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An Approximation to Technical Efficiency in Spanish Toll Roads through a DEA approach

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Abstract

This research has an academic approach to know the relative efficiency of toll roads managed by the Administración General del Estado through a DEA approach. The global technical efficiency, local pure technical efficiency and scale efficiency were estimated. Thus, the possible reasons why there is inefficiency and as reverse it. The great majority of toll roads are not fully effective according to the DEA approach, showing a greater global efficiency, with an increase in their return to scale, with the possibility of improvements in their efficiency levels.

Keywords: DEA; Efficiency; Highway

1. Introduction

The concession model is widely used in Spain, which has allowed a great development of its road network, ruled by two laws (1972 and 2003). According to data from the Ministerio de Fomento (2016) in Spain there are 3,307 km of toll roads under the concession model where the payment for the service is by toll or shadow toll and being operated by 21 concession companies.

It is important to know the efficiency of road concessions in order to have a better management of the infrastructure. To know the efficiency of the highways granted by the Administración General del Estado Español in this article, the Data Envelopment Analysis (DEA) will be used, with which the efficiency of the production of a unit can be estimated in a certain period of time.

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2. Efficiency Measurement

In his research, Farrell (1957), identified two components of efficiency: technical efficiency (TE) is the maximization of the product for a given set of inputs and a price efficiency that reflects the use of inputs allocated in optimal proportions, achieving an allocative efficiency (AE). When both efficiencies are achieved, an economic efficiency (EE) is generated.

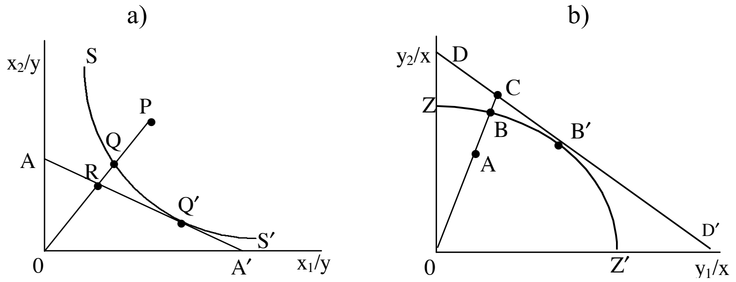

Fig. 1 – Technical and Allocative Efficiencies: a) Input-oriented measurement b) Output-oriented measurement. Source: Coelli (1996)

2.1. Input-Oriented Measurement

Coelli (1996), in his work continuing Farrell's research, mentions that the latter illustrates his ideas in a good way with a simple example of how a firm uses two inputs (X1 and X2) to produce a single product (Y), assuming the constant return of scale. Figure 1 shows the efficiency frontier represented by the curve SS'.

The point P is the number of inputs determined by a firm for a production unit. The technical inefficiency of the firm would be represented by the distance QP, which is the possible reduction in the quantity of inputs without having a reduction in the quantity of product. This can be represented with the relation QP/0P being the percentage in which all the inputs can be reduced.

The input-oriented technical efficiency (TEI) of a firm can be measured by the relationship represented in equation (1):

$$\mathbf{TE_I} = \frac{\mathbf{0Q}}{\mathbf{0P}} = \mathbf{1} - \frac{\mathbf{QP}}{\mathbf{0P}} \tag{1}$$

The numerical value of the TE will oscillate between 0 and 1, providing the efficiency level of the firm. The value of 1 means that it is completely technically efficient. Point Q of Figure 1(a) is on the efficiency frontier so it is technically efficient.

If the input price ratio is also known, which is represented by line AA' in Figure 1, the allocative efficiency can be known. The input-oriented allocative efficiency (AEI) of a firm at point P can be defined by the relationship represented in equation (2):

$$\mathbf{AE_I} = \frac{\mathbf{0R}}{\mathbf{0Q}} \tag{2}$$

where the distance RQ represents the reduction in production costs, which would occur at the point Q' in which the technical and allocative efficiency would be reached, instead of the Q point where only technical efficiency is reached. The economic efficiency input-oriented (EEI) is defined by the relationship represented in equation (3):

$$\mathbf{EE_I} = \frac{\mathbf{0R}}{\mathbf{0P}} \tag{3}$$

where the distance RP represents the reduction in costs. The product of technical efficiency and allocative efficiency is total economic efficiency, represented by equation (4):

$$\mathbf{AE_I} \times \mathbf{TE_I} = \frac{\mathbf{0R}}{\mathbf{0Q}} \times \frac{\mathbf{0Q}}{\mathbf{0P}} = \frac{\mathbf{0R}}{\mathbf{0P}} = \mathbf{EE_I} \tag{4}$$

2.2. Output-Oriented Measurement

Coelli (1996) following with Farrell's work, for the product-oriented measurement two products (Y1 and Y2) per unit of input (X) are considered, this can be represented in Figure 1(b). The curve ZZ` is the possibility of unit production and point A an inefficient firm.

