Scale Economies, technological structure and technical change. Some evidence from the English Water Only Sector.

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Scale Economies, Technology and Technical Change in the Water Industry: Evidence from the English Water Only Sector.

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Abstract

In this paper we estimate a variable cost function to analyze cost economies and technical change in the English water only sector over the 1995-2005 period. We jointly model the impact on costs of output, customers numbers and area size which allows us to consider both the vertical and horizontal (spatial) dimensions of water utilities' operations. Estimates suggest the existence of unexploited economies of output and customer density and small scale economies which appear to be increasing with population density. These findings suggest that moderate cost savings from prudent mergers could be expected; in particular, benefits of merging water utilities might be higher in more densely populated urban areas. Finally, technical change is found to be increasing over the sample period.

L51, L95.

Key Words: Regulation, Water Utilities, Scale Economies.

1 Introduction

After the privatization of the ten large water and sewerage authorities in 1989 and the wave of mergers and acquisitions that characterized the successive decade, the English and Welsh water industry is now characterized by the presence of ten large water and sewerage companies (Wascs, the former water authorities, accounting for more than 70% of the water sector turnover) and by twelve water only companies (Wocs). Both Wascs and Wocs are vertically integrated utilities as they are responsible, within their statutory area, of the abstraction, treatment, and distribution of water. Furthermore, Wascs also manage the sewage collection, transport and treatment services. The industry is regulated by the Water Services Authority (Ofwat). As the other UK privatized public utilities, the regulation is based on a version of the well known RPI-X price cap methodology, namely RPI+K. K can be decomposed in Q-X, where Q represents the price increase necessary to finance the required quality and environmental improvements and X is the productivity offset. Since the 1994 Price Review, Ofwat has used some forms of comparative competition in the regulation of the industry, as the X factor is differentiated according to the companies' efficiency levels in order to provide the less efficient operators

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with sharper incentives to cut slacks and to catch up with the industry frontier. Ofwat uses econometric analysis to disentangle cost differences among firms due to different operating environment from those due to inefficiency.[1] The importance for Ofwat of having a sufficient numbers of comparators was explicitly recognized in legislation at the time of privatization and it has been confirmed in the recent amendments to the Water Industry Act, which requires the Competition Commission to take into account the ability of Ofwat to make comparisons, when deciding whether or not a merger in the water sector is allowed to proceed.

The theoretical curiosity in the effects of privatization and regulation, as well as some more recent interest by policymakers in the horizontal and vertical structure of the industry, has spurred the appearance of a relatively large numbers of new studies that have dealt with such issues as productivity, efficiency and scale economies in the English and Welsh water industry.

Most of the evidence refers to the ten water and sewerage companies. Saal and Parker (2001) estimated a total cost function for the 1985-99 period and find that the 1994 regulatory tightening generated an improvement in technical change. Saal et al. (2007) estimated total factor productivity growth, technical change and efficiency change over the 1985-2000 period using a stochastic input distance function. They found an increase in technical change after privatization and an approximately constant level of technical inefficiency. Finally, Saal and Reid (2004) estimated a variable cost function over the 1992/93-2002/03 period and found that technical change was positive, though declining through time (from 2.02 % to 1.76%). All these papers find slightly negative scale economies for the average Wasc. Bottasso and Conti (2006) estimated a double heterosckedastic stochastic cost frontier for the whole water industry (Wascs and Wocs) and found that technical inefficiency declined over the 1994/95-2001/02 period[2] and that economies of scale were approximately constant at the sample median. However Saal and Parker (2005) argued that modelling the Wascs' water operations together with the Wocs might be inappropriate as they could operate under different technologies and there could be cost complementarities as well as cost allocation problems between water and sewerage operations that make it difficult to separate costs.[3] Stone & Webster Consultants (2004a) estimated both a total and a variable cost function and found negative scale economies for the Wascs and constant scale economies for the Wocs at their respective sample means.[4]

The empirical evidence on cost economies in the water sector outside the UK is considerable.[5] Among recent contributions, we mention the work by Torres and Morrison (2006) who analysed a cross section of 255 US water utilities using a multiproduct flexible cost function: estimates show considerable scale economies for small utilities which are however counteracted by simultaneous increases in customers and service area size, especially in the case of large utilities. Kim and Clark (1988) estimated a translog cost function on a cross section of 60 US water utilities and found that scale economies at the production phase are counteracted by diseconomies at the distribution one so that scale economies were constant at the sample mean. For a three-years panel of 55 French water utilities Garcia and Thomas (2001) estimated a translog cost function and found diseconomies of customer density in the long run and economies of scale slightly decreasing with size. Fabbri and Fraquelli

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[1] See Cubbin (2004) for a critique on the econometric models employed by Ofwat. In particular, he argues that Ofwat's econometric models are likely to provide inaccurate efficiency rankings given the existence of measurment errors, omitted cost drivers, etc. and that, as a result, Ofwat might be overestimating the true scope for efficiency improvement in the English and Welsh water and sewerage sectors.

[2] See also Ashton (2000).

[3] An econometric test confirmed that pooling the two samples leads to biased parameter estimates.

[4] In turn, Stone & Webster Consultants (2004b) reported positive technical change for the Wocs, although declining through time.

[5] For an exhaustive survey of the literature see Amato and Conti (2006).

(2000) analyzed a cross section of 150 Italian water companies using a translog cost function and found increasing returns to output density and approximately constant scale economies at the sample mean. These results in terms of output density and scale economies are confirmed by estimates of a Cobb-Douglas cost function carried out by Antonioli and Filippini (2001) on a panel of 32 Italian water utilities; moreover, they found positive economies of customer density. Finally, Mizutani and Urakami (2001) estimated a translog cost function and found positive returns to output density and slight diseconomies of scale at the sample mean for a cross section 112 Japanese water supply firms. As the results of these papers suggest, in the economic literature there is not a clear-cut result on the existence and extent of scale economies in the water supply industry. In fact, it is very important to bear in mind that the existence of scale economies usually depends on the size and type of utilities considered (e.g. rural versus urban or wholesale versus retail utilities), as well as on the ownership and regulatory structure of the sector. Therefore, comparisons across studies that are based on substantially different samples should be taken with much care.

