Regulation and Efficiency Incentives: Evidence from the England and Wales Water and Sewerage Industry

Fabrizio ERBETTA, Martin CAVE

Working Paper 8, 2006

© HERMES
Fondazione Collegio Carlo Alberto
Via Real Collegio, 30
10024 - Moncalieri (TO)
Tel: 011 670 5250
Fax: 011 6705089
info@hermesricerche.it
http://www.hermesricerche.it

Regulation and Efficiency Incentives:

Evidence from the England and Wales Water and Sewerage Industry

Fabrizio Erbetta[a,b], Martin Cave[c *]

Abstract

The aim of this paper is to assess the impact of the regulatory policy on both technical and allocative efficiency for the England and Wales water and sewerage industry after privatisation. Previous empirical results suggest that the regulatory system introduced at privatisation was too lax (Saal and Parker, 2000) and the evidence that the first price review in 1994 produced efficiency gains is still quite ambiguous (Saal and Parker, 2001 and 2004). The 1999 price review signalled a change in the regulatory policy by imposing a price reduction, which might be expected to lead to a faster increase in efficiency. This paper evaluates the impact of the tightening in the regulatory regime and of other operational factors on efficiency through a two-stage approach derived from Fried *et al*. (2002). The 1999 price setting is shown to have a significant impact on the reduction of technical inefficiency. Furthermore the new economic environment set by price-cap regulation, along with the need for capital renewals and investments, acted to bring inputs closer to their cost-minimising optimal levels.

Keywords: water and sewerage industry, data envelopment analysis, stochastic frontier approach, regulation, input distortions

[a] *Università del Piemonte Orientale "Amedeo Avogadro", Facoltà di Economia, Via Perrone 18, 28100 Novara, Italy*

[b] *HERMES, Centre for Research on Regulated Services, Collegio Carlo Alberto, Via Real Collegio 30, 10024 Moncalieri (TO), Italy*

[c] *Warwick Business School, University of Warwick, Coventry, CV4 7AL, UK*

Corresponding author: Fabrizio Erbetta, Università del Piemonte Orientale "Amedeo Avogadro", Facoltà di Economia, Via Perrone 18, 28100 Novara (Italy), Tel +39 (0)321 375.440, Fax +39 (0)321 375.405, email: fabrizio.erbetta@eco.unipmn.it

[*] We are grateful to Ian Byatt, Giovanni Fraquelli, Mark Stewart and seminar participants at OFWAT for their useful comments. Nevertheless we are responsible for any remaining errors in the text.

1 Introduction

The England and Wales water and sewerage industry was privatised in 1989 and subjected to a sequence of five-year price controls in the form of price caps. Price-cap regulation is a high-powered incentive scheme. But previous empirical work has shown that the cap introduced at privatisation had been too lax (Saal and Parker, 2000) by allowing high price increases, and the evidence that the first price review in 1994 produced efficiency gains is still quite unclear (Saal and Parker, 2001 and 2004). This might be explained by the double duty of the regulator to encourage a higher level of efficiency and provide the companies with the financial resources to support their investment programmes. The 1999 price review signalled a change in the implementation of regulatory policy by imposing for the first time a price reduction.

This paper aims to evaluate the impact on efficiency of this tightening in the regulatory system, as well as of other operational factors, through a DEA-based two stage approach derived from Fried *et al*. (2002). In the first stage, DEA (Data Envelopment Analysis) is run over a balanced panel data composed of the ten water and sewerage companies observed between 1992-93 and 2004-05. Estimates of technical and allocative efficiency have been obtained. In the second stage we calculated input-specific technical excess utilization and allocative distortion measures and regressed them on a set of environmental variables using Stochastic Frontier Approach (SFA). These explanatory variables are chosen to represent both the operational and regulatory environment under which the firms operate. In this way, we provide a decomposition of the DEA-based overall technical and allocative inefficiency into three components: environmental impact, pure managerial inefficiency and statistical noise.

This approach has several advantages. First, it makes it possible to incorporate environmental effects and statistical noise into a DEA-based model. Second it allows us to evaluate the impact of the new regulatory environment on both technical and allocative efficiency. Third, it provides input-specific efficiency measures, which can be decomposed in order to identify the pure managerial efficiency as a residual.

The remainder of the paper is organised as follows. Section 2 provides a general description of the regulatory regime for the English and Welsh water and sewerage industry, intended to offer a context to the research question this paper deals with. Section 3 offers a review of the existing literature dealing with efficiency in the water industry in England and Wales as well as abroad. The model specification is included in section 4. Section 5 focuses on the input and output variables along with the arguments that support their choice, while section 6 specifies the environmental and regulatory factors. Empirical results are presented and discussed in section 7. Section 8 concludes and provides policy implications.

2 Regulation of the Water Industry

With the privatisation of the industry in 1989, the ten Regional Water Authorities (RWA) were transferred to the private sector, with the functions of water supply, sewerage collection and sewage disposal, and they became Water and Sewerage Companies (WaSCs). The responsibility for drinking quality and environment regulation was passed to independent agencies, respectively the Drinking Water Inspectorate (DWI) and the Environmental Agency (EA). The then current integrated structure of the water and sewerage industry was thus almost entirely preserved, with the exception of quality regulation functions which were considered more opportunely managed by public agencies (Hunt and Lynk, 1995).

The ten privatised companies, along with the 29 already privately-owned water only companies, form the England and Wales water and sewerage industry. The industry structure is concentrated, with only ten companies providing both water and sewerage services in England and Wales and accounting for 78% in terms of water supplied to the population in 85% of the served area (Saal and Parker, 2000). Given the large amount of the assets transferred to the private sector, and the (then) monopolistic nature of the established companies the function of regulating prices was given to an independent agency, the Office of Water Services (OFWAT), whose main task is to set price in a way that encourages the companies to generate investment funds, enhance their efficiency level and fulfil programmes for achieving high quality and environmental standards.

Since privatisation in 1989 the England and Wales water and sewerage industry has been subjected to a regulatory regime based on price-cap regulation. This is a substitute for competition and is implemented by allowing companies to change prices according to the inflation rate (RPI, Retail Price Index), plus or minus a K factor decided by the regulator (OFWAT). This factor is composed of a negative component that accounts for the potential increase in efficiency that the regulator judges to be achievable (X-efficiency) and a positive component that is set to accommodate the large capital investment programme of the companies. The price determinations are also based on a comparative performance assessment (yardstick competition). This system allows the regulator partially to circumvent the lack of information that typically characterises the relationship between regulator and regulatees. Once prices are set, if firms manage to deliver service at a lower average cost than that assumed by the regulator, they keep the resulting benefits. The regulator can thus provide firms with the incentive to increase their efficiency and then pass part of the cost savings to the customers through a subsequent reduction in prices. To the extent that changes in price are set appropriately, price cap regulation operates as a high-powered incentive scheme. The attempt to increase efficiency could lead to a reduction in the overuse of the resources, given the amount of demand that the firm faces (technical efficiency), and/or to a change in input mix, given the relative prices of the inputs (allocative efficiency). The aim of the paper is to analyse the trend of both the efficiency components during the regulated period from 1992-93 to 2004-05 and investigate whether the regulatory price reviews succeeded in the purpose of encouraging convergence towards higher efficiency.

The first price limit was set by the Government at privatisation in 1989. New price reviews have been set in 1994, 1999 and 2004 at intervals of five years[1]. Given the data available, we will be able to analyse the impact of the 1994 and 1999 price reviews.

Following privatisation, prices for the water and sewerage service rose, on average, by almost 30% during the years up to the 1994 price review (Saal and Parker, 2000), thus providing firms with the financial resources necessary to sustain their capital investments. The 1994 price review set an average yearly increase by 1.5% up to 1999, with the expectation of a further increase by 0.6% per year over the period 2000-01 to 2004-05 (OFWAT, 1994). However, with the 1999 price review, the regulator reduced prices by 12.3%, on average, for the first year of the new period. The average annual reduction over the whole five years was 2%[2].

The 2004 price review, however, did not continue in this way, as it allowed an average annual increase over the whole five-year period 2005-2010 of 4.3%, one percentage point above the draft price determination (OFWAT, 2004).

The 1999 review thus signalled a change in the regulatory policy and concentrated in one year the greatest part of the price reduction. Hence, we might anticipate different behaviour from firms oriented to the elimination of inefficiency. Firms might also game the system by choosing to suppress efficiency gain at the end of a price control period. At the same time privatisation should have removed the implicit distortion found in public firms, such as the overuse of employment for social and political reasons, so allowing the regulation policy being more effective. We examine what the data tell us about the importance of these various effects.

3 Previous empirical literature

In this section we present a brief description of previous empirical studies that have been conducted on the economic analysis of the water and the integrated water and sewerage industry, in both the UK and other countries.