The distance AB represents the technical inefficiency, this is the improvement in the production without increasing the inputs units. A measure of product-oriented technical efficiency (TEO) is the relationship, represented by equation (5):

$$TE_O = \frac{0A}{0B} \quad (5)$$

If the price is known, the line DD' can be draw and define the allocative efficiency, this is represented by equation (6):

$$AE_O = \frac{0B}{0C} \quad (6)$$

which can be interpreted as the increase in income, similar to the reduction of costs in the inefficiency of allocative input-oriented. The economic efficiency of the output (EEO) can be defined by the product of both efficiencies, as shown in equation (7).

$$AE_O \times TE_O = \frac{0B}{0C} \times \frac{0Q}{0P} = \frac{0A}{0B} = EE_O \quad (7)$$

3. Data Envelopment Analysis

For Cooper et al. (2006) the name of the DEA refers to its way of "envelops" the variables to be evaluated through a frontier that represents the performance of the entities to be evaluated. It is a non-parametric method of linear programming. The DEA takes full advantage of the data limitations and can be used to know the technical efficiency, the allocative efficiency and scale efficiency.

In the work of Charnes et al. (1978) based on Farrell's research, they introduce the term "Decision Making Unit" (DMU) as a way to envelop and evaluate a group of firms that use resources to make a product. The result of these evaluations is a performance score that oscillates between zero and one, which represents the efficiency level obtained by each assessed firm.

The firm with the highest efficiency is considered to be the most efficient in the circumstances approached, and is the reference in the evaluation of the different firms within the group. The difference between the firm with greater efficiency and those with lower efficiency is the potential for improvement under the conditions of evaluation.

3.1. Return to Scale

Cooper et al. (2006) mention that the return to scale (RTS) is the relationship between inputs and outputs when one has changed. In economic terms, reference is made to elasticity, focusing on the increase or decrease of efficiencies based on their magnitude of change.

3.1.1. CCR Model

Cooper et al. (2006) mentions the CCR model, proposed by Charnes et al. (1978), is based on constant returns to scale. It is assumed that the set of production possibilities has the property: if (x, y) is a possible point, then (tx,ty) for any positive point t is also possible. Figure 3 shows a production frontier for a single product for a single input. The result of its efficiency is known as global technical efficiency.

3.1.2. BCC Mode

Cooper et al. (2006) mentions the BCC model, proposed by Banker et al. (1984), it has its production borders in a convex curve, as can be illustrated in Fig. 3b.

In the BCC model, the frontier is variable, having a Variable Return of Scale (VRS), as show in Figure 4, the first segment of the curve shows an increasing return of scale, the second segment being a decreasing return of scale and at the point where the first and second segment of the curve joins there is a constant return of scale. The result of its efficiency is known as pure local technical efficiency.

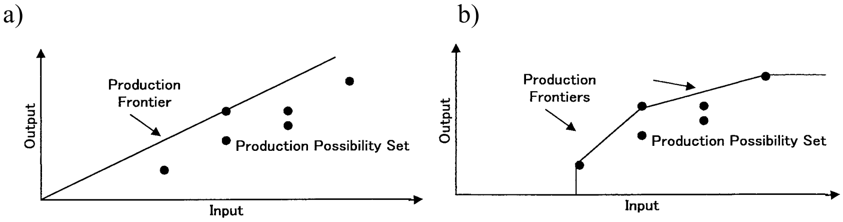

Fig. 2 - Production frontier: a) CCR Model b) BCC Model. Source:(Cooper, Seiford and Tone, 2006)

4. DEA Solver

For the realization of the DEA, the software developed by Cooper et al. (2006) in its educational version was used for this work. The DEA Solver LV software is a spreadsheet-based program designed for use with Excel 1997 or higher. The interface is visual, making it a user-friendly program. The educational version of the DEA Solver has a maximum of 50 DMU's and contains 7 basic models of DEA. Among those that are the model CCR and BCC that will be used in this work.

5. Data

To run the DEA Solver LV, the Excel file must be previous prepare with the necessary data, it must contain the DMUs to evaluate, inputs and outputs. The data for this work was obtained from the "Informe 2016 sobre el sector de autopistas de peaje en España" (Ministerio de Fomento 2016) and Boletín Oficial del Estado.