In this paper we add to the debate over the Wocs technology, technical change and scale economies in different ways. First, we estimate a cost function for the English and Welsh water only sector: previously, only Stone and Webster Consultants (2004a) reported some evidence on economies of scale (at the sample average) for the Wocs, although they did not investigate the magnitude of scale economies at different size percentiles. Moreover, we include in our model, together with water delivered and connected properties, the service area size. The joint consideration of physical output, connected properties and network size, proxied by service area size, is potentially very important in capturing trade-offs between water production and the size of the network, which depends on output density relative to customers and area size (Torres and Morrison, 2006 and Antonioli and Filippini, 2001). On one side, a water company with a relatively low customers to area size ratio would require the use of longer pipelines, while a water company with a high ratio might require multiple complex connections and have pressure problems; on the other side a company operating in a larger area might require higher costs (e.g. more fuel and labour expenditure, because workers have to travel longer distances to fix breaks and repair pipes, for instance) with respect to a situation where a given number of customers are concentrated in a smaller area. Considering both the vertical (i.e. customer) and the horizontal (i.e. area size) dimensions of water utilities' operations could turn out to be an essential step in deriving accurate measures of economies of output, customer and spatial density, as well as scale economies, which in turn provides crucial information as far as the industry design and merger policy are concerned and for setting the X factor in price cap regulation. Finally, given that most utilities are concentrated in the south of England and could be subject to regional specific shocks, we investigate the issue of the possible existence of spatial dependence in the sample, which could lead to misleading results and inferences if not accounted for.

The remainder of this paper is thus organized as follows. In section two we briefly illustrate our data; in section 3 we discuss the theoretical model, the econometric issues involved in the estimation strategy and describe cost economies measurement issues. Finally section four examines the empirical results and section five concludes the paper and discusses policy implications.

2 The data

The data set used in this study consists of an unbalanced panel of 144 firm observations on the Water Only companies observed over the period 1995/96-2004/05. The main source of data comes from the

"June Returns for the Water and Sewerage industries in England and Wales" published by Ofwat[6] and updated at April of each year.[7]

We decided to focus on the water only sector because, as noted in the introduction, the empirical evidence on it is scant. Secondly, given that in some EU countries the water industry is separated from the sewerage one, the analysis of the English water only sector might provide useful policy insights. Moreover Saal and Parker (2004) show that it might be misleading pooling data on Wocs and Wascs' water operations.

The Wocs tend to be concentrated in relatively urban areas and most of them operate in the south east of the country: in particular, in the last five years of the sample, eight companies (out of twelve) share common borders in that region.

The demography of firms included in the panel is driven by the process of mergers and acquisitions which occurred within the sample period. When mergers took place between firms of similar size we have considered the merged entity as a new firm entering the panel;[8] on the other side, if mergers involved companies with considerable size differential we let the bigger survive;[9] if a Woc was acquired by a Wasc, we simply dropped the company from the sample.

In the first year the panel includes 18 firms which reduce to 12 in the last two years. The unbalancedness of the panel is described in Table 1.

In Table 2 we provide some descriptive statistics on the variables used in the empirical application. Variable costs (VC) is defined as operating costs less current cost depreciation and infrastructure renewal charge; total costs (TC) is defined as variable costs plus capital costs (see below); unit labour cost (w) is obtained as the ratio between total labour costs and the number of full-time equivalent employees; the price of other costs (oc) is simply operating expenditure less employee expenditure divided by network length;[10] *vol* represents "physical" output and is proxied by the amount of water delivered; *prop* is the number of connected properties; *sup* is the area size of Woc's statutory area; *aph* stands for average pumping head; *riv* stands for the percentage of water treated which comes from river sources; *den* stands for the density of operations calculated as the ratio between population and the length of the water mains;[11] *nh* is the proportion of water delivered to billed measured non household customers and it is a proxy of the importance of large users.

Table 2 shows that there is considerable variability in terms of connected properties, volumes and area size: the size distribution is left skewed with two large water companies responsible for the large size variability.

A more in depth discussion for the definition of the stock of capital and of capital costs is necessary. Following Saal et al (2007) we proxy the stock of capital, *k,* with the Modern Equivalent Asset (MEA) estimation of the replacement costs of net tangible assets as provided by the "June Returns". However, the MEA value of the capital stock has been subject to periodic re-valuations which result in significant jumps in the capital stock series. To avoid these jumps, we followed Saal et al (2007) and adjusted the capital series by backing out the RPI adjusted value of all MEA revaluations made in the 1995/96-

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[6] Other sources of data employed in this study are the Wocs accounts.

[7] Each year of observation starts at 1st April and ends the following 31st March.

[8] This is the case of the following mergers: Chester Waterworks with Wrexham Water and Midsouthern Water and South East Water.

[9] This was the case for the acquisition of North Surrey Water by Threvalleys.

[10] See, for a similar "normalization", Garcia and Thomas (2001).

[11] Other possible density measures that have been used in the literature are the ratio between the number of connections and network length and the ratio of population to area size. We do not use these definitions of density in order to avoid possible multicollinearity problems given that we already include the area size and the number of connected properties in the model. (See section 3).

2004/05 period.[12] This methodology generates a capital stock series which is consistent with the perpetual inventory method. We decided to adjusted the nominal value of the replacement costs of the Wocs capital stock using the Construction Output Price Index (COPI).[13] For each year in the sample, the capital stock is represented by the mean of the values at 1st April and 31st March of the following year in order to reflect the average capital level through the year. Capital costs have been computed as the product of the capital stock and the price of capital. The latter was computed as the sum of a depreciation rate (i.e. the depreciation and infrastructure renewal charge divided by the capital stock) and the weighted average cost of capital, based on Ofwat's assumptions at the 1994 and 1999 price reviews.[14]

As we noted in the introduction, the English and Welsh water industry has realized a consistent investment programme to increase water quality, refurbish the network and improve service performance. Therefore, the estimation of technical change could be biased unless the improvements in quality that occurred over the sample period are not accounted for in the model specification. In this work, we augmented the cost function with three quality indices, namely q_1, q_2 and q_3 which represent the percentage of each Woc's water supply zones that are compliant with a set of key parameters,[15] the percentage of properties which did not experience pressure problems in a given year and the percentage of properties that did not experience service interruptions longer than twelve hours, respectively.

