DEA-BASED BENCHMARKING MODELS IN SUPPLY CHAIN MANAGEMENT: AN APPLICATION-ORIENTED LITERATURE REVIEW

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Abstract – **Data Envelopment Analysis (DEA) is a mathematical methodology for benchmarking a group of entities in a group. The inputs of a DEA model are the resources that the entity consumes, and the outputs of the outputs are the desired outcomes generated by the entity, by using the inputs. DEA returns important benchmarking metrics, including efficiency score, reference set, and projections. While DEA has been extensively applied in supply chain management (SCM) as well as a diverse range of other fields, it is not clear what has been done in the literature in the past, especially given the domain, the model details, and the country of application. Also, it is not clear what would be an acceptable number of DMUs in comparison to existing research. This paper follows a recipe-based approach, listing the main characteristics of the DEA models for supply chain management. This way, practitioners in the field can build their own models without having to perform**

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detailed literature search. Further guidelines are also provided in the paper for practitioners, regarding the application of DEA in SCM benchmarking.

Keywords – ***Data envelopment analysis (DEA), supply chain management (SCM), survey paper***

INTRODUCTION

Supply Chain Management

Mentzer *et al.* (2001) define *supply chain* as "a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer" and identify three degrees of supply chain complexity: A *direct supply chain* consists of a company, its upstream neighbors (suppliers), and its downstream neighbors (customers, being consumers or intermediary vendors). An *extended supply chain* includes the complete chain, from the ultimate suppliers to the ultimate customers. An *ultimate supply chain* is one where all the organizations (even the financial providers and the market research firms) involved in all the upstream and downstream flows of products, services, finances, and information within the supply chain. Mentzer *et al.* (2001) define supply chain management (SCM) as "the systemic, strategic coordination of … the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole."

SCM is important because effective supply chain strategies be the most influential driving force in the growth and success of companies. One classical example is the global retail giant Walmart, which has become the largest public corporation on earth with respect to revenue (Forbes), with more than 8,500 stores in 15 countries (Daniel, 2010). At the core of Walmart's success lies crossdocking, a supply chain strategy that eliminates most of the product storage and transforms warehouses into transfer locations with minimal materials storage and material handling (Ertek, 2011).

The global logistics market grew by 7.3% in 2007 to reach a value of $805 billion. In 2012, the global logistics market was forecasted to have a value of $1,040 billion, an increase of 29.3% in only five years since 2007 (Datamonitor, 2010). Every physical product on the face of earth is produced and delivered to its ultimate customer through a supply chain, and as the global world population and the demand for physical products increases, the importance of SCM can only increase. This is an important motivation and justification for increasing academic research on SCM.

Benchmarking and DEA

The improvement of any system involves measurement of its performance in the dimensions of interest. Many performance measurement systems are designed to present reports on a set of selected performance metrics, also referred to as performance measures, performance indicators or key performance indicators (KPI). Besides internal performance measurement, it is also essential to compare the performance of the system with other systems of its kind. This comparison of a set of systems or entities with respect to each other is referred to as *benchmarking*.

Benchmarking can be carried out using qualitative and/or quantitative approaches. Ho *et al.* (2010) present a comprehensive review of quantitative methods for *multi-dimensional benchmarking* suppliers in a supply chain. The methods described in Ho *et al.* (2010) are applicable not only for supplier benchmarking, but also benchmarking other types of entities in a supply chain, such as supply chains, 3PL companies and warehouses.

Among the quantitative approaches, *Data Envelopment Analysis (DEA)* is particularly interesting and useful, due to its capability of multi-dimensional benchmarking and the usefulness of the results in generates. The popularity of DEA (Emrouznejad, 2008) makes it a viable alternative as a quantitative technique. DEA takes as model input a set of *input* and a set of *output* values for a set of entities. These entities to be benchmarked are referred to as *decision making units (DMU)*. The primary output of a DEA model is the *efficiency score* for each DMU, which takes a value between 0 and 1. Other results generated include the *reference set* and the *projections* for each DMU. An extensive discussion of the DEA concepts, models and modeling issues can be found in Cooper *et al.* (2006).

Gattoufi *et al.* (2004b) present a classification scheme for the DEA literature, based on the following criteria: (1) Data source, (2) Type of the implemented envelopment, (3) Analysis, and (4) Nature of the paper. Gattoufi *et al.* (2004a) is a comprehensive reference on the content analysis of DEA literature and its comparison with operations research and management science fields.

Research Motivation and Scope

The reviews of both Gattoufi *et al.* (2004a) and Emrouznejad (2008) cite applications of DEA within the domain of SCM. Some of these application papers, as well as others, contain review of similar papers that apply DEA for benchmarking in SCM. However, there is a significant modeling challenge for SCM practitioners who would consider using DEA: What should s/he benchmark, and what inputs and outputs should s/he select?

This practical challenge can be paused as a research question, which calls for a literature survey study:

"What has been done so far in journal papers for benchmarking in SCM using DEA?"

The goal of this paper is to list the main characteristics of the DEA models in the academic journals. This way, practitioners in the field can build their own models without having to perform detailed literature search.

The basic supply chain considered in the review will be the and the direct supply chain, as described by Mentzer *et al.* (2001), involving only three successive stages: The company in the middle, with its neighboring suppliers and customers. Throughout the paper, this will be the terminology used. Any dyadic supply chain, involving only the supplier and buyer, is considered as a subset of the direct supply chain.

The questions whose answers are investigated in this survey paper are as follows:

1) Which papers in the literature have used DEA for SCM?

2) What is the industry where the benchmarking is carried out?