5.1. Toll Roads

There are 29 concessions of toll roads (TR) that are operated by 21 concession companies.

5.2. Data of the Toll Motorways

Table 2 shows the data used for the AED:

- ID: Toll road identifier
- TR: Toll road name
- IP: Operator income in millions of Euros during the year 2016.
- IMD: Daily average intensity of the vehicles that paid toll during the year 2016.
- TO / TC: Ratio of operation years over concession years of the toll road.
- PKm: Average prices of tolls per kilometer in Euros in force in 2016.
- CC: Cost of construction of the toll road through the average value of the budget framed in order FOM/3317/2010 in millions of Euros.
- GO: Operator expenses in millions of Euros during the year 2016.

Table 1 – Toll road data granted by the Administración General del Estado

ID	TR	IP	IMD	TO/TC	PKm	CC	GO
AP-1	Burgos - Armiñon	70.2810	18235	0.8409	0.1444	231.8250	40.1956
AP-2	Zaragoza -Mediterráneo	250.9041	11411	0.8636	0.1252	592.6250	85.6282
AP-4	Sevilla - Cádiz	58.6643	22278	0.8800	0.1215	257.9500	28.2026
AP-6	Villalba - Adanero	150.3180	23137	0.7800	0.2054	191.4000	75.1990
AP-7	Alicante - Cartagena	11.6958	6309	0.3000	0.0775	210.6500	41.9685
AP-7	Circunvalación de Alicante	4.0238	5327	0.2222	0.1274	78.3750	17.8578
AP-7	Estepona - Guadiaro	14.2789	15481	0.2692	0.1242	61.0500	11.1305
AP-7	La Jonquera -Montmeló	158.1103	41528	0.3704	0.1178	373.4500	53.9597
AP-7	Málaga-Estepona	51.4556	13940	0.3400	0.1934	330.0000	40.1098
AP-7	Montmeló - El Papiol	30.9701	109885	0.8085	0.0676	73.1500	10.5694
AP-7	Tarragona - Valencia	140.9069	15829	0.7917	0.1215	619.5750	67.7403
AP-7	Cartagena - Vera	9.6146	1987	0.2500	0.1049	313.5000	23.6899
AP-7	El Papiol - Tarragona	17.3151	46949	0.7736	0.1218	265.6500	38.3837
AP-7	Valencia - Alicante	92.8747	17091	0.7660	0.1218	408.3750	44.6491
AP-9	El Ferrol - Frontera Portuguesa	143.2520	20008	0.4533	0.1204	752.4688	83.1792
AP-36	Ocaña - La Roda	11.2197	2830	0.2778	0.1097	407.0000	14.8166
AP-41	Madrid - Toledo	3.8490	839	0.2500	0.1094	165.0000	19.1871
AP-46	Málaga - Alto de las Pedrizas	14.6755	11544	0.1111	0.1138	101.0625	16.0187
AP-51	Avila - Villacastin	9.5597	7522	0.4375	0.0771	95.2875	12.7532
AP-53	Santiago de Compostela - Santo Domingo	10.1453	5302	0.1733	0.1183	155.6500	8.0185
AP-61	Segovia - San Rafael	11.4633	6670	0.4063	0.1069	76.1750	15.2928
AP-66	León - Campomanes	40.2028	8239	0.6957	0.1596	466.5500	34.8676
AP-68	Bilbao - Zaragoza	143.4690	12342	0.6981	0.1234	1582.4000	91.1010
AP-71	León - Astorga	5.7050	3738	0.2364	0.1141	104.5000	7.7290
M-12	M-110 - M-40	15.2799	7380	0.4400	0.1872	24.2000	14.9861
R-2	Madrid - Guadalajara	10.6829	4830	0.3333	0.1284	176.2750	25.9542
R-3	M-40 - Arganda del Rey	9.1385	8537	0.2400	0.1914	91.0250	21.0162
R-4	Madrid - Ocaña	10.1553	4717	0.1846	0.1389	145.7500	10.4053
R-5	M-40 - Navalcarnero	8.0065	8674	0.2400	0.2201	79.7500	18.4130

5.3. Definition of Inputs and Outputs

The relative technical efficiency will be evaluated, due to the efficiency achieved by an evaluated production unit (TR) within a production group (29 TR) and variables used (inputs and outputs).

To perform the DEA, it must be defined the inputs to make a product. In this case two products and four inputs, the variables are labeled as Inputs with the prefix (I) and Product (O). In table 3, the inputs and products are shown.