3 Model specification

3.1 Theoretical model

In order to take into account the possibility that water companies do not minimize costs with respect to all factor inputs, we estimated a variable cost function assuming that the stock of capital is fixed. For the variable cost function we assumed a translog functional form. Its main advantage is that it is a flexible form as it is a second order approximation to an unknown function and, as such, it does not impose strong a priori restrictions.

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[12] See Saal and Parker (2005) for a comprehensive description of the procedure we followed to adjust the capital series.

[13] We also used the RPI index. However, our main results did not seem to have been materially affected by the choice of the price index. Therefore we decided to report the results obtained with the COPI index.

[14] The weighted average cost of capital considered by Ofwat involved a "small company premium", whereby small companies are allowed to recover a sligthly higher cost of capital in both 1994 and 1999 price reviews: our figures incorporate this adjustment.

[15] Ofwat considers a set of tests carried out by water companies on a set of indicators related to drinking water quality. Each water company has to report the percentage of tests that meet a given threshold in the case of eight key parameters, such as faecal coliforms, taste, odor, nitrate, aluminium, iron, lead, pesticides.

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\begin{aligned}
\ln VC_{it} \quad = \quad & \alpha + \sum_{j=1}^{J} \beta_j \ln p_{jit} + \sum_{n=1}^{N} \beta_n \ln y_{nit} + 1/2 \sum_{j=1}^{J} \sum_{s=1}^{J} \beta_{js} \ln p_{jit} \ln p_{sit} \\
& + 1/2 \sum_{n=1}^{N} \sum_{p=1}^{N} \beta_{np} (\ln y_{nit} \ln y_{pit}) + \sum_{j=1}^{J} \sum_{n=1}^{N} \beta_{jn} \ln p_{jit} \ln y_{nit} \\
& + 1/2 \beta_k (\ln k_{it})^2 + \sum_{j=1}^{J} \beta_{jk} (\ln k_{it} \ln p_{jit}) + \sum_{j=1}^{J} \beta_{nk} (\ln k_{it} \ln y_{nit}) \\
& + \sum_{m=1}^{M} \beta_m z_{mit} + \beta_t t + \beta_{tt} t^2 + \sum_{j=1}^{J} \beta_{jt} \ln p_{jit} t + \sum_{n=1}^{N} \beta_n \ln y_{nit} t + u_{it}
\end{aligned} \tag{1}
$$

VC_{it} denotes variable costs of firm i at time t. The vector of variable factor prices, P, is defined as $[P_l; P_o]$, where the subscript l and o stands for labour and other variables inputs, respectively;[16] the vector of "output dimensions" Y is defined as $[vol, prop, sup]$, where *vol* denotes the volume of water distributed, *prop* denotes connected properties while *sup* is the service area size. The vector Z represents technical and quality variables; depending on model specification it includes *aph*-the log of the average pumping head; *nh* -the proportion of water which is supplied to non-household customers and that is billed (a proxy for large users); *riv* -the proportion of treated water which comes from river sources; *den* and its square -the ratio of total population to network length; q_1, q_2 and q_3 which are our quality variables:[17] in principle the vector Z could be fully interacted with the other regressors: however, in order to save degrees of freedom, we decided to include it additively. Finally, t is a time trend which has been fully interacted with factor and output variables, accounting for the possibility that technological change is not neutral and scale augmenting/reducing.

Within the framework of a variable cost function the cost elasticity with respect to capital gives an indication of whether water utilities are located on their optimal long run equilibrium path. A zero or positive cost elasticity with respect to the capital stock -a common finding in the empirical literature on public utilities- suggests the existence of overcapitalization (Caves et al. 1981, Cowing and Holtmann 1983). This is in turn usually interpreted as the result of an Averch-Johnson effect due to the rate of return regulation features of the regulatory regime, as well as to the structural characteristics of the water industry, where most infrastructure is built in order to meet future demand.[18] In the case of overcapitalization the estimation of a total cost function would be misspecified. Given that our empirical results suggest the existence of overcapitalization in our sample we decided not to rely on results based on the estimation of a total cost function.

To correspond to a well behave production structure, the translog cost function must satisfy a set of regularity conditions: it must be non-decreasing in factor prices and output, linearly homogeneous in factor prices, concave and symmetric.[19]

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[16] From now on, the labour price coefficient will be indicated with with the symbol w.

[17] An alternative way of introducing quality could be to multiply one of the output measures, such as the number of connections (see Saal et al, 2007) with a quality index. The quality adjusted number of connections represents the proportion of connected properties that satisfies certain quality standards. As an anonymous referee suggested, what matters from a cost analysis perspective is all the properties connected to the network, and not only those complying with quality standards. This alternative approach might therefore bias cost economies results.

[18] Filippini (1996) argues that the positive elasticity of the capital stock might be due to a multicollinearity problem that would arise when there is a positive correlation between the capital stock and variable costs.

[19] Homogeneity can be imposed by normalizing the dependent variable and factor prices with the price of one of the

In order to estimate the cost function in equation 1 we employ different econometric techniques, based on different assumptions on the way firm specific heterogeneity is treated, which allows us to check the robustness of the results.

3.2 Econometric issues

The panel nature of the data set can be exploited by assuming that the error term u_{it} can be specified as the sum of two independent components: $u_{it} = e_i + v_{it}$, where e_i reflects a time-invariant firm-specific component, and v_{it} is an IID random component with mean zero, uncorrelated with itself, homosckedastic and uncorrelated with the regressors. If we allow for free correlation between e_i and the regressors, equation 1 can be estimated with the LSDV model. However, if some of the explanatory variables have a very low degree of within group variability, the parameter vector is not estimated at all precisely: this is exactly what happens in our model, where the area size is almost time invariant and the within variations of the other output and network related variables give minor contribution to total variability. For this reason we have decided to discard the fixed effects estimates of equation 1[20] and estimated a random effects (RE) model, which is less reliant on the within variability of the regressors, and assumes zero correlation between e_i and the regressors. Within this framework the component e_i is assumed to be an $IID(0, \sigma^2)$ random variable and equation 1 is estimated with GLS. As we detected the presence of serial correlation by means of a serial correlation test for panel data suggested in Wooldrige (2002), we decided to estimate the Baltagi and Wo (1999) random effects model which assumes that the v_{it} error term follows an autoregressive process of order one.[21]

If the e_i is correlated with some regressors, the random effects model provides biased and inconsistent estimates. In order to address this potential problem, we augmented our model by introducing three size dummy variables which may account for time invariant cost differentials; alternatively we introduced region specific dummy variables which may control for heterogeneity of water firms' statutory areas potentially correlated with some regressors and not already accounted for in the model. Moreover, all estimated models include a set of hedonic variables that reflect heterogeneity of firms' operating conditions.