3) What is the benchmarked DMU?

4) Which years does the data cover?

5) How many DMUs were included in the DEA model?

6) What is the country of application?

7) What are the inputs and the outputs in the DEA model?

8) How many inputs and outputs are used in the DEA models?

9) What is the nature of the inputs and outputs?

We believe that having the answers to the above questions will greatly facilitate the work of SCM practitioners at all managerial levels on the enterprise. The answers to the questions are provided in the tables and figures of this paper. Furthermore, the complete database constructed for the paper is made available online as a supplement spreadsheet (Ertek *et al.* 2012).

In this section, the study has been motivated and introduced, and concise literature review has been presented. In the Methodology section, the methodology applied while conducting the literature survey is described. In the Results section, the results of the literature survey are presented. Finally, in the Conclusions section, the study is concluded with a summary and remarks.

METHODOLOGY

The initial motivation for this paper was to construction of a very comprehensive list of all the DEA models applied in SCM. The process started with the definition of the table structure for the database to be constructed. However, throughout the literature search process, the database structure has been modified several times. The final version of the database, held in a spreadsheet, is v29 (Ertek *et al.*, 2012).

We decided early on that there are far too many papers related with our topic, and that we should focus only on journal papers, discarding other publication types (conference papers, thesis, etc.). While some conference papers go through a very rigorous review process before being published, we subjectively decided that on the overall, it is harder to get a journal paper published than any other publication types. We also decided that we should focus only on the recent papers, and determined the year 2000 as the lower threshold for the year of publication. The two papers before the year 2000 have been included solely because they contain the original data for the models in post-2000 papers.

The literature search advanced as three sub-processes, with many interactions in between. 1) The studies cited in the papers which were readily known by us were searched; 2) Internet search was carried out using Google Scholar online service, as well as Emerald and Ebscohost databases. The search terms were "supply chain and dea", "logistics dea", "supply logistics dea"; 3) Newer studies that cite selected papers were searched using Google Scholar and ISI Web of Science.

Among more than 1000 search results sifted through, more than 2000 were skimmed, and 86 were analyzed thoroughly. Eventually, 41 papers were included in the list of cited papers in our survey. Some of these papers used the same data set (Kleinsorge *et al.* (1992), Talluri and Sarkis

(2010), Saen (2008), Saen (2010)). These four papers (PaperID=1, 10, 27, 36) have the same DataID of 1, as shown in Table 1 under the DataID column. The inputs and outputs of the DEA models in these four papers are given in Table 5. Furthermore, two papers used not only the same data but also used the same inputs and outputs (these two papers are shown in Table1 with PaperID=24&30, and DataID=23). The inputs and outputs of these two papers are given in Table 6.

In any data-involving study, data cleaning is a very important inevitable step. After the database was populated with the collected data, a careful and rigorous data cleaning was carried out, based on the taxonomy of the dirty data by Kim *et al.* (2003).

One particular challenge in the construction of the summary table was the non-standard usage of terminology. In some of the papers (Wu and Chien, 2008; Weber, 2000; Talluri et al, 2006; Liu *et al.*, 2000; Çelebi and Bayraktar, 2008) the term "vendor" was used to refer to the suppliers that the company purchases parts/assemblies from. Therefore, the usage of the term "vendor" in these papers had to be reflected in our tables as "suppliers", since the term "vendor" in our paper refers to downstream supply chain neighbors who purchase from the company, to sell to their customers. In our database, there exists only a single paper that considers vendors as DMUs (Akçay *et al.*, 2012).

Another challenge was the inclusion of the contents of papers with more than one DEA model within. This was the case for Liang *et al.* (2006) and Akçay *et al.* (2012) (PaperID=14 and 41, respectively). For these two papers, only the first of the mentioned models was considered and populated into the database.

Finally, while populating the database, when the inputs or outputs were not clearly stated in the paper we assumed that there was only a single input of output.

RESULTS

The completed database consists of two main tables, which are PAPERS (Table 1) and INPUTS_OUTPUTS (Table 2). In both tables, missing data was shown with blank cells or cells with a "- " sign. The entry "NA" refers to "Not Applicable".

Papers and DMUs in the Models

The PAPERS table contains the fields PaperID, Year (publication year of the paper), Citation, DataID (the unique ID for the data used in the paper), IsDataReal (whether the data is from the real world or not), IsDataOpSurvey (whether the data is completely based on an opinion survey or not), Industry (the industry where the application is made), DMU, DataBegin (the beginning year for the data), DataEnd (the ending year for the data), NoOfDMUs (number of DMUs included in the model), Country1 (the country where the model was applied) and Country2 (the guessed countries as well as the known ones). PaperID is the key attribute for the table. The table, except the fields IsDataReal, IsDataOpSurvey, and Country2, is given in Table 1.

Among the papers listed in PAPERS (Table 1), those with PaperID=12, 14, 20, 33 use syntetic data, generated by the authors. For these four papers (rows in the table), the attribute IsDataReal takes the value of Syntetic. For all other papers, IsDataReal takes the value of RealWorld, meaning that the data is understood to come from the real world.

Among the papers listed in PAPERS, those with PaperID=11, 22, 35 use opinion surveys as the source of data for the inputs and outputs. For these three papers (rows in the table), the attribute IsDataOpSurvey takes the value of OpinionSurvey. For all other papers, IsDataOpSurvey takes the value of DirectData, meaning that the data is not (at least completely) based on opinions expressed in a survey.

Table 2 shows the distribution of number of models with respect to industry. Logistics is the primary industry for which DEA models are constructed. Automotive and machinery industries are also primary application areas.

