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Comparing the Performance of Public and Private Water Companies in the Asia and Pacific Region

What a Stochastic Costs Frontier Shows

Antonio Estache
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Efficiency indicators can be useful to regulators assessing the efficiency of an operation and the wedge between tariff and minimum costs. They allow regulators to control for factors over which the operators have no control (such as diversity of water sources, or water quality or user characteristics).

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Summary findings

Estache and Rossi estimate a stochastic costs frontier for a sample of Asian and Pacific water companies, comparing the performance of public and privatized companies based on detailed firm-specific information published by the Asian Development Bank in 1997.

They find private operators of water companies to be more efficient than public operators. Costs in concessioned companies tend to be significantly lower than those in public companies.

Estache and Rossi compare the ranking of these companies by efficiency performance (obtained from econometric estimates) with rankings by more standard qualitative and productivity indicators typically used to assess performance.

They show that rankings based on standard indicators are not always very consistent.

Productivity indicators recognize simple input-output relations, such as the number of workers per client or connection. *Frontiers* recognize the more complex nature of interactions between inputs and outputs. *Cost frontiers* show the costs as a function of the level of output (or outputs) and the prices of inputs, and are generally more useful to regulators assessing the wedge between tariff and minimum costs. *Production frontiers* reveal technical relations between firms' inputs and outputs and provide a useful backup when cost frontiers are difficult to assess for lack of data.

This paper — a product of Governance, Regulation and Finance, World Bank Institute — is part of a larger effort in the institute to increase understanding of infrastructure regulation. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Gabriela Chenet-Smith, room G2-148, telephone 202-473-6370, fax 202-334-8350, Internet address gchenet@worldbank.org. Policy Research Working Papers are also posted on the Web at http://www.worldbank.org/html/dec/Publications/Workpapers/home.html. Antonio Estache may be contacted at aestache@worldbank.org. July 1999. (26 pages)

Comparing the Performance of Public and Private Water Companies in Asia and Pacific Region What a Stochastic Costs Frontier Shows

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1. Introduction

Since the mid 1990s, with the benefit of a wider understanding of the potential benefits from yardstick competition between regional monopolies (Schleifer, 1985), practioners and academics specialising in regulatory issues have been increasingly interested in developing standardised performance indicators for monopolies in the infrastructure sector. These indicators can be used by the regulators to assess the absolute as well as the relative performance of regulated utilities.

Performance indicators can be separated into two main categories: (i) productivity indicators and (ii) production and cost frontier estimates. The *productivity indicators* are simple input-output relations such as the number of workers per client or connection. The *frontiers* recognise the much more complex nature of interactions between inputs and outputs. The *cost frontiers* show the costs as a function of the level of output (or outputs) and the prices of inputs and is generally much more useful to regulators who are assessed to assess the wedge between tariff and minimum costs. The *production frontiers* reveal technical relations between inputs and outputs of firms and provides a useful backup when cost frontiers are not easy to assess due to lack of data.[1] The inclusion of control variables in the specification of the functional relations estimated ensures that the various operators of a same activity are effectively comparable. Indeed, once the frontier has been estimated, the efficiency of a specific operator can be assessed in relation of the performance of the best operators in the industry when these are confronted with the same factors constraining the performance of the operator being assessed.[2]

The productivity indicators although theoretically inferior to efficiency frontiers are quite commonly used by regulators to assess the performance of utilities. They are useful complements to efficiency frontiers, but seldom good substitutes. However, in most countries, data limitations makes them the only game in town so they tend to be used in conjunction with various types of quality indicators to obtain a multidimensional snapshot of a firm's performance. Moreover, the experience suggests that efficiency frontiers are not flawless. Even when the data controlled by the firm can be requested from the operators, it is not seldom that the data needed to identify the specific constraining characteristics of the activity analysed. This results in an impossibility to decompose the degree of efficiency that the firms can control from factors that influence costs but

[1] In choosing between the estimation of a production or a cost function, the regulator needs to take into account the specificities of the sector he/she is working on. An important characteristic in regulated utilities is that in general, the firms are required to provide the service at a preset tariff. In other words, the firms are required to meet the demand and are not allowed to pick the level of output to supply. Since output is exogenous, the regulated firm maximizes benefits simply by minimizing its costs of producing a given level of output. Under this situation, in principle, the specification of a cost frontier is often the natural choice.

[2] In Chile (water sector) and Spain (electricity), the frontier is calculated on the basis of engineering data instead of relying on best practice.

that the firms cannot control (Burns and Estache, 1998). There is however both in the academic and in the practitioner's literature on regulation an accelerating tendency to try to rely on estimates of frontiers to assess the impact of regulatory decisions on the efficiency of operators. This paper contributes to that growing literature.

The rest of the paper is organised as follows. Section 2 presents the theoretical structure of the cost model estimated. Section 3 provides an overview of earlier studies of the water sector. Section 4 presents the estimates of costs frontiers obtained for a large sample of Asian and Pacific Region water companies, distinguishing between public and private operators. Section 5 compares the performance ranking from efficiency frontier measures to those obtained from productivity indicators. Section 6 concludes.

2. The theoretical cost functions

The theory draws on standard textbook microeconomics. The problem faced by a regulator is to ensure that the regulated firm minimises a total cost function subject to a target output constraint. The solution to this optimisation problem results in an optimal set of inputs, which depend on the level of output, and on the price of inputs. So, it makes sense to estimate a cost function at the firm level, which depends only on its output level and on the price of its input. The theoretical specification of this model is:

$$C = f(Y,Z,P_L,P_K)$$

where C is total cost, Y is the output, (which could be something like the number of customers served by the company), Z is a vector i-dimentional of the relevant exogenous variables needed to allow comparisons across firms, P_L is the price of the labour inputs, and P_K is the price of capital.