The first point of interest concerns the analysis of cost efficiency. As far as UK experience is concerned, a few early papers attempted to evaluate the firms' cost efficiency and total factor productivity after the privatisation of the industry as well as establish the impact of regulation.

Stewart (1993, 1994) investigated water and sewerage costs separately, using an econometric frontier approach. The results are shown to depend on the distributional assumption employed in the econometric specification.

Ashton (2000a) analysed the firm-specific cost efficiency conditions of the UK water and sewerage privatised companies as combined entities over the period between 1987 and 1997, using a translog variable cost specification. This study finds a moderate level of dispersion of average inefficiency which could be indicative of the diversity both of operating environment and of performance in the sector. In another contribution Ashton (2000b) identified the dynamic aspects of performance of the privatised WaSCs between 1989 and 1997, exploring the characteristics of the total factor productivity growth. The results highlight a decline in total factor productivity and technical change, thus drawing the attention to the modest impact of privatisation since 1989.

A joint consideration of the effect of privatisation and regulation on economic efficiency was carried out by Saal and Parker (2000). In this study the ten WaSCs, observed between 1985 and 1999, were modelled using a multi-output translog total cost function. The findings suggest that technological change has been labour-saving and capital-augmenting. The hypothesis of a different total cost growth rate after privatisation and the 1994 price review was tested. While the former hypothesis was rejected, revealing that no effect could be found due to privatisation, the second one was not, so indicating that the main source of cost efficiency is to be found in the industry regulation. In another contribution Saal and Parker (2001) employed labour and total factor productivity (TFP) indices and they rejected the hypothesis of increasing overall productivity due to privatisation, even though labour productivity showed a significant growth rate. The proposed explanation stems from a decreasing trend in capital productivity trend, due to capital for labour substitution in the post-privatisation period and the failure of the regulator to counteract this over-investment process[3]. TFP tendency did not show improved growth rate after the 1994 price review, even though the greater part of the labour productivity increase took effect during this period along with a significant reduction in growth rate of inputs. Further results are found in Saal and Parker (2004), where there is no evidence that privatisation led to a TFP growth but some evidence of improving TFP owing to the 1994 price control. In a more extensive study, Saal and Reid (2004), employing a quality adjusted translog variable cost function, showed that while the 1994 price review improved operating cost productivity, the 1999 price review did not provide evidence of a further productivity growth rate. Saal, Parker and Weyman-Jones (2004) adopt an input distance function approach in order to decompose productivity growth into technical change, efficiency change and scale efficiency change. This study claims that while technical change occurred as a consequence of privatisation, efficiency change did not eventuate because the regulatory price control was lax. Evidence of a decreasing industry operating cost inefficiency as well as of a narrowing of the inefficiency differentials for the whole English and Welsh water industry between 1995 and 2001 is also found in Bottasso and Conti (2003).

The role of regulatory policy has been recently examined by Aubert and Reynaud (2005) for the Wisconsin water system. The particular Wisconsin regulation scheme, based on the simultaneous presence of price-cap and rate-of-return schemes in the same area and at the same time, allowed the authors comparing the effect of the two different regulatory regimes. Using a stochastic cost frontier approach where the inefficiency error term is modelled as a function of the regulatory type, they surprisingly conclude that the most efficient utilities are those operating under a rate-of-return regime[4] and subject to extensive information gathered by the regulator. Price-cap regulation was shown to be a higher-powered incentive mechanism than a hybrid regulatory scheme with less information available for the regulator. The need for the regulator to gather information in order to enforce an effective yardstick competition system is also emphasised by Anwandter and Ozuna (2002), in the context of the public water industry reform in Mexico.

Evidence of a poor effect attributable to the private ownership, given the monopolistic nature of the service, is available also in other studies. Feigenbaum and Teeples (1983), using a sample of government and privately-owned U.S. water suppliers, suggest that, contrary to public choice or property rights theories, no evidence could found of significant differences in the cost functions of public versus private utilities. Bhattacharyya, Parker and Raffiee (1994) and Bhattacharyya *et al.* (1995a and 1995b) modelled the cost structure of a sample of U.S. water utilities embodying the potential input allocative distortion attributable to the ownership nature[5]. The main results highlight a better efficiency performance of the public firms at least when the operational size is large. Lambert, Dichev and Raffiee (1993) examined the question of the ownership structure for U.S. water system using a linear programming approach. They found no difference between private and public categories in selecting the least cost combination of inputs.

An alternative method for modelling the technology and assessing efficiency performance is via DEA (Data Envelopment Analysis), although DEA was criticised by OFWAT in 1994 as a means of setting price limits. A comprehensive description of the use of DEA for regulatory purposes is provided in Thanassoulis (2000a and 2000b), where DEA methodology has been employed with the aim of estimating the potential operating cost savings for the water function. These studies also address to the issue of technology representation. Other applications of DEA can be found in Tupper and Resende

(2004) in the context of the Brazilian water and sewerage system and in Coelli and Walding (2006) in the context of the Australian water industry. The former, in particular, provides a second stage correction of the DEA efficiency scores in order to account for regional operational heterogeneities (density effects and water losses). Cubbin and Tzanidakis (1998) carried out a comparison between regression analysis and DEA for the UK water industry using 1994-95 data. This study concludes that DEA analysis could be useful in identifying possible reasons for poor performance, but it is to be used with caution where large datasets are not available.

Summarising, as far as the UK context is concerned, analysis of the impact of regulation has been limited to the 1994 price setting and the evidence shows a scant effect of regulation on efficiency. The 1999 price review tightened the regulation scheme, imposing for the first time a price reduction. This paper analyses its effect. Furthermore, from a methodological viewpoint, this study seeks to shed light on allocative efficiency, which has received limited attention in the empirical literature.

The dataset used in this study covers the period from 1992-93 to 2004-05 for the ten WaSCs, and although it does not allow us directly to consider the impact of privatisation on the efficiency conditions, it offers the possibility of testing the effects of two consequent price reviews, and in particular of the tightening associated with the 1999 review. This makes it possible to address the question of whether the tightening of the regulatory regime actually succeeded in improving the cost efficiency into the water and sewerage industry.

4 Model specification

Economic efficiency (EE) can be decomposed into technical efficiency (TE) and allocative efficiency (AE). Technical efficiency deals with the overuse of all inputs simultaneously and the reduction of these latter needed to achieve the maximum productivity. Allocative efficiency deals with the distortion in the proportions in which technically efficient inputs are used.

Efficiency conditions can be analysed through an output-oriented or an input-oriented approach. The former maximises the outputs given the amount of inputs, whereas the latter minimises the use of inputs given the level of output which is to be provided. Generally, the adoption of an input-oriented approach is preferred with regard to the public utility industries since the demand level the suppliers face could be seen as exogenous (see Torres and Morrison Paul, forthcoming, for an application with endogenous output). For this reason, we will use an input-oriented approach in this study.

The concepts of technical efficiency stems from the original statements of Debreu (1951) and Farrell (1957).

In Figure 1 a conventional input requirement set is depicted, the two axes showing the amounts of the two inputs that can produce a given level of output. The points lying on the boundary *BB*' are technically efficient since it is no possible to further reduce all the inputs simultaneously. On the contrary, point *D* is technically inefficient since the same amount of output can be produced with a lower quantity of both inputs (as shown by the point *E*).

[Figure 1 around here]

Let *N* be the number of Decision Making Units (DMUs), x_i the *i*-th input ($i = 1 \ldots I$) and y_j represent the *j*-th output ($j = 1 \ldots J$). The input-oriented Debreu-Farrell radial measure of technical efficiency (TE_I) could be calculated solving, for each DMU, the following optimisation problem (Charnes, Cooper and Rhodes, 1978; Banker, Charnes and Cooper 1984), under the hypothesis of variable returns to scale (*VRS*)[6]:

$$
\begin{aligned}
&\min TE_I - \varepsilon\left(\sum_{i=1}^{I} S_i + \sum_{j=1}^{J} S_j\right) \\
&TE_I x_i - S_i = \sum_{n=1}^{N} \lambda_n x_{in} \qquad i = 1 \ldots I \\
&y_j + S_j = \sum_{n=1}^{N} \lambda_n y_{jn} \qquad j = 1 \ldots J \\
&\sum_{n=1}^{N} \lambda_n = 1 \\
&\lambda_n, S_i, S_j \geq 0
\end{aligned}
\qquad [1]
$$

where S_i and S_j indicate the slacks for input *i*-th and output *j*-th (that is affordable single-input reductions and/or single-output increases arising when the inefficient point is projected on a vertical or horizontal branch of the piece-wise linear frontier), ε is an infinitesimal and λ_n is an intensity variable DEA assigns to each DMU in order to compute the linear combinations between inputs and outputs that allow defining the piece-wise convex hull *BB*'. Obviously they assume non-zero values only for those DMUs that lie on the frontier and that represent the peers for the inefficient observed unit. In other words, the λ_n-weights identify the benchmark of an inefficient unit on the best practice frontier that could be achieved if the *n*-th DMU proportionally reduces the usage of inputs by the scalar TE_I. The identification of the benchmark occurs on the basis that the inefficient DMU is compared only with units with a similar size, given the *VRS* hypothesis.

