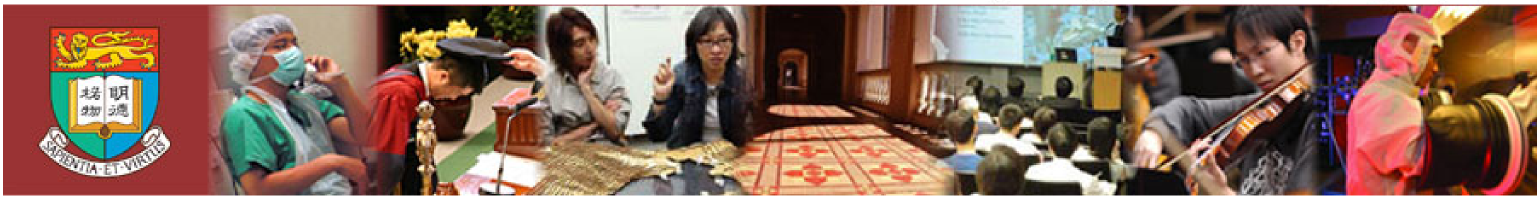
View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by HKU Scholars Hub

The HKU Scholars Hub The University of Hong Kong 香港大學學術庫



Title	Incorporating service quality into yardstick regulation: An application to the Peru water sector
Author(s)	Lin, C; Berg, SV
Citation	Review of Industrial Organization, 2008, v. 32 n. 1, p. 53-75
Issued Date	2008
URL	http://hdl.handle.net/10722/192325
Rights	Creative Commons: Attribution 3.0 Hong Kong License

Incorporating Service Quality into Yardstick Regulation: An Application to the Peru Water Sector*

Chen Lin

Department of Economics, Lingnan University, Hong Kong

Sanford V. Berg**

Department of Economics, Warrington College of Business

University of Florida

July 11, 2007

Abstract: Yardstick regulation requires the utilization of benchmarking, a valuable tool for improving the public service delivery, especially in developing countries where inefficiencies translate into negative health impacts and social unrest. However, research must account for both cost and quality of service. Using data from 38 Peruvian water utilities (1996 to 2001), the paper evaluates quality-incorporated firm performance and identifies changes in efficiency, technology (frontier), and service quality. The study utilizes the nonparametric Data Envelopment Analysis (DEA) model, a preference structure model, and quality-incorporated Malmquist Productivity Index in evaluating firm performance; the study discusses their implications for regulating state-owned enterprises.

JEL Classification:

Key Words: Yardstick regulation, Service quality, DEA, Malmquist productivity index.

---

* We thank the editor and two anonymous referees for very valuable and helpful comments. We also thank Chunrong Ai, David Sappington and David Parker for helpful comments on earlier drafts. An early version of this paper was presented to the benchmarking working group of ADERASA (Asociación de Entes Reguladores de Agua y Saneamiento de las Américas or Association of Water and Sanitation Regulatory Entities of the Americas) at .ADERASA's Conference (Buenos Aires, Argentina May 2004). The authors are responsible for any remaining errors of interpretation.

** Corresponding author: Sanford Berg, Distinguished Service Professor in Economics and Florida Public Utility Professor, University of Florida. E-mail: sberg@ufl.edu; Tel: 1-(352)392-0132. www.purc.ufl.edu

Electronic copy available at: http://ssrn.com/abstract=1327294

1. Introduction

Yardstick (benchmark) regulation for public utilities shows promise for improving the performance of regulated monopolies. Regulatory and institutional reforms in developed and developing countries during the past decade has stimulated interest in benchmarking as a tool for evaluating the effectiveness of the reforms, introducing competition through yardstick comparisons, and providing useful information about the X factor utilized in price cap regulation. (Shleifer, 1985; Carrington et al., 2002)[1]. For instance, benchmarking is now part of the process of setting price caps in the UK. OFWAT, the water regulator in UK, use different econometric models to create efficiency bands and then set the X factor and price cap based on the efficiency bands (Saal and Parker, 2006).

The empirical literature on yardstick regulation contains some studies of the water sector in developing countries. Most of these studies have not considered the role of quality in the benchmarking processes due to data limitations and methodological issues. In an earlier study, Lin (2005) utilized a stochastic cost frontier to illustrate the importance of incorporating quality into performance comparisons. This study extends that work by: (1) providing more empirical evidence about firm performance and productivity and quality change of the water sector in developing countries (using Peru as a case study); (2) proposing a benchmarking framework based on a preference-structure DEA model and quality incorporated Malmquist index; the approach allows regulators to apply their valuations of different quality dimensions to the benchmarking regulation they impose. The framework enables the decomposition of firm-level productivity change into efficiency change, technology change (frontier change) and quality change.

As an indicator of the firm-specific overall multi-dimensional quality change, the quality change indicator can provide useful information to the regulators about the Q (quality) factor in the quality dependent price cap regulation: CPI-X+Q. In addition to traditional performance indicators based on DEA and the Malmquist Productivity index, this study utilizes the preference structure DEA model and

[1] In practice, benchmarking is widely used in the regulatory sectors such as the transportation sector in Costa Rica, telecommunications sector in Hungary, electricity and telecom sectors in Dutch, and electricity sector in Norway and New South Wales (Parker, Dassler and Saal, 2006). Burns et al. (2006) review the information revelation incentives for electricity utilities and the use of benchmarking in setting electricity distribution prices in Austria, Netherlands and Britain.

Electronic copy available at: http://ssrn.com/abstract=1327294

quality-incorporated Malmquist Productivity index. To the authors' knowledge, the preference structure DEA model has not been used in regulatory studies and the quality-incorporated Malmquist Productivity Index has not been used in water studies to date[2] (due to data availability issues).

The results show that the preference structure DEA model can be used to reflect the weight given to quality in regulatory objectives. After imposing preference weights on the quality outputs (based on the current Peru water evaluation system), the correlation between the efficiency results of a basic model (only physical outputs) and comprehensive model (both physical and quality outputs) is seen to be much lower than the correlation between the comprehensive model and quality model (with three quality variables as the only outputs). Inclusion of quality indicators as desired outputs has a significant impact on firm efficiency rankings. In addition, analysis of the quality-incorporated Malmquist Productivity Index shows that on average productivity grew during 1998-1999, 2000-2001 and 1998-2001; productivity appears to have declined during 1999-2000. The average quality of service improved slightly during 1998-1999 and 1999-2000, but declined during 2000-2001. Overall, service quality declined slightly from 1998-2001, indicating inadequate incentives for the publicly-owned companies to improve their service quality under the regulatory scheme applicable for those years. The study also tests the multiplicative separability assumption in the process of decomposing the Malmquist Index using both a t test and nonparametric statistical test.

The rest of the paper is organized as follows. Section 2 provides a short literature review of benchmarking studies in public utility industries and reviews the reasons for taking quality variables into account in the benchmarking process. Section 3 provides background information regarding the Peru water sector and summarizes the current performance evaluation system. Sections 4 and 5 discuss the techniques used in the current evaluation and present empirical models and results.

2. Literature Review

Benchmarking studies based on parametric (e.g. Stochastic Frontier Analysis) and non-parametric (e.g. Data Envelopment Analysis) methods have been conducted in different infrastructure

[2] Giannakis, Jamasb and Pollitt (2005) and Estache, Perelman and Trujillo (2004) applied similar techniques to the electricity and railway industries, respectively.

industries during the past few years. For example, Carrington et al. (2002) evaluate the relative utility performance in Australian natural gas industry. Using DEA and SFA methods, Estache et al.(2004) and Frasi and Fillippini (2004) measure the efficiency of electricity distribution companies in South America and Switzerland, respectively. Lam and Shiu (2004) calculate the efficiency values and the efficiency change in China's electricity generation industry. Using data from Ukraine electricity distribution firms, Berg et. al. (2005) find that private operators respond more aggressively to cost plus regulation to increase shareholder value through cost inflation though privatization improved some dimensions of performance. Knittel (2002) checks the impact of alternative regulatory methods on the utility efficiency in the U.S. electricity distribution industry. For more detailed reviews, see the studies by Jamasb and Pollitt (2001) and Estache et. al. (2005).