The functional form the most commonly used in this type of situation is a Cobb-Douglas[3] where the term which will be used to measure inefficiency (ε) enters the model in a multiplicative way (which becomes additive when the model is estimated using a logarithmic version):

$$C = A\, P_l^{\beta 1}\, P_k^{\beta k}\, Y^{\gamma 0}\, \Pi_{i=1}\, Z_i^{\gamma i} \exp^{\varepsilon}$$

Applying natural logarithm to both sides of the equation results in:

$$c = \alpha + \beta_l p_l + \beta_k p_k + \gamma_0 y + \Sigma_{i=1} \gamma_i z_i + \varepsilon_i \quad (1)$$

where α (lnA), β_i and γ_i are parameters, c is ln(C), p_l is ln(P_L), p_k is ln(P_k), y is ln(Y), z_i is ln(Z_i) and ε_i is the error term.

The systematic part of the model determines the minimum cost that can be reached with a given set of inputs and control variables and is what is labelled the cost frontier. Conceptually, the minimum cost function defined a frontier showing the costs technically possible associated with various levels of inputs and control variables. The error term (ε_i) can be decomposed in two parts:

$$\varepsilon_i = u_i + v_i$$

where $u_i \geq 0$ and v_i are not constrained. The v_i component captures the effects (for the firm i) of the stochastic noise and is assumed to be iid (independent and identically distributed) following a normal distribution $N(0,\sigma^2_v)$. The u_i component represents the cost inefficiency and is assumed to be distributed independently from v_i and the regressors. Various distributions have been suggested in the literature for this term: half normal (Aigner, Lovell and Schmidt, 1977), truncated-normal (Stevenson, 1980), Gamma (Green, 1990) and exponential (Meeusen and van den Broeck, 1977). The most common in empirical papers, and the one that will be used in this paper is the half

[3] An alternative is to estimate a translogarithmic function, although, in this case a Cobb-Douglas specification may be appropriate since the sample size is not quite large enough. Futhermore, using a Cobb-Douglas type of function allows to comply with convexity requirements. Obviously, the estimates of the efficiency measures will depend on the extent to which the specification of the functional form is correct.

normal. This distribution imposed that the majority of the firms are almost quasi efficient. There is however no theoretical reason that impedes that inefficiency be distributed symmetrically as v_i.[4]

The estimation procedure is somewhat cumbersome and requires some additional theoretical assumptions. It requires first running the Standard Least Squares (SLS) to obtain consistent estimates of the slope parameters. The constant term is biased and has to be modified by substracting the average u. In the case of the half normal distribution:

$$E(u) = \sigma_u(2/\pi)^{1/2}.$$

While the inefficiency component cannot be observed directly, it can be inferred from the error term ε_i. Jondrow, Lovell, Materov and Schmidt (1982) present an explicit form to decompose this error term when u_i is distributed as a an average-normal. Both the expected value (E) and the mode (M) of the distribution of the inefficiency term constrained by the composite error term can be used in the estimation of u_i.

$E(u_i/\varepsilon_i) = \sigma\lambda/(1+\lambda^2)\{\varphi(\varepsilon_i\lambda/\sigma)/\Phi(-\varepsilon_i\lambda/\sigma) - \varepsilon_i\lambda/\sigma\}$,

$M(u_i/\varepsilon_i) = \varepsilon_i(\sigma^2_u/\sigma^2)$, if $\varepsilon_i \geq 0$,

$M(u_i/\varepsilon_i) = 0$, if $\varepsilon_i < 0$,

where $\sigma=(\sigma^2_v+\sigma^2_u)^{1/2}$, $\lambda=\sigma_u/\sigma_v$, $\varphi(.)$ is the function of probability density of the distribution and $\Phi(.)$ is the function of accumulated density of the standardised normal distribution function. The parameters σ_v and σ_u can be computed from the moments of the SLS. The efficiency then simply comes from:

$$\text{Efficiency} = \exp(-u_i)$$

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[4] Green has notice that the results depend on the distribution used. He found that the gamma distribution produces results which differ noticeably from those of three (truncated normal, exponential and half normal) alternative formulations (Greene, 1990). However, this is an empirical problem that can be assessed using the consistency condition approach presented below.

The ranking of firms obtained in this fashion are labelled Corrected Least Squares (CLS). It will always be the same at the ranking generated from the residuals of the cost function since the average and the mode constrained by the estimation of the residuals ε_i always increases with the size of the residual.

It may be worth to point out some relevant features of the half normal distribution. By construction, the distribution of the term ε is asymmetric and not normal. This asymmetry can be characterised by the parameter λ. The larger λ is, the larger the asymmetry. In the empirical application, the residuals of the regression must be tested to ensure that the skewness is positive. If the residuals have the asymmetry in the opposite direction, the maximum likelihood estimates is then the Least Square estimator and $\sigma^2_u=0$. This implies that all the firms are operating at their frontier (i.e. are 100% efficient). This could in fact simply be showing that the data is inconsistent with functional specification selected. (Waldman, 1982).

A second estimation approach can then be used. It consist in estimating the parameters of the cost function directly through a maximum likelihood (ML) procedure and to then only follow the procedure described above to decompose the error term. The advantage of relying on ML is that the method takes into account the asymmetric distribution of the error term to assess the technological coefficients.

The following diagrams summarise what has been discussed so far. They also show the indicators that could be used depending on data availability and quality.

