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ScienceDirect
Agriculture and Agricultural Science Procedia 6 (2015) 704 – 711
Agriculture and Agricultural Science
Procedia

“ST26733”, International Conference "Agriculture for Life, Life for Agriculture"

DEA applicability in assessment of agriculture efficiency on areas with similar geographically patterns

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Abstract

Data envelopment analysis (DEA) is a non-parametric research technique based on a mathematical optimization method. Since was first developed in ’78, the method is used in various sectors of economy and at different levels (companies, counties, regions, etc.). Our purpose is to apply DEA at regional level by using various inputs and outputs to analyse the performance of agriculture practiced in plain, hill and mountain areas. Thirty-six counties were classified into three categories based on their geographical main characteristics, respectively: group I – with 50-100% plain areas (20 counties); group II - with 50-80% hill areas (8 counties); group III - with 50-80% mountain areas (8 counties). For these groups were computed, under input-oriented option, CRS and VRS technical scores from which we calculated scale efficiencies. This empirical research shows that exists clear differences of performance between areas with similar geographical characteristics in terms of production factors (work, land and mechanization) allocation and outputs. Our results show that there are only 14 counties (5 in plain areas, 5 in hill areas and 4 in mountain areas) completely achieving DEA efficiency and operate at their optimal scale. In conclusion, in majority of areas the overall efficiency of agriculture is not reached, these regions needing to decrease the input levels (especially work hours that are too high compared with productivity) or to increase the output levels (production value) through a better use of fix capital and higher yields.

Peer-review under responsibility of the University of Agronomic Sciences and Veterinary Medicine Bucharest

Keywords: agriculture; data envelopment analysis; technical efficiency; scale efficiency

1. Introduction

DEA approach is a well-known technique utilized to evaluate the efficiency for peer units compared to the best practice frontier. This method is widely used by researches to analyse the performance of agricultural sector starting

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Peer-review under responsibility of the University of Agronomic Sciences and Veterinary Medicine Bucharest
doi:10.1016/j.aaspro.2015.08.127

from different inputs and outputs. Taking in account that there is no need for a production function relation between inputs and outputs the possibilities of research are various. There are studies at regional level which analyse the production efficiency (Huang and Hu, 2006), productivity (Aldaz and Millán, 2003) (Zhou and Fawen, 2005), land use (Yuan et al, 2009) or irrigation use (Diaz et al, 2004), etc.

However, in agriculture, is very important the selection process of inputs because the outputs (production value, work productivity, etc.) depend upon these input consumption. If an area can obtain the current level of output with lower inputs then there can be assumed to be implemented a sustainable development of agriculture (Dalgaard, 2001). Also we consider that is very important to select 'units' with similar characteristics in terms of agriculture systems.

The geographical main characteristics are basic elements that imprint a pattern in the type of agriculture practiced in an area. We consider that is not entirely correct to apply a DEA analysis to areas that are so different from agricultural practice point of view, so in this paper we propose a classification of areas based on their main geographical characteristics.

2. Materials and methods

2.1. Data Envelopment Analysis

Since the DEA models were first developed, this method of converting multiple inputs into multiple outputs was used to evaluate the performance of business firms, regions, etc. and especially for modelling operational processes in performance evaluations (Cooper, 2011).

Data envelopment analyse is a non-parametric research technique, a mathematical optimization method based on a sequence of simple linear programs, used to evaluate technical efficiencies of "Decision Making Units" (DMU). DEA models can be input-oriented (objective: minimizing inputs while maintaining the same level of outputs) or output oriented (objective: increasing outputs with the same level of inputs) (Malana and Malano, 2006). Due to the specificity of agriculture sector which rely on a limited inputs, an input-orientated model is more appropriate. So our main objective was to measure efficiency under presumption that a DMU can produce the same amount of output by using a smaller quantity of inputs. Because each DMU use varying quantity of inputs to produce different levels of output, the method compare each DMU with the most efficient DMU.

For this type of analysis, in 1978 was created CCR model under the assumption of constant returns to scale (CRS) (Charnes et al., 1978) which estimates the gross efficiency of a DMU (Ramanathan, 2003) and in 1984, the researches were completed by the BCC model which takes in account the assumption of variable returns to scale (VRS) (Banker, 1984) and measures pure technical efficiency.