Let define the prices of the inputs as w_i. In Figure 1 the isocost line is depicted by the straight line, whose slope is equal to the ratio of the two inputs prices. Hence, technical efficiency could be expressed as the ratio between technical efficient cost corresponding to the use of the contracted inputs (C^{TE}) and actual cost (C^a), given the output:

$$\text{Technical efficiency} = \frac{C^{TE}}{C^{a}} = \frac{\sum_{i=1}^{I} w_i \left(TE_I\right) x_i}{\sum_{i=1}^{I} w_i x_i} \qquad [2]$$

Whereas [2] computes a cost-based measure of technical efficiency, it does not take into account the impact on cost due to a wrong input mix. Turning to Figure 1, while points *E* and *F* are equally efficient under a technical viewpoint, point *E* lies on a higher isocost than *F*. The difference between C^{TE} and the economic efficient cost (C^{EE}) is due to a sub-optimal allocative behaviour.

Allocative efficiency can be calculated by solving, for each DMU, the following *VRS* optimisation problem (Coelli *et al.*, 2005):

$$\begin{aligned}
&\min \sum_{i=1}^{I} w_i x_i^* \\
&x_i^* \geq \sum_{n=1}^{N} \lambda_n x_{in} \qquad i = 1 \ldots I \\
&y_j \leq \sum_{n=1}^{N} \lambda_n y_{jn} \qquad j = 1 \ldots J \\
&\sum_{n=1}^{N} \lambda_n = 1 \\
&\lambda_n, x_i^* \geq 0
\end{aligned} \qquad [3]$$

In [3] the unknown values x_i^* correspond to the *i*-th input in the cost-minimising input vector. Hence allocative efficiency can be measured as follows:

$$\text{Allocative efficiency} = \frac{C^{EE}}{C^{TE}} = \frac{\sum_{i=1}^{I} w_i x_i^*}{\sum_{i=1}^{I} w_i \left(TE_I\right) x_i} \qquad [4]$$

By construction, both efficiency measures are bounded between 0 and 1. Moreover the economic efficiency can be calculated as product of the technical and allocative coefficients:

$$\text{Economic efficiency} = \frac{C^{EE}}{C^{TE}} \times \frac{C^{TE}}{C^{a}} = \frac{\sum_{i=1}^{I} w_i x_i^*}{\sum_{i=1}^{I} w_i x_i} \qquad [5]$$

DEA has the disadvantage that it does not accommodate the potential impact of the environmental conditions as well as noise. Yet no efficiency comparative analysis should neglect the operational characteristics under which firms operate. Such operational characteristics might create advantages or disadvantages for the firms, so that the efficiency scores might result heavily affected. In other words, a high/low efficiency score might be attributed to favourable/unfavourable actions of exogenous variables, or to a random component, rather than to the actual effort/inadequacy of the managers.

In order to embody the action of environmental and random components into the results, we adopted a method proposed by Fried *et al*. (2002) in the context of technical efficiency, and now extended, in this study, to allocative efficiency. The aim is to disentangle the technical and allocative input-specific distortions as to capture the role played by environmental non-controllable variables and noise, separately from actual (technical and allocative) managerial efficiency[7].

According to Fried *et al*. (2002), each input-specific over-utilization with respect to its technically optimal level could be a function of a set of environmental variables, random noise or a (pure) managerial technical inefficiency. To this end, the overuse measures derived from the first DEA-based stage have been pooled and then regressed over a set of environmental variables using Stochastic Frontier Approach (SFA), as described below:

$$\left(x_i - TEx_i\right) = f(z;\beta) + u + v \qquad \text{for each } i = 1 \ldots I \qquad [6]$$

where the z's represent the environmental variables outside the control of managers, β are parameters to be estimated, u is a non-negative half-normal distributed $N^+(0,\sigma_u^2)$ error component[8] that captures the excessive use of the i-th input brought about by pure managerial inefficiencies and v is the usual normal distributed $N(0,\sigma_v^2)$ random component.

Analogously, the input allocative distortion with respect to the cost-minimising input levels is regressed by SFA on a set of variables which enable to control for the impact of exogenous factors. In this case, since the input distortion could be either positive or negative, we considered, on the left-hand side of the equation, the absolute value of the allocative differences[9]:

$$\left|TE\ x_i - x_i^*\right| = f(z;\beta) + u + v \qquad \text{for each } i = 1...I \qquad [7]$$

where *z*'s, *β*, *u* and *v* have the same meaning as before. In this case, the inefficiency term *u* should be interpreted as the inability of the managers to combine the resources, given their relative prices, so as to minimise cost.

In order to capture the dynamic of the inefficiency component over time, the inefficiency error term has been modelled according to the time-varying inefficiency model defined in Battese and Coelli (1992), with the *u* following the rule:

$$u_{nt} = \left(e^{-\eta(t-T)}\right) \times u_{nT} \qquad [8]$$

where $t = 1 \ldots T$ is the time, T indicates the final year of the time series and η is a parameter to be estimated. The u_{nt}'s are supposed to be i.i.d. as the half-normal random variable. A positive value of η implies a downward trend in the managerial efficiency term over time while a negative value implies an upward trend. Thus the trend of the managerial inefficiency, along with its statistical significance, is directly derived from the data, once both environmental factors and noise have been removed:

It has to be acknowledged that a restrictive assumption applies in that all the firms are assumed to have a similar trend of the *u* component over time. This could represent a disagreeable restriction of the model. Anyway, this could be justified as all the water and sewerage companies share very similar regulatory conditions and the restrictions enforced by the central regulator is well expected to lead firms in a common direction.

Finally, it should be noted that, in a different way than in Fried *et al*. (2002), the input slacks are not considered in the input-based technical inefficiency equations. The procedure of disentangling technical from allocative inefficiency leads us implicitly to consider slacks into the allocative distortion equations, as the potential non-radial contraction of specific inputs reflects the adjustment of an inappropriate input mix (Coelli *et al*., 2005; Ferrier and Lovell, 1990).

5 Specification of the technology using DEA

A fundamental stage in DEA is the correct identification of the multiple-input multiple-output bundles, so that firms can be compared taking into consideration all the activities they carried out (Thanassoulis, 2001).

With respect to the industry under investigation, the first activity concerns the extraction and treatment of water from rivers or boreholes. Once water has been abstracted and treated to meet quality parameters, it is pumped into the mains and delivered to household or non-household customers through the distribution network. A second set of activities deals with the collection of waste water through the sewage network and the disposal of the effluent in the sewage treatment works so that water can be returned to its natural environment. There is a body of literature that attempted to model water and sewerage technology and cost structure (among the others, see the studies of Fabbri and Fraquelli, 2000; Garcia and Thomas, 2001; Mizutani and Urakami, 2001; Torres and Morrison Paul, forthcoming). The choice of inputs and outputs described below is generally consistent with this literature.

Using this scheme we identified four outputs (Stone and Webster, 2004), each of them able to capture a specific resource-consuming phase of the overall transformation process.

First, the total volume of delivered potable plus non potable water (*WDEL*) has been used as the output of the abstraction and treatment phase. This is a conventional measure of the water production activity. An alternative measure, also tested in this work without significant changes in the results, is the distribution input, which is defined as the amount of water entering the distribution system, including the water losses along the distribution network.

Second, the total number of household and non-household water service-connected properties (*WPROP*) has been adopted as proxy for the scale of the distribution activity.

Third, the total number of household and non-household sewerage service-connected properties (*SPROP*) has been used as to capture the extension of the waste water collection activity.

Finally, the physical amount of waste water (*WASTW*) has been included as output of the effluent disposal and treatment activity.

One important characteristic of these companies is that they must comply with drinking water quality standards (issued by DWI) and river quality standards (issued by EA). Thus water quality could be regarded as an additional output, since the fulfilment of quality programmes is usually highly expensive. However, instead of considering water quality as a separate output we adopted the solution, suggested by Saal and Parker (2000), of adjusting the *WDEL* variable by a firm-specific compliance index with drinking water quality standards and *WASTW* by a firm-specific water quality compliance index with river quality standards. Both the compliance indices have been standardised with respect to the average England and Wales corresponding compliance levels[10].

For modelling the production process we used three inputs: labour, other operating expenditures and capital. All the variables have been expressed in 2002-03 prices.

Labour input (*EMPL*) is measured by the total cost of non-manual and manual manpower which is directly attributable to the water and sewerage businesses. In order to obtain a proxy of the physical use of labour we adjusted this variable by a firm-specific labour price index[11].