Figure 1: Picking Performance Indicators

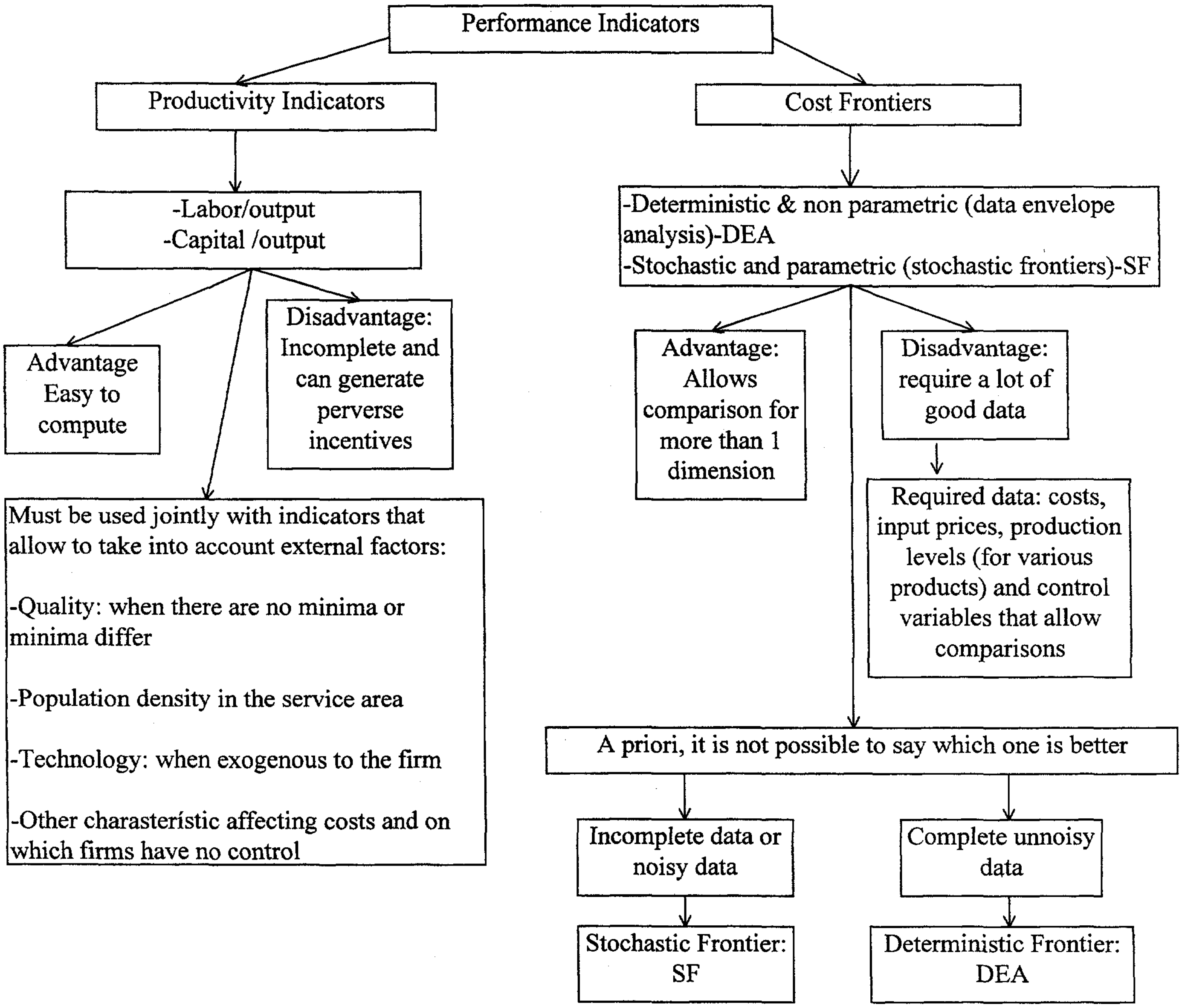
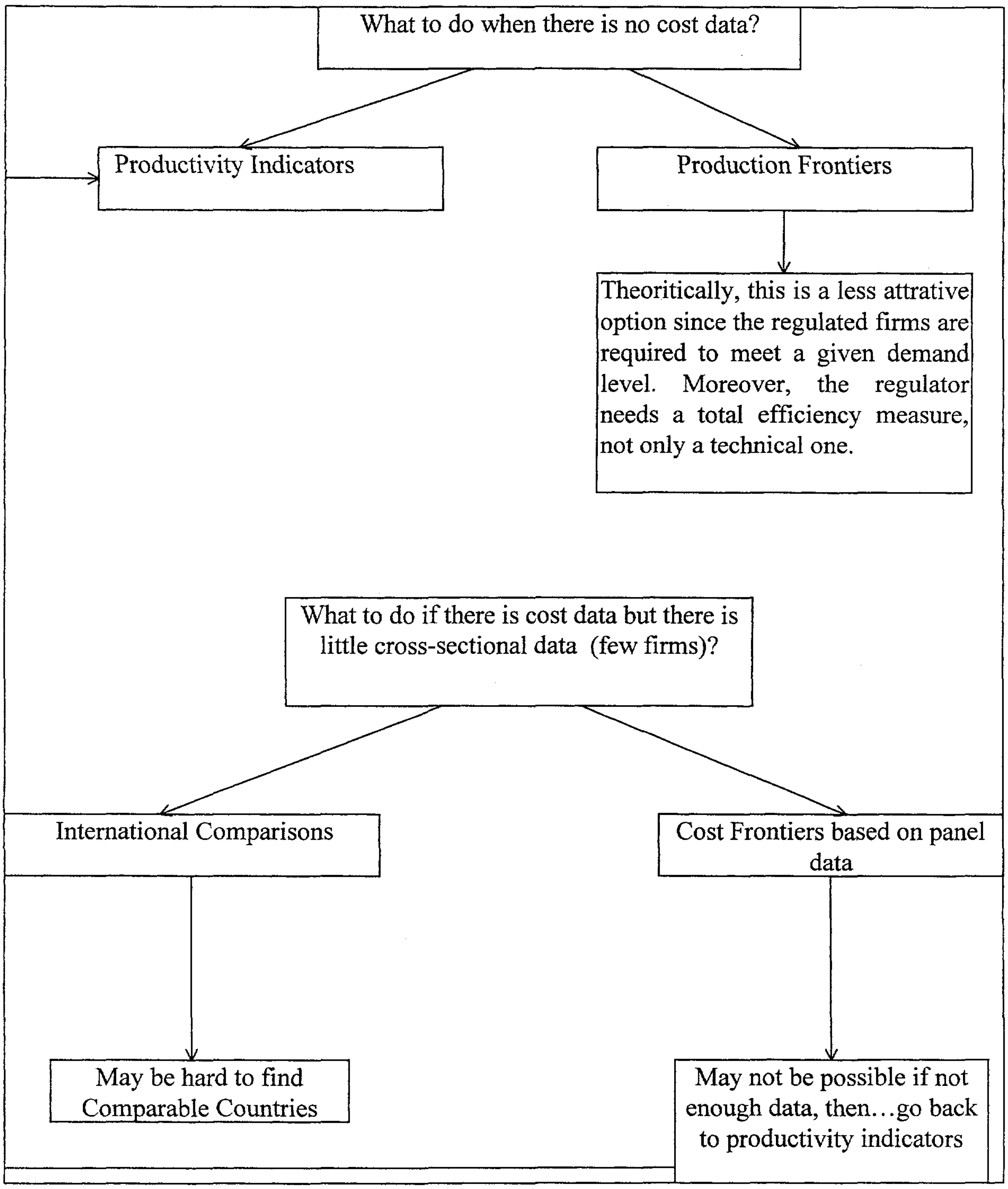