Non-energy network industries have also received attention. In telecommunication, Majumdar (1997) evaluates the effect of incentive regulation on the technical efficiency of U.S. local exchange carriers between 1988 and 1993. Uri (2001) uses the Malmquist Productivity index to calculate productivity change due to the implementation of incentive regulation in telecommunications. In the water sector, Saal and Parker (2000, 2001) check the impact of privatization and regulation on productivity growth and the total cost of the water sector in England and Wales. They underscore the importance of using quality adjusted outputs (adjusted by indices of the relative quality of drinking water and sewerage treatment). Saal and Parker (2006) employs a quality-adjusted panel input distance stochastic frontier to estimate productivity growth rates for the water operations of the water sector in England and Wales between 1993 and 2003. They further decompose the productivity change into efficiency change, technology change and scale change. Wallsten and Kosec (2005) include several dimensions of quality in their comparison of privately and publicly owned water utilities in the U.S.: violations of the maximum levels of health-based contaminants and violations of monitoring and reporting regulations. Berg and Lin (2006) examine a methodological issue associated with benchmarking: the consistency of performance rankings based on non-parametric (DEA) and parametric (Stochastic production frontier and distance function) methods (in the Peruvian context). Two service quality measures (coverage of service and continuity of service) are incorporated as outputs in the models. The present study adds the pass rate of chlorine tests as additional quality indicator and focuses on how prioritizing objectives can be incorporated into the benchmarking process.

Most other water studies have not incorporated quality variables into the analysis, but examine the impacts of other factors. Cubbin and Tzanidakis (1998), and Ashton (2000) estimate the water utility firm efficiency in United Kingdom. Estache and Rossi (2002) use 1995 data from 50 water companies in 19 Asian countries to explore the effects of ownership on utility performance. They do not find significant differences between private and public water utilities. However, Estache and Kouassi, (2002) find empirical evidence supporting the view that private operators are more efficient than public operators in Africa. Corton (2003) uses OLS cost function to evaluate the efficiency of Peruvian water utilities. Tupper and Resende (2004) use the Data Envelopment Analysis (DEA) to develop efficiency scores for twenty Brazilian water utilities during 1996–2000 and propose a procedure for constructing a linear reimbursement rule that constitutes a yardstick competition mechanism. Kirkpatrick et al. (2006) find that private utilities in Africa are associated with better performance than state owned utilities based on DEA results but not in the stochastic frontier analysis (SFA) models.

As noted above, only a few studies focus on the water sector in developing countries and include quality elements in the benchmarking processes. There are two reasons for the inclusion of quality aspects into our study. First, if we ignore the quality aspects in the benchmarking, “low-cost, low quality” companies may be label as “efficient” companies, which may distort the original intention of benchmarking (Sappington, 2005). In addition, quality can be an important issue in Total Factor Productivity (TFP). For instance, Saal and Parker (2001) show that the TFP change in the U.K. water sector appears to have been extremely slow in recent years. However, quality has improved significantly because of the large increases in minimum standards, which required significant outlays. Thus, the use of unadjusted TFP change measures during this period understates actual TFP improvements (measured in a more comprehensive manner).

Second, service quality is an important issue in water sector. According to the World Bank (2003), more than 1 billion people in the developing countries lack access to clean water and almost 1.2 billion people lack adequate sanitation. An estimated 12.2 million people die every year due to the diseases directly related to drinking contaminated water. The World Commission on Water estimated that mitigating water and sanitation problems would require US$600-800 billion between 2000 and 2010. Therefore, water regulators in developing countries may put extra weight on improving service quality and coverage when evaluating sector performance.

3. Peru Water Sector and Its Performance Evaluation System

Corton (2003) characterized the water sector of Peru as one with serious problems, including inadequate system maintenance, a high level of unaccounted-for water, excess staff, low metering rates, and low water quality. In order to effectively monitor the monopoly suppliers and improve their firm performance, in 1992 the Peru government created SUNASS to regulate water and sanitation services. SUNASS attempts to ensure that consumers receive the best possible drinking water and sewerage service, in terms of adequate quality, quantity, continuity, coverage and fair price. Its functions include economic regulation, supervision, sanctions, setting rules/norms and dispute resolution (between customers and service providers). This agency's funding comes from a 1% surcharge on the invoicing from the service providers. The Board of Directors has five members: two from the First Ministry Office (one is appointed as Chairman), one from the Ministry of Finance, one from the Ministry of Housing, Construction and Sanitation and another one from the Office of Fair Competition. To promote better performance, SUNASS developed a Management Indicators System (MIS) with the help of the World Bank. The MIS collects data from utilities, making it possible to compare service providers. The expectation was that low efficiency companies would gradually improve in response to greater pressure to perform efficiently. SUNASS selected nine performance indicators and categorized them into four dimensions:

1. *Quality of Service* includes three variables: compliance with the residual chlorine rule, continuity of service, and percentage of water receiving chemical treatment.

2. *Coverage of Service Attained* consists of two variables: water coverage and sewerage coverage.

3. *Management Efficiency* reflects three variables: operating efficiency (a combination of continuity of service and the volume of water produced to serve each person at a connection), percentage of connections with meter installed, and the ratio of bills not yet collected to the total number of bills.

4. Managerial Finance Efficiency is defined by the ratio of direct costs and other expenses to revenues.

The first two broad areas of efficiency are intended to represent the interests of society. The third reflects the companies' performance, and the fourth represents the citizen-owner's perspective. In order to obtain a single measure of performance, each indicator expressed as a percentage is multiplied by its weight (equal weight=1) and added together to obtain a total score for each company. This total per company is divided by nine, the number of indicators, to get the final score. The emphasis on social concerns is evident in the greater number of indicators related to performance affecting society.

4. Methodology

Efficiency measurement methods can be subdivided into parametric and non-parametric methods. The parametric methods of efficiency analysis rely on specified functional forms of production or cost functions; they utilize econometric techniques. Non-parametric methods use mathematical programming techniques and do not require specification of production or cost functions. Both methods have been applied widely in different industries such as electricity, telecommunication, gas and water. Berg and Lin (2006) examine the consistency of the performance rankings based on DEA and SFA models in the Peruvian context. They find that DEA and SFA distance function yield similar rankings and have comparable success for identifying the best and worst performing utilities[3]. Because DEA analysis can easily accommodate multiple inputs and multiple outputs simultaneously, it is employed as the analytic tool in this paper.[4] DEA has been used in a number of recent water studies. For example, Thanassoulis (2000) reviewed DEA and its use in estimating potential cost savings at water companies in the context of the price review conducted by the regulator of water companies in England and Wales. Similarly, Tupper and Resende (2004) use Data Envelopment Analysis (DEA) supplemented by econometric analyses to provide efficiency scores for twenty Brazilian state water and sewage companies.

4.1. DEA Analysis: CCR and BCC Models

[3] This does not mean DEA and SFA always generate similar results. In some cases, the parametric and non-parametric methods do produce different results.

[4] The distance function can also accommodate multiple inputs and multiple outputs simultaneously (Coelli and Perelman, 2000). The distance function is generally expressed in flexible translog functional form because the Cobb-Douglas function imposes strong assumptions such as fixed returns to scale value and unitary elasticity of substitution. However, given the complexity of our models (3 inputs, 2 physical outputs and 4 quality outputs) and our modest sample size, translog will consume too many degrees of freedom (the model would contain 45 independent variables). Therefore, DEA models are used in this study.

