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Regulation and Efficiency & Productivity Considerations in Water & Wastewater Industry: Case of Iran

Alireza Ebrahimi Nourali [a] *, Mohammad Davoodabadi [b], Hamed Pashazadeh [c]

[a] Department of Regulation, Planning & Economics Affairs, Ministry of Energy, Iran
[b] Department of Financial Monitoring, National Water & Wastewater Eng. Co, Iran
[c] Faculty of Economics, Allameh Tabatabaee University, Iran

Abstract

Since the beginning of 1980s, many countries decided to reform and regulate some public utilities such as water, electricity, gas etc. Since, the public utilities specially water are managed as regional or local entities, the benchmarking approaches are therefore applied to compare the performance of local firms active in an industry on the basis of their relative efficiency along with ways that are used to determine the yardstick model for evaluating the performance of such enterprises. Thus, this study aims at measuring the efficiency of water & wastewater companies (WWCs) as incentive regulation tools for stimulating efficiency of production and supply through cost reduction and improving the quality of services provide by water distributors. In this study, the performances of 34 WWCs were assessed using non-parametric methods as “Data Envelopment Analysis” (DEA) in 2011. Furthermore, we reviewed the DEA-based Malmquist approach for total factor productivity (TFP) and technology change in WWCs over the period of 2008 to 2011. An input variable includes operating costs, number of employees (staff) and number of water connections and output variables are the volumes of water billed and the number of customers. The results of analysis indicate that the average efficiency of WWCs under constant return to scale (CRS) is equal to 77% (technical efficiency) and under variable return to scale (VRS) is equal to 88% (scale efficiency). In other words, given the existing resources and facilities, the potential to improve water production equals to 23% and 12% respectively. Whereas in terms of constant return to scale (CRS), the cost saving potential amounts to 1874 billion Rials or 16% of the operating costs (price=2011). Also, the Malmquist index for total factor productivity (TFP) and technology change are calculated as 0.951 and 0.940 respectively, indicating a decrease of productivity in the Iranian water & wastewater industry during 2008 to 2011.

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Keywords: Incentive Regulation, Benchmarking, Data envelopment analysis (DEA); Malmquist Index;

1. Introduction

In most countries, infrastructural industries or public utilities such as water, electricity, gas, telecommunications and transportation, which are mostly run as monopolies, have always been owned and managed by the public sector, However the late 1980s, the industry started the privatization trend both in terms of management (private sector participation) and in terms of ownership (privatization). In addition to this, the services in some parts of or the entire industry have come out of monopoly. However, evidence shows that privatization can’t improve the cost and the

* Alireza Ebrahimi Nourali. Tel.: +98(21) 81606789 or 00989127081606
E-mail address: ebrahimi@moe.gov.ir

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quality of services provided. Consistent with the provisions of a proper regulation, it is essential to provide sufficient incentives for operators in utilities to reduce costs and to increase efficiency. The regulation systems cover service cost, price cap, yardstick competition (YC) and franchise revenues. Some systems such as price cap and yardstick competition need benchmarking techniques as tools for regulation.

The process of benchmarking has long been used by private enterprises, but has only recently been applied in the public sector, particularly in the infrastructural services. As mentioned by Shleifer (1985), regulators need a simple benchmark, other than the firm's present or past performance, against which they can evaluate the firm's potentials and assure cost control, prevent waste, and promote cost reducing innovation. The basis of a benchmarking technique is the establishment of an efficiency frontier in which each firm occupies a relative position. Comparability of outputs and inputs across each firm is a key element, but the most crucial aspect is the selection of the measures of efficiency. The key point is that regulators must make choices reflecting overriding objectives of water users, firm managers, and policymakers. Selecting a measure of efficiency is also complicated by the fact that, although both financial and non-financial measures are used, there is a lack of an accepted framework for integrating the two.

In this article we have applied a particular benchmarking technique known as "Data Envelope Analysis" (DEA) to compare the performance of local firms operating in the water and wastewater industry of Iran. The performance and technical efficiency rankings extracted from the analysis can be used in the processes or systems of regularization including the price cap.