Figure 2: Dealing with Data Constraints



3. A Survey of Empirical Cost Frontiers in the Water Sector[5]

As suggested in section 2, in practice, the costs of regulated public utilities depend on a variety of factors in addition to output levels and input prices. This section reviews what earlier studies reveal about the relative importance of these additional factors

The first published paper is by Stewart (1993). In a report prepared for the UK water regulator, OFWAT, he estimated a cost function for the UK water sector. Stewart describes the three stages of the water business: water production (i.e. extraction from natural sources), water treatment and water distribution. Costs reflect the costs associated with each one of these stages. In general, these costs can in turn be decomposed into three types themselves: operation, maintenance and the return to capital. Stewart focuses on operational costs only. As explanatory variables, he considers: the size of the distribution network, the volume of water sold (these are in fact his two main variables), the volume of water put through the distribution network, the number of properties rented, the volume of water sold to non-residential users. In addition, Stewart considers also some control variables. This requires the identification of the various stages of the production of water services: production, various treatments, distribution and collection. Each may involve different types of treatment, distribution and collection's technology, which have to be modelled somehow since they have consequences for cost levels. For instance, treatment costs will differ with the sources of raw water. "Raw" water can be extracted from two sources: underground and surface sources. It is important to distinguish because often ground water (also not always) requires less treatment than surface water and these influents of. In addition, Stewart considers as control

[5] From a methodological viewpoints some of the empirical studies done in the UK for Gas (Waddams-Price and Weyman-Jones, 1996) and Electricity (Burns and Weyman-Jones, 1994) are quite useful and relevant. Relying on the Malmquist approach, they separate between the frontier shifts effects of privatization (technological gains) and the catch-up effects reflecting the improvement for a given technology. These studies have however been criticized for not taking into account properly the effects of external effects (hence the relevance of control variables).

variables the nature of demand (peak vs. average) and the need for rehabilitation of pipes in poor state and that will require fixing before long.

The specific frontier he estimates for the period 1992-93 for a sample including all privatised water companies in the UK is:

$$LnCOSTS = 3.34\ (0.39) + 0.57\ (0.08)\ lnSALES + 0.38\ (0.08)\ lnNETWORK \\ - 0.62\ (0.27)\ STRUC + 0.13\ (0.06)\ LnPUMP$$

Where COSTS is the total operational cost in the water sector expressed in 1000 of pounds, SALES is the volume of water sold expressed in ML/d (mega litres per day), NETWORK is the length of of the network in Km, STRUC is the volume of water sold on average to non-residential clients/ total volume of water sold, PUMP is the average water pumping needed.[6] The standard deviations are included in parenthesis showing that all variables are statistically significant at a 90% level of confidence. The R^2 is also very high with 0.99.

OFWAT also commissioned a paper by Price (1993) who estimated the following model:

$$AVOPEX = 17.4 + 1.8\ WSZ + 10.3\ TT + 0.1\ PH - 1.9\ BHSZ - 12.1\ MNHH + 21.4\ BHDIS$$

where AVOPEX are the operational expenses per unit of water distributed (pennies/m3), WSZ is the proportion of ground water subject to more than simple disinfection and derived from treatment generating less than 25 million litres/day, TT is the share of surface water subject to more than primary treatment plus the share of ground water subject to more than disinfection only, PH is the average pumping (expressed in relation to water delivered), BHSZ is the average size of wells weighted by the share of total water form that source, MNHH is the share of total water distributed to non residential users and BHDIS is the share derived from wells and only subject to disinfection. This model has a R^2 of 0.851.

Crampes et al. (1997) estimate a water cost function for Brazil in which they include among other variables the volume of water produced (a size parameter), the relation between the volume of billed water and the volume of water produced (a proxy for commercial and technical losses) and the number of connections per employee (a proxy for the type of technology). This last variable can however also be seen as an efficiency proxy which is reasonable to use the estimation results to discuss costs, but is not when it comes to use the cost function as an estimate of the cost frontier, since the cost frontier can no longer be used to assess efficiency. Estimating the model with weighted least squares yields for total costs:

$$COSTS = 5.599\ (8.36) + 0.380\ (4.18)\ PROD - 0.01\ (-10.0)\ PROP1 + 0.590\ (8.94)\ SALAR \\ - 0.712\ (-3.77)\ PROP2 + 0.689\ (6.04)\ CONE - 0.004\ (-4.0)\ PROP3$$

COSTS is total costs, PROD is the volume of water produced, PROP1 is the relation between operational expenditures and revenues, SALAR is the average salary, PPROP2 is the relation between number of connections and the number of employees. CONE is the number of connections and PROP3 is the relation between the volume of water billed and produced. The t-statistic is included in parenthesis showing that all variables are significant and the R^2 is 0.840.