The models use the following notations: 'n' number of DMUs to be evaluated; each DMU have m inputs and produces s outputs; a DMU_j consumes x_{ij} of input i and produces y_{rj} of output r; λ_j - the weights assigned by the linear program, Θ - the efficiency calculated; s_i and s_r are the input and output slacks; ε is a non-Archimedean element defined to be smaller than any positive real number (Markovits-Somogyi, 2011) (Vukelić, 2013).

CRS input-orientated programming:

$$Min\,\theta + \varepsilon\left[\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+\right] \quad (1)$$

subject to:

$$\sum_{j=1}^{n} x_{ij}\lambda_j + S_i^- = \theta x_{i0}\,, i = 1,2\,\ldots, m$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - S_r^+ = y_{r0}\,, r = 1,2\,\ldots, s$$

$$\lambda_j, S_i^-, S_r^+ \geq 0, \qquad j = 1,2,\ldots,n$$

VRS input-orientated programming:

$$Min\,\theta + \varepsilon\left[\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+\right] \tag{2}$$

subject to:

$$\sum_{j=1}^{n} x_{ij}\lambda_j + S_i^- = \theta x_{i0}\,, i = 1, 2 \ldots, m$$

$$\sum_{j=1}^{n} y_{rj}\lambda_j - S_r^+ = y_{r0}\,, r = 1, 2 \ldots, s$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j, S_i^-, S_r^+ \geq 0, \qquad j = 1,2, \ldots, n$$

The CCR model permits to obtain the technical efficiency (TE) and BCC model to calculate the pure technical efficiency score (PTE). Based on these scores we can measure the scale efficiency (SE) which reflects the potential productivity that can be gained by achieving an optimum size of a DMU [1]:

$$SE = \frac{TE}{PTE} \tag{3}$$

For the analysis, we used MaxDEA 6.3 Beta free software, which permits the compilation of data under our option, respectively CRS (TE), VRS (PTE) and SE in an input-oriented model.

2.2. Data base construction

The Romanians territory comprises a particular pattern of distribution of reliefs 'forms. With the Carpathian Mountains in the middle surrounding the central area of the country, the plain areas are distributed on east, south and west counties. Based on these geographical characteristics and soil types (according to National Research and Development Institute for Soil Science, Agrochemistry and Environment Bucharest) the counties can be grouped into three categories, each of them with specific patterns for agriculture activities: (I) Plain 50-100%; (II) Hill 50-80%; (III) Mountain 50-80%. We classified and described them based on these patterns in Table 1:

Table 1. County types based on their main relief form

	Type	Share of vegetal production(%)	Intervals of share of cereals surfaces (%)	Average size of farms -ha/farm-
BR	(I)	68.2	60-65	7.63
CL		75.8	65-70	5.32
CT		74.8	65-70	11.21
GR		78.0	65-70	3.20
IF		74.2	55-60	1.92
IL		79.4	60-65	5.69
TR		76.2	65-70	4.84
BT		70.0	50-55	3.26
DJ		77.7	70-75	3.63
GL		78.2	65-70	3.60
IS		76.1	60-65	2.52
OT		76.3	75-80	3.01
TL		74.7	60-65	7.58
TM		67.2	75-80	3.45
AG		68.6	75-80	1.99
AR		74.3	70-75	6.31

	Type	Share of vegetal production(%)	Intervals of share of cereals surfaces (%)	Average size of farms -ha/farm-
BH		67.9	70-75	4.03
BZ		71.2	60-65	2.86
DB		74.1	70-75	1.60
SM		70.2	70-75	3.99
BC	(II)	62.7	65-70	1.83
CJ		60.0	60-65	3.52
GJ		64.8	85-90	2.24
MS		64.2	60-65	3.30
SB		55.3	45-50	4.79
SJ		68.0	55-60	2.96
VL		59.5	80-85	1.58
VS		64.8	65-70	3.41
AB	(III)	55.8	55-60	3.96
BN		54.4	50-55	3.62
BV		56.8	40-45	5.14
CS		61.5	60-65	6.07
CV		74.9	45-50	4.40
HD		60.1	60-65	3.97
HR		60.8	40-45	4.96
MM		53.3	40-45	2.40

Source: National Research and Development Institute for Soil Science, Agro chemistry and Environment Bucharest; National Institute of Statistics (Romania) – Tempo Online (2013)

The main characteristic of Romanian agriculture is the preponderance of vegetal production, from which the majority is assured by cereals. In hill and mountain areas, the cereals cover a smaller area but and almost 30-40% of areas are covered by fodder and meadows. The differences inside each group regarding average size of farms are very high and if we take in consideration the reduction of labor force in agriculture (Cofas, 2013) our research regarding the evaluation of the degree in which the production factors (land, work hours and mechanical assets) combination relate with the outputs (value of agricultural production) to assure performance is justified.