Table 3 shows the distribution of number of models with respect to the DMU benchmarked. Most of the DEA models for SCM consider the suppliers as the DMUs. Benchmarking of complete supply chains ranks second with respect to popularity. Four papers, based on Kleinsorge *et al.* (1992), consider the monthly data from a single 3PL company (rather than 3PL companies) as DMUs. There are also four papers where warehouses are benchmarked.

Figure 1 shows the distribution of number of DMUs in the DEA models as a histogram. An overwhelming majority of the models benchmark up to 20 DMUs. Only six of the 41 models benchmark more than 40 DMUs. Therefore, if a DEA model for SCM includes more than 40 DMUs, it is within the top 30% of the models with respect to size.

The analysis of number of DMUs with respect to years has also been conducted, both as a scatter plot (Figure 2) and a statistical hypothesis test, namely the Spearman correlation test. As indicated by a p-value of 0.2643, there does not exist a statistically significant change through the years in the number of DMUs considered in the models.

Inputs and Outputs in the Models

The INPUTS_OUTPUTS table contains the fields PaperID, IsInputOrOutput (is the , IO_Name, IO_Type. The three fields form the key in this table. Each row refers to the information about a particular input or output in one of the models (each model is referred to with the PaperID of the paper it is in). The table is given in Table 4.

As mentioned earlier, four of these papers used the same data set, coming from Kleinsorge *et al.* (1992). The inputs and outputs for these four papers (PaperID=1, 10, 27, 36; DataID=1) are given in Table 5. Furthermore, two papers used not only the same data but also used the same inputs and outputs (PaperID=24&30; DataID=23). The inputs and outputs of these two papers are given in Table 6.

Table 7 shows the number of inputs and outputs in each of the DEA models. Table 7 provides two very important numbers, namely, the average number of inputs and outputs in the 41 models. The average number of inputs is 3.42 and the average number of outputs is 2.39. Furthermore, the median number of inputs is 3, and the median number of outputs is 2. This, we believe, is a very important guideline for practitioners. A very important shortcoming of DEA is that it rewards extreme behavior. In other words, if a DMU has a very low value for even one of its inputs, or a very high value for even one of its outputs, one can expect it to have a high efficiency score. However, the DMU may be doing very poor with respect to its other inputs or outputs. When the number of inputs or outputs is too many, the percentage of "efficient" DMUs with efficiency scores of 1 increases. The average values of 3.42 and 2.39 and the median values of 3 and 2 for the number of inputs and outputs give us a good idea of when to stop adding new inputs or outputs: A "typical" model should not have more than 3 inputs and 2 outputs. The number of inputs and outputs used in literature is a major guideline for practitioners. Due to our work, practitioners can know clearly how many inputs and outputs are typically used and can judge better if they are using too many or too few inputs and/or outputs. If there are more inputs than outputs, a practitioner can start with a DEA model with three inputs and one output. If there are less inputs than outputs, a practitioner can start with a DEA model with one input and three outputs.

Figure 3 brings even more insights into the number of inputs and outputs to select: Figure 3 shows the distribution of number of inputs and outputs in the DEA models. The most frequent selection for the number of inputs is 3. The most frequent selection for the number of outputs is 1.

The final analysis performed was the analysis of the input and output types. Table 8 shows the distribution of types of data in the inputs and outputs. Here, the inputs and outputs were categorized into one of 21 categories. Table 8 suggests that cost-related inputs are the most popular. Quality-related inputs and inputs that consider the infrastructure of the DMUs in terms of assets and/or underlying physical/managerial systems are also popular. With respect to the outputs, quality-related outputs (which were defined to include inputs related with delivery performance and service performance) are the most popular. Performance related outputs are also very popular. Other popular types of outputs are those that summarize the product quantity flowing through the DMUs and the revenue generated by the DMUs.

Selecting the papers only after 2000 has the side benefit of telling us what the important issues in SCM are: Benchmarking suppliers and the complete supply chains is an important focus in the post-2000 SCM literature. Cost is the most important focus as input. Quality is the most important focus as output, but is also popularly considered as an input. Thus, while quality is considered as the most popular output in the post-2000 academic studies (a performance goal to be reached), it is also considered as the second most input (as a given factor that affects the company performance).

CONCLUSIONS

This paper presented a detailed review of the DEA models applied in journal papers in the domain of SCM. The survey includes 41 papers published between 1992 and 2012, all but two published after 2000. Firstly, for each analyzed paper, basic information regarding the DEA model in the paper has been presented as a database table. Next, in a second and more detailed database table, information on the inputs and outputs of each model have been presented. The data has also been analyzed to obtain some critical insights on DEA modeling for the domain of SCM.

Our study provides, for the first time in literature, answers to several important questions that practitioners face as uncertainties and challenges. The answers to the questions are provided in the tables and figures of this paper. Furthermore, the complete database constructed for the paper is made available online as a supplement spreadsheet (Ertek *et al.* 2012). We believe that the results presented in the paper, as well as the detailed data in the supplement will contribute to the modeling projects of SCM practitioners at all managerial levels on the enterprise.

Supply chain practitioners in academia and industry now have a reference where they can look up and learn the different types of DEA models that have been applied in the literature for SCM. Starting with what they want to benchmark, namely, the DMU, they can observe the inputs and outputs that have been selected in the studies that use that DMU. This can speed up the model selection and construction, and also increase the reliability of the practitioners in their models, since such models have been readily used in refereed journals.