And for average costs:

$$COSTAVER = 13.954\ (18.15) - 0.674\ (-5.57)\ PROP4 - 0.01\ (-10.0)\ PROP1 \\ + 0.598\ (8.67)\ SALAR - 0.907\ (-5.85)\ PROP2 - 0.005\ (-5.0)\ PROP3$$

COSTAVER is the average cost and PROP4 is the relation between water produced and the number of connections. The R^2 is 0.46.

[6] The pumping variable is defined as follows: Average pumping = i (li*wpi) di where li is annual average load in location i in meters, wpi is the volume of water pumped during the year in location i, di is the distribution input and i is the location where the pumping takes place.

While these studies are useful to assist in specifying the costs models, they are not sufficient since they do not include any information on the prices of all inputs (including the price of capital) as is required by Cobb-Douglas or translogarithmic specifications typically found in the literature.

4. Data and estimation of the costs frontier for Asia

The cost frontier for the Asian water companies was estimated from a database published by the Asian Development Bank (1997). Their sample covers 50 firms surveyed in 1995. The information included data on operational and maintenance costs (COST), number of clients (CLIEN), daily production (PROD), population density in the area served (DENS), number of connections (CONE), percentage of water from surface sources (ASUP), treatment capacity (CAPAC), market structure (STRU, represented by the relation between residential sales and total sales in cubic meters), number of hours of water availability (QUALI), staff (PERS), salary (SALAR) and a set of qualitative variables on the type of treatment used: conventional (DUMCONV, with a value of 1 when the treatment is conventional, 0 otherwise), rapid sand filters (DUMFRAP, with a value of 1 is the firms use the filter, 0 otherwise), slow sand filters (DUMFLEN, with a value of 1 if used, 0 otherwise), chlorification (DUMCLO, with value 1 if used with sand filters, 0 otherwise and desalinisation (DUMDES, in, fact only 1 does).

The basic statistics are summarised in table 1. The costs refer to operational and maintenance costs and are expressed in thousands of US$. The client's numbers and the population are expressed in thousands. Treatment capacity is expressed in cubic meters per day. Average salaries are found as the ration of total salary cost to the number of workers

The strategy adopted to estimate the model could be summarised as follows. In a first stage, all the variables likely to determine costs are included in the model. Next, going from the general to the specific, variables are eliminated as follows: eliminate sequentially the least significant variable (any variable with a less than 10% level of significance) and reintroduce at each stage the variable eliminated at the previous stage to ensure that the variable eliminated at the previous stage are still not significant (otherwise, the significant ones are restored in the model) .The model is specified to estimate 2 measures of efficiency which can be used to establish a ranking of firms.

Table 1

	Sample	Average	Maximum	Minimum	Standard Deviation
COST	50	42256	532749	49	92271
CLIEN	50	2453	10595	11	2945
PROD	50	935	4959	2.4	1254
DENS	50	16587	236297	165	33479
CONE	50	416	2099	1.8	548
ASUP	50	0.67	1	0	0.41
CAPAC	44	1168	6190	2.8	1552
PERS	50	3145	25057	15	4275
GDP/CAPITA	49	2385	26730	180	5097
SALAR	50	5042	39130	35	8619
QUALI	50	18.98	24	4	6.85
STRU	45	0.42	0.84	0.09	0.16

The first function to estimate is similar to what is done in Stewart (1993) and Crampes et al. (1997), although it also includes the GDP/capita (in US$) as a control variable.[7] In addition, since the quality norms can differ across countries, the model includes a quality indicator (the number of hours during which water is available every day)[8]. To be able to distinguish public and private firms, the specification includes a dummy reflecting ownership (DUMPUB, with a value of 1 is the

[7] Not many papers compare companies in various countries. Yunos and Hawdon (1997), for instance, compare the performance of operators in Malaysia with those of other similar developing countries (countries of the region with similar per capita income). The main challenge stems from the difficulty of comparing distinct monetary units and often different accounting rules. One solution is to assess the production function since it only requires physical measures of inputs and output. (Yunos and Hawdon estimate a production function). However, in the case of regulated operators subject to contracts imposing exogenous output levels, the correct model has to rely on an specification of the cost function.

[8] To monitor the quality of service delivered by the operators, OFWAT relies on a set of indicators:(OfWAT, 1995): water availablility, water pressure, service interruptions, water use restrictions, responsiveness to complaints about bills, and to written complaints. Due to limited data availability, this paper relies only a single indicator of quality: number of hours of water availability

firm is public and 0 otherwise and a variable DUMCON, which takes a value of 1 is the firm is concessioned and 0 otherwise).

$$\ln COST = \alpha + \beta \ln SALAR + \gamma_0 \ln CLIEN + \gamma_1 DENS + \gamma_2 CONE + \gamma_3 E{=}STRU + \gamma_4 ASUP + \gamma_5 CAPAC + \gamma_6 PROD + \gamma_7 DUMCONV + \gamma_8 DUMFRAP + \gamma_9 DUMFLEN + \gamma_{10} DUMCLO + \gamma_{11} DUMDES + \gamma_{12} CALID + \gamma_{13} PBIPC + \gamma_{14} DUMCON + \gamma_{15} DUMPUB$$

One of the problems with this specification is that only one firm (Malé) desalinises and it thus impossible to compare it seriously to any other because it is impossible to separate the firm inefficiency from the effect of the treatment. Our solution was to exclude this firm from the estimation sample. The efficiency of that specific firm was estimated from a comparison of its actual costs and those estimated from the frontier of the sector. This may however be a problem since its inefficiency level may simply reflect the fact that the specific treatment cost used is simply more expensive that the others.