We constructed our database from the data offered by National Institute of Statistic -Agricultural Census Survey from 2002 and 2010. The main characteristics of variables in 2002 and 2010 are presented in table 2:

Table 2. Variables – descriptive statistics

	Land (ha)	**Work (hours)**	**Mechanical assets (number)**	**Production Value (thou RON)**
Plain areas (20 counties)				
2002				
Minimum	103206	8173550	4758	473955
Maximum	703609	29629716	30317	1804029
Mean	392291	17708039	13335	981485
Std. Deviation	131908	5387054	6714	347456
2010				
Minimum	61987	4607874	3717	485169
Maximum	660738	22694715	29317	2562624
Mean	380723	15372168	13688	1308088
Std. Deviation	126796	4548975	6615	428544
Hill areas (8 counties)				
2002				
Minimum	214486	7716270	5214	503451
Maximum	405579	22276083	13134	1386623
Mean	302258	16680596	8208	904022
Std. Deviation	78639	4655251	3181	338626
2010				
Minimum	188871	5504884	6365	547783
Maximum	374464	15602144	13884	1346958
Mean	271644	10891775	8928	834616
Std. Deviation	74119	3118526	2696	254997

	Land (ha)	Work (hours)	Mechanical assets (number)	Production Value (thou RON)
Mountain areas (8 counties)				
2002				
Minimum	171102	8760664	6795	686152
Maximum	399335	20583846	12666	836448
Mean	270469	12830222	9896	777207
Std. Deviation	66996	3773797	2024	53619
2010				
Minimum	180148	4834122	5589	546541
Maximum	381386	11745847	12659	866493
Mean	273756	7791706	9482	709049
Std. Deviation	67153	2308231	2499	122464

Source: Own calculation

3. Results and discussions

3.1. Agriculture efficiency in plain areas

The scores of total technical efficiency (CRS) of counties from plain areas are presented in Table 3. It shows that the majorities of counties (70%) had an increasing score between 2002 and 2010, and that in 2010 almost all had a score over 0.5. Actually, if we analyse the frequency of scores 'distribution for 2010 (Table 4), we can observe that 35% of counties reach an efficiency level between 0.7-0.9. There are also 45% of counties that have outstanding performance efficiency (score value of 0.9-1). If we calculate the rate of technical efficiency under variable return to scale (VRS) we can see that 25% of counties in 2010 are identified as technically efficient and operating at the best practice. The increase of efficiency can be observed from the mean values calculated which reached values higher with 6.2% for CRS and with 2.2% for VRS (Table 5).

Table 3. TE, PTE and SE scores - plain areas – 2002 and 2010

DMU	Technical Efficiency Score(CRS)	Pure Technical Efficiency Score(VRS)	Scale Efficiency Score	RTS	Technical Efficiency Score(CRS)	Pure Technical Efficiency Score(VRS)	Scale Efficiency Score	RTS	SE Variation (%)
	2002				2010				2010/2002
01	0.769937	0.774488	0.994123	IRS	0.679194	0.69029	0.983924	IRS	99.0
02	0.943549	0.965453	0.977312	IRS	0.921326	0.933324	0.987145	IRS	101.0
03	0.800576	0.802224	0.997947	IRS	0.944138	0.956391	0.987188	IRS	98.9
04	0.712728	0.727537	0.979645	IRS	0.769937	0.774488	0.994123	IRS	101.5
05	1	1	1	CRS	0.922997	0.939586	0.982344	IRS	98.2
06	0.795546	0.799078	0.99558	IRS	0.881355	0.890614	0.989603	IRS	99.4
07	0.469187	0.47346	0.990976	IRS	0.943549	0.965453	0.977312	IRS	98.6
08	0.922997	0.939586	0.982344	IRS	0.800576	0.802224	0.997947	IRS	101.6
09	0.691023	0.692119	0.998416	IRS	1	1	1	CRS	100.2
10	1	1	1	CRS	0.691023	0.692119	0.998416	IRS	99.8
11	1	1	1	CRS	1	1	1	CRS	100.0
12	0.713236	0.71808	0.993255	IRS	0.712728	0.727537	0.979645	IRS	98.6
13	0.659825	0.71364	0.924591	IRS	1	1	1	CRS	108.2
14	1	1	1	CRS	0.795546	0.799078	0.99558	IRS	99.6
15	0.679194	0.69029	0.983924	IRS	1	1	1	CRS	101.6
16	0.921326	0.933324	0.987145	IRS	0.713236	0.71808	0.993255	IRS	100.6
17	0.944138	0.956391	0.987188	IRS	0.807558	0.829071	0.974052	IRS	98.7
18	0.881355	0.890614	0.989603	IRS	0.659825	0.71364	0.924591	IRS	93.4
19	1	1	1	CRS	1	1	1	CRS	100.0
20	0.807558	0.829071	0.974052	IRS	0.469187	0.47346	0.990976	IRS	101.7