Observing that the sample considered in this paper is a relatively long panel data set (ten years) with a relatively small number of companies and recalling the relative importance of between group variation compared to within group variation for output and network related variables, we decided to pool the data across different companies and to apply the estimation methodology proposed by Beck and Katz (1995), which consists in removing the serial correlation by applying a Prais-Winsten transformation to the data and then compute "panel corrected standard errors" (PCSE) which are

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inputs: we normalized for the price of other variable costs (this normalization procedure is equivalent to impose the following restrictions: $\sum_{j}^{J} \beta_j = 1$; $\sum_{j}^{J} \beta_{js} = 0$; $\sum_{j}^{J} \beta_{jy} = 0$; $\sum_{j}^{J} \beta_{jk} = 0$), thus reducing the components of the P vector to two. Symmetry of the cost function is imposed by assuming that $\beta_{js} = \beta_{sj}$ and $\beta_{np} = \beta_{pn}$ before estimation. Concavity of the cost function is verified if the Hessian is a negative semi-definite matrix, while monotonicity in factor prices requires that costs rise as factor prices increase; finally monotonicity in output requires positive marginal costs.

[20] Davidson and MacKinnon (2004) suggest that if explanatory variables are well explained by a set of firm specific dummy variables, the fixed effects estimator is likely to deliver imprecise estimates. We regressed each of our regressors on a full set of firm specific dummy variables, and the adjusted R^2 turned out to be very close to one in each regression.

[21] We have also considered a conventional random effects model with standard errors robust to both heterosckedasticity and serial correlation but as the results did not differ from those implied by the Baltagi and Wo random effects model we presented only the results of the latter.

robust to groupwise heterosckedasticity[22] and contemporaneous cross sectional correlation.[23]

As a final robustness check we have derived a system of equations made up by the variable cost equation together with the labour and other costs shares equations. This approach allows to substantially increase the degrees of freedom and to exploit possible correlations among equation disturbances.[24] To avoid the singularity problem stemming from the fact that the share equations add up to one, we have dropped the other costs share equation and estimated a system made up of the variable cost function and the labour share equation. After imposing the cross equation restrictions derived from duality theory we estimated the system with an iterated SUR procedure.[25][26]

An issue that we believe it may be worth exploring is linked to the spatial dimension of the data. Typical problems that may arise when sample data have a locational component are the existence of spatial dependence between the observations and of spatial heterogeneity in the relationships we are modeling.[27] As far as spatial dependence is concerned, we focus on the possible existence of spatial autocorrelation in the regression disturbances that might arise from regional specific shocks (e.g. a drought, or a flood). In the presence of spatial autocorrelation, conventional econometric estimation techniques produce inefficient parameter estimates and biased standard errors. We have explored the existence of spatial autocorrelation in the residuals by carrying out a series of tests statistics. We first computed (on the balanced sample) the Moran's I statistics (see Anselin, 1988) and we could not reject the null hypothesis of spatial independence for all estimated models. The same result has been obtained employing a robust LM test for spatial independence in the error terms for the OLS version of the model in equation 1[28] and using the Baltagi et al (2003) tests for spatial autocorrelation in the random effects model version of equation 1.[29] Finally, we also employed a version of the Kelejian and Robinson (1992) test as implemented by Cohen and Morrison (2007)[30] which confirmed the above

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[22] We have tested for groupwise heterosckedasticity using the Wald modified test outlined in Greene (2002) and we had to reject the null hypothesis of homosckedasticity at conventional confidence level.

[23] An alternative approach is the groupwise heterosckedastic model with autoregressive errors first proposed by Kmenta (1986) and recently applied by Farsi et al (2006) within the context of an analysis of scale and scope economies in local public transportation. Beck and Katz (1995) have shown that the FGLS variance-covariance estimates might be too optimistic when used in panels with 10<N<20 and 10<T<40, where N is the number of cross sectional units and T the number of time periods. Nevertheless, the groupwise heterosckedastic model produced parameter estimates very similar to those of the Beck and Katz methodology and are available from the authors upon request.

[24] By applying Sheppard's Lemma to equation 1: $\frac{\partial \ln VC}{\partial \ln p_i} = \frac{\partial VC}{\partial p_i}\frac{p_i}{VC} = \frac{p_i X_i}{VC} = S_i$

Where S_i (with $i \in \{l, o\}$ is the share of input i in variable costs and X_i is the optimal conditional demand of input i

[25] When maximum likelihood or iterated GLS is used, the estimates are invariant with respect to the share equation that is dropped.

[26] We have also considered the estimation of a SUR system where the error term of the cost function was splitted into two components: an IID homosckedastic and serially uncorrelated term and a time invariant heterosckedastic random effects term, following the methodology outlined in Bhattacharyya et al (1997). Because the main results did not differ substantially, we reporteD only the estimate from the SUR system.

[27] For an exhaustive treatment of spatial econometrics, see Anselin (1988) and Anselin et al (2004).

[28] The spatial weights matrix employed in these tests has been specified as $W_{ij} = 1$ if water utilities i and j share a common border and $W_{ij} = 0$ otherwise.

