FEG WORKING PAPER SERIES
DOCUMENTOS DE TRABAJO FEG

FEG WORKING PAPERS SERIES

Documentos de trabajo de la Facultad de Ciencias Económicas y Empresariales de la Universidad de Granada

FEG-WP Nº 3/09

Performance and ownership in the governance of urban water

M. A. García-Rubio, F. González-Gómez, J. Guardiola

Performance and ownership in the governance of urban water

Miguel A. García-Rubio

magrubio@ugr.es

Francisco González-Gómez

fcojose@ugr.es

Jorge Guardiola

jguardiola@ugr.es

Department of Applied Economics, Faculty of Economics and Business, Universidad de Granada.

Contact information: Miguel A. García-Rubio. Department of Applied Economics, Faculty of Economics and Business, Universidad de Granada. Campus de Cartuja, 18011 Granada (Spain). Tel: +34-958249619

magrubio@ugr.es

Performance and ownership in the governance of urban water

Abstract

In this paper the differences in terms of performance between public and the private governance in urban water management are investigated. A statistical ranking is implemented to determine programmatic efficiency differences in DEA, using an incomplete panel data that gathers information on 20 water utilities in Andalusia, in Southern Spain. In the model, labour and operational costs are considered as inputs. The volume of revenue water, the number of connections and the network length are used as outputs. The analysis indicates that private management is more efficient. The efficiency indicators adjusted by a variable related to quality are estimated and demonstrate that privatization of the service does not mean any loss in terms of quality. However, there are no significant differences between both types of management including as a desirable input hydraulic yield as a proxy of the degree of network renovation. A lower hydraulic efficiency in private management would suggest that the need to make significant investments could be an important factor when making the decision to privatize the management of the urban water service.

Keywords: Water supply; Management; Local government.

1. Introduction

In developing nations the standards demanded of the management of the urban water service are increasing. It is not merely sufficient to guarantee the universalization of the service, as the population also demands efficient management in terms of the use of resources. Within this context, there is currently much debate as to which is the best option of ownership: public or private.

The law in some countries permits the privatization of the urban water service. Greater efficiency has usually been the main argument used to justify the privatization process, which is based on Agency Theory, Public Choice Theory, the numerous objectives dealt with by public companies, labour relationships and the process of the choosing the managing directors of the service.

There is currently no consensus regarding the superiority of a certain type of ownership over the other. Most studies have found no significant evidence between both kinds of ownership (Table 1), therefore it is not possible to draw any clear conclusion. Some of the open questions are: Is there any kind of relationship between the management option and performance that could indicate the superiority of one governance system over the other? Which governance style offers better results in terms of social interest? Is privatization a way to obtain improvements in business performance?

Table 1. Empirical evidence

Superiority of public management	Superiority of private management	Without significant differences
Mann y Mikesell[1],1976 Bruggink[2], 1982 Lambert et al.[3], 1993 Lynk[4], 1993 Hall y Lobina[5], 2002	Morgan[6], 1977 Crain y Zardkoohi[7], 1978 Raffiee et al.[8], 1993 Bhattacharyya et al.[9], 1995 Estache y Trujillo[10], 2003 Picazo-Tadeo et al., 2007[11], 2009[12]	Feigenbaum y Teeples[13], 1983 Byrnes et al.[14], 1986 Fox y Hofler[15], 1986 Teeples et al.[16], 1986 Teeples y Glyer[17], 1987 Bhattacharyya et al., 1994[18], 1995[19] Aida et al.[20], 1997 Shaoul[21], 1997 Ashton, 2000[22,23] Ménard y Saussier[24], 2000 Saal y Parker, 2000[25], 2001[26] Estache y Rossi[27], 2002 Faria et al.[28], 2005 García Sánchez[29], 2006 Kirkpatrick et al.[30], 2006 Serpa da Motta y Moreira[31], 2006 Saal et al.[32], 2007 Sabbioni[33], 2008

The questioning of privatization on the part of some authors[34, 35] is related to the nature of the industry. Some characteristics of the industry can be highlighted: Firstly, it is structured in local monopolies. Secondly, it is extremely difficult to notice the positive effects of the competition that should come into existence after privatization. Thirdly, the regulatory framework in each country is very important in order to achieve efficient performance in a non-competitive environment. Some measures such as benchmarking and public tenders to grant licences are not perfect substitutes for a competitive environment. The different benchmarking laws and regulatory frameworks from one country to another makes searching for evidence in each country an interesting task.