Table 2 – Inputs and Outputs

(O)IP	(O)IMD	(I)TO/TC	(I)PKm	(I)CC	(I)GO

6. Results and Empirical Analysis

Table 5 and 6 show the results of the analysis of the CCR and BCC models, for each TR the efficiency level obtained in both models is shown. The BCC model shows the Return to Scale (RTS) indicating whether the efficiency level has Increase (I), Decrease (D) or is Constant (C). The Scale Effiency (SE) is the relationship of global technical efficiency and local technical efficiency.

6.1. Input-Oriented Efficiency

According to the results shown in Table 5, DMU No. 2, 4, 8 and 10 operate under the dimension of most productive scale. DMU No. 5, 7, 18, 19, 20, 24 and 25 have the highest level of local efficiency due to the lower use of inputs, but they are global inefficient. The RTS in the toll roads shows 25 with increase, indicating that they could have an improvement in their efficiency and 4 are constant.

Table 3 - Results-oriented DEA results

			CCR-I	BCC-I		
No.	ID	DMU	Score	Score	RTS	SE
1	AP-1	Burgos-Armiñon	0.6513	0.6954	I	0.9366
2	AP-2	Zaragoza-Mediterráneo	1.0000	1.0000	C	1.0000
3	AP-4	Sevilla-Cádiz	0.7099	0.7267	I	0.9769
4	AP-6	Villalba-Adanero	1.0000	1.0000	C	1.0000
5	AP-7	Alicante-Cartagena	0.1694	1.0000	I	0.1694
6	AP-7	Circunvalación de Alicante	0.1814	0.9597	I	0.1890
7	AP-7	Estepona-Guadiaro	0.4888	1.0000	I	0.4888
8	AP-7	La Jonquera-Montmeló	1.0000	1.0000	C	1.0000
9	AP-7	Málaga-Estepona	0.4378	0.5962	I	0.7343
10	AP-7	Montmeló- El Papiol	1.0000	1.0000	C	1.0000
11	AP-7	Tarragona-Valencia	0.7099	0.8384	I	0.8467
12	AP-7	Cartagena-Vera	0.1385	0.9211	I	0.1504
13	AP-7	El Papiol-Tarragona	0.4489	0.6346	I	0.7074
14	AP-7	Valencia-Alicante	0.7099	0.7584	I	0.9360
15	AP-9	El Ferrol-Frontera Portuguesa	0.8196	0.9255	I	0.8856
16	AP-36	Ocaña-La Roda	0.2584	0.9088	I	0.2843
17	AP-41	Madrid-Toledo	0.0685	0.9084	I	0.0754
18	AP-46	Málaga-Alto de las Pedrizas	0.8100	1.0000	I	0.8100
19	AP-51	Avila-Villacastin	0.2558	1.0000	I	0.2558
20	AP-53	Santiago de Compostela-Santo Domingo	0.4318	1.0000	I	0.4318
21	AP-61	Segovia-San Rafael	0.2978	0.9592	I	0.3105
22	AP-66	León-Campomanes	0.3935	0.5739	I	0.6857
23	AP-68	Bilbao-Zaragoza	0.6512	0.8474	I	0.7685
24	AP-71	León-Astorga	0.2519	1.0000	I	0.2519
25	M-12	M-110 - M-40	0.8706	1.0000	I	0.8706
26	R-2	Madrid-Guadalajara	0.1418	0.7461	I	0.1901
27	R-3	M-40 - Arganda del Rey	0.2741	0.8512	I	0.3220
28	R-4	Madrid-Ocaña	0.3331	0.9276	I	0.3591
29	R-5	M-40-Navalcarnero	0.2762	0.9195	I	0.3004
		Average	0.5097	0.8861		0.5840

On average, the TR in the input-orientation has an average efficiency of 50.97% for the CCR model and 88.61% for the BCC model, indicating that they only use this amount of inputs for the generation of outputs. To become efficient, they would have to reduce their inputs by 49.03% and 11.39% respectively.

6.2. Output-Oriented Efficiency

According to the results presented in Table 6, DMU No. 2, 4, 8 and 10 operate under the dimension of most productive scale. DMU No. 7, 18, 20 and 25 have the highest local efficiency due to their greater product increase, but they are inefficient globally. The RTS in the toll roads show 18 with increase, indicating that they could have an increase in efficiency and 11 are constants.

Table 4 - Output-Oriented DEA results.