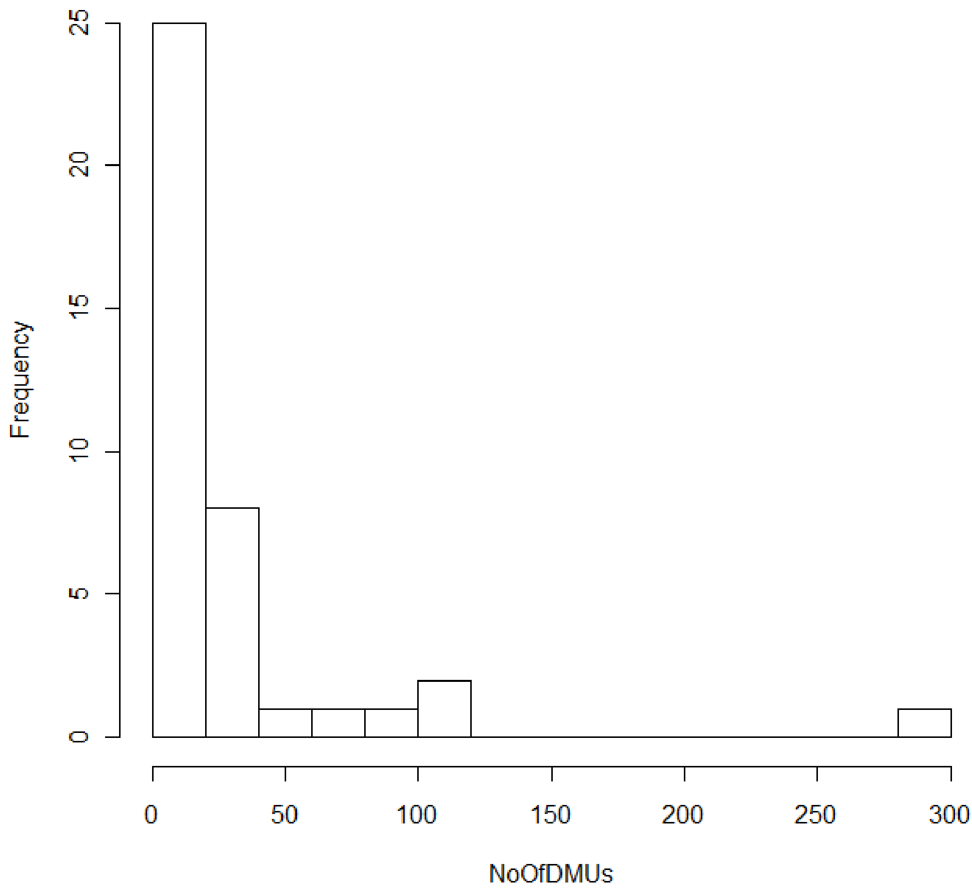

FIGURE. 1

Distribution of number of DMUs in the DEA models

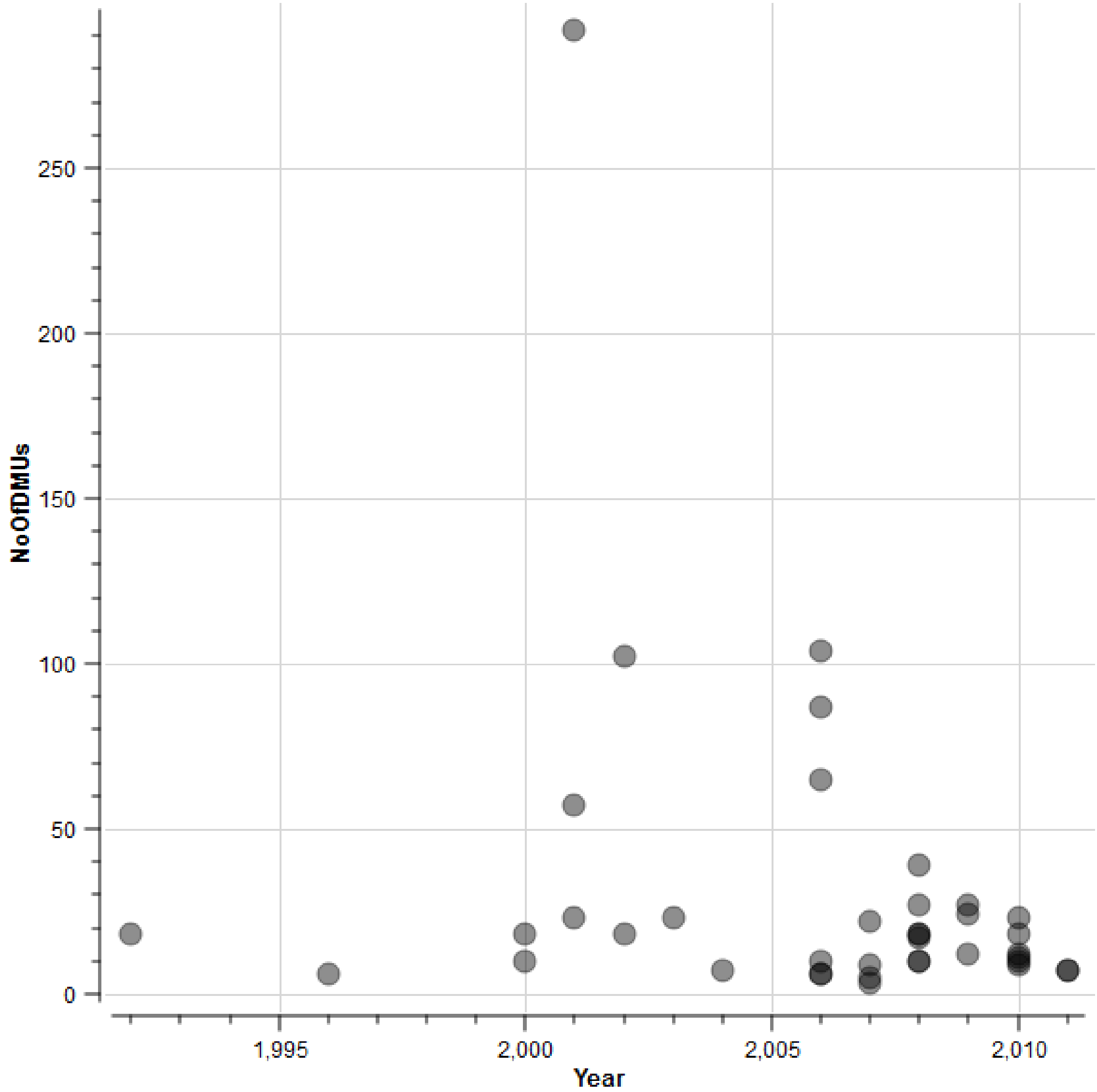

FIGURE. 2

Number of DMUs used in the DEA models over the years of publication

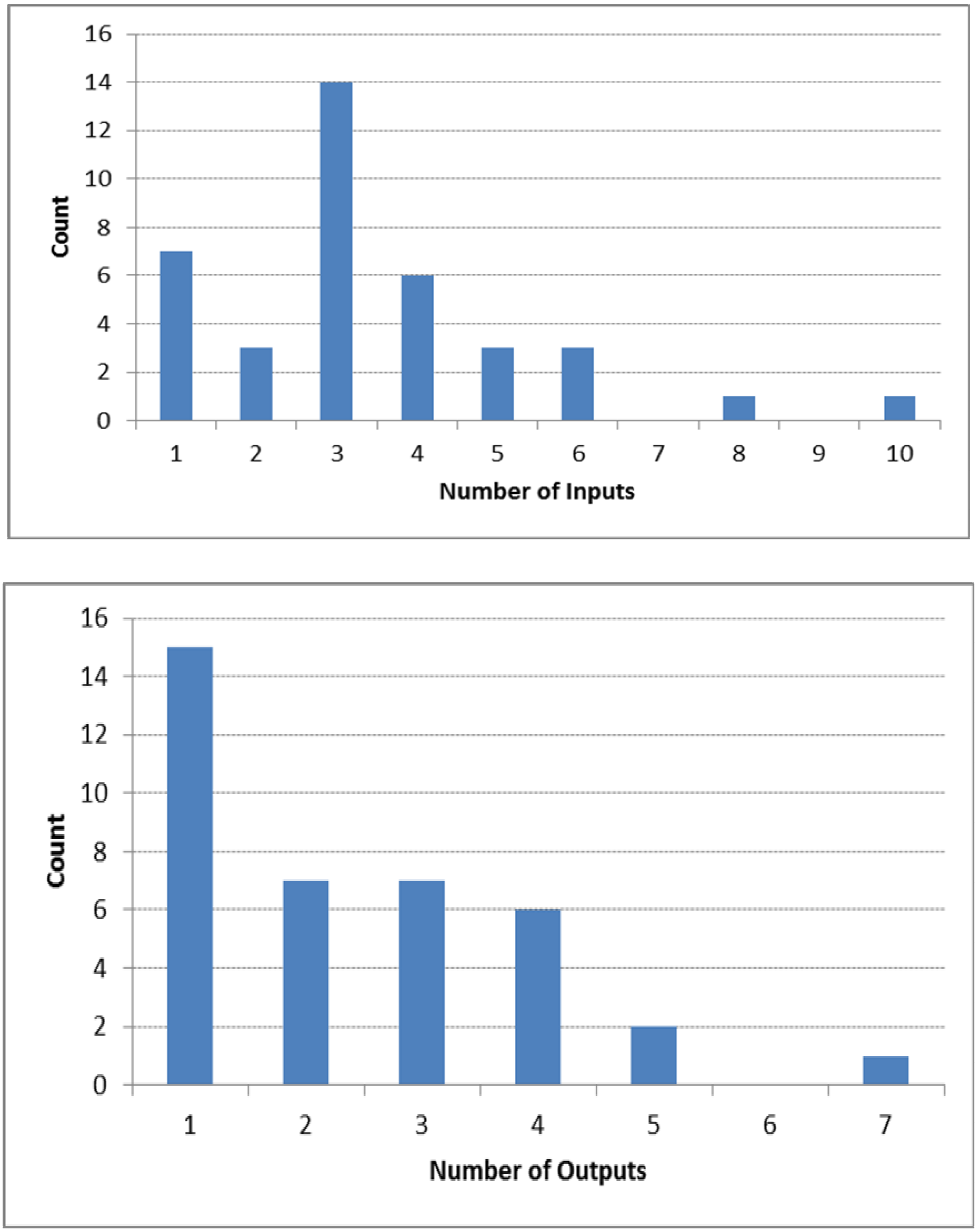

FIGURE. 3

Distribution of number of inputs and outputs in the DEA models

TABLE 1

Recent journal papers that implement DEA for benchmarking in SCM

PaperID	Year	Citation	DataID	Industry	DMU	DataBegin	DataEnd	NoOfDMUs	Country1
1	1992	Kleinsorge *et al.* (1992)	1	Logistics	3PL Company	1988	1989	18	
2	1996	Weber (1996)	2	Food	Suppliers	1996	1996	6	
3	2000	Braglia and Petroni (2000)	3	Machinery	Suppliers			10	
4	2000	Liu *et al.* (2000)	4	Machinery	Suppliers			18	
5	2000	Weber *et al.* (2000)	5	Manufacturing	Suppliers				
6	2001	Forker and Mendez (2001)	6	Electronics	Suppliers			292	North America
7	2001	Hackman *et al.* (2001)	7	Logistics	Warehouses			57	USA
8	2001	Narasimhan *et al.* (2001)	8	Telecommunications	Suppliers			23	
9	2002	Ross and Droge (2002)	9	Petroleum	Warehouses	1993	1996	102	
10	2002	Talluri and Sarkis (2010)	1	Logistics	3PL Company	1988	1989	18	
11	2003	Haas *et al.* (2003)	10	Logistics	Supply Chains			23	USA
12	2004	Ahn and Lee (2004)	11	TFT LCD Manufacturing	Suppliers			7	

13	2006	Biehl *et al.* (2006)	12	Manufacturing	Supply Chains			87	Canada
14	2006	Liang *et al.* (2006)	13	NA	Supply Chains	NA	NA	10	NA
15	2006	Min and Joo (2006)	14	Logistics	3PL Companies	1999	2002	6	USA
16	2006	Reiner and Hofmann (2006)	15	Across Industries	Processes			65	Europe and USA
17	2006	Talluri *et al.* (2006)	16	Fortune 500 Pharmaceutical Company	Suppliers			6	USA