2. Need for Regulations in public utilities

According to economic theory, monopoly naturally provides a lower efficiency than the competitiveness, because firms holding monopoly have the market power to charge higher prices than the cost of the products and obtain a higher rate than normal profits. This leads to economic inefficiencies through higher prices, lower quality products, and non-optimal allocation of resources loss of welfare due to inefficiencies in the community.

Establishment of a regulation system is essential to ensure efficiency and to create incentives for monopoly firms in adjusting their pricing and production strategies to a fully competitive approach with the aim of protecting the consumers against monopoly power and maximizing the social welfare provided. Water and wastewater services in Iran were relegated to water and wastewater companies since 1990. According to legislation, these companies should be managed as private entities but the competition in this field is slow. It is necessary that this issue be investigated in Iran to actualize the potential for competition in the industry. In this context with proper regulation, regulatory reforms and deregulation of the economy, indicators of efficiency and public satisfaction should be defined to evaluate the provided services.

3. Regulation systems

In general, there are two types of approach to deal with the problem posed by the existence of natural monopolies. First, the regulatory agency approached. Second, the operation of a public enterprise that is self-regulated. The first approach is characterized by the presence of a regulatory agency, which has a duty to design regulatory schemes for natural monopoly operation, and the enforcement for compliance of such regulatory regime. Under the second general approach, there is a state owned company that operates as a public enterprise, which ideally, should allow the provision of services at least cost without the exertion of market power. In this second approach, because of political pressures, and financial constraints, self‑regulated public companies are expected to provide water and sanitation services at very low tariff levels, without possibilities of raising enough revenues to fund their operational costs. They therefore face serious restrictions to develop investment intended to either improve supply coverage or the quality of the provision. For this reason, and considering the aim of this report, we focused on the first approach to deal with natural monopoly problems; i.e. the existence of a regulatory agency. In this approach, there are different specific forms of regulations. Here we have considered cost-of-service (cost +), price-cap, yardstick competition, and franchise. A hybrid of these alternative systems can also be considered as alternative regulatory regimes[†]:

- Cost of service (Cost +)
- Price-Cap
- Yardstick Competition
- Franchise regulation

4. Benchmarking for regulatory purposes

One of the prime functions of quantitative benchmarking is to assist regulators to define the appropriate policy instruments for the water distribution sector, as well as for individual companies. Efficiency analysis and benchmarking was first applied to the price reviews of the UK water industry. The Water Service Regulation Authority (OFWAT) conducts these price reviews every 5 years (1994, 1999, 2004, and 2009). The approach is used by OFWAT in the 1994 review was described by Thanassoulis (2000a, b). OFWAT applied Data Envelopment Analysis (DEA) on a company-function level in order to facilitate discrimination in the model (i.e. fewer output variables; OFWAT recognized the potential problems resulting from limiting observations, but chose not to use panel data). The efficiency results were then compared to regression results, and entered into the price determination, with the exact usage being confidential. It is important to note that price caps are not automatically determined by OFWAT (stern, 2005), where the calculated efficiency scores are in practice not plugged one–to–one into the price cap formulas. The rationale is in general the reliability of data and performance measurement techniques as well as controlling the differences in operating characteristics and quality.

An outline of the use of DEA in the regulation of UK water companies by OFWAT through price cap is shown as$\boldsymbol{PC_t^j = RPI_t + K_t^j}$, where $\boldsymbol{PC_t^j}$ is change to the average annual charges company j is permitted to make in year t, RPIt is the change in the Retail Prices Index from year t-1 to year t and $\boldsymbol{K_t^j}$ is a company – specific factor, determined by the regulator for year t.

