

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

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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 44 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 to evaluate firm performance; the study discusses their implications for regulating state-owned enterprises.

JEL Classification: L51, L95, D24

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

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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; Estache et al., 2004).

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. The authors also evaluated the consistency of water utility performance rankings for Peruvian water utilities, finding that Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis yield similar rankings in this particular case. The current paper extends these studies by: (1) providing more empirical evidence on 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, issues not addressed in the authors' earlier work.

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 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 date¹ (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

¹ Giannakis, Jamasb and Pollitt (2005) and Estache, Perelman and Trujillo (2004) applied similar techniques to the electricity and railway industries, respectively.

(e.g. Data Envelopment Analysis) methods have been conducted in different infrastructure 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) show that privatization can improve some dimensions of performance; however, inappropriate incentives lead to lower efficiency scores. They find that private operators respond more aggressively to cost plus regulation to increase shareholder value through cost inflation which has been passed on to users through higher tariffs. Arocena and Price (2002) calculated the Malmquist TFP index for public and private Spanish electricity generators. They conclude that publicly owned generators are more efficient under cost of service regulation; private utilities respond to incentive regulation more actively by increasing efficiency to similar levels of public utilities. Using SFA methods, Knittel (2002) checks the impact of alternative regulatory methods on the utility efficiency in the U.S. electricity distribution industry. For more detailed literature 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, providing useful information for implementing 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). 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 chlorine tests and “accounted for” water as additional quality indicators 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. Kirkpatrick et al. (2006) find that private utilities in Africa are associated with better performance than state owned utilities according to the summary statistics and DEA models. However, using the stochastic cost frontier, they cannot find a statistically significant difference between private and state owned utilities. Tupper and Resende (2004) use the nonparametric linear programming method, Data Envelopment Analysis (DEA), to develop efficiency scores for twenty Brazilian state water and sewerage companies during 1996–2000 and propose a procedure for constructing a linear reimbursement rule that constitutes a yardstick competition mechanism.

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. To promote better sector 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 indicators and it categorized them into four dimensions of performance:

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

(nonpayment).

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.

Corton (2003) developed an OLS cost function model to evaluate the performance of the Empresas Proveedoras de Servicios (EPS) regulated by SUNASS. The dependent variable in Corton's regression model was operating cost; the independent variables are volume of water produced the length of mains measured in kilometers, and the number of districts administered by each company. Regional dummy variables are also included in the model.

Each of the two performance comparisons has limitations. In the SUNASS model, an equal weight of 1 is assigned to each of the nine indicators. This weighting does not differentiate among the different performance dimensions: equal weighting needs some justification. More importantly, most indicators in the SUNASS scheme lack input-output causative relationships. Only the managerial financial efficiency considers the issue of cost. Since the definition of productivity is outputs divided by inputs, the benchmarking scheme in the Peru water sector is not primarily efficiency-driven. The Corton study focused on the cost efficiency of the company, ignoring other important factors such as quality of service and coverage of service. Besides the problem of omitted variables, another problem of regression analysis is the risk of inappropriate model specification. In addition, the Corton regression model is limited to only one dependent variable: operating cost. Thus, it is useful to consider how other methodologies could be used to construct alternative performance evaluation systems.

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 have comparable success for identifying the best and worst performing utilities. Because DEA analysis can easily accommodate multiple inputs and multiple outputs simultaneously, it is employed as the analytic tool in this paper.² 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

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. However, these measures are not good substitutes for efficiency frontiers, which recognize the complex nature of interactions between multiple inputs and multiple outputs.³ Suppose m input items and s output

² 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.

³ 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.

items are selected. Let the input and output data for Decision-making Unit j (DMU $_j$) be $(x_{1j}, x_{2j}, \dots, x_{mj})$ and $(y_{1j}, y_{2j}, \dots, y_{sj})$, respectively. The output oriented CCR model is expressed with a real variable θ and a non-negative vector $\lambda = (\lambda_1 \ \lambda_2 \ \dots \ \lambda_n)^T$ of variables as follows:

$$\begin{aligned} & \phi^* = \max \phi \\ \text{s.t.} \quad & \sum_{j=1}^n \lambda_j x_{ij} + s_i^- = x_{io} \\ & \sum_{j=1}^n \lambda_j y_{rj} - s_r^+ = \phi y_{ro} \\ & \lambda_j \geq 0 \end{aligned} \quad (i=1, 2, \dots, m; r=1, 2, \dots, s; j=1, 2, \dots, n) \quad (1)$$

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

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

$$\text{Efficient Targets: } \begin{cases} \hat{x}_{io} = x_{io} - s_i^- \\ \hat{y}_{ro} = \phi^* y_{ro} + s_r^+ \end{cases} \quad (3)$$

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) and Cooper et al. (2000).

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) 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:

$$\begin{aligned} & \max \frac{1}{S} \sum_{r=1}^s \phi_r \\ \text{s.t.} \quad & \sum_{j=1}^n \lambda_j x_{ij} + s_i^- = x_{io} \\ & \sum_{j=1}^n \lambda_j y_{rj} = \phi_r y_{ro} \\ & \phi_r \geq 1; \lambda_j \geq 0; s_i^- \geq 0 \end{aligned} \quad (i=1, 2, \dots, m; r=1, 2, \dots, s; j=1, 2, \dots, n) \quad (4)$$

$$\text{Efficient target: } \begin{cases} \hat{x}_{io} = x_{io} - s_i^{-*} \\ \hat{y}_{ro} = \phi_r^* y_{ro} + s_r^{+*} \end{cases} \quad (5)$$

Both the radial and non-radial DEA models yield efficient targets for inefficient DMUs. However, these targets may not be the most preferred by the decision maker. According to Cooper et al.(2004), 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. In this case, it is necessary to construct a model which integrates the DMUs' preferences and value judgments in DEA models and estimate the targets according to these preferences.

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 increase the service coverage and 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. Following Zhu (1996), the output oriented weighted non-radial preference model can be expressed as:

$$\begin{aligned} & \max \frac{\sum_{r=1}^s B_r \phi_r}{\sum_{r=1}^s B_r} \\ \text{s.t. } & \sum_{j=1}^n \lambda_j x_{ij} + s_i^- = x_{io} \quad (i=1, 2, \dots, m; r=1, 2, \dots, s; j=1, 2, \dots, n) \\ & \sum_{j=1}^n \lambda_j y_{rj} = \phi_r y_{ro} \\ & \phi_r \geq 1; \lambda_j \geq 0; s_i^- \geq 0; B_r \geq 0 \end{aligned} \quad (6)$$

where B_r ($r=1, 2, \dots, s$) 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 r th output. The basic non-radial DEA model (5) is a special case of (6) when all the B_r ($r=1, 2, \dots, s$) are equal. The preference weights can be

obtained by using Delphi-like techniques or an analytic process yielding some value hierarchy. 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.