The other operating expenditures variable (*OTHEX*) has been calculated by subtracting the cost of labour from the total operating expenditures (*OPEX*) for the appointed water and sewerage businesses, and it includes cost for materials and consumables, hired services and energy (see Ashton 2000a and 2000b for a similar approach). Since the price of energy followed a decreasing trend both in real and nominal terms – the fall in the price of energy for the industrial sector is about 20% in current terms and 60% in nominal terms from 1993 to 2005 – it was impossible to deflate this aggregate value using a common price index. Therefore, we deflated the materials and services cost and the energy cost through two different indices. The former variable has been adjusted by the conventional RPI index whereas the latter one by an energy price index for the industrial sector derived from the Department for Trade and Industry (DTI)[12].

Capital expenditure (*CAPEX*) has been included in the DEA specification because of the capital-intensive nature of the water and sewerage industry (Saal and Parker, 2000, 2001; Saal *et. al*, 2004; Coelli and Walding, 2006). The annual capital consumption has been calculated by multiplying the yearly monetary value of capital, given by the annual average modern equivalent asset (MEA) estimation of the replacement cost of fixed tangible assets[13], by a depreciation rate. This latter has been, in turn, derived considering the current depreciation and infrastructure renewal charges[14], directly attributed to water and sewerage businesses, out of the average MEA gross capital value at the same year. In this way, the consumption of capital, as captured by *CAPEX*, is proportional to the stock of capital.

Some descriptive statistics on output and input variables are presented in Table 1.

[Table 1 around here]

In order to derive the contribution of allocative efficiency to overall economic efficiency, input price data are needed. A deflation procedure based on 2002-03 has been followed, in order to isolate the real movements of prices.

The price of labour has been calculated by dividing the overall cost of employment by the number of full time equivalent employees (see note 11), and then deflating the resulting values by the RPI index.

A price for other operating expenditures is problematic, given the heterogeneous nature of this input. We adopted a weighted average of RPI and a real price index of energy for the industrial sector, taken from DTI, where the weights are represented by the respective cost shares[15].

Finally the price of capital has been computed as the percentage rate resulting from the sum of the above described depreciation (and infrastructure renewal) rate and the opportunity cost of capital. This latter has been directly imputed from the regulatory assessment on the fair rate of return on the employed capital. The opportunity cost is represented by the real regulatory cost of capital assessment, elaborated by OFWAT in correspondence to the periodical price settings. According to OFWAT's assessments the capital cost we used is equal to 5.5% up to 2000 and 4.75% for the subsequent years.

In addition, it should be noted that the inclusion of four output variables ensures that firms with similar customer density (where customer density is measured as volumes per customer) and similar combination between water and sewerage activities are benchmarked by one another. Furthermore, comparison between firms which are similar in terms of network density (where network density is measured as customers per kilometre of network) is also indirectly accommodated. Low network density firms are generally more capital-intensive than high network density firms. The joint consideration of operating and capital expenditures ensures that firms with similar ratios among inputs, that is with similar network density conditions, are benchmarked each other (Coelli and Walding, 2006).

6 Environmental and regulatory variables

The efficiency of a firm could be affected by exogenous conditions that are not under the direct control of managers. Hence, these effects should be removed in a correct efficiency assessment. The exogenous variables we used in the second stage are of two types: environmental variables and policy variables. The former allow considering the impact attributable to the different characteristics of the network and of the area where the service is provided, and thus control for the heterogeneity among firms. The latter regard the regulatory policy and, more specifically, the change in the economic environment that occurs after the introduction of new regulatory constraints. These variables do not differentiate across firms, since the regulatory framework is common for the whole industry, but differ along time.

The set of environmental variables should be such as to represent the exogenous characteristics on the whole range of activities. The variables we chose have been previously adopted in the most part of the above mentioned empirical literature. In the following we will briefly describe these variables.

The proportion of water abstraction from underground sources (*SOURCE*) reflects the different conditions of the water production. A larger amount of abstraction from boreholes than from surface sources requires higher power consumption but, at the same time, less treatment cost because of the higher purity of underground water. With regard to capital, a higher proportion of underground water requires a larger endowment of pumps while a higher proportion of surface water is associated to a larger number of treatment plants. For these reasons we assign no a priori impact to this variable.

The percentage of water losses (*WLOSS*) with respect to the overall distribution input represents a general proxy of the operational condition of the distribution network. A higher proportion of losses implies more critical conditions of the network and thus a higher input use is expected.

The water population density (*WDENS*) is calculated as the ratio between water served population and length of water distribution network. In a rough way, a higher density could also be associated to a greater proportion of household properties. In general, the provision of service to a more concentrated population is more convenient than serving a population distributed on a widely sparse territory, since in this latter case more diversions of the network, more frequent maintenance activities, more energy cost are needed.

The percentage of sewerage population density (*SDENS*) is calculated as the ratio between the equivalent sewerage population and the length of the sewerage network. A higher density could be associated to a major proportion of household connected properties as well. Analogous economies of density arguments, as described above for the water activity, apply even though a more ambiguous effect has been empirically found (see Tupper and Resende, 2004)[16]

Since the sewerage density could not entirely capture the effect due to the users' composition, we also considered the trade effluent variable (*TREFFL*), which represents the proportion of industrial effluent on total waste water. In general, we would expect that greater industrial effluent higher input requirements, especially with respect to treatment cost and energy.

Time trend (*TIME*) is included to account for technological progress/regress. The *TIME* variable is interpreted as proxy for technological movements but not of changes in technical efficiency conditions, which are embodied in the one-sided distributed error component. Furthermore, as privately-owned firms are profit-maximising agents we would expect that a technical progress was encouraged after privatisation.

Finally, regulatory variables have been introduced to take into account the potential impact of changes in the economic environment. As during the period under observation two price reviews have been enforced, we introduced in the model two distinct dummy variables, *REG94* and *REG99*, which assume value 1 for, respectively, the five years after 1994 and 1999[17]. Even though in both the occasions price-cap rules have been applied, the second regulatory intervention appeared as more severe since it stated for the first time a price reduction. Hence, we could expect a stronger input-reducing impact associated with the *REG99* variable.

As above mentioned, the managerial (technical and allocative) efficiency is embodied into the one-sided inefficiency error term (u). The unidirectional efficiency trend is directly estimated by the model. This inefficiency error component should be interpreted as the residual inefficiency of the firms as if they face the same environmental and noise conditions, and they operate in a neutral context with respect to regulatory policy and technical progress/regress. Thus, another reason has to be searched in order to explain the inefficiency term level and trend. Since the water and sewerage companies have been subjected to a privatisation process in 1989, the change in ownership regime could be interpreted as driver of the managerial inefficiency trend. As stated above, the private firms are usually viewed as profit-maximising (or cost-minimising) agents more than public firms are, so that they are expected to make more effort for the rationalisation of the input consumption. Moreover the introduction of a yardstick competition regime in the period after privatisation could have well worked as an incentive mechanism as it allows a firm's performance to be judged in relation to the performance of the other units. At least in the long run, it could be expected to narrow the efficiency differentials and to induce the firms to undertake a cost-reducing path. For such reasons we should expect a positive efficiency trend, that is a convergence towards an optimal use of the inputs, from both a technical and an allocative viewpoint[18].

7 Empirical results

7.1 DEA technical and allocative efficiency results

The first stage DEA results are represented in Table 2. The mean technical efficiency score is equal to 0.909, which indicates that the average firm could reduce all the inputs simultaneously by 9.1%, still producing the same amount of output. The minimum value is 0.657, indicating that there is a substantial discriminatory power among observations as well as quite critical technical conditions. The mean allocative efficiency score is 0.810, a very low level, which indicates that, even though technical efficiency were achieved, a 19.0% excess of total operating (capital plus non capital) cost with respect to the minimum cost there would still exist, which could be eliminated by adjusting the inappropriate input mix. The minimum score is 0.349, so revealing the presence of very critical allocative distortions. Moreover the variability of the allocative scores is higher that that one of technical efficiency. These results indicate that a major part of the economic efficiency is attributable to allocative distortions in the input utilization, rather than to overuse due to technical inefficiency.

[Table 2 around here]

The technical and allocative efficiency trends are depicted in Figure 2. Technical efficiency trend is initially comprised in an interval between 0.88 and 0.90 and then shows an upwards shift to around 0.94 after 1999. The average efficiency value before 1999 price review is 0.891, while the average value during the 1999 price setting period is 0.940. Thus, it seems that the 1999 price review has worked in a way of stimulating a technical efficiency progress of around 5%, whereas 1994 price review did not. On the contrary, allocative efficiency showed a continuous increasing trend which does not seem to depend on regulatory interventions. This upwards trend reduced by a great deal the allocative inefficiency, from 0.650 to more than 0.900, so indicating that the firms mainly addressed their efforts to reduce economic inefficiency through a better input mix settlement.

[Figure 2 around here]

The input-specific allocative distortion measures, calculated as difference between technical efficient input levels and corresponding cost-minimising values, are depicted in Figure 3.