Single-measure gap analysis is the simplest form of performance evaluation and benchmarking. For example, regulators in the water industry commonly use efficiency indicators, such as number of workers per connection and number of connections per 100 families, to assess utilities' performance[5]. However, these measures are not good substitutes for efficiency frontiers, which recognize the complex nature of interactions between multiple inputs and multiple outputs.[6] Suppose m input items and s output items are selected. Let each Decision-making Unit j $(DMU_j,\ j = 1,2,\cdots,n)$ produces a vector of outputs ($y_{1j}, y_{2j}, \ldots, y_{sj}$) by using a vector of inputs ($x_{1j}, x_{2j}, \ldots, x_{mj}$). The output oriented CCR model is expressed with a real variable θ and a non-negative vector $\lambda = (\lambda_1 \quad \lambda_2 \quad \ldots \quad \lambda_n)^T$ of variables as follows: $\phi^* = \max \phi$ s.t. $\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{io}$; $\sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = \phi y_{ro}$; $\lambda_j \geq 0$

(i =1, 2,…, m; r =1,2,…,s; j =1,2,…,n) (1)

We define the input excesses s^- and the output shortfalls s^+ and identify them as “slack” vectors by:

$$s^- = \theta x_o - X\lambda, s^+ = Y\lambda - y_o \qquad (2)$$

The CCR model is built on the assumption of constant returns to scale (CRS) of activities. According to the BCC (Banker-Charnes-Cooper 1984) model, if the condition $\sum_{j=1}^{n} \lambda_j = 1$ is added, then variable returns to scale (VRS) are imposed. For detailed information about CCR and BCC models, readers are referred to Cooper et al. (2004).

4.2. DEA with Preference Structure

The basic DEA models (CCR & BCC) are called radial efficiency measures, because these models adjust all inputs, or outputs, of a DMU by the same proportion. Färe and Lovell (1978)

5 For instance, the high ratio of staff per connection in Peru may not indicate the inefficiency of the utility companies. It could be due to cheaper labor substituting for other inputs rather that over-staffing. Therefore, we need to use the multiple inputs/outputs frontier model to evaluate utility efficiency.

6 DEA, the most typical non-parametric frontier method, is utilized here. DEA provides a mathematical programming method for estimating production frontiers and evaluating the relative efficiency of different decision-making units—here, water utilities. The advantages of the DEA model are that it does not require the specification of a functional form to be fitted, and can simultaneously accommodate multiple inputs and outputs. The technique also has its limitations: Rossi and Ruzzier (2000) show that the efficiency measures obtained with DEA can be very sensitive to the number of variables included in the model. As the ratio of *number of variables/sample size* goes up, the ability of DEA to discriminate among firms is sharply reduced, because it becomes more likely that a certain firm will find some set of weights to apply to its outputs and inputs which will make it appear as efficient. Another limitation of the non-parametric approach is that the DEA models cannot take the impacts of random noise or random error into account.

introduce a non-radial measure which allows non-proportional reduction in inputs, or non-proportional augmentation of outputs. The output oriented CRS model can be expressed as:

$$\max \frac{1}{s}\sum_{r=1}^{s}\phi_r \ \text{ s.t.} \sum_{j=1}^{n}\lambda_j x_{ij} + s_i^- = x_{io};\ \sum_{j=1}^{n}\lambda_j y_{rj} = \phi_r y_{ro};\ \phi_r \geq 1; \lambda_j \geq 0; s_i^- \geq 0 \qquad (3)$$

In original DEA formulations, DMUs are in a position to choose the weights to be assigned to each input and output in a way that maximizes its efficiency, subject to the system of weights being feasible for all other DMUs. This freedom of choice is equivalent to assuming that no input or output is more important than any other (Cooper et al., 2004). In our case, it is necessary to construct a model which integrates the regulator' s preferences and value judgments in DEA models and estimate the targets according to these preferences[7]. Following Zhu (1996), the output oriented weighted non-radial preference model can be expressed

$$\max \frac{\sum_{r=1}^{s} B_r\phi_r}{\sum_{r=1}^{s} B_r} \ \text{ s.t.} \sum_{j=1}^{n}\lambda_j x_{ij} + s_i^- = x_{io};\ \sum_{j=1}^{n}\lambda_j y_{rj} = \phi_r y_{ro}; \phi_r \geq 1; \lambda_j \geq 0; s_i^- \geq 0; B_r \geq 0 \quad (4)$$

where B_r (r =1,2,…,s) are user-specified preference weights which reflect the relative degree of desirability of the adjustments of the current input and output levels, respectively. The greater the weight B_r , the higher the priority DMUo will give to increase its rth output. The basic non-radial DEA model (5) is a special case of (6) when all the B_r (r =1,2,…,s) are equal. The preference weights can be obtained by using Delphi-like techniques or an analytic process yielding some value hierarchy[8].

4.3. Malmquist Productivity Index

So far, the focus has been on evaluating firm performance at a point in time. To evaluate the efficiency change over time, the Malmquist Productivity Index is used in the following analysis[9].

Suppose each $DMU_j (j = 1,2,\cdots,n)$ produces a vector of outputs $y_j^t = (y_{1j}^t,\cdots,y_{sj}^t)$ by using a vector of inputs $x_j^t = (x_{1j}^t,\cdots,x_{mj}^t)$ at each time period t, $t = 1,2,\cdots,T$. When multiple inputs

[7] In the current SUNASS evaluation scheme, the emphasis on social concerns is evident in the greater number of indicators related to performance affecting society (coverage and treated water having implications for public health). This implicit weighting suggests that the regulator may prefer that companies improve service quality rather than cut their costs. Therefore, the regulator may want the benchmarking scheme to induce the DMUs to place greater emphasis on service quality outputs.

[8] For instance, Lynch, Buzas and Berg (1994) use hierarchical conjoint analysis to derive weights for dimensions of telephone service quality; the methodology could also be applied to water and other infrastructure industries.

[9] Please see, Fare, Grosskopf and Lovell (1994), for detail background and estimation based on DEA models.

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: $d_0(x, y) = \min\{\delta : y/\delta \in P(x)\}$ (5)

The distance function $d_o(x, y)$ will take a value which is less than or equal to one if the output vector, u, is an element of the feasible production set, P(x). The Malmquist productivity index is defined as:

$$M_o = \left[\frac{d_o^t(x_o^{t+1}, y_o^{t+1}) \times d_o^{t+1}(x_o^{t+1}, y_o^{t+1})}{d_o^t(x_o^t, y_o^t) \times d_o^{t+1}(x_o^t, y_o^t)}\right]^{\frac{1}{2}} \quad (6)$$

M_o measures the productivity change 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 indicates negative productivity growth from period t to period t+1. The distance function $d_o(x, y)$ is calculated using the output oriented DEA model (Färe , Grosskopf and Lovell, 1994).

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

Efficiency change: $EC = \left[\frac{d_o^{t+1}(x_o^{t+1}, y_o^{t+1})}{d_o^t(x_o^t, y_o^t)}\right]$

Technology change: $TC = \left[\frac{d_o^t(x_o^{t+1}, y_o^{t+1}) \times d_o^t(x_o^t, y_o^t)}{d_o^{t+1}(x_o^{t+1}, y_o^{t+1}) \times d_o^{t+1}(x_o^t, y_o^t)}\right]^{\frac{1}{2}}$ (7)

M_o = EC*TC (8)

According to Fare et al. (1994), 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. So this research uses the accepted decomposition shown in (8).