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 can be derived by combining time series and cross sectional analysis. Malmquist (1953) first suggested comparing the input of a firm at two different points in time in terms of the maximum factor by which the input in one period could be decreased such that the firm could still produce the same output level of the other time period. While this is the original idea of Malmquist Index, Caves et al. (1982) extended the Malmquist input index to define a Malmquist productivity index. A resurgence of interest in its application was triggered by the work of Färe, Grosskopf and Lovell (1994) who showed that the index can be estimated using a nonparametric DEA-like approach.

Suppose each $DMU_j (j = 1, 2, \dots, n)$ produces a vector of outputs $y_j^t = (y_{1j}^t, \dots, y_{sj}^t)$ by using a vector of inputs $x_j^t = (x_{1j}^t, \dots, x_{mj}^t)$ at each time period $t, t = 1, 2, \dots, T$. When multiple inputs are used to produce multiple outputs, Shephard's (1953, 1970) 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:

$$d_o(x, y) = \min \{ \delta : y / \delta \in P(x) \} \quad (7)$$

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, $P(x)$. Since an output distance function is defined in terms of the output set $P(x)$, which satisfy certain properties, the output distance function should satisfy some properties (Kumbhakar and Lovell, 2000, chapter 2). The properties are listed also in the appendix and are assumed to be satisfied.

In the output orientation, the Malmquist productivity index is defined as:

$$M_o = \left[\frac{d_o^t(x_o^{t+1}, y_o^{t+1}) \times d_o^{t+1}(x_o^t, y_o^t)}{d_o^t(x_o^t, y_o^t) \times d_o^{t+1}(x_o^{t+1}, y_o^{t+1})} \right]^{\frac{1}{2}} \quad (8)$$

$$\text{where: s.t.} \quad \begin{aligned} & \left[d_o^t(x_o^t, y_o^t) \right]^{-1} = \max \phi_o & \left[d_o^{t+1}(x_o^{t+1}, y_o^{t+1}) \right]^{-1} = \max \phi_o \\ & \sum_{j=1}^n \lambda_j x_j^t \leq x_o^t & \sum_{j=1}^n \lambda_j x_j^{t+1} \leq x_o^{t+1} \end{aligned} \quad (9) \quad (10)$$

$$\begin{aligned} & \sum_{j=1}^n \lambda_j y_j^t \geq \phi_o y_o^t & \sum_{j=1}^n \lambda_j y_j^{t+1} \geq \phi_o y_o^{t+1} \\ & \lambda_j \geq 0, j = 1, \dots, n & \lambda_j \geq 0; j = 1, \dots, n \\ & \left[d_o^{t+1}(x_o^t, y_o^t) \right]^{-1} = \max \phi_o & \left[d_o^t(x_o^{t+1}, y_o^{t+1}) \right]^{-1} = \max \phi_o \\ & \sum_{j=1}^n \lambda_j x_j^{t+1} \leq x_o^t & \sum_{j=1}^n \lambda_j x_j^t \leq x_o^{t+1} \end{aligned} \quad (11) \quad (12)$$

$$\begin{aligned} & \sum_{j=1}^n \lambda_j y_j^{t+1} \geq \phi_o y_o^t \\ & \lambda_j \geq 0, j = 1, \dots, n \end{aligned}$$

$$\begin{aligned} & \sum_{j=1}^n \lambda_j y_j^t \geq \phi_o y_o^{t+1} \\ & \lambda_j \geq 0, j = 1, \dots, n \end{aligned}$$

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

$$\text{Efficiency change: } EC = \left[\frac{d_o^{t+1}(x_o^{t+1}, y_o^{t+1})}{d_o^t(x_o^t, y_o^t)} \right] \quad (13)$$

$$\text{Technology change: } TC = \left[\frac{d_o^t(x_o^{t+1}, y_o^{t+1}) \times d_o^t(x_o^t, y_o^t)}{d_o^{t+1}(x_o^{t+1}, y_o^{t+1}) \times d_o^{t+1}(x_o^t, y_o^t)} \right]^{\frac{1}{2}} \quad (14)$$

$$M_o = EC * TC \quad (15)$$

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 (15).

4.4 Quality-incorporated Malmquist Productivity Index

Fare et al. (1995) extended the Malmquist Productivity Index to incorporate quality attributes into

the technology in a productivity analysis of Swedish pharmacies. The quality attributes are used together with ratios of distance functions to measure service quality of the production units. 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 four quality attributes and test our hypothesis about the separation of the quality attributes.

The technology set at t is defined as $S^t = \{(x^t, y^t, a^t) : x^t \text{ can produce } y^t \text{ and } a^t\}$

The output distance function becomes:

$$d_i^t(x^t, a^t, y^t) = \min \{ \delta : (x^t, a^t / \delta, y^t / \delta) \in S^t \} \quad (16)$$

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

$$Q^{t,t+1}(x^{t+1}, a^{t+1}, y^{t+1}, x^t, a^t, y^t) = \sqrt{\frac{d_i^t(x^t, a^{t+1}, y^t) \times d_i^{t+1}(x^{t+1}, a^{t+1}, y^{t+1})}{d_i^t(x^t, a^t, y^t) \times d_i^{t+1}(x^{t+1}, a^t, y^{t+1})}} \quad (17)$$

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:

$$M_{q,i}^{t,t+1}(x^{t+1}, a^{t+1}, y^{t+1}, x^t, a^t, y^t) = \sqrt{\frac{d_i^t(x^{t+1}, a^{t+1}, y^{t+1}) \times d_i^{t+1}(x^{t+1}, a^{t+1}, y^{t+1})}{d_i^t(x^t, a^t, y^t) \times d_i^{t+1}(x^t, a^t, y^t)}} \quad (18)$$

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

$$M_{q,i}^{t,t+1} = \frac{d_i^{t+1}(x^{t+1}, a^{t+1}, y^{t+1})}{d_i^t(x^t, a^t, y^t)} \sqrt{\frac{d_i^t(x^{t+1}, a^{t+1}, y^{t+1}) \times d_i^t(x^t, a^t, y^t)}{d_i^{t+1}(x^{t+1}, a^{t+1}, y^{t+1}) \times d_i^{t+1}(x^t, a^t, y^t)}} \quad (19)$$