18	2006	Wang and Cullinane (2006)	17	Logistics	Container Ports	2003	2003	104	Europe
19	2007	Akdeniz and Turgutlu (N.D.)	18	Retailing	Suppliers	2005	2005	9	Turkey
20	2007	Korpela *et al.* (2007)	19	Retailing	Warehouses			5	

TABLE 1 (continued)

Recent journal papers that implement DEA for benchmarking in SCM

PaperID	Year	Citation	DataID	Industry	DMU	DataBegin	DataEnd	NoOfDMUs	Country1	Country2
21	2007	Ramanathan (2007)	20	NA	Suppliers			3	NA	NA
22	2007	Wong and Wong (2007)	21	Semiconductor	Supply Chains			22	Malaysia	Malaysia
23	2008	Çelebi and Bayraktar (2008)	22	Automotive	Suppliers			17		Turkey
24	2008	Ha and Krishnan (2008)	23	Automotive	Suppliers			27		USA
25	2008	Koster and Balk (2008)	24	Logistics	Warehouses	2000	2004	39	Netherlands	Netherlands
26	2008	Ng (2008)	25	Machinery	Suppliers			18		Hong Kong
27	2008	Saen (2008)	1	Logistics	3PL Company	1988	1989	18		USA
28	2008	Wu and Olson (2008)	26	NA	Suppliers			10		USA
29	2008	Zhou *et al.* (2008)	27	Logistics	3PL Companies	2000	2004	10	China	China
30	2009	Ha *et al.* (2009)	23	Automotive	Suppliers			27		Korea
31	2009	Min and Joo (2009)	28	Logistics	3PL Companies	2005	2007	12	USA	USA
32	2009	Ozdemir and Temur (2009)	29	Metal	Suppliers			24	German	German

33	2010	Azadeh and Alem (2010)	30	NA	Suppliers			10		Iran
34	2010	Kang and Lee (2010)	31	Packaging	Suppliers			9		Taiwan
35	2010	Kuo *et al.* (2010)	32	Electronics	Suppliers			12	Taiwan	Taiwan
36	2010	Saen (2010)	1	Logistics	3PL Company	1988	1989	18		USA
37	2010	Sharma and Yu (2010)	33	FMCG	Processes			11		South Korea