The graphs allow comments in terms of both sign and trend of the distortion. Figure 3 shows an initial systematic over-utilization of labour and under-utilization of capital (respectively of more than 80% and –25% with respect to the technically optimum value), which tend to cancel out during time. Therefore, these results reconcile with previous evidence found out by Saal and Parker (2000, 2001). One explanation for this could stem from the previous public nature of these firms which did not allow achieving the cost-minimising equilibrium. Pint (1991) and Boycko, Shleifer and Vishny (1996) describe the workforce over-utilization as a direct consequence of public governance social objectives. However, it appears that the change in the governance rules did not occur immediately but rather the reorganisation process carried out gradually. Furthermore the wide capital investments programmes required during the same years in order to expand/renew the network as well as to conform the service with general quality standards, contributed to enhance the under-sized capital level, so as to absorbing the allocative inefficiency. The capital allocative distortion trend seems to be affected by the 1999 price review. However this could also be due to the reduction in the capital opportunity cost. Anyway, differently than in Saal and Parker (2001), we do not find evidence of a over-capitalisation process.

As regards the *OTHEX* variable, the results point out an initial over-utilization followed by a negative allocative distortion. This could be due to the major flexibility of this input. Another reason could lie in the rapid energy price reduction experienced in the same period. This could have worked in the sense of enhancing the cost-minimising level of energy. However, as energy consumption is quite rigidly linked to the capital endowment, it seems difficult to interpret the rising distortion as allocative inefficiency.

[Figure 3 around here]

7.2 Input-specific environmental and regulatory impact

In this section we will discuss the impact of the environmental and regulatory factors on the input-specific efficiency performance. Since we are particularly interested in understanding the impact of regulation policy we will mainly focus on this latter in the following.

The results from the second stage input-based SFA equations with regards to technical inefficiency are presented in Table 3. The *SOURCE* variable is always associated to negative and significant parameters, indicating that a greater proportion of underground water has beneficial effects on the input requirements. The major effort for abstraction seems, thus, a less input requiring environmental characteristic than the treatment of river or surface water. The *WLOSS* variable shows a positive and significant parameter with respect to *EMPL* and *OTHEX* inputs, so indicating an unfavourable context due to more critical operational characteristics of the network. Capital expenditure is reasonably not influenced as it reflects, in itself, the network along which the losses occur. The associated parameter is indeed not significant even though positive. The negative and significant impact of *WDENS* variable on *EMPL* and *OTHEX* reflects a favourable condition associated to a higher water network density. The *SDENS* does not present a similar evidence even though the parameter is negative in two cases (see Tupper and Resende, 2004 for similar results).

Turning to the regulatory dummies, it should be note that *REG94* has generally the expected (negative) sign but it is not significant, whereas *REG99* is associated to negative and always strongly significant parameters. This result could be explained by invoking the change in the regulatory policy that took place in 1999, so revealing the incentive power of the price-cap scheme. Finally, *TIME* is significant but with a positive sign. This evidence does not allow accepting the hypothesis of a favourable technical progress (see Ashton 2000b), but rather supports the view of more intensive input requirements associated to an infrastructure and non-infrastructure investment process in order to ensure quality and serviceability to customers.

The γ parameters are close to 1 and always statistically significant at 1%[19]. This indicates that the variability of the one-sided inefficiency term (u) dominates the variability due to noise (v). In other words it means that, once exogenous operational characteristics have been purged out and all the firms are considered as operating in a virtual context without regulatory and time effects, firms still differently succeed in managing inputs. This difference just reflects the intrinsic inefficiency of the firms.

The η parameters are in all the cases positive and statistically significant at 1%. This means that the trend of the intrinsic input-specific technical inefficiency is negative, that is the managerial ability in reducing inputs technical overuse improved over time.

[Table 3 around here]

The percentages of overuse with respect to the technically optimal best practice are presented, input-by-input, in Table 4.

The greatest reduction regards *CAPEX* (-24.6%), which starts from the most inefficient position (49.6% of inefficiency in financial year 1992-93), whereas the lowest one belongs to *EMPL* factor (-10.3%) which starts from a lesser 28.0% coefficient of overuse.

[Table 4 around here]

The estimates relative to the allocative distortions are presented in Table 5. Here the regulatory dummies do not play a significant role, even though they have the expected sign. This lack of significance could be explained by arguing that the convergence to the cost-minimising input mix characterized as a gradual process leaded by the managers' modified perception of the reformed economic context. The η parameters are positive and highly significant, so indicating that the above described convergence process could be attributed to an increased attitude of the managers in organising the resources. This is however a non immediate task. It has indeed taken effect through a continuous reorganisation process, once the ownership nature has been changed.

This process dealt particularly with the labour factor, as can be pointed out by the extent of the corresponding η parameter (0.373).

The *TIME* variable is negative, so revealing a favourable action of the time trend, but not significant. It is interesting to note that *TIME* works in opposite direction for technical and allocative input-specific inefficiency measures. This result seems to shed some light on the role of the technical progress/regress which has a quite unclear impact in the literature (see Ashton 2000b and Saal and Parker, 2001).

[Table 5 around here]

The input-by-input allocative managerial inefficiencies have been extracted out by computing the coefficients of distortion depicted in Table 6. As we used the absolute values of the overall input slacks into the equations [9], these coefficients should be interpreted as mere percentages of distortion without consideration about the sign of this latter[20].

As already anticipated, the labour factor shows a powerful convergence (-71.3%). Starting from a position of abundant over-utilisation, the reorganisation process led *de facto* the average usage of the factor on its allocative optimal level. The correction of *OTHEX* factor has been equal to -4.4%, while a percentage of –16.0% is observed for *CAPEX*, in this latter case starting from a sub-optimal under-utilisation condition. These findings also suggest that the fulfilment of the reorganisation process could have took place through the introduction of automation, which allowed a substitution between labour and capital.

[Table 6 around here]

8 Conclusions and policy remarks

In this study we extend the previous analysis on the regulatory policy impact in the context of the England and Wales water and sewerage industry, so as to include the assessment of the 1999 price review. As far as the 1994 price review is concerned, the previous empirical evidence did not provide strong support of a positive effect of regulatory interventions on cost efficiency. However, the 1999 price setting signed a change in the regulatory policy, which for the first time enforced a price reduction, and thus a change in the firm behaviour would be expected.

Furthermore, we analyse the impact of regulation on both technical and allocative efficiency components, using a DEA-based two-stage method, derived from Fried *et al*. (2002), which allows taking into account environmental effects as well as noise. This permitted us to circumvent the major drawbacks inherent DEA methodology and to build up input-specific efficiency measures.

The results can summarise as follows:

- The 1994 price review confirms its poor impact on firms' performance, whereas the 1999 review reveals a general and input-specific high significant effect as far as technical efficiency is concerned;
- The overall allocative efficiency measure as well as the input-specific allocative distortions improve continuously during the observed period;
- The firms present an initial large over-utilization of labour and under-utilization of capital, which bring about allocative inefficiency. However, these distortions reduce gradually over time.
- The pure managerial efficiency trends provide evidence of significant improving managerial conditions during the observed period.

On the light of these results, and considering that our dataset does not allows any direct judgement about privatisation, some conclusions can be trace out. The evidence is consistent with the hypothesis of tightening regulatory environment, as the overall and input-specific technical efficiency measures improve in correspondence to the 1999 price limits setting. The regulatory environment set after privatisation seems anyway to have improved the allocative component through the absorption of the initial input distortions. In such a way, the previous evidence of a labour-saving capital-augmenting technology change is confirmed. The introduction of indirect competition through a yardstick competition system might have induced the firms to be more efficient by setting appropriate least cost input combinations. Furthermore, the results seem consistent with those theories that predict an overuse of labour in the publicly-owned structures. The removal of the public nature constraints could have induced this input substitution. Anyway, our findings do not support the evidence of firms' over-capitalisation. Both labour and capital moved along a convergence path towards their optimal use.

Once operational environment and economic (regulatory) effects have been purged out, pure managerial efficiency could be evaluated. Both under a technical and an allocative viewpoint, there is evidence of improving managerial conditions. This might be seen as consequence of the change in ownership as well as of the performance assessment system that has been set after privatisation.

NOTES

[1] A debate rose regarding the desirability of maintaining a five-year cyclical review as the firms might be induced to enhance efficiency early in the period in order to keep the benefits for a longer time before passing them to the customers through the successive price regulation. A longer price setting period might induce the firms to outperform the regulatory assumptions for a higher number of years. The five-year period has not been changed till now but in the 1999 price review OFWAT established a rolling incentive mechanisms so as to avoid this problem.

[2] After the first price reduction, the regulator set a further decrease by –0.4% for the financial year 2001-02 and increases by +0.2%, +1.3% and +1.7% for the last three years.

[3] This process is mainly explained by the authors in terms of the environmental constraints that forced the privatised companies into extensive investment programmes.