Equation (18) can be rewritten as:

$$M_{q,i}^{t,t+1} = Q^{t,t+1}(x^{t+1}, a^{t+1}, y^{t+1}, x^t, a^t, y^t) \times \sqrt{\frac{d_i^t(x^{t+1}, a^{t+1}, y^{t+1}) \times d_i^{t+1}(x^{t+1}, a^t, y^{t+1})}{d_i^t(x^t, a^{t+1}, y^t) \times d_i^{t+1}(x^t, a^t, y^t)}} \quad (20)$$

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

$$d_i^{t+1}(x^{t+1}, a^t, y^{t+1}) = A^{t+1}(a^t) \times \overline{d_i^{t+1}}(x^{t+1}, y^{t+1}) \quad (21)$$

Quality-incorporated Malmquist Index can be expressed as:

$$M_{q,i}^{t,t+1} = Q^{t,t+1}(x^{t+1}, a^{t+1}, y^{t+1}, x^t, a^t, y^t) \times \sqrt{\frac{\overline{d}_i^t(x^{t+1}, y^{t+1}) \times \overline{d}_i^{t+1}(x^{t+1}, y^{t+1})}{\overline{d}_i^t(x^t, y^t) \times \overline{d}_i^{t+1}(x^t, y^t)}} \quad (22)$$

The second part in the right hand side of (22) is exactly the same as equation (8), which can be further decomposed into technical change and efficiency change according to (13) and (14). Thus,

$$M_{q,i}^{t,t+1} = Q^{t,t+1} \times TC^{t,t+1} \times EC^{t,t+1} \quad (23)$$

If the productivity growth is the same with and without imposition of separability, (Malmquist Index calculated using equation (19) is similar to that calculated using equation (23)), 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 44 Peruvian EPS from 1996-2001. Due to the missing value problem, the sample size is 198 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 in each period 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. In this study, the models are based on pooled data in order to increase their 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. (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, labor 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. There are some implicit assumptions about using 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. 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.⁴

The number of employees⁵ (sum of the permanent workers and contract workers) is the third input in the list of inputs. Because all the companies in water industry of Peru are state-owned companies, excessive labor may be a serious problem due to the interference of unions and politicians. For example, the mean value of the ratio of staff per 1000 connections is 6.04, which is significantly higher than the mean value of the ratio (2.1) in developed countries (Tynan and Kingdom 2002). *Volume of water billed* and *the number of customers* (two widely used outputs) are both incorporated into Model 1. 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. Four outputs capture dimensions of service quality: *accounted-for water ratio*, *positive rate of chlorine tests*, *coverage of service* and *continuity of service*. The accounted-for water ratio is equal to 1 minus unaccounted-for water ratio—the difference between water supplied and water sold as a percentage of water supplied. As Tynan and Kingdom (2002) point out, the unaccounted-for water ratio captures not

⁴ 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).

⁵ Using the number of employees imposes an implicit assumption that the average number of working hours is similar across firms. Therefore, total hours worked may be a better measure for labor input. However, data availability required the use of this variable.

only physical losses but also commercial losses, due to inefficient billing or illegal connections. Thus, high levels of unaccounted-for water (or low levels of accounted-for water) indicate poor system management and poor commercial practice as well as inadequate pipeline maintenance. According to Tynan and Kingdom (2002), a target for unaccounted-for water less than 23 percent is recommended, based on the performance of top 25% of developing countries. (The mean for developed countries is 16 percent.) The average unaccounted-for water ratio for Peru is 46% which is significantly higher than the suggested target. The best performance is 0.12% while the worst is 91.64%. Coelli et al. (2002) regard the water loss as an indicator of technical quality of service, which has been ignored by many studies.

Coverage can be considered as one of the indicators of service quality because it is a direct measure of water availability to citizens. Since water tends to be viewed as a citizen's "right", coverage reflects an important aspect of water service quality.

Percentage of samples with satisfactory residual chlorine and continuity of service are two of the 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 2 hours per day. These patterns suggest that quality should be taken into account when conducting benchmarking studies. The three latter variables are taken to be customer service quality variables.

[Table 1 here]

Model 3 (Quality Outputs): In Model 3, all the outputs are quality-related variables. The results of Model 3 are compared to the results of Model 1 and Model 2. The models are summarized in Table 2. The operating costs have been adjusted by using the GDP Deflator.

[Table 2 here]

Model 4 (Preference Structure Weights): After comparing the results of the three models in the

next section, Model 4 (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. The results of this Preference Structure DEA are then compared to the other models. Then, the Malmquist productivity index and quality-separated Malmquist productivity index are calculated respectively to analyze the quality and efficiency change and test the assumption of the quality separation.

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. The other results are available from the author.

[Table 3 here]

Correlation matrix of efficiency score and ranking

The Pearson Correlation matrix of efficiency scores 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 relative low correlation with the quality-only model, although it is positive and significant at the 0.05 level. This shows that the "efficient" firms are not necessary the high quality suppliers. Thus, a more comprehensive model might be needed. The correlation between the basic model and comprehensive model is 0.89 and that between quality-only model and comprehensive model is 0.43, 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 0.44 while the correlation between quality-only model and weighted model is 0.77: the quality output dimensions now play a more important role in determining the firm efficiency for the weighted model (preference Model 4).

This pattern is confirmed by examining the ranking coefficient matrix calculated using non-parametric Spearman's ranking correlation (Table 5). The correlation between the basic model and comprehensive model is 0.88 and that between quality-only model and comprehensive model is 0.27, both of which are significant at 0.01 level. For Model 4, we impose the preference weights to the outputs; the correlation between basic model and weighted model is only 0.30 while the correlation between quality-only model and comprehensive model is 0.84. The weighted model gives quality a more important role in determining the firm efficiency. The preference weight DEA benchmarking scheme can capture the regulator's preferences: when applied through appropriate incentive mechanisms, it can induce the firms to pay more attention to the service quality.

[Table 5 here]

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 (8), (15), (18) and (19). The Quality-separated Malmquist Productivity Index is calculated using (17) and (20)-(23). 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 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 35 DMUs /year.