38	2010	Tektas and Tosun (2010)	34	Food and Beverage	Supply Chains	2007	2007	23	Turkey	Turkey
39	2011	Jalalvand *et al.* (2011)	35	Broiler	Supply Chains			7	Iran	Iran
40	2011	Zeydan *et al.* (2011)	36	Automotive	Suppliers	2007	2010	7	Turkey	Turkey
41	2012	Akçay *et al.*(2012)	37	Automotive	Vendors				Turkey	Turkey

TABLE. 2

Distribution of number of models with respect to industry

Industry	Count
Logistics	11
Automotive	4
NA	4
Machinery	3
Electronics	2
Manufacturing	2
Retailing	2
Across Industries	1
Broiler	1
FMCG	1
Food	1
Food and Beverage	1
Fortune 500 Pharmaceutical Company	1
Metal	1
Packaging	1
Petroleum	1
Semiconductor	1
Telecommunications	1
TFT LCD Manufacturing	1

TABLE. 3

Distribution of number of models with respect to the DMU benchmarked

DMU	Count
Suppliers	20
Supply Chains	6
3PL Company	4
Warehouses	4
3PL Companies	3
Processes	2
Container Ports	1

TABLE 4

Inputs and outputs in the reviewed papers

PaperID	IsInputOrOutput	IO_Name	IO_Type
2	Input	price	Price
2	Input	quality	Quality
2	Input	delivery	Quality
2	Output	efficiency	Performance
3	Input	financial position	Asset
3	Input	experience	Experience
3	Input	geographical location	Geographical
3	Input	profitability	Profit
3	Input	quality	Quality
3	Input	delivery compliance	Quality
3	Output	-	NA
4	Input	the price index	Price
4	Input	delivery performance	Quality
4	Input	distance factor	Geographical
4	Output	the number of parts that a suppliers supplies	ProductVariety
4	Output	the quality of parts	Quality
5	NA	NA	NA
6	Input	role of quality department	System
6	Input	role of mangement and quality policy	System
6	Input	product/service design	System
6	Input	employee relations	Social