Quality-incorporated Malmquist Productivity Index

Fare et al. (1995) extended the Malmquist Productivity Index to incorporate quality attributes into it in a productivity analysis of Swedish pharmacies. Similar to the preference structure model, this is a very useful model which has been rarely used in regulatory research and practice due to the lack of data on service quality. This study will extend the Malmquist Productivity Index to incorporate three quality attributes and test our hypothesis about the separation of the quality attributes. Specifically, the technology set at t is defined as $S^t = \{(x^t, y^t, a^t): x^t$ can produce y^t and $a^t\}$

The output distance function becomes:

$$d_i^t(x^t, a^t, y^t) = \min\{\delta : (x^t, a^t/\delta, y^t/\delta) \in S^t\} \qquad (9)$$

The quality change index between t and t+1 is defined as:

$$Q^{t,t+1}(x^{t+1}, a^{t+1}, y^{t+1}, x^t, a^t, y^t) = \sqrt{\frac{d_i^t(x^t, a^{t+1}, y^t) \times d_i^{t+1}(x^{t+1}, a^{t+1}, y^{t+1})}{d_i^t(x^t, a^t, y^t) \times d_i^{t+1}(x^{t+1}, a^t, y^{t+1})}} \qquad (10)$$

From equation we can see, if $a^{t+1} \geq a^t$, $Q^{t,t+1} \geq 1$

The Quality-incorporated Malmquist Productivity Index between period 0 and 1 can be expressed as:

$$M_{q,i}^{t,t+1}(x^{t+1}, a^{t+1}, y^{t+1}, x^t, a^t, y^t) = \sqrt{\frac{d_i^t(x^{t+1}, a^{t+1}, y^{t+1}) \times d_i^{t+1}(x^{t+1}, a^{t+1}, y^{t+1})}{d_i^t(x^t, a^t, y^t) \times d_i^{t+1}(x^t, a^t, y^t)}} \qquad (11)$$

As before, this can be decomposed into technology change and efficiency change:

$$M_{q,i}^{t,t+1} = \frac{d_i^{t+1}(x^{t+1}, a^{t+1}, y^{t+1})}{d_i^t(x^t, a^t, y^t)} \sqrt{\frac{d_i^t(x^{t+1}, a^{t+1}, y^{t+1}) \times d_i^t(x^t, a^t, y^t)}{d_i^{t+1}(x^{t+1}, a^{t+1}, y^{t+1}) \times d_i^{t+1}(x^t, a^t, y^t)}} \qquad (12)$$

Equation (18) can be rewritten as:

$$M_{q,i}^{t,t+1} = Q^{t,t+1}(x^{t+1}, a^{t+1}, y^{t+1}, x^t, a^t, y^t) \times \sqrt{\frac{d_i^t(x^{t+1}, a^{t+1}, y^{t+1}) \times d_i^{t+1}(x^{t+1}, a^t, y^{t+1})}{d_i^t(x^t, a^{t+1}, y^t) \times d_i^{t+1}(x^t, a^t, y^t)}} \qquad (13)$$

A further decomposition of (20) is obtained if the distance functions are multiplicatively separable in quality attributes and inputs/outputs, i.e., if

$$d_i^{t+1}(x^{t+1}, a^t, y^{t+1}) = \mathrm{A}^{t+1}(a^t) \times \overline{d_i^{t+1}}(x^{t+1}, y^{t+1}) \qquad (14)$$

Quality-incorporated Malmquist Index can be expressed as:

$$M_{q,i}^{t,t+1} = Q^{t,t+1}(x^{t+1}, a^{t+1}, y^{t+1}, x^t, a^t, y^t) \times \sqrt{\frac{\overline{d_i^t}(x^{t+1}, y^{t+1}) \times \overline{d_i^{t+1}}(x^{t+1}, y^{t+1})}{\overline{d_i^t}(x^t, y^t) \times \overline{d_i^{t+1}}(x^t, y^t)}} \qquad (15)$$

The second part in the right hand side of (15) is exactly the same as equation (6), which can be further decomposed into technical change and efficiency change according to (7). Thus,

$$M_{q,i}^{t,t+1} = Q^{t,t+1} \times TC^{t,t+1} \times EC^{t,t+1} \qquad (16)$$

If the productivity growth is the same with and without imposition of separability, (Malmquist Index calculated using equation (13) is similar to that calculated using equation (16)), the service quality aspect may be interpreted as consistent with the assumption of multiplicative separability.

5. Empirical Model and Results

We are now in a position to analyze the actual performance of 38 Peruvian EPS from 1996-2001. Due to the missing value and extreme value problems, the sample size is 186 and involves an unbalanced panel. As Estache et al. (2004) note in their study, there are several possible ways to deal with the panel data within the context of DEA. One is to compute a frontier for each period and compare the efficiency of each firm relative to the frontier in each period. Another possibility is to treat the panel as a single cross-section (each firm year being considered as an independent observation) and pool the observations. This way, a single frontier is computed, and the relative efficiency of each firm in each period is calculated by reference to this single frontier. We follow this approach in order to increase the models' discriminating power. CCR model is chosen because its result is highly correlated with that of BCC model and more importantly, the Malmquist Productivity Index is built on the CRS model[10]. (Färe et al. 1994).

5.1. Model Specification

The models investigated here draw from the extensive benchmarking literature and earlier research on the characteristics of Peru's water industry (high water loss, low water quality, and excess staff). Model 1 is the widely-used and standard model in evaluating the utility performance. Model 2 is comprehensive (including water volume, number of customers, and quality outputs). Model 3 includes only quality outputs. Model 4 applies a preference structure approach to DEA.

Model 1 (Standard): the inputs are operating costs and the number of water connections. The outputs are volume of water billed and the number of customers. *Operating cost* is calculated by adding sales cost, sales expenses and administrative expenses[11]. There are some implicit assumptions about using

[10] As discussed earlier, CCR model is based on constant return to scale while the BCC model is built on variable returns to scale.
[11] Salary expenses are included into the operation costs. Specifically, salary expenses are contained in sale cost, sales expenses and administrative expenses, according to the type of work performed and whether it is under a contract. In the case of Peru, salary expenses represent more than 40% of the operating costs in 66% of the EPS (Corton, 2003). Therefore, we do not include the number of employees as an input in our models. By doing so, we also avoid the ambiguity of measuring the number of employees in Peru water sector, where many of the employees are contract workers. Using the number of total employees imposes an implicit assumption that the average number of working hours is similar across different types of workers and firms, which is a very strong assumption.

Operating cost as an input. For example, firms face the same accounting rules and comparable input prices. These would be strong assumptions for conducting cross-country benchmarking. For this reason, empirical studies such as Estache et al (2004) use only physical inputs and outputs. Since the focus here is on Peru, the assumptions are not unreasonable. More importantly, it is not always possible or desirable to use only physical inputs and outputs due to the difficulty of including all categories of inputs (from paper clips to computers) and accounting for input mix and input quality. Therefore, the operating cost, adjusted by GDP deflator, is used as an input in our study. Either the network length or the number of water connections can be used to measure the capital of the companies. Due to serious missing data problem for network length in 1996-98, the number of connections is used as an indicator of capital.[12]

Volume of water billed and *the number of customers* (two widely used outputs) are both incorporated into Model 1[13]. Because volume of water billed is highly correlated with the revenue, revenue is not included as an output.

Model 2 (Comprehensive): In model 2, service quality elements are introduced as outputs since firms can always lower costs by reducing service quality. Table 4-1 shows the average and variance among firms. Three outputs capture dimensions of service quality: *positive rate of chlorine tests*, *coverage of service* and *continuity of service*.

Coverage is defined as the population with access to water services as a percentage of the /total population under utility's nominal responsibility. It can be considered as one of the indicators of service quality because it is a direct measure of water availability to citizens in a municipality. Since water availability tends to be viewed as a citizen's "right", coverage reflects an important aspect of water service quality (Lin, 2005). According to a recent paper in *Economist* (Feb. 18, 2006, "The Americas: Quenching thirst; Peru's water industry"), fewer people in Peru have access to piped water (72%) than anywhere else in South America except Bolivia though the country has lots of fresh water.

Percentage of samples with satisfactory residual chlorine and continuity of service are two of the

---

[12] We also test the model with both network length and number of connections as inputs, the result is quite robust to our current model (correlation>0.94).