From Table 6, we can see that (on average) productivity has a positive growth except for 1999-2000. Frontier shift accounts for the productivity increase. From Table 7, 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 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 6 and Table 7 here]

Because quality improvement comes at a cost, municipal utilities may not have sufficient incentives to improve their service quality under this regulatory scheme. Furthermore, the SUNASS' benchmarking scheme is not linked to the water loss issue directly. This will not provide strong enough incentive to encourage the companies to improve their technical quality of service. An example from the sample is EMAPA Y S.R.LTDA., which had the highest positive growth rate of service quality among the group during 1999-2000. Its (Counted-for water ratio, Coverage, Positive rate of Chlorine test, Continuity of service) increased from 42.65%, 85%, 77%, and 20%, respectively to 61.76%, 91%, 85%, 21%. However, due to the lack of sustainable incentives for quality improvement, it had the highest negative growth rate of service quality among the group during 2000-2001. Its (Counted-for water ratio, Coverage, Positive rate of Chlorine test, Continuity of service) declined from (61.76%, 91%, 83%, 21) to (28.68%, 78%, 80%, 20).

This example 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 0.924 and the non-parametric Spearman ranking correlation is 0.920, 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. ($t=0.941$).

The assumption underlying the t-test required that the populations be normally distributed. In order to confirm this assumption, we conduct the Kolmogorov-Smirnov goodness of fit Test. The test compares the observed cumulative distribution function for a variable with a specified theoretical distribution, which may be normal, uniform, Poisson, or exponential.

The result of Table 8 shows that the MPI does not resemble a normal distribution. A non-parametric test should be employed to confirm the conclusion. The Kruskal-Wallis Test is conducted. The result ($p=0.236$) can not reject the null hypothesis that the two approaches generate the same distribution of index numbers. Therefore, the assumption of multiplicative separability is not rejected.

[Table 8 here]

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”. In addition to the traditional DEA models, the non-radial preference structure DEA model

is introduced here in order to capture the regulator's preferences. Different DEA models are compared to illustrate how important it is that regulators specify weights to be given to different dimensions of performance. The low correlation between the basic model and quality-only model shows that the companies labeled as "efficient" are not always the high quality providers. After giving more weight to quality variables, the correlation between preference structure model and quality-only model is shown to be higher than that between preference structure model and basic model.

The Quality-separated Malmquist Productivity Index is then introduced in order to analyze the quality change, efficiency change and shifts in the frontier. An understanding of broad patterns of quality change and the pace at which utilities as a whole are moving toward a shifting opportunity set. 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. SUNASS had oversight responsibilities for water utilities, collecting data on inputs and outputs and serving as a repository for business plans. However, during this time period, it lacked instruments for rewarding or penalizing firms for performance. Thus, 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 receive "bad grades" from SUNASS.

It is useful to know how quality fits into the production structure when developing incentives. The general Malmquist Productivity Index is calculated in order to test the assumption of quality multiplicative separability. Both the parametric and non-parametric tests confirmed the assumption. This result means the decomposition is valid and the QC can provide the regulator with useful information about the Q factor in a quality-dependent incentive schemes. Of course, implementing externally-driven incentives for municipally-owned or state-owned enterprises (SOEs) is a challenge (Shleifer, 1998). Cost of service regulation has weak incentives for cost containment; furthermore, if price is less than incremental cost (as is the case for many water utilities in developing countries), there is no incentive for network expansion. Quality-dependent price cap mechanisms raise similar issues. If coverage targets are set, establishing a system of rewards and penalties remains problematic. For example, who is penalized if

the targets are not met? If prices are reduced (because quality falls), that may further exacerbate the financial situation facing the SOE. Lowering prices more rapidly for a poorly performing high-cost utility (based on benchmarking studies) can be accomplished by increasing the X-factor. However, the lower cash flows are likely to translate into reduced outlays on maintenance or other activities. Ultimately, future consumers (and potential customers) are harmed rather than current managers.

One potential remedy is to use benchmarking comparisons to link managerial compensation more directly to performance. There is evidence that if management bonuses were based on meeting performance targets for quality and for efficiency improvements, utility performance would improve (Mugisha, Muhairwe, and Berg, forthcoming). Even though no single performance score provides a complete diagnostic regarding the status of a particular utility, rankings provide an important indicator that can be incorporated into compensation review systems, strengthening incentives. However, affected parties must agree that the scoring system is objective, robust, and not subject to manipulation.

These observations raise important policy implementation issues. For example, Shuttleworth (2005) is skeptical of applying benchmarking scores to create different X-factors for utilities, but acknowledges the usefulness of yardstick comparisons for identifying outliers. The burden of proof might then be placed on those managers whose operations appear have weak performance. On the other hand, he supports using trends in total factor productivity for setting cost reduction targets. Similarly, Cubbin (2005) calls for caution in regulatory claims regarding the efficacy of cost models (in this case, by Ofwat). Thus, it is important to include relevant cost-drivers and to take care in applying both parametric and non-parametric models to utility (and managerial) incentive plans. 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. 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.

Technical Appendix:

A.1. Properties of output distance function:

1. $d_o(x,0) = 0$ and $d_o(0,y) = +\infty$
2. $d_o(x,y)$ is a lower-semicontinuous function.
3. $d_o(x,\lambda y) = \lambda d_o(x,y)$ for $\lambda > 0$
4. $d_o(\lambda x,y) \leq d_o(x,y)$ for $\lambda > 1$
5. $d_o(x,\lambda y) \leq d_o(x,y)$ for $0 \leq \lambda \leq 1$
6. $d_o(x,y)$ is a convex function in y .

Table 1: Sample Summary Statistics

Variable	Mean	Standard Deviation	Minimum	Maximum
<i>Outputs</i>				
Water Billed (m3)	6464635	8130557	103270	32990614
Number of customers	135053	175889	6908	809158
Counted-for water ratio (%)	53.94	16.37	8.36	99.88
Coverage (%)	78.38	13.66	26.00	100.00
Positive rate of chlorine tests (%)	85.41	17.89	4.32	100.00
Continuity of service (hours/day)	15.05	5.71	2	24
<i>Inputs</i>				
Operation Cost (S/.)	5394252	7995872	117737	44465016
Water Connection	23327	30198	1003	148511
Number of employees	141	175	6	856

Table 2: DEA Model Specification

	Model 1 (Basic Model)	Model 2 (Comprehensive)	Model 3 (Quality only)
Inputs	Operating costs	Operating costs	Operating costs
	Number of water connections	Number of water connections	Number of water connections
	Number of Employees	Number of Employees	Number of Employees
Outputs	Volume of water billed	Volume of water billed	Counted-for water ratio
	Number of customers	Number of customers	Coverage
		Counted-for water ratio	Positive rate of chlorine tests
		Coverage	Continuity of service
		Positive rate of chlorine tests	
	Continuity of service		