In this study, the nonparametric data envelopment analysis (DEA) methodology is applied to a sample of 20 companies from Andalusia in Southern Spain over the period 1993-2006. Spain can be considered an excellent case in order to carry out studies concerning the governance of the urban water sector, as it is one of the few countries that grant local governments the possibility to choose between several types styles of governance. Nowadays, in this industry there are both public and private companies as a result of municipal autonomy. Public companies supply water services to 47 per cent of the population and private companies provide this service to 52 per cent of the population[36].

The DEA technique is adapted to programmatic efficiency estimation. Additionally, through the specification of several DEA models, the effect of both quality and of the degree of network renovation is evaluated, in order to check if these factors modify the level of efficiency in public and private programs. One specific contribution of this

paper to the literature on the subject is the fact that it obtains performance measurements that can be interpreted as efficiency in the reduction of costs which must be taken into account in order to maintain a sufficiently renovated network. Water utilities manage a basic need service, therefore their efficiency is of interest to companies, but society as a whole is also interested. From an environmental point of view, an obsolete network demands a greater exploitation of hydric resources.

The rest of the article is structured as follows: The second section describes the DEA model and the methodology used to estimate the programmatic efficiency. The third section shows the data and the variables as well as the specified DEA models used in the research. The fourth section provides the results of the analysis, and in the last section the conclusions are drawn.

2. Methodology

Data envelopment analysis (DEA) is a technique based on mathematical programming. A technological frontier representing the best practices is designed using the inputs and outputs from a sample of companies by comparing the position of each company in relation to that frontier in terms of a performance index. Therefore, efficiency is a relative concept.

The measurement of efficiency in the DEA requires two steps: firstly, to determine the characteristics of the technology and the estimation of the technological frontier. Secondly, to implement the comparison in terms of a performance index of each productive unit of the sample in relation to the technological frontier. In this paper, it is assumed that the technology achieves the following axioms: no free lunch, impossibility of free production, strong free disposability of inputs and outputs, convexity and variable returns to scale. The estimation is performed by using an input-oriented radial efficiency index, which represents the maximum possible equiproportional reduction in the input vector of inputs, while leaving constant the output vector. Therefore, a DEA-BCC[37] input-oriented envelopment model is used.

One complexity of this method is that multiple optimal solutions can be obtained if the sample contains weak units in terms of efficiency –with radial efficiency indexes equal to one but slacks different to zero. In this particular case, the DEA-BCC basic model can fail to identify every slack, therefore justifying the calculation of a two stage process model[38]. This consists of the estimation of the efficiency indexes ignoring the slacks in the first stage, and afterwards the slacks are optimized from the previous efficiency results.

Programmatic efficiency estimation is proposed in a seminal study in DEA literature[39]. The objective of this focus is to distinguish between two kinds of efficiency: managerial efficiency, which is a result of the management of an individual service provider, and programmatic efficiency, which is related to different productive programs. In the literature about urban water supply, some productive programs have been considered: large and small scale water suppliers[20], different geographical areas[20], estimation of the effect of the institutional reforms[40] or public and private management[29].

The estimation of managerial efficiency assumes that every unit analyzed has the same best practices frontier. Its estimation requires the implementation of DEA analysis to all of the sample units. In programmatic efficiency estimation this assumption is relaxed, as it is understood that every productive program has a different frontier. Therefore, the first step consists of the division of the sample into two groups and the implementation of the DEA model to each of them. Subsequently, in each group, the original data is modified projecting the inefficient units over their own frontier, therefore deleting the intra-program differences. Lastly, applying the DEA model to the sample of modified data, the potential inter-program differences or programmatic efficiency are obtained.