[13] Peru has a serious problem with water loss. According to official estimates, more than 40% of water is not billed, because of leaks or unauthorized connections. Therefore, we use water billed, not water delivered, as an output to measure the utility company's capability in system management, pipeline maintenance and commercial practice.

three indicators used by SUNASS to evaluate the service quality. Due to the serious missing data problem, the percentage of water receiving chemical treatment is not included as an output. Percentage of Samples with satisfactory residual chlorine is measured as a percentage of the sample where the residual chlorine (found in the water) satisfied the minimum requirements. Water is normally analysed for many quality parameters; residual chlorine is chosen by SUNASS to show the degree of protection against bacterial contamination (http://www.ib-net.org). Great variation also exists for these two variables. The lowest satisfactory rate is only 4.32% while the minimum continuity of service is 5 hours per day. These patterns suggest that quality should be taken into account when conducting benchmarking studies. Therefore, these two variables are taken to be customer service quality variables.

[Table 1 here]

Model 3 (Preference Structure Weights): After comparing the results of the three models in the next section, Model 3 (the preference structure DEA model) is presented. The SUNASS benchmarking scheme emphasizes social concerns: six out of nine indicators are related to the customer service quality we defined above. Due to the lack of other studies that might establish the weights, we regard the current SUNASS benchmarking scheme as a proxy of regulators' preferences and give a weight 2 (6/3) to each of the three customer service quality variables while giving a weight of 1 to the other outputs[14]. The results of this Preference Structure DEA are then compared to the other models. The models are summarized in table 2.

[Table 2 here]

5.2 Empirical Results

Efficiency Score (Model 2)

Due to space constraints, the detailed results of only the quality-incorporated Model 2 are presented in Tables 3 below to illustrate the range of efficiency scores and the ranking of firms[15]. The

[14] In the current SUNASS benchmarking scheme, six indicators (compliance with the residual chlorine rule, continuity of service, percentage of water receiving chemical treatment, water coverage, sewerage coverage and operating efficiency) are related to service quality. Since the SUNASS assigns an equal weight to the nine indicators, it implicitly imposes more (double) weight on service quality.

[15] To make the results more intuitive, the input-oriented efficiency scores are presented. The output-oriented efficiency scores are the inverse of the input-oriented efficiency scores in the CCR model.

other results are available from the author.

[Table 3 here]

Correlation matrix of efficiency score and ranking

The Pearson Correlation matrix of efficiency scores[16] is shown in Table 4 in order to check the pattern of correlations associated with the different models.

[Table 4 here]

The results shown in the correlation matrix are consistent with our expectation. The basic model has a very high correlation with the comprehensive model but a relatively low correlation with the preference weighted model. This shows that the “efficient” firms are not necessary the high quality suppliers.. The correlation between the basic model and comprehensive model is 0.882, which means physical outputs (customers and water billed) play more important roles in determining the firm efficiency if we use the original radial DEA model. After imposing the preference weight to the outputs (more weight to the 3 customer service quality variables), the correlation between basic model and weighted model is 0.168 while the correlation between comprehensive model and weighted model is 0.292.: the quality output dimensions now play a more important role in determining the firm efficiency for the weighted model (preference Model 3).

The above analysis showed that the regulators should first decide their target — reducing cost, improving service quality or considering both of them. Which aspect is preferred to the other? And then, they can choose the appropriate tools to conduct the benchmarking study.

Malmquist Productivity Index and Quality-separated Malmquist Productivity Index

In order to analyze the quality and efficiency change and test the assumption of quality separation, the Malmquist Productivity Index and Quality-separated Malmquist Productivity Index are calculated, respectively. The calculation is based on the comprehensive model (Model 3). The Malmquist Productivity Index is calculated using equation (6), (8), (11) and (12). The Quality-separated Malmquist Productivity Index is calculated using (10) and (13)-(16). Then the two indices are compared one another. If the results (performance ratings) are similar, it means the data are consistent with the assumption of

[16] The Spearman’s ranking correlation matrix generates very similar results.

multiplicative separability. The calculation of Malmquist index requires a balanced panel data. Because of a serious missing data problem in year 1996 and 1997, the time period from 1998 to 2002 is utilized in the analysis. In addition, all the DMUs under evaluation are required to have complete data during this period. We exclude some problematic DMUs, and the sample size becomes 32 DMUs /year.

From Table 5, we can see that (on average) productivity has a positive growth except for 1999-2000. Frontier shift accounts for the productivity increase. This result is consistent with the finding by Saal and Parker (2006), who find that technical change (frontier shift) has been the dominant source of productivity growth in English and Welsh water sector. From Table 6, we can see that the quality-separated Malmquist productivity index depicts the same trend as before: on average, productivity only declines during 1999-2000. We also see on average the quality of service improved slightly during 1998-1999 and 1999-2000, but it declined a bit during 2000-2001. In general, the average quality of service declined slightly from 1998-2001, which suggests a lack of incentives for companies to improve their service quality under the current regulatory scheme. In the current regulatory scheme, no formal rewards or penalties are linked to SUNASS' ranking and the ranking is not widely distributed.

[Table 5 & 6 here]

Because quality improvement comes at a cost, municipal utilities may not have sufficient incentives to improve their service quality under this regulatory scheme. Some firms (like firm 3 and 7) have the highest quality growth during 1999-2000, followed by a lower growth during 2000-2001 and the lowest quality growth during 2000-2001. Given the poor status of service coverage and quality in Peru's water sector, For most other firms, the service quality level is quite stable over the time period. Overall, this result shows the importance of incorporating quality variables into a benchmarking scheme, publishing the report to public, and linking the scheme to reward/penalty. As we mentioned in the beginning of the paper, performance-based incentive standards such as quality-dependent price cap can be expressed as: CPI-X+Q, where CPI is the Consumer Price Index and the X-factor is the productivity offset, which is based on the regulator's assessment of the potential productivity growth of the regulated firms. Q is a quality factor which allows the companies to increase/decrease rates or retain more/less revenue when quality improves/degrades. The quality change (QC) component provides useful information about Q. The regulator can use other relevant information such as the minimum quality standards and single dimension quality indicators to select appropriate Q targets. However, our QC index is based on the assumption of multiplicative quality separability (equations (20)-(23)), which has to be tested. Based on Fare et al. (1995), the Malmquist Productivity Index (MPI) is compared to the Quality-separated Malmquist Productivity Index (QMPI). If the results are similar, the data are consistent with the assumption of multiplicative separability.

The Pearson correlation between MPI and QMPI is 0.926 and the non-parametric Spearman ranking correlation is 0.943, both of which are significant at 0.01 level. A two sample t-test assuming unequal variance is conducted. The null hypothesis that the sample means are equal cannot be rejected. (p=0.368)[17]. Therefore, the assumption of multiplicative separability is not rejected.

6. Concluding Observations

In emerging markets, those developing and implementing public policy must give attention to service quality issues, including low coverage for many infrastructure services (Holt, 2005). As a tool to reduce the information gap between regulators and firms and introduce competition through regulation, yardstick regulation should include quality, otherwise low cost and low quality companies will be labeled as "efficient". This study uses different types of DEA models (CCR and preference structure) to capture the regulator's preferences and illustrate the importance of including service quality measures and regulatory preference into benchmarking. The Quality-separated Malmquist Productivity Index is then introduced in order to analyze the quality change, efficiency change and shifts in the frontier. The results show a small decline in service quality from 1998-2001, which indicates the lack of appropriate incentives for the companies to improve their service quality under the regulatory system utilized during this time frame[18]. .

One additional use of benchmarking comparisons is to link managerial incentives more directly

[17] The assumption underlying the t-test required that the populations be normally distributed. In order to test the robustness of the result, we conduct the Kruskal-Wallis Test, a non-parametric test. Again, the null hypothesis can not be rejected.