5. Efficiency measurement concepts and Benchmarking Approaches

The primary purpose of this section is to outline a number of commonly used efficiency measures and to discuss how they may be calculated relative to an efficient technology, which is generally represented by some form of frontier function. Frontiers have been estimated using many different methods over the past 40 years (represented in figure1). The two principal methods are:

- Data envelopment analysis (DEA) and
- Stochastic frontiers analysis (SFA),

Which involve mathematical programming and econometric methods, respectively. This paper is concerned with the use of DEA methods. The discussion in this section provides a very brief introduction to modern efficiency measurement. A more detailed provided by Fare, Grosskopf and Lovell (1985, 1994) and Lovell (1993). Modern efficiency measurement begins with Farrell (1957) who drew upon the work of Debreu (1951) and Koopmans (1951) to define a simple measure of firm efficiency, which could account for multiple inputs. He proposed that the efficiency of a firm consists of two components: *technical efficiency*, which reflects the ability of a firm to obtain maximal output from a given set of inputs, and *allocative efficiency*, which reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices. These two measures are then combined to provide a measure of

† - For more details about regulatory regimes, see Chavez CA, Quiroga MA. (2002).

total *economic efficiency*. The following discussion begins with Farrell's original ideas which were illustrated in input/input space and hence had an input-reducing focus. These are usually termed *input-orientated* measures.
Farrell illustrated his ideas using a simple example involving firms which use two inputs (x1 and x2) to produce a single output (y), under the assumption of constant returns to …… Knowledge of the unit isoquant of the *fully efficient firm*, represented by SS' in Figure 2, permits the measurement of technical efficiency. If a given firm uses quantities of inputs, defined by the point P, to produce a unit of output, the technical inefficiency of that firm could be represented by the distance QP, which is the amount by which all inputs could be proportionally reduced without a reduction in output. This is usually expressed in percentage terms by the ratio QP/0P, which represents the percentage by which all inputs could be reduced. The technical efficiency (TE) of a firm is most commonly measured by the ratio:
TE = OQ / OP0
Which is equal to one minus QP/0P. It will take a value between zero and one, and hence provides an indicator of the degree of technical inefficiency of the firm. A value of one indicates that the firm is fully technically efficient. For example, the point Q is technically efficient because it lies on the efficient isoquant.

6. Non – Parametric Method: Data Envelop Analysis (DEA)

Data envelopment analysis (DEA) was pioneered by Charnes et al (1978) and based on the work by Farrell (1957). DEA is a linear programming technique, which estimates organizational efficiency by measuring the ratio of total inputs employed to total output produced for each organization. This ratio is then compared to others in the sample group to derive an estimate of relative efficiency. DEA identifies the most efficient providers of a good or service by their ability to produce a given level of output using the least number of inputs. Other organizations in the sample group receive an efficiency score determined by the variance in their ratio of inputs employed to outputs produced relative to the most efficient producer in the sample group. DEA is therefore a measure of relative efficiency against the sample group's benchmark best practice. The advantage is that it can be used without input or output prices, which is useful in the case of the water industry where these are often distorted by a lack of competitive forces or political decisions. Instead, simply volumes of output (including quality indicators) and inputs can be used. DEA analysis undertaken to date has tended to rely on a small number of variables (e.g. volume of water delivered, the number of properties connection; operating expenditure, capital) (see Lambert, Dichev and Raffiee 1993. Sawkins and Accam 1994; Thanassouloulis 2000, 2002; Coelli and Walding 1994. Garcia-Sanchez 2006), although there are also a number of instances where a greater number of variables have been utilized (see Anwandter and Ozuna 2002; Byrnes, Grosskopf and Hayes 1986; Woodbury and Dollery 2004).

Charnes proposed a flexible approach, Cooper & Rhodes CCR (1978) and it is relative efficiency measurement. The model can be briefly described as follows.

There are m inputs (indexed by the subscript i), s outputs (indexed by subscript r) and n decision making units-DMUs indexed by subscript j); additionally one assumes that $\boldsymbol{x_{ij} > 0}$ and $\boldsymbol{y_{rj} > 0}$ denote positive inputs and outputs respectively. CCR consider the following optimization problem:

The problem needs to be solved for each DMU and represents the objective of maximizing a virtual output relative to a virtual input subject to the constraint that no DMU can operate beyond the efficiency frontier (constraint 2) and the constraint relating to non-negative weights (constraint 3). In this paper, we will focus on the behavior of technical efficiency as obtained from a DEA model that allows variable returns to scale. Inputs and outputs weights are endogenously determined as the solution to the problem for each DMU. In fact, Banker, Charnes & Cooper-BCC (1984) and Banker (1984) extended the CCR model from the constant returns to scale to the variable returns to scale case. That extension accounts to including an extra convexity restriction in the CCR model. An important result that emerges from those papers refers to the possibility of factoring total efficiency (as obtained from de CCR model) as the product of technical efficiency (as obtained from the BCC model) and scale efficiency. Therefore, the BCC model is more relevant for analyzing sectors where variable returns to scale is an important feature.