[29] Given a general model $C_{it} = X'_{it}\beta + u_{it}$ with $u_{it} = e_i + v_{it}$ and $v_{it} = \lambda W v_{it} + \xi_{it}$, where W is the conventional weight matrix and λ the spatial autocorrelation parameter, we employed the Baltagi et al. (2003) joint LM test $\sigma_v^2 = \lambda = 0$, where σ_v^2 is the variance of e_i, which, under the null, is distributed as a χ_2^2: although we failed to reject the null at 10%, we had to reject it at 5% suggesting that either random effects or spatial autocorrelation (or both) might be present in the data. We then employed the LM conditional test for spatial autocorrelation proposed by Baltagi et al. (2003) which does not assume that $\sigma_v^2 = 0$. In this case, we could not reject the null of $\lambda = 0$ at conventional confidence levels, which we interpret as against the presence of spatial autocorrelation in our data.

[30] This test does not require knowledge of the actual spatial weighting matrix, but just of which utilities have potentially correlated disturbances. Cohen and Morrison (2007) propose to run the following OLS regression: $u_{it}u_{jt} = c + \mu_{ijt}$, where u are the regression residuals of equation 1 (for the sure model we applied this procedure to the residuals of the

results. Moreover, we argue that possible problems of spatial heterogeneity are likely to be accounted for by our model specification which includes a set of hedonic variables reflecting differences in the topographic features of the companies supply areas, in the mix of water sources, in the density of population and customer composition; furthermore, we augmented the baseline model specified in equation 1 with a set of regional dummy variables and parameter estimates were virtually unaltered.

The above results might be explained recalling that most of the heterogeneity among companies that could lead to spatial correlation is already accounted for in the model; moreover, infrastructure variables like the network of water mains or the capital stock of each water company cannot have important spillover effects on other nearby water companies because in the UK water utilities are local natural monopolies that do not compete and do not trade water with each other as there is not a national or interregional water grid. Furthermore, while it is possible that exogenous regional specific shocks (e.g. a drought) might induce spatial autocorrelation, the tests mentioned above reject this hypothesis.

3.3 Cost economies

The inclusion in the cost function of the service area size allows for the distinction of economies of output density, economies of customer density, economies of spatial density as well as economies of scale (Torres and Morrison, 2006; Garcia and Thomas, 2001 and Antonioli and Filippini, 2001).

As Roberts (1986) noted, increases in demand from existing customers or from new customers in the same area or from new customers from new areas might all lead to increased output, "but each can have a different impact on unit costs and thus lead to a different measure of scale effects".

For example, high volumes could be the result of a vertically extensive network, typical of densely populated urban areas. Torres and Morrison (2006) argue that in this case the water company can serve its customers with relatively short pipelines, saving distribution costs, but also, perhaps, incurring in higher pressure problems, congestions and electricity expenses.

On the other side, a company can have large volumes because its service area is large: in this case pipelines tend to be longer, and distribution costs larger because it is necessary to convey water to customers located far away from the water sources. Furthermore, workers are forced to travel longer distances to repair breaks and leaks with the consequent increase in costs.

In the case of a variable cost function, it is possible to distinguish between short run (i.e. with the capital stock held fixed) and long run (with capital stock free to vary) economies of output, customer and spatial density, as well as short run and long run scale economies.

Short run economies of output density (EOD) are defined as the proportional increase in costs brought about by a proportional increase in output, keeping all other variables fixed (area size, connected properties, input prices, capital stock and technical variables). EOD is the relevant cost economy measure to consider when physical output increases because of higher demand coming from the existing customers (i.e. output per customer and output per squared Km rise).[31] Short run economies of customer density (ECD) are defined as the proportional increase in costs brought about by a proportional increase in output and connected properties, holding network size and the other variables fixed. ECD is the relevant measure to consider when physical output increases because of demand arising from new customers (for instance, because the population grows) and new connections that need to be set up.

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two equations) and i and j represent all neighbouring utilities, c is a constant term and μ is a disturbance term assumed to satisfy the classical assumptions of the error term in the OLS model. The null hypothesis is that u_{it} and u_{jt} are not spatially correlated: if the costant term c is not significantly different from zero, then we can not reject the null. We have also carried out an heterosckedasticity robust version of this test and the results were unchanged.

[31] $EOD = 1/(\ \partial \ln VC/\partial \ln vol)$.

Output per customer remains constant, but output and connections per squared Km rise.[32] Short run economies of spatial density (ESD) are the relevant cost measure to consider when output expansion is associated with a larger service area size. Torres and Morrison (2006) define economies of spatial density (or economies of horizontal network expansion) as the "combined effect of volume and service area size" on costs.[33] Finally short run economies of scale (ES) can be defined as the proportional increase in variable costs brought about by a proportional increase in output, connected properties and service area size.[34] This measure is relevant when assessing possible cost savings deriving from the merger of two nearby utilities.

In the long run firms usually need to adjust their capital stock, hence all cost economies measures need to take into account capital stock variations and their long run counterparts are obtained by multiplying each measure by $(1 - \partial \ln VC / \partial \ln K)$. In the empirical section we report and comment results on long run measures, given that in the case of the economies of spatial density and economies of scale, only the long run measures would appear to be of interest, as the change in area size often involves significant restructuring that make the hypothesis of a fixed capital stock not very interesting (see also Garcia and Thomas, 2001).[35]

4 Empirical results

In this section we discuss the econometric estimates of the empirical models outlined above.

Table 3 reports coefficient estimates and standard errors for the variable cost function estimated with the different econometric methods considered in section 3.2.[36]

Since all right-hand side variables in equations (1) and (2) have been normalized by their sample medians, first order coefficients can be directly interpreted as cost elasticities evaluated at median values. However, as we fully interact factor prices and output and network variables with the time trend, first order coefficients should be more correctly interpreted as cost elasticities in the year zero of the panel.[37]

Among the hedonic variables the only regressor that is always significant in all estimated models is Aph which is positive: companies with high values of the average pumping head have, ceteris paribus, higher pumping requirements and, therefore, higher energy expenditure; Riv is negative but imprecisely estimated: it is possible that the lower cost of abstracting water from river sources (as opposed to boreholds) is couteracted by higher expenditures needed to purify water and bring it to potable standars. Finally, nh is negative, although never significantly so. The evidence regarding the quality variables is inconclusive. Give the definition of our quality indices, the absence of a positive effect of quality on costs might be due to the possibility that firms with a more favorable "environment" not already accounted for in the model (e.g. a better management) might tend to have lower costs and higher quality, which might cause a downwards bias on the quality coefficients. We attempted to control for firm's heterogeneity by including three size dummy variables and although we observed a

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[32] $ECS = 1/(\frac{\partial \ln VC}{\partial \ln vol} + \frac{\partial \ln VC}{\partial \ln prop})$.