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

DMU (1996)	e	DMU (1997)	e	DMU (1998)	e
EMUSAP AMAZONAS	0.98106	EMUSAP AMAZONAS	0.93361	EPS EMSAP CHANKA S.A.	1.00000
SEMAPA HUANCVELIC	0.92480	SEMAPA HUANCVELIC	1.00000	EMAPA Y S.R.LTDA.	1.00000
EMAPAT S.R.LTDA.	0.90352	EMAPAT S.R.LTDA.	0.84630	EMUSAP AMAZONAS	0.88109
EPS MOQUEGUA S.R.LTD	0.65438	EMUSAP ABANCAY S.A.	0.65420	EPS MARANON S.R.L.	0.80713
EPS SEDA ILO	0.56061	EMPSSAPAL S.A.	0.67108	SEMAPA HUANCVELICA	1.00000
EMAPA HUARAL S.A.	0.76809	EPS MOQUEGUA S.R.LTI	0.73958	EMAPAU S.R.LTDA.	0.73805
EPS CHAVIN S.A.	0.87940	EPS MANTARO S.A.	0.70050	EMAPAT S.R.LTDA.	0.81338
EMAPA HUACHO S.A.	0.77586	EPS SEDA ILO	0.54508	EMAPAVIGSSA.	0.75006
SEDA HUANUCO	0.73830	EMAPA HUARAL S.A.	1.00000	EMUSAP ABANCAY S.A.	0.78148
EMSA PUNO S.A.	0.60740	EPS CHAVIN S.A.	0.83935	EMPSSAPAL S.A.	0.91612
SEDACAJ S.A.	0.86071	EPS SELVA CENTRAL S.A.	0.83218	EPS MOYOBAMBA S.R.LTD	0.65701
EPS AYACUCHO S.A.	0.76758	EMAPA HUACHO S.A.	0.71522	EPS MOQUEGUA S.R.LTDA	0.79017
EPS SEMAPACH S.A.	0.69335	SEDA HUANUCO	0.70202	EPS MANTARO S.A.	0.73082
SEDAJULIACA S.A.	0.61354	EMSA PUNO S.A.	0.60000	EPS SEDA ILO	0.53554
EMAPA SAN MARTIN S.A	0.75093	SEDACAJ S.A.	0.76454	EMAPA HUARAL S.A.	0.76105
EPS TACNA S.A.	0.80199	EPS AYACUCHO S.A.	0.75279	SEMAPA BARRANCA S.A.	0.68733
SEDALIB	0.96289	EPS SEMAPACH S.A.	0.59498	EMAPAPISCO S.A.	0.74114
EPS GRAU S.A.	0.66676	SEDAJULIACA S.A.	0.64154	EPS CHAVIN S.A.	1.00000
		EMAPA SAN MARTIN S.A.	0.79477	EMAPACOP S.A.	1.00000
		EPS TACNA S.A.	0.80000	EPS SELVA CENTRAL S.A.	0.79844
		EPSEL S.A.	0.88849	EMAPA CANETE S.A.	0.74196
		SEDALIB	0.84616	EMAPA HUACHO S.A.	0.79178
		EPS GRAU S.A.	0.63865	SEDA HUANUCO	0.71567
				EMSA PUNO S.A.	0.64845
				SEDACAJ S.A.	0.68174
				EPS EMAPICA S.A.	0.73237
				EPS AYACUCHO S.A.	0.69396
				EPS SEMAPACH S.A.	0.64517
				SEDAJULIACA S.A.	0.86564
				EMAPA SAN MARTIN S.A.	0.97825
				EMFAPATUMBES	0.55796
				SEDA CUSCO S.A.	0.82280
				EPS LORETO S.A.	0.78054
				EPS TACNA S.A.	0.73859
				SEDA CHIMBOTE	0.77980
				EPSEL S.A.	0.73143
				SEDALIB	0.82215

Table 3 (cont.): Efficiency score of Model 2 (1996-2001)