6	Input	quality data and reporting	System
6	Input	training	System
6	Input	process management/operating procedures	System
6	Input	supplier quality management	System
6	Output	acceptable parts per million (APPM)	Quality
7	Input	labor	Cost
7	Input	space	Asset
7	Input	equipment	Asset
7	Output	movement	Performance
7	Output	storage	Cost
7	Output	accumulation	Performance
8	Input	quality management practices and systems	System
8	Input	documentation and self-audit	System
8	Input	process/manufacturing capability	System
8	Output	quality	Quality
8	Output	price	Price
8	Output	delivery	Quality
8	Output	cost reduction performance	Performance

TABLE 4 (continued)

Inputs and outputs in the reviewed papers

PaperID	IsInputOrOutput	IO_Name	IO_Type
9	Input	fleet size	Asset
9	Input	average experience	Experience
9	Input	mean order throughput time	Time
9	Output	product HH1	ProductQuantity
9	Output	product SX2	ProductQuantity
9	Output	product SD4	ProductQuantity
9	Output	product HH4	ProductQuantity
11	Input	annual cost of collecting and disposing of the solid waste stream	Cost
11	Input	annual recycling program administrative costs	Cost
11	Input	annual recycling program education and promotion costs	Cost
11	Input	annualized capital equipment costs	Cost
11	Input	annual cost of materials and supplies	Cost
11	Input	the size of the total solid waste stream	Sustainability
11	Output	quantity recycled	Sustainability
11	Output	percent of the solid waste stream recycled	Performance
11	Output	revenue from the sale of recyclables	Revenue
11	Output	recycling incentive payments	Revenue
12	Input	-	NA
12	Output	capacity	Asset
12	Output	price advantage	Price

13	Input	cost efficiency	Attitude
13	Input	order entry procedures	Attitude
13	Input	delivery schedules	Attitude
13	Input	product/service design	Attitude
13	Input	quality monitoring/ improvement	Attitude
13	Output	the supplier's satisfaction with the performance of the relationship	Performance
13	Output	the buyer's satisfaction with the performance of the relationship	Performance
14	Input	labor	Employees
14	Input	operating cost	Cost
14	Input	shipping cost	Cost
14	Output	number of product A shipped	Shipments
14	Output	number of product A shipped	Shipments
14	Output	number of product C shipped	Shipments
15	Input	account receivables	Asset
15	Input	salaries and wages of employees	Cost
15	Input	operating expenses other than salaries and wages	Cost
15	Input	property and equipment	Asset
15	Output	the overall performance of 3PLs	Quality

TABLE 4 (continued)

Inputs and outputs in the reviewed papers

PaperID	IsInputOrOutput	IO_Name	IO_Type
16	Input	production costs	Cost
16	Input	inventory costs	Cost
16	Input	logistics costs	Cost
16	Input	number of warehousing facilities	Asset
16	Output	delivery performance to request date	Quality
16	Output	Revenue	Revenue
17	Input	Price	Price
17	Output	quality performance	Quality
17	Output	delivery performance	Quality
18	Input	terminal length	Asset
18	Input	terminal area	Asset
18	Input	equipment costs	Asset
18	Output	container throughput	ProductQuantity
19	Input	markup	Cost
19	Input	delivery	Quality
19	Input	selling history	Revenue
19	Output	purchased quantity	ProductQuantity
20	Input	direct costs	Cost
20	Input	indirect costs	Cost
20	Output	delivery time	Time

20	Output	urgent deliveries	Time
20	Output	quality	Quality
20	Output	quantity	ProductQuantity
20	Output	special requests	Quality
20	Output	frequency	Shipments
20	Output	capacity	Asset
21	Input	total cost	Cost
21	Output	AHP weight for quality	Quality
21	Output	AHP weight for technology	System
21	Output	AHP weight for service	Quality
22	Input	internal manufacturing capacity	Asset
22	Input	cycle time	Time
22	Input	cost	Cost
22	Output	Revenue	Revenue
22	Output	on-time delivery rate	Quality

TABLE 4 (continued)

Inputs and outputs in the reviewed papers

PaperID	IsInputOrOutput	IO_Name	IO_Type
23	Input	Delivery	Quality
23	Input	Price	Price
23	Input	Quality	Quality
23	Input	Service	Quality
23	Output	overall performance value	Performance
25	Input	number of direct FTE's	Employees
25	Input	size of the warehouse in square meters	Asset
25	Input	degree of automation	System
25	Input	number of different SKUs	ProductVariety
25	Output	number of daily order lines picked	ProductQuantity
25	Output	the level of value-added logistics activities carried out on a regular basis	Performance
25	Output	number of special processes carried out to optimize warehouse performance	Performance
25	Output	the percentage of error-free orders shipped	Quality
25	Output	order flexibility	Performance
26	Input	unity (1)	Dummy
26	Output	supply variety	ProductVariety
26	Output	quality	Quality
26	Output	1 / distance	Distance
26	Output	delivery	Quality

26	Output	1 / price index	Price
29	Input	net fixed assets including properties and equipment	Asset
29	Input	salaries and wages of employees	Cost
29	Input	operating expenses other than salaries and wages	Cost
29	Input	current liabilities	Cost
29	Output	the overall performance of 3PLs	Performance
31	Input	cost of sales	Cost
31	Input	selling, general and administrative costs (SG&A)	Cost
31	Input	depraciation and amortization	Cost
31	Output	revenue	Revenue
31	Output	C assets	Asset
31	Output	F assets	Asset
31	Output	O assets	Asset
32	Input	material quality	Quality
32	Input	discount on amount	Cost
32	Input	discount on cash	Cost
32	Input	payment term	Time
32	Input	delivery time	Time
32	Output	annual revenue	Revenue