[33] $ESD = 1/(\frac{\partial \ln VC}{\partial \ln vol} + \frac{\partial \ln VC}{\partial \ln \sup})$.

[34] $ES = 1/(\frac{\partial \ln VC}{\partial \ln vol} + \frac{\partial \ln VC}{\partial \ln prop} + \frac{\partial \ln VC}{\partial \ln \sup})$.

[35] Short run EOD and ECD results are not reported for reasons of space. In any case, their pattern is quite similar to that identified by the long run measures.

[36] For all models we have tested the null hypothesis of a Cobb-Douglas technology but we had to reject it at conventional statistical level. Moreover for one model we could not reject the hypothesis of homotheticity of the cost function: however overall results are fully robust to the imposition of the restrictions implied by homotheticity.

[37] For aph, riv and nh, cost elasticities are not time-varying, as we did not interact them with the trend.

slight improvement in the significance of quality coefficients, we were not able to reject the null for all estimated models at conventional levels of confidence.

Estimates show that the wage elasticity is significantly positive and declining through time: this might derive from labour saving technological progress (materials and third party services have been substituted for labour over the years).[38] The elasticity of variable costs with respect to the capital stock is positive and significantly so in two models: this result suggests that the water only sector is overcapitalized, thus discouraging us from trusting estimates of a total cost function.[39]

The output and other network related variable elasticities are better understood within the framework analysis of the different cost economies measures described in section 4.

Table 4 reports the results for long run economies of output density, customer and spatial density as well as for economies of scale at the 25th, 50th and 75th percentile. The different cost economies measures have been computed keeping the labour price fixed at the sample median of the entire sample and letting output, service areas, connected properties and the capital stock vary across different percentiles.[40][41] The standard errors reported in Table 4 have been computed using the Delta method, where the null hypothesis was that the relevant cost economy measure was constant (i.e. equal to one).

EOD appear to be large both for small and large utilities and significantly greater than one, although they tend to decline with firms' size. Our results would therefore suggest that in the water only sector if water companies would experience an increase in demand, given the number of customers and the area size, costs would tend to rise less than proportionally and that economies of output density, though declining with size, are not exhausted even at the 75th percentile.

Estimated ECD are all significantly greater than one and seem to slightly increase with firm size: when output increases because of new connections (i.e. both volume and connections grow at the same rate, for a given area size), costs rise less than proportionally. This cost measure is relevant to assess the impact on costs of distributing more water in a given service area when it becomes more densely populated (see Antonioli and Filippini, 2001): our estimates would therefore suggest that in our sample an increase in population density -as observed in the last years especially in the South of England- is not likely to determine an increase in average variable costs of water distribution.

Estimated ESD are positive and statistically greater than one up to the 50th percentile, and tend to decline with size: this implies than an increase in output associated with proportionally greater service area size entails cost economies only for small and medium-sized utilities. For large utilities the impact on average costs of increasing volume is exactly compensated by the impact of increase in area size, giving rise to constant returns associated with proportional changes in volumes and area size.

The different pattern of ECD and ESD along the size distribution of utilities may be better understood considering that, for firms of small size, the cost from additional customers (holding constant service area and volume) seems relatively higher than the costs associated with marginal increases in service area size (given number of customers and volume) and this is reflected in ESD being larger than ECD; on the other side, for larger firms, the number of customers has, ceteris paribus, a lower influence on costs than the breadth of the service area so that ECD tend to be larger than ESD.

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[38] Furthermore, the magnitude of the first order labour price coefficients is quite similar to the sample median labour shares.

[39] Nevertheless we also estimated a total cost function and we found that the main results in terms of cost economies measures were broadly similar to those obtained with the variable cost fuction. We do not report results for reasons of space.

[40] Furthermore, we fixed the trend at the 5th year. However, given the small magnitude of the interaction term between the trend and the output and network related variables, the main results are not affected by this choice.

[41] In other words, when we computed a cost economy measure at, say, the 25th percentile, we substituted in the relevant formula the 25th percentile value for each variable, with the exception of the labour price for which we always substituted the sample median value.

This result might be due to the fact that larger firms in our sample tend to operate in higher density areas and it may be argued that, to a certain extent,[42] marginal costs of serving an additional customer might be lower in more densely populated areas, for instance because pipelines can be shorter.[43] A similar result is reported by Torres and Morrison (2006) for the US water utility industry where the differential between the cost elasticity of connections and the cost elasticity of area size shrinks with firm's size.[44]

Looking at the pattern of economies of scale, estimate results show that economies of scale are present at the 25th, 50th and 75th percentile for all models, with average values across models of about 1.09, 1.11 and 1.13, respectively.[45] Similar results have been found by computing scale economies as suggested by Farsi et al, (2006), in order to ensure that the values used in computations better reflect the characteristics of our sample: we have identified the *ith* percentile company with respect to volume and used that company's corresponding capital stock, area size and connection values in the formulae for scale economies. Alternatively, we have split the sample into four group sizes according to volume [46]and for each group we have taken the median values for all variables involved in the computation of scale economies.The average values across models range from 1.02 for small utilities, to 1.14 and 1.13 for medium and medium-large utilities, respectively and to 1.16 for very large utilities (see Table 4b).[47]

All estimated models consistently imply that proportional changes in volume, customer and area size are associated with less than proportional increases in variable costs; furthermore, the slight increase of scale economies with respect to size may be explained with the behaviour that ECD and ESD exhibit along the size distribution of utilities as discussed above.[48] These findings would suggest that for all companies in the sample there seems to be positive economies of scale, and therefore benefits might arise from merging water utilities, but that these benefits are relatively small (a 1 per cent increase in volumes, area size and customers would tend to increase variable costs by about 0.91 per cent in the long run).