[4] Rate-of-return regulation emerged for limiting the profits of franchised monopolies. It consists in letting the firms to freely choice their price under the constraint that return on capital should be fair but below a pre-specified level. This method allows prices can increase for covering costs, and, in such a way, it is expected to provide less incentives to pursue cost efficiency.

[5] In these studies the authors employed a generalised or shadow cost function approach (Kumbhakar, 1992; Parker, 1995, Maietta, 2000; Kumbhakar and Sarkar, 2003) which accommodates the possible violation that arises when cost are minimised with respect to internal (shadow) prices rather than market input prices. The input price distortions bring about allocative inefficiency. The application of this methodology might be particularly suitable for public utilities, as they are often subjected to the public control. It is also to be noted that an alternative solution to the problem of not exogenous input prices consists in the use of an input-distance function (see Saal and Parker, 2004), since this method does not need information on prices.

[6] For a comprehensive description of DEA, see Thanassoulis (2001) and Coelli, Prasada Rao and battese (1998) and Coelli *et al*. (2005).

[7] In Fried *et al*. (2002) a third stage is defined where DEA is re-run once environmental and noise effects are removed. Since the calculation of firms' ranking is beyond our aim we will not implement this stage.

[8] In this paper a half-normal distribution has been adopted rather than a more general truncated-normal specification of the inefficiency term, in order to minimise computational problems. Although the truncated-normal specification is more general, we do not think that this assumption creates serious problems.

[9] The left-hand side differences in equation [7] should be considered as mere distortion measures as they only allow considering if distortions are systematically explained by external or internal factors, without distinguishing between over or under-utilisation for each input.

[10] Consistent time series of drinking water and river quality compliance indices have been taken from the DWI and the EA annual reports.

[11] The labour price index is based on the trend of the average wage for each firm. In turn, the average wage has been calculated dividing the total employment cost by the number of full total equivalent employees (the information have been taken from the annual reports of the companies). This is the best available proxy of the yearly average wage for the water and sewerage industry. The resulting wages have been then compared with the data from the New Earnings Survey and this confirmed their validity. We preferred to use this specification of the labour input instead of directly using the number of employees since this latter sometimes relates to the whole group, so including workers of non appointed businesses.

[12] Different energy price indices are available. We considered the energy price index for industrial use expressed in current terms and including the climate levy charge for UK.

[13] Following Stone and Webster (2004), the MEA values available in the OFWAT dataset have been adjusted using the COPI (Construction Price Index) as deflation index instead of the RPI index. Furthermore the MEA annual values have been corrected in order to eliminate the impact due to the periodic AMP adjustments. This smoothing of the capital stock time series has been carried out considering the MEA value in the financial year 2002-03 as base and then adding (for the successive years) or subtracting (for the previous years) the amount of the annual net investments, calculated for each year at 2002-03 prices.

[14] The depreciation regime is different according to the type of asset. While superficial assets (like treatment plants, pumps, reservoirs, sewage disposal works) are depreciated, the underground assets are not directly depreciated but an infrastructure renewals charge is computed and included in the Profit and Loss statement.

[15] A better solution might have been to disentangle material and services from energy. In this latter case, the first choice for the energy price would have been a measure calculated by dividing the cost of power by the consumption of energy, but unfortunately none consumption value is available in the OFWAT dataset. The most natural alternative would have been to use an energy price index but in this case we must have employed two across-firms invariant price indices (the RPI index and the DTI energy price index). On the contrary, the weighted average price index here adopted is variant given that the cost shares vary across firms and years.

The DTI real energy price index has been deflated using the GDP deflator. We recomputed the energy price time series index using the RPI index but no sensible differences rose.

[16] The *WDENS* and *SDENS* variables are expected to capture far effects than those ones already accommodated by the multi-input DEA specification. WDENS and SDENS use the population rather than the number of customers and they are included to reflect the different operational characteristics associated to the network conformation.

[17] At this purpose it should be noted that the allowed price changes took effect on 1 April 1995 and 1 April 2000.

[18] While the regulation and time variables have been used as explanatory factors for both the technical and allocative frameworks, the set of operational characteristics have been consider to have only a technical nature. This is consistent with several papers within the shadow cost function approach literature stream which only use regulation, ownership and time as potential explanatory factors for allocative distortions.

[19] The one-sided generalised likelihood-ratio test of H_0: $\gamma=0$ always exceeds the 1% critical value of 5.412. Hence the traditional average response function is not a correct representation of the data (Coelli, Prasada Rao and Battese, 1998).

[20] Anyway it is to note that *EMPL* and *CAPEX* are characterised, respectively, by over and under-utilisation for the most part of the observations. Only *OTHEX* shows alternate signs in the allocative distortions.

References

Anwandter L., Teofilo O., 2002, "Can Public Sector Reforms Improve the Efficiency of Public Water Utilities?", Environment and Development Economics, 7, 687-700

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

Ashton J.K., 2000b, "Total Factor Productivity Growth and Technical Change in the Water and Sewerage Industry", The Service Industries Journal, 20 (4), 121-130

Aubert C., Reynaud A., 2005, "The Impact of Regulation on Cost Efficiency: An Empirical Analysis of Wisconsin Water Utilities", Journal of Productivity Analysis, 23, 383-409

Banker R.D., Charnes A., Cooper W.W., 1984, "Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis", Management Science, 30, 1078-1092

Bhattacharrya A., Harris T.R., Narayanan R., Raffiee K., 1995a, "Specification and Estimation of the Effect of Ownership on the Economic Efficiency of the Water Utilities", Regional Science and Urban Economics, 25, 759-784

Bhattacharrya A., Harris T.R., Narayanan R., Raffiee K., 1995b, "Allocative Efficiency of Rural Nevada Water Systems: A Hedonic Shadow Cost Function Approach", Journal of Regional Science, 35 (3), 485-501

Bhattacharrya A., Parker E., Raffiee K., 1994, "An Examination of the Effect of Ownership on the Relative Efficiency of Public and Private Water Utilities", Land Economics, 70 (2), 197-209

Bottasso A., Conti M., 2003, "Cost Inefficiency in the English and Welsh Water Industry: An Heteroskedastic Stochastic Cost Frontier Approach", mimeo, DIEM Università di Genova

Battese G.E., Coelli T.J., 1992, "Frontier Production Function, Technical Efficiency and Panel Data: With Application to Paddy Farmers in India", in Journal of Productivity Analysis, 3, 153-169

Boycko M., Shleifer A., Vishny R.W., 1996, "A Theory of Privatisation", Economic Journal, 106 (435), 309-319

Charnes A., Cooper W.W., Rhodes E., 1978, "Measuring the Efficiency of Decision Making Units", European Journal of Operational Research, 2, 429-444

Coelli T.J., Walding S., 2006, "Performance Measurement in the Australian Water Supply Industry: A Preliminary Analysis", in Coelli T., Lawrence D. (eds.), Performance Measurement and Regulation of Network Utilities, Edward Elgar Publishing, Cheltenham, fortcoming

Coelli T.J., Prasada Rao D.S., Battese G., 1998, An Introduction to Efficiency and Productivity Analysis, first edition, Kluwer Academic Publishers, Boston/Dordrecht/London

Coelli T. J., Prasada Rao D.S., O'Donnell C.J., Battese G.E., 2005, An Introduction to Efficiency and Productivity Analysis, second edition, Springer, New York

Cubbin J., Tzanidakis G., 1998, "Regression Versus Data Envelopment Analysis for Efficiency Measurement: An Application to the England and Wales Regulated Water Industry, Utilities Policy, 7, 1998, 75-85

Debreu G., 1951, "The Coefficient of Resource Utilisation", Econometrica, 19, 273-292

Fabbri P., Fraquelli G., 2000, "Cost and Structure of Technology in Italian Water Industry", Empirica, 27, 65-82

Farrell M.J., 1957, "The Measurement of Productive Efficiency", Journal of the Royal Statistical Society, Series A, CXX, Part 3, 253-290

Feigenbaum S., Teeples R., 1983, "Public Versus Private Water Delivery: A Hedonic Cost Approach", The Review of Economics and Statistics, 65, 672-678

Ferrier G.D., Lovell C.A.K., 1990, "Measuring Cost Efficiency in Banking: Econometric and Linear Programming Evidence", Journal of Econometrics, 46, 229-245

Fried H.O., Lovell C.A.K., Schmidt S.S., Yaisawarng S., 2002, "Accounting for Environmental Effects and Statistical Noise in Data Envelopment Analysis", Journal of Productivity Analysis, 17, 157-174

Garcia S., Thomas A., 2001, "The Structure of Municipal Water Supply Costs: Application to a Panel of French Local Communities", Journal of Productivity Analysis, 16, 5-29

Hunt L.C., Lynk E.L., 1995, "Privatisation and Efficiency in the UK Water Industry: An Empirical Analysis", Oxford Bulletin of Economics and Statistics, 57, 371-388