Source: Own calculation

Table 4. Efficiency distribution on score intervals in 2002 and 2010

Scores intervals	2002		2010	
	CRS TE	VRS PTE	CRS TE	VRS PTE
<0.5	10.0	5.0	5.0	5.0
0.5-0.7	25.0	20.0	15.0	10.0
0.7-0.9	15.0	25.0	35.0	40.0
0.9-1	30.0	10.0	20.0	20.0
1	20.0	40.0	25.0	25.0

Source: Own calculation

Table 5. Mean efficiency measures in 2002 and 2010

	2002	2010	Variation (%)
CRS – TE	0.787	0.836	106.2
VRS –PTE	0.827	0.845	102.2
Scale efficiency - SE	0.939	0.988	105.2

Source: Own calculation

The scale efficiency indicates that 75% of counties operate at an average of 0.988 score. This means that these counties could increase their technical efficiency by continuing to increase their inputs. Only 25% are operating at their optimal scale.

3.2. Agriculture efficiency in hill areas

The scores of total technical efficiency (CRS) of counties from hill areas (Table 6) show that the majorities of counties (62.5%) had also an increasing score between 2002 and 2010, and that in 2010 all had a score over 0.7. The frequency of scores from 2010 (Table 7) shows that 50% of counties reach an efficiency level between 0.7-0.9. There are also 50% of counties that have outstanding performance efficiency (score value of 0.9-1). The scores of efficiency under variable return to scale (VRS) prove that 37.5% of counties in 2010 are identified as technically efficient and operating at the best practice. The mean values calculate for the eight counties are higher with 3.4% for CRS and lower with 4.8% for VRS (Table 8).

Table 6. TE, PTE and SE scores - plain areas – 2002 and 2010

DMU	Technical Efficiency Score(CRS)	Pure Technical Efficiency Score(VRS)	Scale Efficiency Score	RTS	Technical Efficiency Score(CRS)	Pure Technical Efficiency Score(VRS)	Scale Efficiency Score	RTS	SE Variation (%)
	2002				2010				2010/2002
01	1	1	1	CRS	1	1	1	CRS	100.0
02	1	1	1	CRS	0.835212	0.863052	0.967743	IRS	96.8
03	0.524631	1	0.524631	IRS	0.714609	0.882601	0.809663	IRS	154.3
04	0.966262	0.984722	0.981253	DRS	1	1	1	CRS	101.9
05	1	1	1	CRS	0.900326	1	0.900326	IRS	90.0
06	0.787751	1	0.787751	IRS	0.832121	1	0.832121	IRS	105.6
07	0.634304	1	0.634304	IRS	1	1	1	CRS	157.7
08	0.887295	0.891412	0.995382	DRS	0.74873	0.748752	0.999971	IRS	100.5

Source: Own calculation.

Table 7. Efficiency distribution on score intervals in 2002 and 2010

Scores intervals	2002		2010	
	CRS TE	VRS PTE	CRS TE	VRS PTE
0.5-0.7	25.0	0	0	0
0.7-0.9	25.0	12.5	50.0	37.5
0.9-1	12.5	0	12.5	0
1	37.5	87.5	37.5	62.5

Source: Own calculation

Table 8. Mean efficiency measures in 2002 and 2010

	2002	2010	Variation (%)
CRS – TE	0.850	0.879	103.4
VRS –PTE	0.985	0.937	95.2
Scale efficiency - SE	0.865	0.939	108.5

Source: Own calculation.