[18] During this time period, SUNASS lacked instruments for rewarding or penalizing firms for performance. The overall weak record in service quality should be a signal to policy-makers that the "naming and shaming" approach (reflected in the nine-component scoring system) was not well publicized or that managers were not disciplined by local authorities when their utilities received "bad grades" from SUNASS

to performance. Some scholars (e.g. Shuttleworth 2005, Cubbin, 2005) are skeptical of applying efficiency scores due to the sensitivity of the model specification and estimation. However, caution should not preclude the thoughtful application of appropriate models. The types of models presented here serve as catalysts for (1) collecting data to mitigate information asymmetries, (2) identifying sector trends and performance outliers, and (3) designing incentive-based managerial compensation plans (Mugisha, Berg, and Muhairwe, 2007). It is likely that far more waste has occurred due to poor management practices (and weak incentives) in developing countries than to the misapplication of infrastructure benchmarking techniques**.**

Table 1: Sample Summary Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
Outputs				
Water Billed (m3)	6786308	8285202	132917	32990614
Number of customers	141379	179617	6908	809158
Coverage (%)	78	14	26	99
Positive rate of chlorine tests (%)	86	17	4	100
Continuity of service (hours/day)	16	5	5	24
Inputs				
Operation Cost (S/.)	5651864	8180070	117737	44465016
Water Connection	24329	30866	1003	148511

Table 2: DEA Model Specification

<table>
<tr><th></th><th>Model 1 (Basic Model)</th><th>Model 2 (Comprehensive)</th><th>Model 3 (Preference Structure)</th></tr>
<tr><td rowspan="2">Inputs</td><td>Operating costs</td><td>Operating costs</td><td>Operating costs</td></tr>
<tr><td>Number of water connections</td><td>Number of water connections</td><td>Number of water connections</td></tr>
<tr><td rowspan="5">Outputs</td><td>Volume of water billed</td><td>Volume of water billed</td><td>Volume of water billed</td></tr>
<tr><td rowspan="4">Number of customers</td><td>Number of customers</td><td>Number of customers</td></tr>
<tr><td>Coverage</td><td>Coverage</td></tr>
<tr><td>Positive rate of chlorine tests</td><td>Positive rate of chlorine tests</td></tr>
<tr><td>Continuity of service</td><td>Continuity of service</td></tr>
</table>

Table 3: Efficiency Score of Model 2 (1996-2001)

Firm\Year	1996	1997	1998	1999	2000	2001
1				1.000		1.000
2			1.000	0.938		0.853
3			1.000	0.857	1.000	1.000
4				0.848	0.914	0.821
5				1.000	0.995	0.995
6	0.975	0.921	0.877	0.846	0.789	0.700
7	0.917	0.995	0.972	1.000	0.921	0.932
8	0.901	0.838	0.807	0.882	0.716	0.680
9				0.697	0.692	0.663
10		0.652	0.778	0.863	0.690	0.826
11		0.647	0.731	0.674	0.670	0.550
12			0.657	0.676	0.673	0.689
13	0.654	0.717	0.725	0.781	0.754	0.782
14		0.700	0.697	0.733	0.791	0.818
15	0.768	1.000	0.761	0.722	0.777	0.914
16			0.624			
17	0.869	0.832	0.854	0.871	0.794	0.756
18			0.994	1.000	0.872	0.904
19		0.832	0.747	0.854	0.976	1.000
20			0.715	0.832	0.830	0.815
21	0.683	0.710	0.726	0.790	0.795	0.897
22	0.738	0.696	0.705	0.881	0.940	0.931
23	0.574	0.567	0.604	0.606	0.576	0.612
24	0.755	0.657	0.682	0.580	0.583	0.573
25			0.732	0.908	0.766	0.786
26	0.768	0.737	0.669	0.748	0.768	0.762
27	0.683	0.581	0.637	0.842	0.788	0.806
28	0.558	0.593	0.731	0.649	0.675	0.766
29	0.749	0.735	0.842	0.698	0.683	0.678
30			0.558	0.895	1.000	0.800
31			0.667	0.731	0.704	0.800
32			0.664	0.799	0.808	0.795
33	0.751	0.764	0.685	0.690	0.666	0.692
34			0.780	0.785	0.763	0.800
35		0.674	0.723	0.769	0.815	0.746
36	0.809	0.691	0.682	0.731	0.627	0.654
37	0.667	0.618	0.560	0.658	0.816	0.819
38			0.569	0.603	0.647	0.661

Table 4: Correlations of Efficiency Scores (order by Models 1,2,3)

Correlation	Basic	Comprehensive	Preference
Basic	1		
Comprehensive	0.882**	1	
Preference	0.168*	0.292**	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed)

Table 5: Malmquist Indexes, Efficiency Change and Frontier Shift (1998-2001)

Company	1998-1999			1999-2000			2000-2001			1998 vs 2001		
	Malmquist Index	Efficiency Change	Frontier Shift	M	EC	FS	M	EC	FS	M	EC	FS
3	0.968	1.000	0.968	1.181	1.000	1.181	1.259	1.000	1.259	1.406	1.000	1.406
6	0.968	1.000	0.968	0.954	1.000	0.954	0.917	0.780	1.176	0.920	0.780	1.180
7	1.148	1.000	1.148	0.969	1.000	0.969	1.019	1.000	1.019	1.077	1.000	1.077
8	1.248	1.061	1.176	0.884	0.998	0.886	0.968	0.778	1.243	1.078	0.824	1.308
10	1.080	0.901	1.198	0.880	0.937	0.939	1.149	1.076	1.068	1.058	0.908	1.165
11	1.008	0.916	1.101	0.961	0.939	1.023	0.764	0.708	1.079	0.809	0.609	1.329
12	1.078	0.851	1.266	0.945	1.010	0.935	1.000	0.918	1.089	1.073	0.790	1.358
13	1.017	0.898	1.133	0.962	1.081	0.890	0.991	0.992	0.999	1.001	0.963	1.040
14	1.105	0.908	1.217	1.088	1.033	1.053	1.034	0.980	1.056	1.183	0.919	1.287
15	1.069	0.870	1.229	1.039	1.155	0.899	1.111	1.099	1.011	1.208	1.104	1.094
17	1.031	0.934	1.104	0.929	0.939	0.989	0.965	0.934	1.034	0.942	0.819	1.150
18	1.285	1.000	1.285	0.856	1.000	0.856	1.022	1.000	1.022	1.067	1.000	1.067
19	1.137	1.020	1.114	1.184	1.046	1.132	1.106	1.000	1.106	1.526	1.067	1.430
20	1.247	0.981	1.271	1.001	0.978	1.023	0.981	0.962	1.020	1.132	0.923	1.227
21	1.166	0.907	1.285	1.039	1.012	1.026	1.121	1.080	1.038	1.272	0.992	1.283
22	1.457	1.096	1.330	1.051	1.000	1.051	0.991	0.985	1.006	1.361	1.079	1.261
23	1.079	0.811	1.331	0.995	0.982	1.014	1.083	0.994	1.090	1.029	0.791	1.300
24	1.113	0.860	1.294	0.986	0.978	1.009	1.005	0.965	1.042	0.986	0.811	1.215
25	1.240	1.025	1.210	0.849	0.886	0.958	1.014	0.996	1.018	1.138	0.905	1.258
26	1.123	0.932	1.205	1.018	1.152	0.883	0.937	0.905	1.036	1.126	0.972	1.159
27	1.607	1.161	1.385	0.905	0.874	1.035	1.017	0.981	1.036	1.354	0.996	1.360
28	1.017	0.916	1.111	1.061	0.983	1.079	1.147	0.859	1.335	1.111	0.773	1.437
29	1.001	0.786	1.273	0.980	1.056	0.928	0.986	0.970	1.017	0.919	0.806	1.140
30	1.701	1.113	1.529	1.109	1.011	1.097	0.832	0.867	0.959	1.458	0.976	1.494
31	1.141	0.776	1.471	0.976	1.038	0.940	1.107	1.113	0.995	1.263	0.896	1.410
32	1.415	0.970	1.459	1.003	0.953	1.053	1.007	0.965	1.044	1.291	0.892	1.448
33	1.104	0.920	1.199	0.966	1.040	0.929	1.000	0.973	1.028	1.081	0.932	1.161
34	1.137	0.918	1.239	0.981	1.024	0.958	1.026	1.009	1.016	1.114	0.948	1.175
35	1.098	0.878	1.251	1.063	1.048	1.014	0.917	0.906	1.013	1.075	0.833	1.291
36	1.170	0.843	1.389	0.862	0.944	0.913	1.031	1.007	1.024	1.041	0.800	1.301
37	1.281	0.890	1.439	1.208	1.278	0.945	0.977	1.023	0.955	1.582	1.164	1.359
38	1.114	0.857	1.300	1.109	1.029	1.078	1.021	0.948	1.077	1.160	0.835	1.388
Average	1.167	0.937	1.246	1.000	1.013	0.989	1.016	0.962	1.060	1.151	0.910	1.267