The Mann-Whitney[41] rank test makes it possible to check the following null hypothesis (H_0): both programs have the same distribution in terms of efficiency values. If this hypothesis is rejected, then there will be differences in efficiency between both productive programs, and one will be superior to the other.

3. Data, variables and model specification

The dataset used in this study consists of an incomplete panel data containing 20 water companies in Andalusia, in Southern Spain, over the period 1993-2006. When the companies decide to modify their tariffs they have to send the tariff revision file to a regulatory body known as the Andalusian Price Comission. The information for this dataset has been obtained from the direct examination of these files. Table 2 shows the descriptive statistics of the variables used in this study.

Table 2. Sample description

VARIABLE	MEASUREMENT UNIT	MEAN	STANDARD DEVIATION	MAXIMUM	MINIMUM
Inputs					
Labour costs	Thousands of euros	5 372.59	5 557.73	23 671.91	721.50
Operational costs	Thousands of euros	4 528.89	4 714.91	22 734.39	837.76
Desirable inputs					
Hydraulic yield	Percentage	62.63	7.69	77.76	44.47
Outputs					
Water delivery	Thousands of m^3	15 769.34	16 742.16	71 354	3 160
Connections	Number of connections	75 077.79	55 391.23	270 920	23 864
Delivery network	Kilometres	624.39	695.79	3 130	96
Quality	Number of parameters	3 367.07	1 414.84	7 640	1 034

The estimation of the best practice frontier using DEA could cause a problem in terms of lack of degrees of freedom when the number of variables is quite high in relation to the number of observations. This drawback means that most of the efficiency estimations obtained have a value equal to one, because each unit of analysis is compared to itself. In order to avoid this, it is possible to treat each unit as a distinct comparative entity in each unit of time, following the proposal made by García-Valiñas and Muñiz[42]. However, this approach requires a relatively stable level of technology over a period of time[43]. Following the Färe, Grosskopf, Lindgren and Roos procedure

(FGLR)[44], an input based Malmquist productivity index has been estimated, finding a low rate of technological improvement in the sector – 0.064% per annum on average over the period of analysis-.

In the sector considered in this study, the importance of environmental factors is recognized[45]. Representing the output of a water supply service only through the volume of water delivery could be inadequate. In the literature on the subject, the existence of economies of customer density[46,47] and economies of production density[48,49] are identified as important in the sector.

A network-dependent industry that is more efficient when increasing its production to satisfy the demand from new customers, leaving its network size unchanged, is exploiting economies of customer density. The geographical distribution of the population supplied is not a variable that can be controlled by the company. The non-consideration of the unequal population density among companies could penalize those that supply area with lower population density. However, this cannot be understood as a less efficient performance. Thanassoulis[43] solves this problem by including as an output the network length variable, which is the same approach followed in this research.

There are economies of production density when as production increases for a given network size and a given number of customers, the average variable costs decrease. The water consumed by each user is a variable which is not controlled by the company. Nevertheless, it could be expected that a company would incur higher costs when it supplies the service to many small scale consumers rather than a few large scale ones. To take this into account, the number of connections is included as an output.

Regarding the specification of the models used in this study, the basic DEA is implemented. Table 3 shows the different models specified in the present research.

Table 3. DEA models

VARIABLE	DEA1	DEA2	DEA3	DEA4
Inputs				
Labour costs	X	X	X	X
Operational costs	X	X	X	X
Desirable inputs				
Hydraulic yield			X	X
Outputs				
Water delivery	X	X	X	X
Connections	X	X	X	X
Delivery network	X	X	X	X
Quality		X		X

The so-called DEA1 model uses as outputs the volume of water delivery, the network length and the number of connections. The volume of water delivery is the most frequently used output variable in efficiency analysis in the sector. The other two variables are included to consider the aforementioned environmental factors. Therefore,

with this model, the net efficiency measurements of the effect of the economies of customer density and economies of production density are obtained. As for the included inputs, these are the labour costs and other operational costs. Therefore, the Thanassoulis approach[43] is followed, which adapts the DEA method in order to estimate the potential cost savings in water distribution. From this basic model, the additional variables are included.