The scale efficiency indicates that 62.5% of counties operate at an average of 0.939 score. The scale efficiency was increasing with 8.5% and 62.5% of the counties are operating below their optimal scale. In this situation, we can affirm that, in hill areas, 62.5% could increase their technical efficiency by continuing to increase their inputs and almost 37.5% are operating at their optimal scale.

3.3. Agriculture efficiency in mountain areas

In mountain areas, 62.5% of counties show an increasing technical efficiency (Table 9). The scores calculated under constant return to scale (CRS) show that the majorities of counties had a score over 0.6. Compared with other counties, with plain and hill forms of relief, 50% of counties from mountain areas have high efficiency (score of 0.9-1), but their number decrease face to 2002 (from 62.5%) (Table 10).

However, even if the number of efficient counties decreased, the CRS and VRS average scores increased with 6.4% and respectively 5.2 (Table 11).

The scale efficiency indicates that 50% of counties operate at optimal scale, 37.5% operate under optimal scale and 12.5% operate above their optimal scale.

Table 9. TE, PTE and SE scores - plain areas – 2002 and 2010

DMU	Technical Efficiency Score(CRS)	Pure Technical Efficiency Score(VRS)	Scale Efficiency Score	RTS	Technical Efficiency Score(CRS)	Pure Technical Efficiency Score(VRS)	Scale Efficiency Score	RTS	SE Variation (%)
		2002				2010			2010/2002
01	1	1	1	CRS	1	1	1	CRS	100.0
02	1	1	1	CRS	0.835212	0.863052	0.967743	IRS	96.8
03	0.524631	1	0.524631	IRS	0.714609	0.882601	0.809663	IRS	154.3
04	0.966262	0.984722	0.981253	DRS	1	1	1	CRS	101.9
05	1	1	1	CRS	0.900326	1	0.900326	IRS	90.0
06	0.787751	1	0.787751	IRS	0.832121	1	0.832121	IRS	105.6
07	0.634304	1	0.634304	IRS	1	1	1	CRS	157.7
08	0.887295	0.891412	0.995382	DRS	0.74873	0.748752	0.999971	IRS	100.5

Source: Own calculation

Table 10. Efficiency distribution on score intervals in 2002 and 2010

Scores intervals	2002		2010	
	CRS TE	VRS PTE	CRS TE	VRS PTE
0.5-0.7	0	0	12.5	0
0.7-0.9	37.5	25.0	37.5	37.5
0.9-1	12.5	25.0	25.0	25.0
1	50.0	50.0	25.0	37.5

Source: Own calculation

Table 11. Mean efficiency measures in 2002 and 2010

	2002	2010	Variation (%)
CRS – TE	0.864	0.919	106.4
VRS –PTE	0.911	0.958	105.2
Scale efficiency - SE	0.947	0.959	101.2

Source: Own calculation

4. Results

The presented analyse comprise the data regarding the land use, work hours and level of mechanization from 36 counties that are grouped in three categories based on their predominant form of relief. As we can see from table 12, in 2010, the most technically efficient counties (CRS and VRS) are from mountain areas (with 50-80% mountain areas and around 75% cultivated area with cereals, fodder and meadows).

Table 12. Technical and scale efficiency situation on relief groups

	Category	2002	2010
CRS TE	Plain	0.787	0.836
	Hill	0.850	0.879
	Mountain	0.864	0.919
VRS TE	Plain	0.827	0.845
	Hill	0.985	0.937
	Mountain	0.911	0.958
SE	Plain	0.939	0.988
	Hill	0.865	0.939
	Mountain	0.947	0.959

Source: Own calculation.

5. Conclusions

Our analyse shows that there are only 14 counties (5 in plain areas, 5 in hill areas and 4 in mountain areas) completely achieving DEA efficiency and operate at their optimal scale. The other counties need to change their input combination to reach a higher efficiency by decreasing especially the working hours (that are too high compared with productivity) or by increase the output levels (production value) through a better use of fix capital and higher yields. The results confirm the utility of using DEA models in the assessment of agriculture in areas with similar geographical patterns. But the method can be applied for other sectors too, like tourism or industry, due to more and more available software (like MaxDEA, DEA Frontier, PIM-DEAsoft, etc). The assessment of technical and scale efficiency at regional level remains in this way a real opportunity for future research in the field.

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