Table 6: Malmquist Indexes with Quality Change

Company	1998-1999				1999-2000				2000-2001				1998-2001			
	Malmquist Index	Quality Change	Efficiency Change	Frontier Shift	Malmquist Index	Quality Change	Efficiency Change	Frontier Shift	Malmquist Index	Quality Change	Efficiency Change	Frontier Shift	Malmquist Index	Quality Change	Efficiency Change	Frontier Shift
3	1.386	1.210	1.028	1.114	1.221	1.038	1.000	1.176	1.144	0.926	1.000	1.235	1.998	1.169	1.028	1.663
6	0.959	1.042	0.749	1.229	1.038	1.003	1.240	0.835	0.872	1.000	0.839	1.039	0.982	1.072	0.778	1.178
7	1.245	1.150	1.000	1.083	0.965	1.062	0.985	0.923	0.957	1.008	0.930	1.021	1.186	1.199	0.916	1.080
8	1.278	1.037	0.877	1.405	0.935	0.995	1.084	0.867	0.989	1.002	1.030	0.958	1.233	1.021	0.979	1.235
10	1.134	0.998	0.978	1.162	0.859	1.038	0.838	0.988	1.186	0.985	1.156	1.042	1.083	1.011	0.948	1.131
11	1.008	1.002	0.917	1.097	0.881	0.969	0.917	0.991	0.791	1.032	0.723	1.061	0.813	1.008	0.608	1.326
12	1.192	1.001	0.883	1.350	0.987	0.989	1.019	0.980	1.033	0.999	1.002	1.032	1.178	0.995	0.902	1.313
13	1.068	0.989	1.026	1.052	0.962	1.000	1.073	0.897	0.983	1.006	0.952	1.027	1.051	0.984	1.048	1.019
14	1.114	1.002	0.927	1.200	1.092	1.002	0.997	1.094	1.046	1.002	1.016	1.028	1.233	1.017	0.938	1.293
15	1.067	1.033	0.844	1.223	1.088	0.993	1.252	0.875	1.098	1.003	1.069	1.023	1.284	1.026	1.130	1.107
17	1.031	1.000	0.934	1.104	0.926	1.001	0.931	0.994	0.968	1.000	0.942	1.028	0.936	1.000	0.819	1.142
18	1.288	1.012	1.000	1.272	0.862	1.010	1.000	0.853	1.021	0.999	1.000	1.022	1.079	1.020	1.000	1.058
19	1.133	1.000	1.020	1.110	1.185	0.998	1.046	1.135	1.106	0.998	1.000	1.109	1.519	0.996	1.067	1.429
20	1.248	1.003	0.992	1.254	1.003	0.999	0.972	1.033	0.979	1.001	0.968	1.011	1.153	1.003	0.934	1.231
21	1.165	1.002	0.908	1.281	1.029	1.000	0.984	1.046	1.128	1.003	1.111	1.013	1.289	1.007	0.992	1.291
22	1.455	1.000	1.108	1.314	1.056	1.000	1.000	1.055	0.991	1.000	0.985	1.006	1.371	1.000	1.091	1.258
23	1.077	1.000	0.822	1.310	0.998	1.000	0.979	1.019	1.085	1.000	0.997	1.088	1.036	1.001	0.803	1.290
24	1.141	1.002	0.874	1.301	0.991	1.000	0.965	1.027	1.005	1.000	0.990	1.014	1.003	1.002	0.835	1.198
25	1.240	1.000	1.025	1.210	0.849	1.000	0.886	0.958	1.014	1.000	0.996	1.018	1.138	1.000	0.905	1.258
26	1.123	1.000	0.932	1.205	1.018	1.000	1.152	0.883	0.937	1.000	0.905	1.036	1.126	1.000	0.972	1.159
27	1.626	1.002	1.175	1.381	0.906	1.004	0.860	1.050	1.026	1.001	0.998	1.028	1.389	1.008	1.008	1.367
28	1.022	1.009	0.916	1.105	1.061	1.000	0.983	1.079	1.147	1.000	0.859	1.335	1.115	1.003	0.773	1.437
29	0.994	1.000	0.786	1.264	0.979	0.999	1.056	0.929	0.988	1.001	0.971	1.016	0.919	1.000	0.806	1.140
30	1.871	0.997	1.172	1.601	1.120	0.996	1.034	1.088	0.835	1.004	0.867	0.959	1.543	1.005	1.050	1.462
31	1.142	1.001	0.776	1.471	0.976	1.000	1.038	0.940	1.107	1.000	1.113	0.995	1.269	1.006	0.896	1.409
32	1.418	1.002	0.970	1.459	1.003	1.000	0.953	1.053	1.007	1.000	0.965	1.044	1.292	1.001	0.892	1.448
33	1.104	1.000	0.920	1.199	0.966	1.000	1.040	0.929	1.000	1.000	0.973	1.028	1.081	1.000	0.932	1.161
34	1.137	1.000	0.918	1.239	0.981	1.000	1.024	0.958	1.026	1.000	1.009	1.016	1.114	1.000	0.948	1.175
35	1.098	1.000	0.878	1.251	1.063	1.000	1.048	1.014	0.917	1.000	0.906	1.013	1.075	1.000	0.833	1.291
36	1.170	1.000	0.843	1.389	0.862	1.000	0.944	0.913	1.031	1.000	1.007	1.024	1.041	1.000	0.800	1.301
37	1.281	1.000	0.890	1.439	1.208	1.000	1.278	0.945	0.977	1.000	1.023	0.955	1.582	1.000	1.164	1.359
38	1.114	1.000	0.857	1.300	1.109	1.000	1.029	1.078	1.021	1.000	0.948	1.077	1.160	1.000	0.835	1.388
Average	1.198	1.015	0.936	1.262	1.006	1.003	1.019	0.988	1.013	0.999	0.976	1.041	1.196	1.017	0.926	1.269

References:

Ai, C., Martinez, S. and Sappington, D. (2004) "Incentive regulation and Telecommunications Service Quality," *Journal of Regulatory Economics*, 26, 3, 263-285

Ashton, J. K. (2000), "Cost Efficiency in the UK's Water and Sewerage Industry," Applied Economics Letters, 7, 455-458.

Banker, R.D., A.Charnes and W.W.Cooper (1984) "Some Models for Estimation Technical and Scale Inefficiencies in Data Envelopment Analysis", Management Science, 30, 1078-109

Berg, S., Lin, C. and Tsaplin, V. (2005) "Regulation of State-owned and Private Utilities: Ukraine Electricity Distribution Company Performance," Journal of Regulatory Economics 28, 259-287.