The DEA2 model includes an additional output variable related to quality. In the analysis within this industry it is important to consider the quality of the service supplied. Some diverse variables are used in the literature in order to account for quality: number of interruptions in supply[40], water losses[47], number of hours of daily supply[30], coverage of the service or population served[50], number of analyses of water sanitation control[29], etc. In this research, the number of parameters identified in water analysis -organoleptics, physical-chemical and microbiological- are used as a proxy for quality. In the literature, two different focuses are applied to consider quality: On the one hand, quality is included in a second stage analysis, normally a Tobit regression, using as a dependent variable the results obtained for efficiency[40,47]. On the other hand, quality is incorporated as an output variable in the model[30,50]. The latter is the focus used in this research; thus making it possible to obtain from the DEA2 model net efficiency results in terms of the influence of quality.

The DEA3 model incorporates to the basic model a desirable input, hydraulic yield. This variable is a proxy of the degree of renovation in the supply network as well as the age of this network; therefore, it is related to the investment effort made by companies. From a corporative point of view, a greater hydraulic performance can mean lower costs in water capture, water treatment and water pumping. From a social point of view, the reduction in water loss is welcome due to its environmental implications. As it is a desirable input, the inverse value is considered[51]; this transformation makes it possible to account for the transformed variables as a traditional input.

Finally, the DEA4 model adds to the basic model quality as well as hydraulic yield.

4. Results

In this section, programmatic efficiency is estimated for each of the models specified in the above section. In Table 4 the results of the Mann-Whitney rank tests between the two programs –public and private- are shown.

Table 4. Mann-Whitney rank statistic results

							Mean of DMU ranks	
Models	n_1	n_2	n	R_1	U	Z	Public	Private
DEA1	67	53	120	4 888.5	940.5	-4.4127	72.96	44.75
DEA2	67	53	120	4 855.0	974.0	-4.2357	72.46	45.38
DEA3	67	53	120	4 423.0	1 406.0	-1.9527	66.01	53.53
DEA4	67	53	120	4 413.0	1 416.0	-1.8999	65.87	53.72

The Z statistic obtained for the basic DEA1 model (Z=-4.4127) makes it possible to reject the null hypothesis at the 5 % level of significance, thus allowing to conclude that both types of management have significant programmatic differences. Moreover, the negative sign of the Z statistic shows that public governance is less efficient than private governance. This model offers net efficiency measurements of the effect of economies of customer density and economies of production density. Therefore, taking into consideration environmental factors, private management is superior to public management in order to reduce costs. Thus, privatization would be associated with an improvement in terms of efficiency and cost minimization.

In the DEA2 model the quality effect is included, obtaining a Mann-Whitney statistic equal to Z=-4.2357, which is only slightly less than that obtained in the previous model. The null hypothesis of equality in the distribution of the efficiency results is also rejected in this case with the same level of significance. Its negative value shows once again the superiority of private management over public management. Hence, the consideration of quality does not modify the initial result. In the public-private debate, one of the reasons to reject the option of privatization is the supposed loss in quality associated with this option. These results do not support this belief.

The DEA3 model takes into account hydraulic performance as a proxy of the degree of renovation and the age of the network. The Mann-Whitney statistic corresponding to this model is Z=-1.9527 which does not allow to reject the null hypothesis at the 5 % level of significance. These results indicate that the inter-program difference does not remain, and therefore there is no type of management which is superior to the other in terms of efficiency. Although private companies are more efficient in cost reduction, they are inferior in terms of their hydraulic efficiency. Public companies could face a great number of objectives, and they could consider the conservation of hydraulic resources within these objectives. This objective is less evident in private firms.

However, every private company in the sample experienced a process of privatization immediately before the start of the period considered in this study, or in the first years of this period. The relatively short period of time involved cannot lead to the conclusion that the state of the network has deteriorated due to privatization. Therefore, how can this result be explained? The decision regarding the privatization of water management can be related with the degree of renovation and the age of the network. When a public company faces important investments in the network, the local council could decide to privatize. This could be attributed to the funding limitations of local governments. However, local politicians can also consider the necessary increase in tariffs to be contrary to their electoral interests. Thus, privatization could be seen as a way to elude this responsibility. Consequently, another of the common arguments against privatization could be deemed less important: the rise in tariffs after privatization; which would not be motivated by the search for private profit, but by the expenses that renovation of a low quality network would demand.