TABLE 4 (continued)

Inputs and outputs in the reviewed papers

PaperID	IsInputOrOutput	IO_Name	IO_Type
33	Input	expected costs	Cost
33	Input	quality acceptance level	Quality
33	Input	on-time delivery distributions	Performance
33	Output	-	NA
34	Input	defect rate	Quality
34	Input	price	Price
34	Input	response-to-change time	Time
34	Output	on-time delivery rate	Quality
34	Output	process capability	Performance
34	Output	capacity	Asset
35	Input	quality	Quality
35	Input	cost	Cost
35	Input	delivery	Quality
35	Input	service	Quality
35	Input	environment	Sustainability
35	Input	corporate social responsibility	Social
35	Output	performance	Performance
37	Input	customer order cycle	Performance
37	Input	replenishment process cycle	Performance
37	Input	manufacturing cycle	Performance

37	Input	procurement cycle	Performance
37	Output	performance	Performance
38	Input	supply chain cost	Cost
38	Input	total inventory	Asset
38	Input	full-time employee number	Employees
38	Output	profit	Profit
38	Output	export	Revenue
39	Input	total costs	Cost
39	Output	cash-to-cash cycle time	Time
40	Input	unitary inputs for all units (dummy input)	Dummy
40	Output	quality management system audit	System
40	Output	warranty cost ratio	Quality
40	Output	defect ratio	Quality
40	Output	quality management	Quality
41	Input	spare parts area	Asset
41	Input	total expenses	Cost
41	Input	spare parts employees	Employees
41	Output	total revenue	Revenue

TABLE 5

Inputs and outputs in the papers that use the same dataset as in PaperID=1 (Kleinsorge *et al.*, 1992).

PaperID	IsInputOrOutput	IO_Name	IO_Type
1	Input	total cost	Cost
1	Input	number of shipments	Shipments
1	Output	number on time	Quality
1	Output	number of bills	Orders
1	Output	Experience	Experience
1	Output	Credence	Performance
10	Input	total cost per 100 shipments	Cost
10	Input	number of shipments	Shipments
10	Output	number of shipments arrive on time	Quality
10	Output	number of bills received from the suppliers without errors	Orders
10	Output	ratings for experience and credence	Performance
27	Input	total cost of shipment	Cost
27	Input	Price	Price
27	Input	number of shipments per month	Shipments
27	Input	Distance	Distance
27	Input	supplier reputation	Performance
27	Output	number of shipments to arrive on time	Quality
27	Output	number of bills received from the suppliers without errors	Quality
27	Output	number of parts that supplier supplies	ProductVariety
36	Input	total cost of shipments	Cost
36	Input	price	Price
36	Input	supplier reputation	Performance
36	Output	number of bills received from the suppliers without errors	Quality

TABLE 6

Inputs and outputs in the papers PaperID=24&30 (same dataset and model in both papers)

PaperID	IsInputOrOutput	IO_Name	IO_Type
24	Input	production facilities	Asset
24	Input	quality management intention	Attitude
24	Input	quality system outcome and claims	Quality
24	Input	response to claims	Quality
24	Input	on-time delivery	Quality
24	Input	organizational control	System
24	Input	business plans	System
24	Input	customer communication	Social
24	Input	internal audit	System
24	Input	data administration	System
24	Output	the factor quality system outcome	Quality
30	*		

TABLE 7

Number of inputs and outputs in the DEA models

PaperID	Input	Output	Total
1	2	4	6
2	3	1	4
3	6	1	7
4	3	2	5
6	8	1	9
7	3	3	6
8	3	4	7
9	3	4	7
10	2	3	5
11	6	4	10
12	1	2	3
13	5	2	7
14	3	3	6
15	4	1	5
16	4	2	6
17	1	2	3
18	3	1	4
19	3	1	4
20	2	7	9
21	1	3	4

22	3	2	5
23	4	1	5
24	10	1	11
25	4	5	9
26	1	5	6
27	5	3	8
29	4	1	5
31	3	4	7
32	5	1	6
33	3	1	4
34	3	3	6
35	6	1	7
36	3	1	4
37	4	1	5
38	3	2	5
39	1	1	2
40	1	4	5
41	1	3	4
Average	3.42	2.39	
Median	3	2	

TABLE. 8

Distribution of types of data in the inputs and outputs

IO_Type	Input	IO_Type	Output
Cost	35	Quality	26
Quality	18	Performance	17
Asset	16	ProductQuantity	8
System	15	Revenue	8
Performance	7	Asset	6
Price	7	Shipments	4
Attitude	6	Price	3
Time	5	ProductVariety	3
Employees	4	Time	3
Shipments	3	Orders	2
Social	3	System	2
Dummy	2	Cost	1
Experience	2	Distance	1
Geographical	2	Experience	1
Sustainability	2	Profit	1
Distance	1	Sustainability	1
ProductVariety	1	Attitude	0
Profit	1	Dummy	0
Revenue	1	Employees	0
Orders	0	Geographical	0
ProductQuantity	0	Social	0

ACKNOWLEDGMENT

The authors thank Gulcin Buyukozkan at Galatasaray University and Alp Eren Akçay at Carnegie Mellon University for their literature review on the topic, which was published in earlier paper (Akçay *et al.*, 2012) with the first author, which provided us with some of the references in the study.

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