DMU(1999)	e	DMU(2000)	e	DMU(2001)	e
EPS NOR PUNO S.A.	1.00000	EMAPA Y S.R.LTDA.	1.00000	EPS NOR PUNO S.A.	1.00000
EPS EMSAP CHANKA S.A.	0.94701	EMAPAB S.R.LTDA.	0.95927	EPS EMSAP CHANKA S.A.	0.86970
EMAPA Y S.R.LTDA.	0.93407	EMAQ S.R.LTDA.	1.00000	EMAPA Y S.R.LTDA.	1.00000
EMAPAB S.R.LTDA.	0.92555	EMUSAP AMAZONAS	0.79690	EMAPAB S.R.LTDA.	1.00000
EMAQ S.R.LTDA.	1.00000	SEMAPA HUANCVELICA	0.94401	EMAQ S.R.LTDA.	0.99715
EMUSAP AMAZONAS	0.85936	EMAPAU S.R.LTDA.	0.53167	EMUSAP AMAZONAS	0.70433
SEMAPA HUANCVELICA	1.00000	EMAPAT S.R.LTDA.	0.73071	SEMAPA HUANCVELICA	0.93352
EMAPAU S.R.LTDA.	0.93282	EMAPAVIGSSA.	0.79024	EMAPAU S.R.LTDA.	1.00000
EMAPAT S.R.LTDA.	0.88667	EPS SIERRA CENTRAL S.A.	0.73212	EMAPAT S.R.LTDA.	0.68675
EMAPAVIGSSA.	0.76563	EMUSAP ABANCAY S.A.	0.69147	EMAPAVIGSSA.	0.74985
EPS SIERRA CENTRAL S.A.	0.77432	EMPSSAPAL S.A.	0.74971	EPS SIERRA CENTRAL S.A.	0.70789
EMUSAP ABANCAY S.A.	0.86560	EPS MOYOBAMBA S.R.LTDA.	0.67623	EMUSAP ABANCAY S.A.	0.82608
EMPSSAPAL S.A.	0.74847	EPS MOQUEGUA S.R.LTDA.	0.82755	EMPSSAPAL S.A.	0.58031
EPS MOYOBAMBA S.R.LTDA.	0.67621	EPS MANTARO S.A.	0.86929	EPS MOYOBAMBA S.R.LTDA.	0.70104
EPS MOQUEGUA S.R.LTDA.	0.86619	EPS SEDA ILO	0.42370	EPS MOQUEGUA S.R.LTDA.	0.83298
EPS MANTARO S.A.	0.78683	EMAPA HUARAL S.A.	0.77660	EPS MANTARO S.A.	0.87984
EPS SEDA ILO	0.49633	EPS CHAVIN S.A.	0.80047	EPS SEDA ILO	0.56436
EMAPA HUARAL S.A.	0.72247	EMAPACOP S.A.	0.87250	EMAPA HUARAL S.A.	0.91397
EPS CHAVIN S.A.	0.88200	EPS SELVA CENTRAL S.A.	0.97642	EPS CHAVIN S.A.	0.76727
EMAPACOP S.A.	1.00000	EMAPA CANETE S.A.	0.84951	EMAPACOP S.A.	0.97940
EPS SELVA CENTRAL S.A.	0.86701	EMAPA HUACHO S.A.	0.82274	EPS SELVA CENTRAL S.A.	1.00000
EMAPA CANETE S.A.	0.83233	SEDA HUANUCO	1.00000	EMAPA CANETE S.A.	0.82945
EMAPA HUACHO S.A.	0.79875	EMSA PUNO S.A.	0.65800	EMAPA HUACHO S.A.	0.93084
SEDA HUANUCO	0.95552	SEDACAJ S.A.	0.67555	SEDA HUANUCO	0.96052
EMSA PUNO S.A.	0.70182	EPS EMAPICA S.A.	0.79855	EMSA PUNO S.A.	0.67765
SEDACAJ S.A.	0.66606	EPS AYACUCHO S.A.	0.81623	SEDACAJ S.A.	0.65916
EPS EMAPICA S.A.	0.95013	EPS SEMAPACH S.A.	0.92016	EPS EMAPICA S.A.	0.81719
EPS AYACUCHO S.A.	0.77860	SEDAJULIACA S.A.	0.75164	EPS AYACUCHO S.A.	0.81666
EPS SEMAPACH S.A.	0.90651	EMAPA SAN MARTIN S.A.	0.73903	EPS SEMAPACH S.A.	0.90435
SEDAJULIACA S.A.	0.90664	EMFAPATUMBES	1.00000	SEDAJULIACA S.A.	0.91944
EMAPA SAN MARTIN S.A.	0.76444	SEDA CUSCO S.A.	0.82168	EMAPA SAN MARTIN S.A.	0.76284
EMFAPATUMBES	0.89509	EPS LORETO S.A.	0.85529	EMFAPATUMBES	0.80088
SEDA CUSCO S.A.	0.78239	EPS TACNA S.A.	0.70707	SEDA CUSCO S.A.	0.89768
EPS LORETO S.A.	0.95462	SEDA CHIMBOTE	0.77574	EPS LORETO S.A.	0.87531
EPS TACNA S.A.	0.73136	EPSEL S.A.	0.82038	EPS TACNA S.A.	0.73392
SEDA CHIMBOTE	0.78500	SEDALIB	0.72799	SEDA CHIMBOTE	0.80024
EPSEL S.A.	0.78933	EPS GRAU S.A.	0.82856	EPSEL S.A.	0.74554
SEDALIB	0.93466	SEDAPAR S.A.	0.70528	SEDALIB	0.75386
EPS GRAU S.A.	0.75072			EPS GRAU S.A.	0.82470

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

		Basic	Comprehensive	Quality	Weighted
Basic	Pearson Correlation	1	0.89**	0.14*	0.44**
	Sig. (2-tailed)	.	0	0.04	0
	N	198	198	198	198
Comprehensive	Pearson Correlation	0.89**	1	0.43**	0.66**
	Sig. (2-tailed)	0	.	0	0
	N	198	198	198	198
Quality	Pearson Correlation	0.14*	0.43**	1	0.77**
	Sig. (2-tailed)	0.04	0	.	0
	N	198	198	198	198
Weighted	Pearson Correlation	0.44**	0.66**	0.77**	1
	Sig. (2-tailed)	0	0	0	.
	N	198	198	198	198

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

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

Table 5: Spearman's Rank Correlation (again sequence from models 1, 2, 3, and 4)

		Basic	Comprehensive	Quality	Weighted
Basic	Correlation coefficient	1	0.88**	0.02	0.30**
	Sig. (2-tailed)	.	0	0.84	0
	N	198	198	198	198
Comprehensive	Correlation coefficient	0.88**	1	0.27**	0.51**
	Sig. (2-tailed)	0	.	0	0
	N	198	198	198	198
Quality	Correlation coefficient	0.02	0.27**	1	0.84**
	Sig. (2-tailed)	0.84	0	.	0
	N	198	198	198	198
Weighted	Correlation coefficient	0.30**	0.51**	0.84**	1
	Sig. (2-tailed)	0	0	0	.
	N	198	198	198	198