Kumbhakar S.C., 1992, "Allocative Distortions, Technical Progress, and Input Demand in U.S. Airlines: 1970-1984", International Economic Review, 33 (3), 723-737

Kumbhakar S.C., Sarkar S., 2003, "Deregulation, Ownership, and Productivity Growth in the Banking Industry: Evidence from India", Journal of Money, Credit and Banking, 35 (3), 403-424

Lambert D.K., Dichev D., Raffiee K., "Ownership and Sources of Inefficiency in the Provision of Water Services", Water Resources Research, 29 (6), 1573-1578

Maietta O.W., 2000, "The Decomposition of Cost Inefficiency into Technical and Allocative Components with Panel Data of Italian Dairy Farms", European Review of Agricultural Economics, 27 (4), 473-495

Mizutani F., Urakami T., 2001, "Identifying Network Density and Scale Economies for Japanese Water Supply Organisations", Papers in Regional Science, 80, 211-230

OFWAT, 1994, Future Charges for Water and Sewerage Services: The Outcome of the Periodic Review, Office for Water Services, Birmingham

OFWAT, 1999, Future Water and Sewerage Charges 2000-05: Final Determinations, Office of Water Services, Birmingham

OFWAT, 2004, Future Water and Sewerage Charges 2005-10: Final Determinations, Office of Water Services, Birmingham

Stone and Webster Consultants, 2004, Investigation into Evidence for Economies of Scale in the Water and Sewerage Industry in England and Wales, Report commissioned and published by OFWAT, Office of Water Service, Birmingham

Parker E., 1995, "Shadow Factor Price Convergence and the Response of Chinese State-Owned Construction Enterprises to Reform", Journal of Comparative Economics, 21, 54-81

Pint E., 1991, "Nationalisation versus Regulation of Monopolies: The Effects of Ownership on Efficiency", Journal of Public Economics, 44 (2), 131-164

Saal D., Parker D., 2000, "The Impact of Privatization and Regulation on the Water and Sewerage Industry in England and Wales: A Translog Cost Function Model", Managerial and Decision Economics, 21, 253-268

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

Saal D., Parker D., 2004, “The Comparative Impact of Privatisation and Regulation on Productivity Growth in the English and Welsh Water and Sewerage Industry, 1985-99”, International Journal of Regulation and Governance, 4 (2), 139-170

Saal D., Reid S., 2004, “Estimating Opex Productivity Growth in English and Welsh Water and Sewerage Companies: 1993-2003”, Aston Business School Working Paper, RP0434

Saal D., Parker D., Weyman-Jones T., 2004, “Determining the Contribution of Technical, Efficiency, and Scale Change to Productivity Growth in the Privatized English and Welsh Water and Sewerage Industry: 1985-2000”, Aston Business School Working Paper, RP0433

Stewart M., 1993, “Modelling Water Costs 1992-93: Further Research into the Impact of Operating Conditions on Company Costs”, OFWAT Research Paper, No. 2

Stewart M., 1994, “Modelling Sewage Treatment Costs 1992-93: Research into the Impact of Operating Conditions on the Costs of the Sewerage Network”, OFWAT Research Paper, No. 4

Thanassoulis E., 2000a, “The Use of Data Envelopment Analysis in the Regulation of UK Water Utilities: Water Distribution”, European Journal of Operational Research, 126, 436-453

Thanassoulis E., 2000b, “DEA and Its Use in the Regulation of Water Companies”, European Journal of Operational Research, 127, 1-13

Thanassoulis E., 2001, Introduction to the Theory and Application of Data Envelopment Analysis, Kluwer Academic Publishers, Boston/Dordrecht/London

Torres M., Morrison Paul C., “Driving Forces for Consolidation or Fragmentation of U.S: Water Utility Industry: A Cost Function Approach with Endogenous Output”, Journal of Urban Economics, forthcoming

Tupper H.C., Resende M., 2004, “Efficiency and Regulatory Issues in the Brazilian Water and Sewerage Sector: An Empirical Study”, Utilities Policy, 12, 29-40

Figure 1: Technical and allocative efficiency

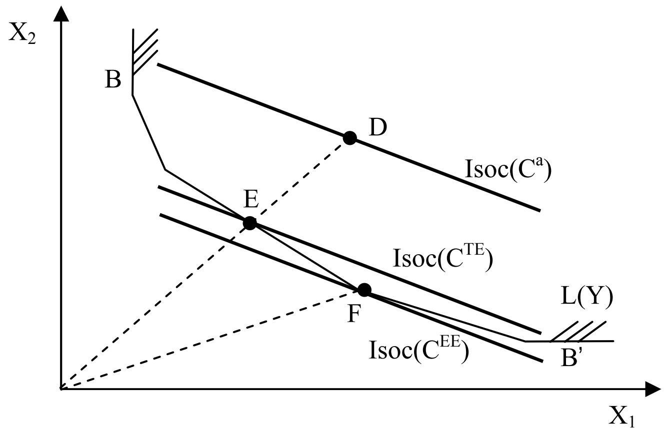


Table 1: Descriptive statistics

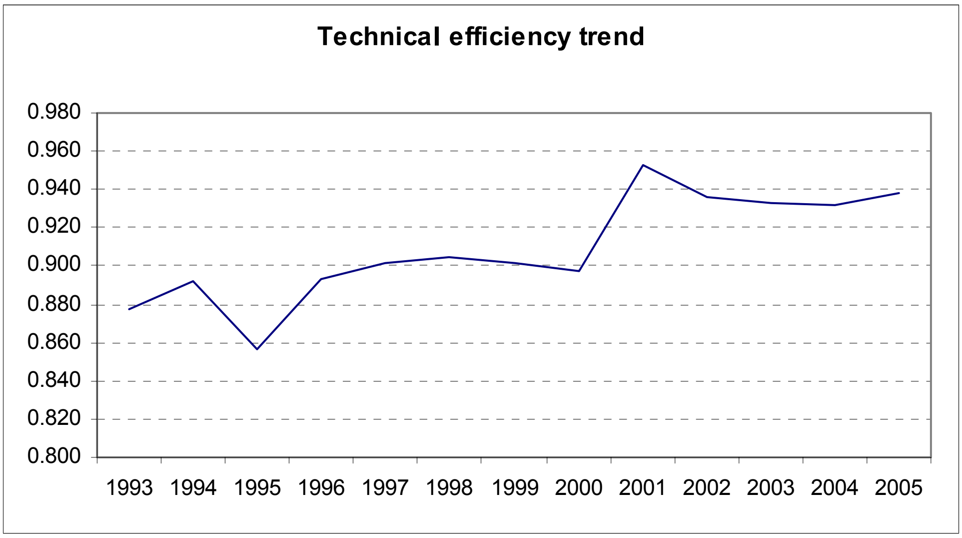
Variable		Mean	Std. Dev.	Var. Coeff [(a)]	Min	Max
WDEL	Ml/d	1072.5	560.1	0.522	288.9	2179.4
WPROP	000	1895.3	1016.6	0.536	455.8	3684.1
SPROP	000	2123.5	1292.9	0.608	565.9	5272.3
WASTW	Ml/d	1036.0	703.2	0.678	246.6	3020.0
EMPL	£m	34.1	20.7	0.607	7.7	137.5
OTHEX|	£m	226.1	108.6	0.480	69.2	446.1
CAPEX	£m	181.4	85.7	0.472	38.2	361.7

([a]) Calculated as standard deviation on mean

Table 2: Average technical and allocative efficiency

	TE (1993-2005)	AE (1993-2005)
Mean	0.909	0.810
Min	0.657	0.349
Dev. St	0.103	0.147