The previously mentioned model admits a linear programming representation that has to be solved for each DMU. The resulting scores are relative efficiency measures where a score of 1 indicates an efficient unit whereas scores that are less than 1 indicate inefficient units. Inefficient units are identified by comparison with reference units (peers). Therefore, it is desirable that the involved units must be comparable. It is also important to emphasize that the model imposes few restrictions on the production set and an associated convenience is that one does not need to assume a direct transformation of the postulated inputs into the chosen outputs.

7. Malmquist Productivity Index

So far, the focus has been on evaluating firm performance at appointed in time. To evaluate the efficiency change overtime, the Malmquist productivity index is issued in the following analysis:

Suppose each $\boldsymbol{DMU_j (j = 1, 2, \dots, n)}$ produces a vector of outputs $\boldsymbol{Y_j^t = (Y_{1j}^t, \dots, Y_{sj}^t)}$ by using a vector of inputs $\boldsymbol{X_j^t = (X_{1j}^t, \dots, X_{mj}^t)}$at each time period t, t=1, 2, T. When multiple inputs are used to produce multiple outputs, Shephard's (1953) distance functions provide a functional characterization of the Structure of production technology. The output distance function is defined on the output set, P (x), as:

$$\boldsymbol{d_0(x, y) = min\{\delta: y/\delta \in P(x)\}} \qquad (1)$$

The Malmquist productivity index is defined as:

$$\boldsymbol{M_0} = \sqrt{\frac{d_0^t(x_0^{t+1}, y_0^{t+1}) \times d_0^{t+1}(x_0^{t+1}, y_0^{t+1})}{d_0^t(x_0^t, y_0^t) \times d_0^{t+1}(x_0^t, y_0^t)}} \qquad (2)$$

$\boldsymbol{M_0}$ Measures the productivity change of $\boldsymbol{DMU_0}$ between period t and t+1. A value greater than one indicates positive productivity growth from period t to period t+1. A value less than one indicate negative productivity growth from period t to period t+1(Färeetal.1994a).

The Malmquist productivity index can be decomposed in to two components: efficiency change (catch-up effect) and frontier shift (technological change).

$$\text{Efficiency change: EC=}\left[\frac{d_0^{t+1}(x_0^{t+1}, y_0^{t+1})}{d_0^t(x_0^t, y_0^t)}\right] \qquad (3)$$

$$\text{Technology Change: TC=}\sqrt{\frac{d_0^t(x_0^{t+1}, y_0^{t+1}) \times d_0^{t+1}(x_0^{t+1}, y_0^{t+1})}{d_0^t(x_0^t, y_0^t) \times d_0^{t+1}(x_0^t, y_0^t)}} \qquad (4)$$

$$\boldsymbol{M_0 = EC \times TC} \qquad (5)$$

According to Fare et al. (1994b), EC can be further decomposed into scale efficiency change and pure technology change. Ray and Desli (1997) pointed out the internal potential inconsistency problem of the further decomposition — both CRS and VRS models are used in the same decomposition. Consequently, the current paper uses the accepted decomposition shown in (6).

8. Inputs and Outputs Variables

Table 2 presents the name of input and output variables. And Table 3 presents means and standard deviations for input and output variables of the 35 water & wastewater companies.

9. Results

Technical and scale efficiency scores for water & wastewater companies can be found in table 4. Also the potential cost saving and productivity changes based on Malmquist Index can be found in tables 4 and 5 respectively.