In order to better understand the relevance of these results we have carried out further analysis for all estimated models on economies of scales in order to investigate their behaviour with respect to sample characteristics other than size. First, we have ranked water utilities with respect to low, medium and high density, calculated as population per km of network,[49] and we found evidence of higher scale economies for utilities operating in higher density areas (Table 4b). In particular, scale economies evaluated for the median company of each density group resulted to be approximately

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[42] See below for a discussion of an extended model which includes a density variable and its square as additional regressors.

[43] See, for instance, Fabbri and Fraquelli (2000) who argue that density of operations might have a positive impact on the efficient scale of operations as they found a strong negative impact of density on the operating costs of a sample of Italian water utilities.

[44] It must be noted than large firms belonging to our sample are significantly bigger than those in Torres and Morrison (2006).

[45] We have also computed scale economies for the median water company in each year and they appear to be remarkaby stable over time for all models.

[46] Size groups are defined as utilities distributing less than 100 Ml/day, between 100 and 200 Ml/day, between 200 and 500 Ml/d and more than 500Ml/day, with each group containing respectively 52, 49, 32 and 11 observations.

[47] With the exception of the small utilities group all scale economies are statistically different from one in each estimated model.

[48] Stone & Webster Consultants (2004a) found, for the same sample, a value of about 1.06 for ES at the sample mean although they could not reject the hypothesis of constant scale economies. This difference with our result might be due to the fact that they used a slightly different time span and estimated a model without area size.

[49] The low, medium and high density groups consider utilities with a density between 106 and 152, 152 and 188 and 188 and 216 inhabitants per km of network, respectively.

constant for utilities operating in low density areas, positive and about 1.02 (not significantly different from one) for those active in medium density areas and 1.21 for those located in high density areas:[50] this implies that the benefits of merging water utilities might be higher for those utilities located in densely populated urban areas. By observing that larger utilities tend to be concentrated in more densely populated areas, this last result is broadly consistent with our findings on scale economies for firms of different size. Moreover, arguing that most cost effective mergers are likely to be those involving nearby water utilities (given the structural features of a network industry), we have examined scale economies for the subsample of firms which share common borders (all of which currently located in the South East of the country) and found positive and significant scale economies of about 1.12 for the median firm (see Table 4b).[51] The convenience of mergers in the South East of England was acknowledged as recently as 2006 by the UK Competition Commission which allowed a merger between Mid Kent and South East Water, both located in the South East of the country. The merging utilities argued that cost savings could have been achieved through consolidation of facilities and by developing the grid interconnection between the two areas.

We then carried out a robustness check for our findings on scale economies by augmenting our baseline models with three size dummy variables to pick up firm invariant heterogeneity linked to size, but the results were virtually unaltered. A similar exercise was repeated by including a set of regional dummy variables and also in this case our main results were not affected.

The main novelty of our estimated model is the inclusion of area size together with volume of distributed water and connected properties in a variable cost function. Nevertheless it might be argued that the size of the area served might be empty or that population might be distributed less than uniformly across areas so that the area size variable might not pick up true cost differences linked to horizontal network expansion.

In order to tackle this issue we have built a density variable defined as population per km of network as we argue that differences in network length can reflect differences in the way population is distributed within each area.[52] We extended the variable cost equation by including the density variable as well as its square to pick up possible non-linear effects of density on costs: estimates consistently show that density has indeed a non linear effect on costs.[53] In particular, at low levels of density, an increase in density tend to reduce costs while, at very high level of density, congestion problems arise and successive increases in density would tend to raise variable costs. However, it is important to observe that the congestion effect of density becomes significant (i.e. the marginal effect of density become significantly positive) only for levels of density not experienced in our sample. This finding suggests that, in our sample, companies operating at medium-high level of density tend to have lower costs than those located in less densely populated areas.[54] Most importantly, as can be seen in Table 5, economies of scale are not affected by the inclusion of the density variables in the cost function and display a very similar pattern to that reported in Table 4.[55]

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[50] See, for a similar finding, Garcia and Thomas (2001).

[51] Economies of scale for nearby utilities have been computed by plugging into the ES formula the median values of the relevant variables over the last five years of our sample, when the panel becomes balanced: in this way our results reflect only the mix of utilites still existent as of 2004/2005.

[52] It would be interesting to have information on the mean difference in distance between customer locations, but unfortunately that was not avaliable to us.

[53] Both *den* and its square are individually and jointly statistically significant.

[54] We do not report estimates of the augmented model for reasons of space. However they are available from the authors upon request.

[55] As far as EOD, ECD and ESD is concerned, the overall pattern is broadly confirmed, even if their magnitude is somewhat different. In fact, as argued by Torres and Morrison (2006), by including the density variable "network size is in some sense controlled for", potentially causing some bias in the intermediate results (i.e. ECD and ESD).

Turning to the discussion on technical change, we follow Coelli at al (1998) and compute it as a two years moving average of the logarithmic derivative of variable costs with respect to time[56] as in equation 2:

$$TechCh_{t,t+1} = -0.5 * (\partial \ln VC_t/\partial t + \partial \ln VC_{t+1}/\partial t) \tag{2}$$

Table 6 reports technical change figures computed according to equation 2 for the median water company in each year.[57] Generally, technical change is positive (and significantly so) in all but the first two years of the panel and increasing over time.[58] The yearly average rate of technical change ranges from 0.9% in the SURE model to 1.3% for the RE and PCSE models. In particular, technical change appears to be mainly driven by its neutral component, with a far smaller role played by the labour saving and output and capital augmenting technical change components. The figures in Table 5 suggest that the average rate of technical change has been higher in the second regulatory period (1999-2004): in particular, it is virtually zero in the first regulatory period, and rises to 1.8%, 1.9% and 1.6%, in the RE, PCSE and SURE models respectively, during the last five years of our panel. This pattern might have been driven by the stringent X factors decided by Ofwat in the 1999 price review.