Figure 2: DEA Technical and allocative efficiency trends



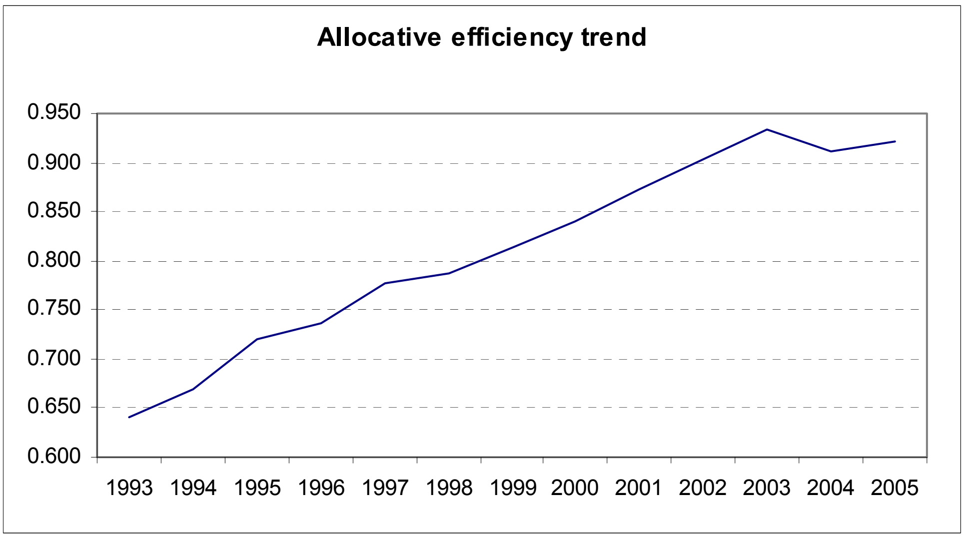
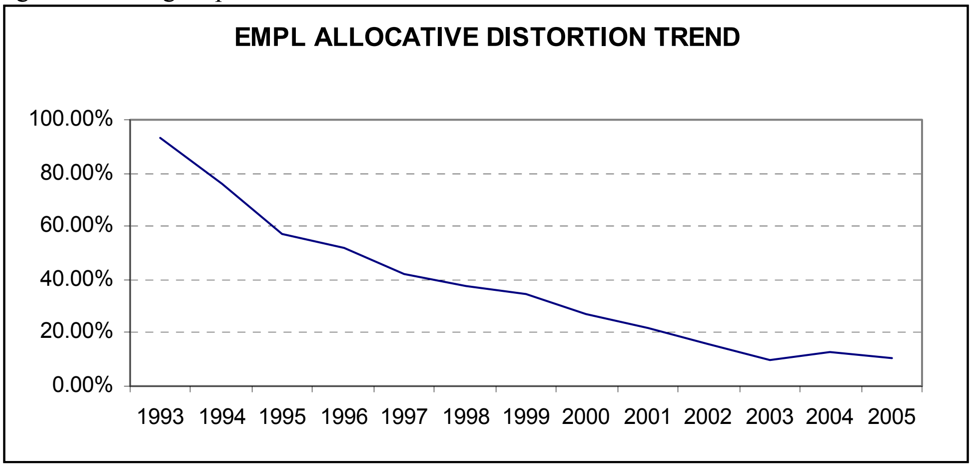
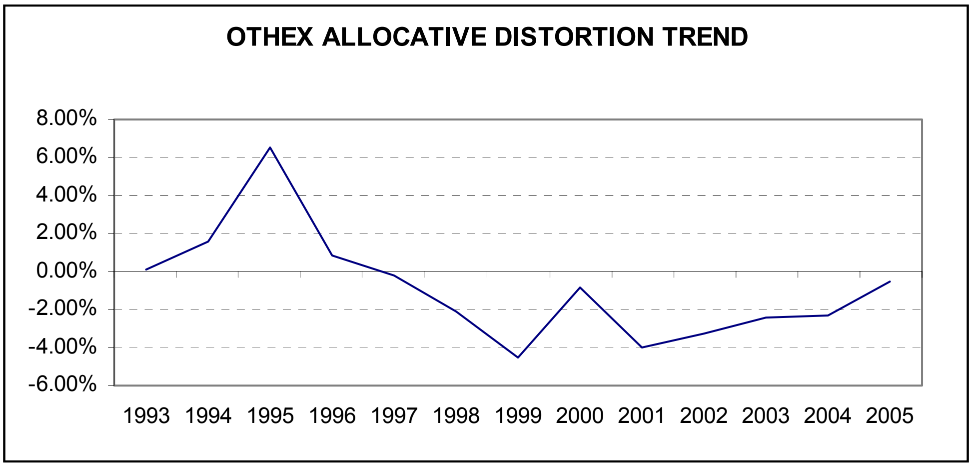


Figure 3: Average input allocative distortion trends





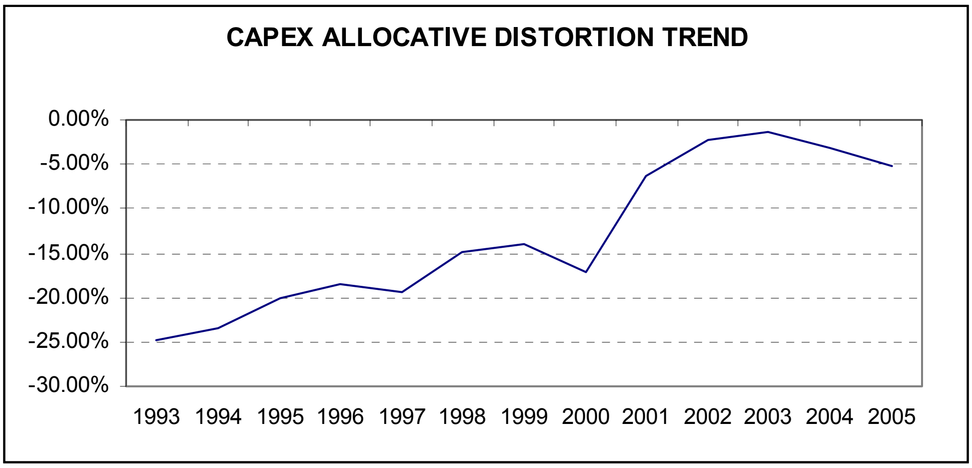


Table 3: Environmental and regulatory impact on input-specific technical inefficiency

	EMPL			OTHEX			CAPEX		
	Parameter			Parameter			Parameter		
SOURCE	-7.249	(-2.936)	***	-61.916	(-3.457)	***	-84.907	(-5.633)	***
WLOSS	18.271	(3.346)	***	97.948	(2.652)	***	29.288	(1.039)	
WDENS	-37.978	(-2.813)	***	-222.181	(-2.338)	**	-98.553	(-0.794)	
SDENS	0.292	(0.036)		-17.047	(-0.333)		-9.366	(-0.233)	
TREFFL	5.662	(0.341)		-5.564	(-0.050)		-155.325	(-1.601)	*
REG94	-0.645	(-0.900)		-2.844	(-0.622)		-4.124	(-1.190)	
REG99	-1.893	(-2.575)	***	-13.362	(-2.857)	***	-10.427	(-2.848)	***
TIME	0.588	(3.436)	***	3.815	(3.385)	***	1.886	(1.962)	**
γ	0.855	(11.080)	***	0.889	(14.341)	***	0.957	(41.718)	***
η	0.071	(5.619)	***	0.064	(4.963)	***	0.034	(3.322)	***
Llf	-284.856			-526.279			-497.353		

Estimated t-ratios are given in parentheses.
Estimates marked with (***) are statistically significant at 1% level
Estimates marked with (**) are significant at 5% level
Estimates marked with (*) are significant at 10% level

Table 4: Input-specific technical overuses coefficients [(a)]

	EMPL	OTHEX	CAPEX
1993	1.280	1.380	1.496
1994	1.267	1.335	1.417
1995	1.287	1.334	1.408
1996	1.276	1.314	1.385
1997	1.277	1.289	1.376
1998	1.262	1.284	1.336
1999	1.272	1.268	1.333
2000	1.263	1.236	1.334
2001	1.239	1.234	1.291
2002	1.221	1.214	1.277
2003	1.209	1.197	1.258
2004	1.188	1.186	1.255
2005	1.177	1.171	1.250
Overall reduction	-10.3%	-20.9%	-24.6%

[(a)] The yearly average values are calculated as $(U_{it} + TE^*x_{it})/TE^*x_{it}$ (where U_{it} is the input-specific technical overuse)

Table 5: Regulatory impact on input-specific allocative distortion

	EMPL			OTHEX			CAPEX		
	Parameter			*Parameter*			*Parameter*		
REG94	-2.469	(1.390)		-1.244	(-0.297)		5.001	(0.770)	
REG99	-2.023	(-1.102)		-2.419	(-0.530)		-1.314	(-0.190)	
TIME	-0.078	(-0.235)		-0.204	(-0.242)		-1.647	(-1.230)	
γ	0.006	(1.269)	***	0.353	(2.019)	***	0.518	(3.121)	***
η	0.373	(13.487)	***	0.071	(2.295)	**	0.094	(4.054)	***
Llf	-400.642			-513.308			-571.629		

Estimated t-ratios are given in parentheses
Estimates marked with (***) are statistically significant at 1% level
Estimates marked with (**) are significant at 5% level

Table 6: Input-specific allocative convergence coefficients [(a)]

	EMPL	OTHEX	CAPEX
1993	1.721	1.079	1.247
1994	1.480	1.071	1.218
1995	1.343	1.069	1.204
1996	1.230	1.064	1.182
1997	1.159	1.059	1.163
1998	1.111	1.056	1.149
1999	1.076	1.052	1.135
2000	1.052	1.049	1.123
2001	1.036	1.045	1.111
2002	1.024	1.044	1.112
2003	1.016	1.041	1.100
2004	1.011	1.038	1.097
2005	1.008	1.035	1.087
Overall reduction	-71.3%	-4.4%	-16.0%

([a]) The yearly average values are calculated as $(U_{it}+x_{it}^*)/x_{it}^*$
(where Uit is the input-specific allocative distortion)