10. Conclusion

The results of analysis indicate that average efficiency of WWCs under constant return to scale (CRS) is equal to 77% (technical efficiency) and under variable return to scale (VRS) to 88% (scale efficiency). In other words, there is a possibility for improvement of water production equal to 23% and 12% respectively with the existing resources and possibilities. Also, in terms of constant return to scale (CRS), by improving technical efficiency, cost savings potential account to 1874 billion Rials, which is over 16% of the total operating cost of 35 major water & wastewater companies in 2010/2011. Also, the Malmquist index for total factor productivity (TFP) and technology change were calculated as 0.951 and 0.940 respectively, indicating a decrease of productivity in Iran's water & wastewater industry during 2008 to 2011.

The results prove that DEA analysis is a powerful tool for water industry regulators who seek to defend the public interest against the potential abuse of monopoly power and to encourage water providers to improve efficiency.

11. Tables

Table 1: DEA Model Specification

Variables	Model 1 CCR; Model 2 BCC
Inputs	Operating costs
	Number of Employees
	Number of water connections
Outputs	Volume of water billed
	Number of customers

Table 2: Means and Standard Deviations for Efficient and Inefficient water & wastewater companies

Sample Summary Statistics				
Variable	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Outputs:				
Water Billed (m^3)	117,746,791	196,727,822	22,464,299	1,201,337,762
Number of customers	528,413	733,183	104,977	4,397,155
Inputs:				
Operating costs (Million Rials)	342,748	651,902	60,210	4,002,776
Number of Employees	616	817	133	4,937
Number of water connections	410,051	474,822	104,196	2,874,757

Table 3: Technical & Scale Efficiency Scores

Firm	Efficiency			Scale type	Firm	Efficiency			Scale type
	CRS	VRS	SC			CRS	VRS	SC	
1	0.917	1	0.917	drs	19	0.674	0.706	0.955	drs
2	1	1	1	-	20	0.856	0.858	0.998	irs
3	0.699	0.745	0.938	irs	21	0.504	1	0.504	irs

4	1	1	1	-	22	0.954	0.958	0.995	irs
5	0.482	0.99	0.487	irs	23	0.723	0.76	0.952	irs
6	0.667	0.912	0.731	irs	24	0.892	0.897	0.994	drs
7	0.971	1	0.971	drs	25	0.886	0.933	0.949	irs
8	0.568	0.844	0.673	irs	26	0.78	1	0.78	irs
9	0.693	0.697	0.994	drs	27	0.797	0.957	0.833	irs
10	0.778	0.817	0.952	drs	28	0.834	0.842	0.99	irs
11	0.612	0.857	0.715	irs	29	0.56	0.618	0.906	irs
12	0.632	0.783	0.807	irs	30	0.635	1	0.635	irs
13	0.593	0.733	0.809	irs	31	0.74	0.759	0.976	drs
14	0.488	0.495	0.986	irs	32	0.608	0.747	0.814	irs
15	1	1	1	-	33	0.934	0.952	0.981	irs
16	0.947	0.959	0.987	irs	34	0.902	0.905	0.997	irs
17	0.815	1	0.815	irs	35	1	1	1	-
18	0.915	0.922	0.993	irs	**Mean**	**0.773**	**0.876**	**0.887**	-------

Note: Observations, which score less than 1, are inefficient.
CRS = Constant returns to scale, VRS = variable returns to scale, SC = scale efficiency
irs= increasing returns to scale, drs= decreasing returns to scale, - = constant returns to scale