Berg, S., and Lin, C. (2006) "Consistency in Performance Rankings: The Peru Water Sector," Applied Economics, forthcoming.

Burn, P., Jekins, C., and Reichmann, C. (2007), "The Role of the Policy Framework for the Effectiveness of Benchmarking in Regulatory Proceedings", in Performance Measurement and Regulation of Network Utilities, edited by Coelli T., and Lawrence, D., Edward Elgar Publishers, Northampton MA.

Carrington, R., Coelli, T. and Groom, E. (2002) "International Benchmarking for Monopoly Price Regulation: The Case of Australian Gas Distribution," Journal of Regulatory Economics, 21:2, 191-216.

Coelli, T.J.,, and Perelman, S. (2000) "Technical Efficiency of European Railways: a Distance Function Approach," Applied Economics, 32, 1967-1976.

Cooper, W.W., L.M. Seiford and J. Zhu (2004), Handbook on Data Envelopment Analysis, Kluwer Academic Publishers, Boston, xi-592.

Corton, Maria Luisa (2003), "Benchmarking in the Latin American Water Sector: the Case of Peru," Utilities Policy, 11, 133-142.

Cubbin, John (2005), "Efficiency in the Water Industry," Utilities Policy, Vol. 13, No. 4, 289-293.

Estache, Antonio and Martin A. Rossi (2002) "How Different Is the Efficiency of Public and Private Water Companies in Asia?" The World Bank Economic Review, Vol. 16, No.1 39-148

_____, and E. Kouassi, 2002. Sector organization, governance, and the inefficiency of African water utilities. World Bank Policy Research Working Paper 2890.

______, and Martin A. Rossi and Christian A. Ruzzier, (2004) "The Case for International Coordination of Electricity Regulation: Evidence from the Measurement of Efficiency in South America" Journal of Regulatory Economics, 25:3 271-295

______, S. Perelman and L. Trujillo (2005). Infrastructure Performance and Reform in Developing and Transition Economies: Evidence from a Survey of Productivity Measures. World Bank Policy Research Working Paper 3514.

_____, S. Perelman and L. Trujillo (2004). "Measuring Efficiency Quality Tradeoffs: An Application to Brazil's Freight Railways," VIIIth European Workshop on Efficiency and Productivity Analysis meeting.

Färe, R., and C. A. K. Lovell (1978). "Measuring the technical efficiency," Journal of Economics Theory, 19, 150-162

_____. Grosskopf and C. A. K. Lovell (1994). "Production Frontiers" Cambridge University Press.

_____., Grosskoff, S., Norris, M., and Zhang, Z. (1994), "Productivity growth, technical progress and efficiency change in industrialized countries," American Economic Review, 84(1):66-83.

_____., Grosskopf, S., and Roos, P. (1995), "Productivity and quality changes in Swedish pharmacies," International Journal of Production Economics, 39, 137-147

Farsi, M. and Filippini, M. (2004), "Regulation and Measuring Cost-efficiency with Panel Data Models: Application to Electricity Distribution Utilities," Review of Industrial Organization, 25, 1-19

Giannakisa, D., T.Jamasbb and M. Pollitt, 2005. Benchmarking and incentive regulation of quality of service: an application to the UK electricity distribution networks. Energy Policy, 33, 2256–2271.

Holt, Lynn (2005) "Utility Service Quality—Telecommunications, Electricity, Water" Utilities Policy, Vol. 13, No. 3, 189-2000.

Jamasb, T., and M. Pollitt (2001) "Benchmarking and regulation: international electricity experience", Utilities Policy, vol.9, pp.107-130.

Knittel, C. (2002) "Alternative Regulatory Methods and Firm Efficiency: Stochastic Frontier Evidence From the U.S. Electricity Industry," The Review of Economics and Statistics, 84(3),530-540

Kirkpatrick, C., Parker, D., and Zhang, Y-F (2006) "State Versus Private Sector Provision of Water Services in Africa: a Statistical, DEA and Stochastic Cost Frontier Analysis," World Bank Economic Review, forthcoming.

Lam, Pun-Lee and Shiu, Alice (2004) "Efficiency and Productivity of China's Thermal Power Generation," Review of Industrial Organization, 24, 73-93.

Lin, Chen (2005) "Service Quality and Prospects for Benchmarking: Evidence from the Peru Water Sector," Utilities Policy, Vol. 13, No. 3, 230-239.

Lynch, John, Tom Buzas, and Sanford Berg (1994), "Regulatory Measurement and Evaluation of Telephone Service Quality," Management Science, Vol. 40, No. 2, February, 169-194.

Majumdar, S. (1997), "Incentive Regulation and Productive Efficiency in the U.S. Telecommunications Industry," Journal of Business, 70, 547-576

Mugisha, Silver, William T. Muhairwe, and Sanford Berg (2007). "Using Internal Incentive Contracts to Improve Water Utility Performance: The Case of Uganda's NWSC," Water Policy. 9, 271-284.

Nicola Tynan and Bill Kingdom (2002) "A Water Scorecard: Setting Performance Targets for Water Utilities", April 2002, Public Policy for the Private Sector, The World Bank Group

Parker, D., Dassler, T., and Saal, D.S. (2006a), "Performance Benchmarking in Utility Regulation: principles and problems", in International Handbook on Economic Regulation, edited by Crew M., and

Parker, D., Edward Elgar Publishers, Northampton MA.

Ray, Subhash C. and Evangelia Desli (1997) “Productivity growth, technical progress and efficiency change in industrialized countries: Comment” American Economic Review, 87, 5:1033-1039.

Rossi, M. and C. Ruzzier (2000). “On the regulatory application of efficiency measures.” Utilities Policy 9 (June), 81-92.

Saal, D.S, Parker, D., (2000), The Impact of Privatisation and Regulation on the Water and Sewerage Industry in England and Wales: A Translog Cost Function Approach. Managerial and Decision Economics 21(6): 253-268.

_______, Parker, D., (2001), Productivity and Price Performance in the Privatised Water and Sewerage Companies of England and Wales, Journal of Regulatory Economics 20, 1, 61-90

_______, Parker, D., (2006), “Assessing the Performance of Water Operations in the English and Welsh Water Industry: A Lesson in the Implications of Inappropriately Assuming a Common Frontier”, in Performance Measurement and Regulation of Network Utilities, edited by Coelli T., and Lawrence, D., Edward Elgar Publishers, Northampton MA.

Sappington, D. (2005) “Regulating Service Quality: A Survey,” Journal of Regulatory Economics, 27, 2, 123-154

Shephard, R.W. (1953). “Cost and production Functions.” Princeton: Princeton University Press.

Shleifer, A. (1985) “A Theory of Yardstick Competition,” Rand Journal of Economics, 16, 319-327

Shuttleworth, Graham (2005) “Benchmarking of Electricity Networks: Practical Problems witih its use for Regulation,” Utilities Policy, Vol. 13, No. 4, 310-317.

Tupper, Henrique Cesar and Marcelo Resende, (2004) “Efficiency and Regulatory Issues in the Brazilian Water and Sewage Sector: An Empirical Study,” Utilities Policy, 12, 29-40.

Thanassoulis, Emmanuel (2000) “DEA and its use in the regulation of water companies,” European Journal of Operational Research 127, 1-13

Uri, N., (2001) “Productivity Change, Technical Progress, and Efficiency Improvement in Telecommunications,” Review of Industrial Organization, 18, 283-300.

Wallsten, Scott, and Katrina Kosec, 2005. “Public or Private Drinking Water? The Effects of Ownership and Benchmark Competition on U.S. Water System Regulatory Compliance and Household Water Expenditures.” AEI-Brookings Joint Center Working Paper 05-05,

Zhu, Joe (1996) “Data Envelopment Analysis with Preference Structure,” The Journal of the Operational Research Society, 47, 1, 136-150