			CCR-O	BCC-O		
No.	ID	DMU	Score	Score	RTS	SE
1	AP-1	Burgos-Armiñon	0.6513	0.6513	C	1.0000
2	AP-2	Zaragoza-Mediterráneo	1.0000	1.0000	C	1.0000
3	AP-4	Sevilla-Cádiz	0.7099	0.7099	C	1.0000
4	AP-6	Villalba-Adanero	1.0000	1.0000	C	1.0000
5	AP-7	Alicante-Cartagena	0.1694	0.9998	I	0.1694
6	AP-7	Circunvalación de Alicante	0.1814	0.3084	I	0.5882
7	AP-7	Estepona-Guadiaro	0.4888	1.0000	I	0.4888
8	AP-7	La Jonquera-Montmeló	1.0000	1.0000	C	1.0000
9	AP-7	Málaga-Estepona	0.4378	0.4510	I	0.9707
10	AP-7	Montmeló- El Papiol	1.0000	1.0000	C	1.0000
11	AP-7	Tarragona-Valencia	0.7099	0.7099	C	1.0000
12	AP-7	Cartagena-Vera	0.1385	0.2206	I	0.6278
13	AP-7	El Papiol-Tarragona	0.4489	0.4490	I	0.9998
14	AP-7	Valencia-Alicante	0.7099	0.7099	C	1.0000
15	AP-9	El Ferrol-Frontera Portuguesa	0.8196	0.8246	C	0.9939
16	AP-36	Ocaña-La Roda	0.2584	0.3592	I	0.7194
17	AP-41	Madrid-Toledo	0.0685	0.1010	I	0.6782
18	AP-46	Málaga-Alto de las Pedrizas	0.8100	1.0000	I	0.8100
19	AP-51	Avila-Villacastin	0.2558	0.9999	I	0.2558
20	AP-53	Santiago de Compostela-Santo Domingo	0.4318	1.0000	I	0.4318
21	AP-61	Segovia-San Rafael	0.2978	0.5120	I	0.5816
22	AP-66	León-Campomanes	0.3935	0.3935	C	1.0000
23	AP-68	Bilbao-Zaragoza	0.6512	0.6528	C	0.9975
24	AP-71	León-Astorga	0.2519	0.9999	I	0.2519
25	M-12	M-110 - M-40	0.8706	1.0000	I	0.8706
26	R-2	Madrid-Guadalajara	0.1418	0.1630	I	0.8699
27	R-3	M-40 - Arganda del Rey	0.2741	0.4177	I	0.6562

28	R-4	Madrid-Ocaña	0.3331	0.6669	I	0.4995
29	R-5	M-40-Navalcarnero	0.2762	0.4629	I	0.5967
		Average	0.5097	0.6815		0.7606

In output-orientation, the average efficiency for the CCR model is 50.97% and 68.15% in the BCC model, indicating that it is the amount of product generated with the inputs used. For TR to be efficient, they would have to increase their production by 49.03% and 31.85%.

6.3. Overall Analysis

Input-oriented tells us how inefficient toll roads can achieve full efficiency by reducing their inputs, that is, by improving their practices. Output-orientation requires adopting best practices to generate greater outputs with the same inputs. Technical inefficiency is a management problem where a certain number of products are necessary for a given number of inputs.

From the results of efficiency levels of the CCR and BCC models shown in Table 5 and 6, DMU No. 2, 4, 8 and 10 operate under the dimension of most productive scale, due to their maximum efficiency in both models, which means that they operate under constant scale conditions (CCR).

Toll roads with only local efficiency are due to their scale size. In the results, the toll roads with the maximum level of efficiency under the BCC model, operate under conditions of scale increase, which means that they can reduce the marginal cost of production in the long term. Toll roads present inefficiency of scale, due to the greater use of input generating a smaller number of outputs. Most toll roads operate under variable scale conditions (BCC).

SE shows the extent to which a toll road deviates from the optimal scale, the vast majority suffer from scale inefficiency. On average in the inputs-orientation with 41.40% of inefficiency and in its output-orientation a 23.06% of inefficiency. To achieve efficiency in toll roads, an average reduction in their inputs would be needed: 11.38% for the TO/TC, 13.88% for PKm, 23.29% for CC and 15.97% for GO.

7. Conclusions

This study is an academic exercise, since the specific data of the variables to be evaluated were not possible to obtain, the individual public data existing for each toll road or a relation by the concessionaire operator were taken. But it is a good exercise to have an approximation of the level of efficiency in the toll roads. Taking the toll roads that will be rescued by the State as reference, they are found with low levels of efficiency in comparison to the others toll roads, except for "M-110 - M-40" that presents higher levels of efficiency. This may be because this analysis shows the level of efficiency at a certain point in time, so there could be a change in efficiency levels for this toll road from its opening to this analysis.

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