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

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

Table 6: 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
EMAPA Y S.R.LTDA.	0.978	1.000	0.978	1.291	1.000	1.291	1.016	1.000	1.016	1.153	1.000	1.153
EMUSAP AMAZONAS	0.984	1.000	0.984	0.950	1.000	0.950	0.899	0.824	1.091	0.912	0.824	1.107
SEMAPA HUANCAMELICA	1.091	1.000	1.091	0.929	1.000	0.929	0.971	1.000	0.971	0.942	1.000	0.942
EMAPAU S.R.LTDA.	1.088	1.000	1.088	0.828	0.859	0.965	1.633	1.164	1.402	1.228	1.000	1.228
EMAPAT S.R.LTDA.	1.190	1.032	1.153	0.884	0.998	0.886	0.940	0.784	1.200	1.012	0.807	1.254
EMAPAVIGSSA.	1.151	1.000	1.152	0.997	1.035	0.964	0.967	0.790	1.225	1.070	0.817	1.311
EMUSAP ABANCAY S.A.	1.080	0.921	1.172	0.825	0.916	0.900	1.120	1.096	1.021	1.048	0.925	1.133
EMPSSAPAL S.A.	0.838	0.860	0.974	1.028	0.951	1.081	0.783	0.800	0.978	0.599	0.655	0.915
EPS MOYOBAMBA S.R.LTDA.	1.075	0.854	1.259	0.947	1.016	0.932	1.003	0.920	1.090	1.059	0.798	1.326
EPS MOQUEGUA S.R.LTDA.	1.088	1.055	1.032	0.875	1.000	0.875	0.960	1.000	0.960	0.948	1.055	0.899
EPS MANTARO S.A.	1.099	0.933	1.178	1.169	1.160	1.008	0.942	1.000	0.942	1.226	1.082	1.133
EPS SEDA ILO	1.070	0.779	1.375	0.799	0.817	0.978	1.264	1.238	1.020	1.081	0.788	1.372
EMAPA HUARAL S.A.	1.067	0.874	1.220	1.023	1.167	0.876	1.110	1.096	1.013	1.217	1.118	1.088
EPS CHAVIN S.A.	0.634	0.896	0.708	0.914	0.937	0.975	0.967	0.937	1.032	0.519	0.787	0.659
EMAPACOP S.A.	1.271	1.000	1.271	0.819	1.000	0.819	1.096	1.000	1.096	1.053	1.000	1.053
EPS SELVA CENTRAL S.A.	1.135	1.020	1.112	1.181	1.046	1.129	1.106	1.000	1.106	1.408	1.067	1.319
EMAPA CANETE S.A.	1.193	0.985	1.212	1.002	0.981	1.022	0.973	0.962	1.011	1.113	0.929	1.198
EMAPA HUACHO S.A.	1.039	0.903	1.150	1.043	1.021	1.022	1.125	1.092	1.031	1.129	1.006	1.122
SEDA HUANUCO	1.433	1.099	1.304	1.038	1.000	1.038	0.943	1.000	0.943	1.373	1.099	1.249
EMSA PUNO S.A.	1.131	1.023	1.105	0.943	0.968	0.975	1.057	1.126	0.939	1.163	1.115	1.043
SEDACAJ S.A.	1.148	0.917	1.252	1.007	1.020	0.987	0.966	0.928	1.042	1.020	0.868	1.176
EPS EMAPICA S.A.	1.261	1.060	1.189	0.852	0.922	0.925	1.003	0.950	1.056	1.153	0.929	1.242
EPS AYACUCHO S.A.	1.128	1.014	1.112	1.057	1.163	0.909	0.969	0.982	0.987	1.186	1.158	1.024
EPS SEMAPACH S.A.	1.596	1.164	1.371	0.985	1.000	0.985	1.004	1.000	1.004	1.472	1.164	1.265
SEDAJULIACA S.A.	1.085	1.000	1.085	0.879	0.986	0.891	1.105	1.014	1.090	1.120	1.000	1.120
EMAPA SAN MARTIN S.A.	0.897	0.818	1.096	0.937	1.044	0.897	1.042	1.010	1.031	0.886	0.863	1.028
EMFAPATUMBES	1.704	1.117	1.526	1.109	1.011	1.097	0.875	0.867	1.009	1.459	0.979	1.490
SEDA CUSCO S.A.	1.018	0.799	1.275	1.017	1.111	0.915	1.088	1.043	1.043	1.116	0.925	1.206
EPS LORETO S.A.	1.301	1.024	1.271	0.920	0.941	0.978	1.039	0.956	1.087	1.207	0.921	1.310
EPS TACNA S.A.	1.063	1.007	1.055	0.953	1.025	0.930	1.012	1.010	1.002	1.094	1.042	1.050
SEDA CHIMBOTE	1.137	0.918	1.239	0.968	1.026	0.944	1.024	1.007	1.018	1.114	0.948	1.175
EPSEL S.A.	1.098	0.878	1.251	1.053	1.056	0.997	0.913	0.898	1.017	1.075	0.833	1.291
SEDALIB	1.123	1.077	1.043	0.732	0.755	0.970	1.078	1.159	0.931	0.940	0.942	0.998
EPS GRAU S.A.	1.228	0.988	1.244	1.154	1.248	0.925	0.976	0.945	1.033	1.570	1.164	1.348
SEDAPAR S.A.	1.069	0.946	1.130	1.039	1.031	1.007	0.983	1.046	0.940	1.100	1.020	1.078
Average	1.128	0.970	1.162	0.976	1.006	0.971	1.027	0.990	1.039	1.108	0.961	1.152

Table 7: Malmquist Indexes, Quality Change, Efficiency Change and Frontier Shift (1998-2001)

Company	1998-1999				1999-2000			
	Malmquist Index	Quality Change	Efficiency Change	Frontier Shift	Malmquist Index	Quality Change	Efficiency Change	Frontier Shift
EMAPA Y S.R.LTDA.	1.360	1.188	1.028	1.114	1.677	1.448	1.000	1.158
EMUSAP AMAZONAS	1.097	1.104	0.874	1.138	0.956	1.005	1.149	0.828
SEMAPA HUANCVELICA	1.297	1.205	1.000	1.076	0.930	1.110	1.000	0.838
EMAPAU S.R.LTDA.	1.302	1.118	1.056	1.103	0.782	0.863	0.858	1.056
EMAPAT S.R.LTDA.	1.204	0.977	0.877	1.405	0.938	0.991	1.115	0.850
EMAPAVIGSSA.	1.272	0.957	1.030	1.290	1.128	1.026	1.032	1.065
EMUSAP ABANCAY S.A.	1.135	0.999	0.978	1.162	0.784	1.000	0.916	0.856
EMPSSAPAL S.A.	0.862	1.030	0.860	0.973	1.028	1.000	0.951	1.081
EPS MOYOBAMBA S.R.LTDA.	1.194	1.001	0.883	1.350	0.975	0.976	1.040	0.960
EPS MOQUEGUA S.R.LTDA.	1.079	0.954	1.226	0.922	0.887	1.014	1.000	0.875
EPS MANTARO S.A.	1.097	0.982	0.952	1.174	1.171	1.000	1.160	1.009
EPS SEDA ILO	1.168	1.033	0.755	1.498	0.922	1.021	0.929	0.973
EMAPA HUARAL S.A.	1.109	1.073	0.846	1.222	1.052	0.987	1.268	0.841
EPS CHAVIN S.A.	0.655	1.033	0.896	0.708	0.914	1.003	0.932	0.978
EMAPACOP S.A.	1.239	0.982	1.000	1.262	0.822	1.007	1.000	0.816
EPS SELVA CENTRAL S.A.	1.133	1.000	1.020	1.110	1.166	0.988	1.046	1.129
EMAPA CANETE S.A.	1.199	1.004	0.992	1.202	1.006	1.000	0.981	1.025
EMAPA HUACHO S.A.	1.044	1.003	0.904	1.152	1.029	1.001	0.984	1.044
SEDA HUANUCO	1.431	1.000	1.108	1.292	1.043	1.000	1.000	1.042
EMSA PUNO S.A.	1.118	1.000	1.016	1.100	0.947	0.990	0.986	0.970
SEDACAJ S.A.	1.139	0.986	0.902	1.281	1.026	1.023	1.015	0.988
EPS EMAPICA S.A.	1.261	1.000	1.060	1.189	0.852	1.000	0.922	0.925
EPS AYACUCHO S.A.	1.128	1.000	1.014	1.112	1.057	1.000	1.163	0.909
EPS SEMAPACH S.A.	1.603	1.002	1.175	1.361	0.979	1.005	1.000	0.974
SEDAJULIACA S.A.	1.104	1.018	1.000	1.084	0.881	1.002	0.986	0.891
EMAPA SAN MARTIN S.A.	0.888	1.001	0.812	1.093	0.938	0.997	1.052	0.894
EMFAPATUMBES	1.869	0.996	1.172	1.601	1.115	0.991	1.034	1.088
SEDA CUSCO S.A.	1.024	1.001	0.799	1.281	1.017	1.000	1.111	0.915
EPS LORETO S.A.	1.297	0.997	1.024	1.271	0.923	1.003	0.941	0.978
EPS TACNA S.A.	1.063	1.000	1.007	1.055	0.953	1.000	1.025	0.930
SEDA CHIMBOTE	1.137	1.000	0.918	1.239	0.968	1.000	1.026	0.944
EPSEL S.A.	1.098	1.000	0.878	1.251	1.053	1.000	1.056	0.997
SEDALIB	1.123	1.000	1.077	1.043	0.734	1.002	0.755	0.970
EPS GRAU S.A.	1.228	1.000	0.988	1.244	1.154	1.000	1.248	0.925
SEDAPAR S.A.	1.069	1.000	0.946	1.130	1.039	1.000	1.031	1.007
Average	1.172	1.018	0.974	1.185	0.996	1.013	1.020	0.964