The final model used to calculate the efficiency measures is:

$$ln\ COST = \alpha + \beta\, ln\ SALAR + \gamma_0\, ln\ CLIEN + \gamma_1\, DENS + \gamma_2\, CONE + \gamma_3\, STRU + \gamma_4\, QUALI + \gamma_5\, DUMCON$$

For the CLS (corrected least squares) results, the signs of the coefficients are expected. The labour price elasticity is positive (0.43) and an improvement in quality increases costs and so does an increase in production (clients or connections). The density of population has a negative elasticity suggesting that it is cheaper to supply the same population in a smaller service area. Finally, the sign of the concession dummy is negative suggesting that costs are lower in concessionaire firms.[9] More specifically,

$$ln\ COST = -\ 0.56\ (0.91) + 0.43\ (0.05)\ ln\ SALAR + 0.72\ (0.08)\ ln\ CLIEN - 0.19\ (0.08)\ ln\ DENS + 0.32\ (0.05)\ ln\ CONE - 0.56\ (0.19)\ ln\ STRU + 0.32\ (0.16)\ ln\ QUALID - 0.82\ (0.47)\ DUMCON$$

9 The coefficient of asymmetry of the CLS residuals has the correct sign (see section 2).

Number of observations: 44; $R^2 = 0.947$; *F-Statistic* $= 93.70$;
$\lambda = 2.465$; $\sigma = 0.514$; $E(u) = 0.38$.

The standard deviations are in parenthesis. The individual efficiency measures and the firm's associated rankings are presented in table 2.

Table 2

Firm	Efficiency (CLS)	Ranking	Efficiency (ML)	Ranking
Almaty	0.71	28	0.56	26
Apia	0.39	42	0.24	43
Bandung	0.28	44	0.15	44
Bangkok	0.72	27	0.78	14
Beijing	0.69	29	0.66	23
Bishkek	0.98	7	0.97	5
Calcutta	0.81	16	0.63	24
Cebu	0.60	33	0.40	36
Chennai	Sd	sd	Sd	sd
Chiangmai	0.96	9	0.96	6
Chittagong	0.74	23	0.47	32
Chonburi	0.45	41	0.41	34
Colombo	0.68	30	0.51	28
Davao	0.96	10	0.74	19
Delhi	0.77	19	0.70	21
Dhaka	1.00	1	0.87	10
Faisalabad	0.74	24	0.43	33
Hanoi	0.85	12	0.50	29
Ho Chi Minh	0.65	32	0.47	31
Hong Kong	0.66	31	0.77	15
Honiara	0.58	34	0.36	37
Jakarta	0.35	43	0.24	42
Johor Bahru	0.57	35	0.60	25
Karachi	1.00	1	1.00	1
Kathmandu	Sd	sd	Sd	sd
Kuala Lumpur	0.83	13	0.87	11
Lae	0.74	25	0.68	22
Lahore	1.00	1	0.97	4
Malé	Sd	sd	Sd	sd
Mandalay	0.98	26	0.76	3
Manila	0.72	8	0.99	16
Medan	0.48	37	0.33	39
Mumbai	0.47	38	0.31	41
Nuku'alofa	0.76	21	0.48	30
Penang	0.80	18	0.74	18
Phnom Penh	1.00	1	0.86	12
Port Vila	Sd	sd	Sd	sd
Rarotonga	Sd	sd	Sd	sd
Seoul	0.81	15	0.81	13
Shangai	0.83	14	0.96	7
Singapore	0.74	22	0.75	17
Suva	0.94	11	0.96	8
Taipei	Sd	sd	Sd	sd
Tashkent	0.77	20	0.72	20
Thimphu	1.00	1	0.95	9
Tianjin	0.46	40	0.40	35
Ulaanbaatar	0.52	36	0.33	38
Ulsan	1.00	1	1.00	2
Vientiane	0.47	39	0.32	40
Yangon	0.80	17	0.52	27

The individual efficiency measures (and the rankings) of Chennai, Kathmandu, Port Vila, Rarotonga and Taipei, could not be calculated at this stage because there was no data available on the market structure. To address these limitations, we estimated first the cost frontier through CLS by assuming that the 5 firms for which we did not know the actual market structure, the average structure was a reasonable proxy. The results are summarised in table 3.

Table 3

Firm	Efficiency
Chennai	0.57
Kathmandu	0.88
Port Vila	0.32
Rarotonga	1.00
Taipei	0.98
Malé	0.23

The regression results from the ML estimates are as follows and the resulting efficiency measures and ranking are covered by table 2.

$$\ln COST = -2.15\ (1.80) + 0.41\ (0.09) \ln SALAR + 0.80\ (0.14) \ln CLIEN \\ - 0.31\ (0.16) \ln DENS + 0.38\ (0.09) \ln CONE - 0.75\ (0.40) \ln STRU \\ + 0.40\ (0.19) \ln QUALI - 0.55\ (0.72)\ DUMCON$$

$$\lambda = 173.51\ (24582);\ \sigma = 1.32\ (0.21).$$

5. Other performance measures

This section compares the ranking resulting from the efficiency indicators with the ranking from efficiency frontiers to assess their consistency and to see if the conclusion reached above in particular with respect to the relation between ownership and performance. For consistency to hold, the efficiency measures generated by the two approaches must show at least a positive correlation with the partial productivity indicators, even if weak since they are not all as effective at taken into account the control variables (Bauer et al., 1998).

5.1. Assessing the consistency of measurements

To assess these consistency conditions, we rely on the indicators estimated by the Asian Development Bank (1997). These indicators cover tariffs (average tariff/cubic meter, average monthly bill, technical efficiency measures such as water losses, operational characteristics (number of hours/day when service is available, purchasing power of the population in relation to their water bill, consumption, subsidies, share of households with water meters, access to public fountains, salary of the directors) and measures of performance such as accounts receivable and number of employees per 1000 connection).