Model DEA4 simultaneously considers quality and hydraulic performance. The Mann-Whitney statistic has a value equal to Z=-1.8999. This value confirms the previous results.

5. Conclusions

In this paper, programmatic efficiency has been calculated for public and private companies, using incomplete panel data for 20 water supply companies in Southern Spain. Disregarding the effect of the economies of customer density and economies of production density, the superiority of private governance is found in terms of cost reduction.

The consideration of the quality of the supplied water does not modify the previous result. Therefore, it is no confirmation of the supposed loss in quality associated with the privatization phenomenon, at least with reference to the quality of the water supplied to the end user.

However, the differences between both governance options disappear if hydraulic yield is taken into consideration as a proxy of the degree of renovation network; private companies are more efficient in cost reduction, but they have less hydraulic efficiency than public ones. This could be explained by the fact that public companies have numerous objectives, including the conservation of hydric resources, which may be less evident in the case of private firms.

Due to the short period of time elapsed since the privatization of the companies, it is not yet possible to state with certainty whether or not the state of the network has deteriorated after the introduction of private management. The decision regarding the privatization of the water service can be related to the degree of renovation and the age of the network. When heavy investments in the network are needed, local governments can opt for privatization. The strong financial restrictions that municipalities face and the political unpopularity derived from increases in tariffs could explain this decision. Therefore, increases in tariffs after privatization could not be motivated by the search for private profits, but rather by expenses involved in the renovation of a sub-standard network.

References

[1] MANN, P.C. and MIKESSELL, J.L. Ownership and water system operation. *Water Resources Bulletin*, 1976, **12**, No 5, 995-1004.
[2] BRUGGINK, T.H. Public versus regulated private enterprise in the municipal water industry: A comparison of operating costs. *Quarterly Review of Economics and Business*, 1982, **22**, 111-125.
[3] LAMBERT, D.K., DICHEV, D. and RAFFIEE, K. Ownership and sources of inefficiency in the provision of water services. *Water Resources Research*, 1993, **29**, No 6, 1573-1578.
[4] LYNK, E.L. Privatisation, joint production and the comparative efficiencies of private and public ownership: The UK water industry case. *Fiscal Studies*, 1993, **14**, No 2, 98-116.