Table 7 (cont.): Malmquist indexes, quality change, efficiency change and frontier shift (1998-2001)

Company	2000-2001				1998 vs 2001			
	Malmquist Index	Quality Change	Efficiency Change	Frontier Shift	Malmquist Index	Quality Change	Efficiency Change	Frontier Shift
EMAPA Y S.R.LTDA.	0.552	0.464	1.000	1.189	1.316	0.812	1.028	1.576
EMUSAP AMAZONAS	0.840	0.993	0.775	1.091	0.834	0.910	0.778	1.178
SEMAPA HUANCVELICA	0.934	1.014	0.916	1.005	1.151	1.234	0.916	1.018
EMAPAU S.R.LTDA.	1.627	1.088	1.176	1.270	1.351	1.020	1.067	1.242
EMAPAT S.R.LTDA.	0.979	0.978	1.002	0.999	1.154	0.955	0.979	1.235
EMAPAVIGSSA.	0.943	1.004	0.894	1.051	1.169	0.961	0.951	1.279
EMUSAP ABANCAY S.A.	1.140	1.005	1.058	1.072	1.059	0.988	0.948	1.131
EMPSSAPAL S.A.	0.750	0.979	0.784	0.977	0.597	0.954	0.642	0.976
EPS MOYOBAMBA S.R.LTDA.	1.013	0.988	0.984	1.042	1.169	0.986	0.904	1.312
EPS MOQUEGUA S.R.LTDA.	0.980	0.988	1.000	0.992	1.001	0.927	1.226	0.880
EPS MANTARO S.A.	0.952	1.005	1.000	0.947	1.225	0.996	1.105	1.114
EPS SEDA ILO	1.262	1.000	1.238	1.019	1.189	1.011	0.868	1.355
EMAPA HUARAL S.A.	1.111	1.006	1.062	1.041	1.291	1.028	1.139	1.102
EPS CHAVIN S.A.	0.968	0.999	0.943	1.028	0.548	1.047	0.787	0.665
EMAPACOP S.A.	1.099	1.004	1.000	1.096	1.059	1.001	1.000	1.058
EPS SELVA CENTRAL S.A.	1.106	0.997	1.000	1.109	1.395	0.991	1.067	1.319
EMAPA CANETE S.A.	0.966	1.000	0.962	1.004	1.127	1.004	0.936	1.199
EMAPA HUACHO S.A.	1.143	1.008	1.131	1.002	1.151	1.007	1.005	1.136
SEDA HUANUCO	0.946	1.003	1.000	0.943	1.382	1.000	1.108	1.248
EMSA PUNO S.A.	1.058	1.000	1.123	0.942	1.180	0.997	1.125	1.052
SEDACAJ S.A.	0.971	1.011	0.976	0.984	1.039	1.004	0.894	1.159
EPS EMAPICA S.A.	1.003	1.000	0.950	1.056	1.153	1.000	0.929	1.242
EPS AYACUCHO S.A.	0.969	1.000	0.982	0.987	1.186	1.000	1.158	1.024
EPS SEMAPACH S.A.	1.006	1.005	1.000	1.001	1.501	1.008	1.175	1.266
SEDAJULIACA S.A.	1.102	0.998	1.014	1.090	1.128	1.005	1.000	1.122
EMAPA SAN MARTIN S.A.	1.042	1.000	1.010	1.032	0.885	1.000	0.862	1.027
EMFAPATUMBES	0.882	1.008	0.867	1.009	1.537	1.001	1.050	1.462
SEDA CUSCO S.A.	1.088	1.000	1.043	1.043	1.129	1.012	0.925	1.205
EPS LORETO S.A.	1.039	1.000	0.956	1.087	1.210	1.002	0.921	1.310
EPS TACNA S.A.	1.012	1.000	1.010	1.002	1.095	1.000	1.042	1.050
SEDA CHIMBOTE	1.024	1.000	1.007	1.018	1.114	1.000	0.948	1.175
EPSEL S.A.	0.913	1.000	0.898	1.017	1.075	1.000	0.833	1.291
SEDALIB	1.078	1.000	1.159	0.931	0.940	1.000	0.942	0.998
EPS GRAU S.A.	0.976	1.000	0.945	1.033	1.570	1.000	1.164	1.348
SEDAPAR S.A.	0.983	1.000	1.046	0.940	1.100	1.000	1.020	1.078
Average	1.013	0.987	0.997	1.030	1.143	0.996	0.984	1.167

Table 8: One-Sample Kolmogorov-Smirnov Test

		QMPI	MPI
N		140	140
Normal Parameters	Mean	1.081	1.06
	Std. Deviation	0.201	0.177
Most Extreme Differences	Absolute	0.114	0.117
	Positive	0.114	0.117
	Negative	-0.073	-0.079
Kolmogorov-Smirnov Z		1.345	1.39
Asymp. Sig. (2-tailed)		0.054	0.042
a. Test distribution is Normal.		b. Calculated from data.	

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