Table 4: Potential Cost Saving

DMUs	Score	Inefficiency	Operation	Potential Cost	Score	Scale
DMU_01	0.917	0.083	370115	30,720	1	0.917
DMU_02	1.000	0	211957	-	1	1.000
DMU_03	0.699	0.301	138159	41,586	0.745	0.938
DMU_04	1.000	0	557377	-	1	1.000
DMU_05	0.482	0.518	113517	58,802	0.99	0.487
DMU_06	0.667	0.333	169156	56,329	0.912	0.731
DMU_07	0.971	0.029	4002776	116,081	1	0.971
DMU_08	0.568	0.432	123686	53,432	0.844	0.673
DMU_09	0.693	0.307	276341	84,837	0.697	0.994
DMU_10	0.778	0.222	636030	141,199	0.817	0.952
DMU_11	0.612	0.388	168700	65,455	0.857	0.715
DMU_12	0.632	0.368	133659	49,186	0.783	0.807
DMU_13	0.593	0.407	385646	156,958	0.733	0.809
DMU_14	0.488	0.512	484550	248,089	0.495	0.986
DMU_15	1.000	0	88862	-	1	1.000
DMU_16	0.947	0.053	131192	6,953	0.959	0.987
DMU_17	0.815	0.185	78763	14,571	1	0.815
DMU_18	0.915	0.085	96217	8,178	0.922	0.993
DMU_19	0.674	0.326	289599	94,409	0.706	0.955
DMU_20	0.856	0.144	180326	25,967	0.858	0.998
DMU_21	0.504	0.496	96885	48,055	1	0.504
DMU_22	0.954	0.046	184771	8,499	0.958	0.995
DMU_23	0.723	0.277	176659	48,935	0.76	0.952
DMU_24	0.892	0.108	357514	38,611	0.897	0.994
DMU_25	0.886	0.114	241738	27,558	0.933	0.949
DMU_26	0.78	0.22	60210	13,246	1	0.780
DMU_27	0.797	0.203	310500	63,032	0.957	0.833
DMU_28	0.834	0.166	151406	25,133	0.842	0.990
DMU_29	0.56	0.44	279839	123,129	0.618	0.906
DMU_30	0.635	0.365	73492	26,824	1	0.635
DMU_31	0.74	0.26	221823	57,674	0.759	0.976
DMU_32	0.608	0.392	223533	87,625	0.747	0.814
DMU_33	0.934	0.066	229437	15,143	0.952	0.981
DMU_34	0.902	0.098	390614	38,280	0.905	0.997

DMUs	Score	Inefficiency	Operation	Potential Cost	Score	Scale
DMU_35	1.000	0	361140	-	1	1.000
	0.7730286			**1,874,498**	**0.8756**	**0.887**

Table 5: Productivity changes based on Malmquist Index

Firm	EFCH	TCH	PECH	SECH	TFPCH	Firm	EFCH	TCH	PECH	SECH	TFPCH
1	1.032	1.012	1.071	0.963	1.044	18	0.959	0.946	0.967	0.992	0.907
2	1	1.049	1	1	1.049	19	1.011	0.916	1.001	1.01	0.926
3	0.945	0.949	0.966	0.979	0.897	20	1.008	0.955	1.012	0.996	0.962
4	1	1.007	1	1	1.007	21	1.083	0.87	1	1.083	0.942
5	1.034	0.835	1.007	1.027	0.863	22	1.072	1.011	1.053	1.018	1.084
6	1.027	0.915	0.996	1.032	0.94	23	0.882	0.899	0.884	0.998	0.793
7	1	0.865	1	1	0.865	24	1	0.921	1	1	0.921
8	0.978	0.948	0.958	1.02	0.926	25	1.038	0.99	1.027	1.011	1.028
9	1.029	0.953	1.033	0.996	0.98	26	0.998	0.999	1	0.998	0.997
10	1.103	0.801	1.091	1.011	0.883	27	1.02	0.954	1.042	0.979	0.973
11	1.025	0.922	1.011	1.014	0.944	28	0.998	0.954	1.008	0.99	0.952
12	0.931	0.937	0.934	0.997	0.873	29	1.082	0.931	1.103	0.982	1.008
13	1.06	0.872	1.112	0.953	0.925	30	0.973	0.982	1	0.973	0.955
14	0.993	0.872	0.976	1.018	0.866	31	0.992	0.99	0.993	0.999	0.982
15	1	0.946	1	1	0.946	32	1.025	0.943	1.014	1.01	0.966
16	1.034	0.954	1.014	1.02	0.986	33	1.07	0.925	1.026	1.043	0.99
17	1.05	0.964	1	1.05	1.012	34	0.973	1.029	0.965	1.008	1.001
						mean	**1.012**	**0.94**	**1.007**	**1.005**	**0.951**

EFCH = efficiency change, TCH = technical change, PECH = pure efficiency change, SECH = scale efficiency change, TFPCH = total factor productivity change

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