[5] HALL, D. and LOBINA, E. *Water privatization in Latin America, 2002*. Public Services International Research Unit, Greenwich University, 2002, Report PSIRU, pp. 1-27.
[6] MORGAN, W.D. Investor owned vs. publicly owned water agencies: An evaluation of the property rights theory of the firm. *Water Resources Bulletin*, 1977, **13**, No 4, 775-781.
[7] CRAIN, W.M. and ZARDKOOHI, A. A test of the property-rights theory of the firm: Water utilities in the United States. *Journal of Law and Economics*, 1978, **21**, 395-408.
[8] RAFFIEE, K., NARAYANAN, R., HARRIS, T., LAMBERT, D. and COLLINS, J.M. Cost analysis of water utilities: A goodness-of-fit approach. *Atlantic Economic Journal*, 1993, **21**, No 3, 18-29.
[9] BHATTACHARYYA, A., HARRIS, T.R., NARAYANAN, R. and RAFFIEE, K. Technical efficiency of rural water utilities. *Journal of Agricultural and Resource Economics*, 1995, **20**, No 2, 373-391.
[10] ESTACHE, A. and TRUJILLO, L. Efficiency effects of "privatization" in Argentina's water and sanitation services. *Water Policy*, 2003, **5**, No 4, 396-380.
[11] PICAZO-TADEO, A.J., SÁEZ-FERNÁNDEZ, J. and GONZÁLEZ-GÓMEZ, F. The role of environmental factors in water utilities' technical efficiency. Empirical evidence from Spanish companies. *Applied Economics*, 2007, in press.
[12] PICAZO-TADEO, A.J., GONZÁLEZ-GÓMEZ, F. and SÁEZ-FERNÁNDEZ, J. Accounting for operating environments in measuring water utilities' managerial efficiency. *The Service Industries Journal*, 2009, in press.
[13] FEIGENBAUM, S. and TEEPLES, R. Public versus private water delivery: A hedonic cost approach. *Review of Economics and Statistics*, 1983, **65**, 672-678.
[14] BYRNES, P., GROSSKOPF, S. and HAYES, K. Efficiency and ownership: Further evidence. *Review of Economics and Statistics*, 1986, **68**, 337-341.
[15] FOX, W.F. and HOFLER, R.A. Using homothetic composed error frontiers to measure water utility efficiency. *Southern Economic Journal*, 1986, **53**, No 2, 461-477.
[16] TEEPLES, R., FEIGENBAUM, S. and GLYER, D. Public versus private water delivery: Cost comparisons. *Public Finance Quarterly*, 1986, **14**, No 3, 351-366.
[17] TEEPLES, R. and GLYER, D. Cost of water delivery system: Specification and ownership effects. *Review of Economics and Statistics*, 1987, **69**, No 3, 399-408.
[18] BHATTACHARYYA, A., PARKER, P. and RAFFIEE, K. An examination of the effects of ownership on the relative efficiency of public and private water utilities. *Land Economics*, 1994, **70**, No 2, 197-209.
[19] BHATTACHARYYA, A., HARRIS, T.R., NARAYANAN, R. and RAFFIEE, K. Specification and estimation of the effect of ownership on the economic efficiency of the water utilities. *Regional Science and Urban Economics*, 1995, **25**, 759-784.
[20] AIDA, K., COOPER, W.W., PASTOR, J.T. and SUEYOSHI, T. Evaluating water supply services in Japan with RAM: A range-adjusted measure of inefficiency. *International Journal Management Science*, 1997, **26**, No 2, 207-232.
[21] SHAOUL, J. A critical financial analysis of the performance of privatised industries: The case of the water industry in England and Wales. *Critical Perspectives on Accounting*, 1997, **8**, 479-505.
[22] ASHTON, J.K. Total factor productivity growth and technical change in the water and sewerage industry. *The Service Industries Journal*, 2000, **20**, No 4, 121-130.
[23] ASHTON, J.K. Cost efficiency in the UK water and sewerage industry. *Applied Economics Letters*, 2000, **7**, 455-458.