Relying on accounts receivable and number of employees per 1000 connection as performance indicators yields two ranking (one for each indicator).

Table 4

Firm	Accounts Receivable	Ranking	Employee/1000 connections	Ranking
Almaty	5.4	34	13.9	33
Apia	s.d.	s.d.	15.8	35
Bandung	1	11	7.7	24
Bangkok	2	22	4.6	12
Beijing	0.1	2	27.2	46
Bishkek	7.7	41	6.9	21
Calcutta	1.5	16	17.1	38
Cebu	1.9	21	9.3	27
Chennai	5.8	36	25.9	45
Chiangmai	1.2	15	2.9	9
Chittagong	10	42	27.7	47
Chonburi	1.6	19	2.6	7
Colombo	3.2	27	7.3	22
Davao	0.5	7	6.2	18
Delhi	4.5	32	21.4	42
Dhaka	11	43	18.5	41
Faisalabad	12	45	25	43
Hanoi	0.1	2	13.3	31
Ho Chi Minh	3.4	2.9	6.4	20
Hong Kong	4	30	2.8	8
Honiara	5.4	34	10.7	29
Jakarta	1	11	5.9	16
Johor Bahru	2.5	25	1.2	4
Karachi	16.8	46	8.4	25
Kathmandu	4.5	32	15	34
Kuala Lumpur	0.5	7	1.1	2
Lae	3	26	17.1	38
Lahore	7	40	5.7	15
Malé	1	11	7.6	23
Mandalay	0.2	6	6.3	19
Manila	6	37	9.8	28
Medan	0.1	2	4.9	13
Mumbai	19.7	47	33.3	48
Nuku'alofa	1.5	16	16	36
Penang	2	22	4.4	11

Phnom Penh	0.9	10	13.5	32
Port Vila	0	1	5	14
Rarotonga	s.d.	s.d.	3.5	10
Seoul	1.5	16	2.3	6
Shangai	11.1	44	6.1	17
Singapore	1.1	14	2	5
Suva	6	37	8.9	26
Taipei	1.7	20	1.1	2
Tashkent	6.3	39	17.9	40
Thimphu	4	30	25.5	44
Tianjin	0.1	2	49.9	49
Ulaanbaatar	2	22	579.2	50
Ulsan	0.5	7	0.8	1
Vientiane	3.3	28	16.1	37
Yangon	s.d.	s.d.	12	30

To test the assumption that the 3 rankings are not correlated, we run a Spearman test of ranking correlation. The correlation's measured are summarised in table 5.

Table 5

	Stochastic Frontier CLS	Stochastic Frontier ML	Accounts Receivable	Employees per 1000 connections
Stochastic Frontier CLS	1.000	0.861**	-0.205	0.090
Stochastic Frontier ML		1.000	-0.172	0.371*
Accounts Receivable			1.000	0.332*
Employees per 1000 connections				1.000

* means that correlation is significantly different from 0 at a 20% level of significance.
** means that correlation is significantly different from 0 at a 10% level of significance.

The correlation between the rankings from the account receivable and number of workers per 1000 connections) is positive and significantly different from 0 at the 10% level of significance. However, the correlation from the ranking resulting from accounts receivable is negative with the two rankings derived from the frontiers suggesting that the two approaches are not consistent (ie, frontiers vs. partial indicators). This means that the regulatory assessments would vary with the approach adopted![10] As for the number of employees per 1000 connections, the correlation with the

[10] It could be argued that all the firms with accounts receivable for less than 3 months cannot be considered inefficient. However, even if all firms with receivable under 3 months were assigned a ranking of 1, the correlation between the rankings would be similar.

two frontiers ranking is positive and significantly different from zero but it is relatively low. According to Bauer et al. (1998), this is an expected result in view of the control issue raised earlier.[11]

To assess the relation between a firm's performance, its ownership and the degree of private sector participation (public enterprise, concession, private provision only on production, or only on billing and collection), the following covariance matrix is useful, with the t statistics needed to test that the correlation is zero (null hypothesis) is given in parentheses.

Table 6

	Public Operators	Concessions to Private Operators	Firms in which the private sector only intervenes at the production stage	Firms in which the private sector only operates at the *billing and collection stage*
Accounts Receivable	0.13 (0.95)	-0.09 (-0.68)	-0.12 (-0.86)	-0.16 (1.15)
Employees per 1000 connections	0.19 (1.34)	-0.04 (-0.34)	-0.086 (-0.59)	-0.08 (-0.61)

Table 6 shows that the signs of the correlation coefficients confirms that the private sector is more efficient since any time the private sector is involved the correlation is negative. The larger the accounts receivable (best practise is no more than 3 months), the larger the inefficiency of the firm. And similarly the larger the number of employees per 1000 connections. This means that we can reject the assumption that there is no correlation between performance and ownership with a strong degree of certainty (with a 10% level of statistical significance). This result is consult with the one derived from the cost frontiers and hence provides a strong presumption of robust evidence that private participation cut costs.

[11] See section 5.2.

5.2. The conditions for consistency

Up to now, we have presented two broad approaches to analyse the performance of firms: partial productivity indicators and frontiers. We have argued that these frontiers provide a better, more complete, snapshot. However, there is no real consensus among researchers as to how to measure this frontier. Yet, the choice of method can influence regulatory decisions. The problem stems from the multiplicity of individual efficiency measures available. So a far question is whether efficiency studies are useful at all.

Trying to answer this question, Bauer et al. (1998) propose a set of consistency conditions with which the efficiency measures derived from the various sources must comply to be relevant to regulators. They must be consistent over time, and with the other performance measures used by the regulators. More specifically, the consistency measures are:

- The efficiency measures generated by the various frontiers methods must yield similar averages and standard deviations
- The various approaches must rank firms in a similar way;
- The various approaches must identify the same best and worse firms;
- The individual measures must be reasonably consistent over time and should not vary significantly from year to year;
- The various measures must be reasonably consistent with the results expected from the developments in the industry. In the particular case of regulated enterprises, for instance, the firms regulated through a price cap mechanisms are expected to be more efficient than those regulated through a rate of return regulation; and
- The efficiency measures must be reasonably consistent with other performance measures (accounts receivable and employees per 1000 conections, in this paper) used by the regulators.

