.

The paper is organized as follows: Section 2 outlines the DEA methodology and describes the DEA versions implemented in our study. Section 3 provides a brief description of the National Road Safety Authority (NRSA). Section 4 details the inputs, outputs, and models used in the study. Section 5 provides the results of the various models. Section 6 provides analyses of the results. In the last section, summary and conclusions are given.

2. Methodology

DEA is an ideal tool for assessing performance and accountability in the public sector in general, and of local municipalities in particular, as it allows considering multiple outputs measured in various Decision Making Units (DMUs) that share the same types of inputs. The basic DEA model – CCR was developed by Charnes et al. (1978), by utilizing the efficiency, which is defined as the ratio between the sum of the weighted outputs and the sum of the weighted inputs, when the weights are not known. For each DMU the model finds the ideal weights of each input and output that maximize its efficiency. The scale of the efficiency measure is between 0 and 1 (or 100%). If this optimal efficiency achieves the

Table 1
Past studies that compared performance of organizational units in term of traffic safety.

Year published	State	Author	Years researched	Units type	No. units	No. of variables	Main analysis
2000	Norway	Odeck	1989–1991	Motor Vehicle Inspection Agencies	67	1 input, 4 outputs	DEA, Malmquist
2006	Israel	MATAT	2004–2005	Municipalities	92	39	Overall Safety Index
2006	Norway	Odeck	1996–2000	Norwegian Public Roads Administration (NPRA)	19	No input, 3 outputs	DEA
2006	Belgium	Cruijssen	2003	Flemish road transportation companies	82	2 inputs, 2 outputs	DEA
2008	U.K.	Ren-de et al.	2003–2004	Cities	5	12	Quadratic relative evaluation methods
2008	Israel	Cohen	2006–2007	Cities	114	68	Overall Safety Index
2008	Europe	Wegman	2006	Counties	27	21	Composite Road Safety Performance Index
2008	Europe	Hermans	Based on (Safetynet, 2005)	Countries	21	7	Road safety performance indicator
2009	Europe	Hermans	Based on (Safetynet, 2005)	Countries	21	6 inputs 2 outputs	Road safety performance indicator
2009	Israel and Europe	Gitelman	2006	Counties	28	21	Composite Road Safety Performance Index
2012	Europe	Shen	2008	Countries	27	3 inputs 1 output	Road safety performance indicator