[24] MÉNARD, C. and SAUSSIER, S. Contractual choice and performance. The case of water supply in France. *Revue d'Économie Industrielle*, 2000, **92**, No 2-3, 385-404.
[25] SAAL, D.S. and PARKER, D. The impact of privatization and regulation on the water and sewerage industry in England and Wales: A translog cost function model. *Managerial and Decision Economics*, 2000, **21**, No 6, 253-268.
[26] SAAL, D.S. and PARKER, D. Productivity and price performance in the privatized water and sewerage companies of England and Wales. *Journal of Regulatory Economics*, 2001, **20**, No 1, 61-90.
[27] ESTACHE, A. and ROSSI, M.A. How different is the efficiency of public and private water companies in Asia? *The World Bank Economic Review*, 2002, **16**, No 1, 139-148.
[28] FARIA, R.C., SOUZA, G. and MOREIRA, T.B. Public versus private water utilities: Empirical evidence for Brazilian companies. *Economics Bulletin*, 2005, **8**, No 2, 1-7.
[29] GARCÍA-SÁNCHEZ, M.I. Efficiency measurement in Spanish local government: The case of municipal water services. *Review of Policy Research*, 2006, **23**, No 2, 355-371.
[30] KIRKPATRICK, C., PARKER, D., and ZHANG, Y.F. An empirical analysis of state and private sector provision of water services in Africa. *The World Bank Economic Review*, 2006, **20**, No 1, 143-163.
[31] SEROA DA MOTTA, R. and MOREIRA, A. Efficiency and regulation in the sanitation sector in Brazil. *Utilities Policy*, 2006, **14**, 185-195.
[32] SAAL, D.S., PARKER, D. and WEYMAN-JONES, J.G. Determining the contribution of technical change, efficiency change and scale change to productivity growth in the privatized English and Welsh water and sewerage industry: 1985-2000. *Journal of Productivity Analysis*, 2007, **28**, 127-139.
[33] SABBIONI, G. Efficiency in the Brazilian sanitation sector. *Utilities Policy*, 2008, **16**, No 1, 11-20.
[34] HALL, D. and LOBINA, E. Private and public interests in water and energy. *Natural Resources Forum*, 2004, **28**, 268-277.
[35] HALL, D., LOBINA, E. and DE LA MOTTE, R. Public resistance to privatisation in water and energy. *Development in Practice*, 2005, **15**, No 3-4, 286-301.
[36] ASOCIACIÓN ESPAÑOLA DE ABASTECIMIENTOS DE AGUA Y SANEAMIENTO. *Suministro de agua potable y saneamiento en España*, 2006, AEAS-AGA, Madrid.
[37] BANKER, R.D., CHARNES, A. and COOPER, W.W. Some models for estimating technical and scale inefficiencies in Data Envelopment Analysis. *Management Science*, 1984, *30*, No 9, 1078-1092.
[38] ALI, A.I. and SEIFORD, L.M. The mathematical programming approach to efficiency analysis. In: FRIED, H.O., LOVELL, C.A.K. and SCHMIDT, S.S. (editors). *The measurement of productive efficiency: Techniques and applications*. Oxford University Press, Oxford, 1993.
[39] CHARNES, A., COOPER, W.W. and RHODES, E. Evaluating program and managerial efficiency: An application of Data Envelopment Analysis to Program Follow Through. *Management Science*, 1981, **27**, Nº 6, 668-697.
[40] ANWANDTER, L. and OZUNA, T.JR. Can public sector reforms improve the efficiency of public water utilities? *Environment and Development Economics*, 2002, **7**, No 4, 687-700.

[41] BROCKETT, P. and GOLANY, B. Using rank statistics for determining programmatic efficiency in data envelopment analysis. *Management Science*, 1996, **42**, No 3, 466-472.

[42] GARCÍA-VALIÑAS, M.A. and MUÑIZ, M.A. Is DEA useful in the regulation of water utilities? A dynamic efficiency evaluation (A dynamic efficiency evaluation of water utilities). *Applied Economics*, 2007, **39**, No 2, 245-252.

[43] THANASSOULIS, E. DEA and its use in the regulation of water companies. *European Journal of Operational Research*, 2000, **127**, No 1, 1-13.

[44] FÄRE R., GROSSKOPF, S., LINDGREN, B. and ROOS, P. Productivity changes in Swedish Pharmacies 1980-89: A nonparametric Malmquist approach. *Journal of Productivity Analysis*, 1992, **3**, No 3, 85-101.

[45] GONZÁLEZ-GÓMEZ, F. and GARCÍA-RUBIO, M.A. Efficiency in the management of urban water services. What have we learned after four decades of research? *Hacienda Pública Española / Revista de Economía Pública*, 2008, 185, No 2, 39-67.

[46] ANTONIOLI, D. and FILIPPINI, M. The use of variable cost function in the regulation of the Italian Water Industry. *Utilities Policy*, 2001, **10**, No 3-4, 181-187.

[47] TUPPER, H.C. and RESENDE, M. Efficiency and regulatory issues in the Brazilian Water and Sewage Sector. *Utilities Policy*, 2004, **12**, No 1, 29-40.

[48] MIZUTANI, F. and URAKAMI, T. Identifying network density and scale economies for Japanese water supply organizations. *Papers in Regional Science*, 2001, **80**, No 2, 211-230.

[49] GARCIA, S. and THOMAS, A. The structure of municipal water supply costs: Application to a panel of French local communities. *Journal of Productivity Analysis*, 2001, **16**, No 1, 5-29.

[50] BERG, S. and LIN, CH. Consistency in performance rankings: the Peru water sector. *Applied Economics*, 2008, **40**, No 6, 793-805.

[51] GOLANY, B. and ROLL, Y. An application procedure for DEA. *International Journal of Management Science*, 1989, **17**, No 3, 237-250.