Overall, the first three measures show the extent to which the various frontiers approaches are mutually consistent, while the other conditions show the degree with which the efficiency measures generated by the various approaches are consistent with basic facts. In other words, these last condition provide an "external criterion" to assess the various approaches.

5.3. Using efficiency measures in the practice of regulation

One of the main changes of the last decade in the practice of regulation has been the adoption by a large number of regulators of some form of price cap regimes. The main purpose of a switch from rate of return regulation to price cap regulation has been to increase the incentive for firms to minimise its costs and to ensure that eventually users will benefit from these reduction in costs—typically within 3-5 years after a regulatory review of improvements in the efficiency in the regulated sector. The adoption of price cap regulation is one of the main reasons for this increase in the efforts to measure efficiency in regulated sectors. Indeed the cost reductions observed will be associated with efficiency gains which have to be measured. Efficiency measures are no longer a side show as they are under rate of return regulation.

The initial regulatory challenge at the time of a price review is the following. If the productivity gain used to assess the new price cap is specific to the firm and based on gains achieved by this firm in the past, this firm will not have strong incentives to improve efficiency to cut costs because this would result in a lower price cap. An alternative for the regulator would be to measure efficiency gains by relying on factors which are not under the control of the regulated firm. But in that situation, if the regulator has very little knowledge of the past costs of the firm and based its measure of efficiency gain on, for instance, the productivity gains in a related sector in the economy, some perverse effects may penalise the firm. This is why the suggestion to rely on yardstick competition is so tempting for regulators. Price can be set for an industry based on the aggregate industry performance. For instance, the price cap can be based on the average unit cost in the industry rather than on the firm specific average unit cost and this gives a strong incentive to the firm to have a unit cost below average. In this context, efficiency measures are an input in the regulatory mechanism in an even more direct way than under rate of return regulation.

The next regulatory challenge is to understand that efficiency gains of a firm can come from two main sources, which require some idea on the part of the regulator of where the cost frontier lies. Indeed, gains can come from shifts in the frontiers reflecting efficiency gains at the sectorial level. Efficiency gains at the firm level can also reflect a *catching up effect*. These are the gains to be made by firm not yet on the frontier. These firms should be able to achieve not only the industry gain but also specific gains offsetting firm specific inefficiencies explaining why the firm is not on the frontier. This is why it is so important for a regulator to be able to use all the information provided by frontier based measures in the firm specific tariff revision.

This can be done by recognising that efficiency indicators are by construction index numbers varying from 0 to 1, when 1 reflects the fact that a firm is totally efficient and 0 that it is completely inefficient (i.e. as far as possible from the sector frontier). For instance, if a firm has an efficiency index of 0.8, it means that it could produce the same level of output at 80% of its current costs. This means that the cap should be based on 80% of current cost, not 100%. With this approach, only the firms reaching 100% of efficiency would be allowed to recover their opportunity cost of capital while the others would have lower rates of return.

A simple example will clarify this point. Imagine, that an industry regulated through price caps has a recognised cost of capital of r with a stock of capital of K. If the firm sells a unit at a unit cost of C, the price P that the regulator would approve would usually have been

$$P = r^*K + C$$

Now under the adjusted rule, and using α as the efficiency index for the firm, the new price NP that the regulator should allow would be:

$$NP = r^*K + \alpha C$$

This new mechanism automatically cuts the rate of return for the inefficient firm and to get to the industry rate of return, the firm has to cut cost to reach the industry efficiency standards.

The implementation of this mechanism however requires that at the minimum, the first two consistency conditions are met (consistency in efficiency levels and ranking). If these are not meet, these mechanism cannot be applied since the individual efficiency measures would be somewhat subjective and hence unreliable. However, if the third consistency rule is met, (consistency in identifying best and worse performers), it would still be possible to use a third approach: publish the results. This approach is used in the UK in the water and electricity sectors. The idea is to inform the users and allow them to compare prices and services across regions and give them a reason to put pressure on their own operator if it is not performing well.

A fourth mechanism requires none of the consistency conditions and is proposed by London Economics. The idea is to estimate a stochastic average cost function (different from the frontier)

$$C = m_0 + m_i Z_i,$$

where the parameters measure the sensitivity of costs (C) to variables Z_i. Then, the regulated prices are fixed according to the estimated costs. The difference with the second mechanism, is that the regulator now recognises the average cost of the firm instead of the frontier costs. For instance, the idea to use average cost instead of minimum cost to set the efficiency parameter has been proposed for electricity in the UK (CIE, 1994).

6. Conclusions

The main point of this discussion is that these efficiency indicators are not just simple "academic" exercises but that they can be used to yield results with very direct applications in the regulatory process.

The results presented here stress the advantages of relying on efficiency frontiers over the usual alternative options in the process of implementing yardstick competition. This methodology allows to control for factors over which the operators have no control (i.e. diversity of water sources or of water quality, characteristics of users). For instance, Dhaka is ranked first if the stochastic frontier is estimated using CLS. It is ranked 43 and 41 respectively, relying on more traditional indicators such as account receivable or numbers of workers per 1000 connections.

As for the impact of ownership on the efficiency of operators, both the CLS and the ML models show that the private operators are more efficient. In monetary terms, the total gains for the region of an efficiency level similar to the one achieved by private operators would be around US$85 millions per year.[12] This means that the gains of every new concession would be on average of around US$1.8 million per year.

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[12] This number was calculated using the coefficient of the dummy variable in the ordinary least square regression.

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