We have also formally tested whether the trend rate of reduction in variable costs was significantly different in the two regulatory periods included in our sample by interacting the time trend with a dummy variable equal to one for the last five years of the panel and zero otherwise. The coefficient of the interaction variable was negative in all models (suggesting that the trend rate of reduction in variable costs has been stronger in the second regulatory period); however, in none of them we were unable to reject the null hypothesis that it was equal to zero. In any case, the inclusion of the interaction variable did not materially alter the technical change figures computed with our baseline specification.[59]

Finally, we tried to assess whether the 1999 price review had any impact on the cost structure of the Wocs sector by interacting the first order coefficients of labour price, capital stock, volume, customers and area size with a dummy variable which took the values of one for the last five years of the panel and zero otherwise. The evidence is mixed, as we could not reject the null hypothesis that the interaction variables (as well as a constant shifting dummy) were jointly equal to zero in the RE and SURE models, while we had to reject it at 1% in the PCSE model, although in the latter model the rejection of the null seems to be mainly driven by a statistically significant increase in the volume elasticity after the 1999 price review.

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[56] Equation 2 computes technical change by evaluating the logarithmic derivatives at both year t and t+1 points, rather than only at year t (Caves et al, 1982). The result of this specification is that technical change is somewhat smoothed. However, as noted by Coelli et al (1998) the impact on estimated technical change figures is in practice generally negligible, as it is the case in our application.

[57] Our technical change figures are referred to the median water company in each year: in other words all variables that enter in equation 2 are evaluted at their median value for each year. In this way we account for changes in variables occurred over the sample period that might affect technical change (factor prices, output, customers, capital and area size).

[58] We also tested the null hypothesis of neutral technical change with a Wald test but we had to reject it at the 5% level in two models. Only in the case of the PCSE model we could not reject the null at 1%.

[59] When we estimated a total cost function we found that technical change was always negative in all estimated models, suggesting that costs tended to increase over the sample period, although not at an increasing rate. This finding might be explained recalling that, if overcapitalzation does exist, then the total cost function estimates, and the associated technical change figures, might be misleading and underestimate "true" technical change (see Caves et al, 1981).

5 Conclusion

In this paper we estimate a variable cost function for the English water only sector. The main novelty of this study is that we jointly consider connected properties and area size along with water delivered: this allows us to compute economies of output, customers and spatial density, as well as scale economies. Overall results on cost economies can be summarized as follows: economies of output density exist and tend to decrease with firm's size, economies of customer density are positive and slightly increasing with size while economies of spatial density fall with size and are about constant for larger firms; finally, scale economies are positive, albeit small, and tend to slightly increase with size; moreover, economies of scale resulted to be higher for firms located in high density areas. In particular, our estimates show that even companies of relatively large dimensions (e.g. with a production of about 270 Ml/day, serving about 480000 customers and operating in an area of about 2000 squared kms) could be enjoying small scale economies. Overall results are consistent across different econometric techniques employed to estimate the cost function and are not affected by possible biases induced by the presence of untreated spatial dependence in the data.

The main findings of this study would suggest that moderate cost savings from prudent mergers between utilities could be expected; in particular, benefits of merging water utilities might be higher in more densely populated urban areas. Moreover, by noting that mergers in the water sector are more likely to deliver cost savings when involve nearby utilities, our results suggest that in the South-East of the country some further consolidation between Wocs might be economically justifiable. This in turn provides further support to the 2006 UK Competition Commission decision which allowed a merger in that region notwithstanding Ofwat's aversion towards it. Furthermore, results on economies of customer density imply that the growth in population taking place in the south of England should not lead to increase in average production costs for water utilities.[60]

Our estimated models might have some other useful policy implications within the framework of the economic regulation of the water industry and, in particular, in the determination of the X factor in the price cap formula. It is well known (Bernstein and Sappington, 1999) that the X factor should include the effects of scale economies on costs.[61] However, the assumptions made in the regulatory practice over the relevant cost economy to apply are often not clear. In fact, scale economies might not be the right measure to consider if over the regulatory period output growth is expected to come either from existing customers or from new customers located within the service area: in this case, the economies of output density or customer density, respectively, would appear more relevant. Our results show that economies of output and customer density are larger than economies of scale, and therefore their use in the regulatory practice would lead to more aggressive X factors and, consequently, to lower prices for customers.

The other main finding of this paper is that the overall performance of the sector, as measured by technical change, has been improving over the sample period. In particular, technical change turned out to be accelerating and became significantly positive in the third year of the panel. This result might have been due to the 1999 Price Review when Ofwat imposed tougher X factors in the price cap formula, which might have provided strong incentives for water companies to improve efficiency and productivity.

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[60] More extended implications for the organization of the whole English and Welsh water and sewerage sectors could be derived from a study which pools both Wascs and Wocs and fully takes into account the multiouput nature of Wascs' operations and therefore the possibility that (dis)economies of scope might exist between water and sewerage (see Stone and Webster Consultants, 2004a).

[61] Positive output growth over the sample period coupled with positive scale economies should lead to lower costs, ceteris paribus.

References

[1] Amato, A., Conti, M., 2006. *The Economics of the Water Industry: Technology, Ownership and Efficiency.* Milan: Franco Angeli.

[2] Anselin, L. 1988., *Spatial Econometrics: Methods and Models.* Kluwer Academic Publishers.

[3] Anselin, L., Florax, R.J., Rey, S.J., 2004. Econometrics for Spatial Models, Recent Advances. In: Anselin, L., Florax, R.J., Rey, S.J., (Eds.). *Advances in Spatial Econometrics. Methodology, Tools and Applications.* Berlin: Springer-Verlag.

[4] Antonioli, B., Filippini, M., 2001. The Use of a Variable Cost function in the Regulation of the Italian Water Industry. *Utilities Policy* 3-4.

[5] Ashton, J.*K*., 2000. Cost Efficiency in the UK Water and Sewerage industry. *Applied Economics Letters* 7, 455-58.

[6] Baltagi, B.H. and Wo, P.X. 1999. Unequally Spaced Panels Data Regressions with AR(1) Disturbances. *Econometric Theory* 15.

[7] Baltagi, B.H., Song, S.H., Koh, W., 2003. Testing Panel Data Regression Models with Spatial Error Correlation. *Journal of Econometrics* 117, 1.

[8] Bhattacharyya, A., Bhattacharyya, A., Mitra, K., 1997. Decomposition of Technological Change and Factor Bias in Indian Power Sector: An Unbalanced Panel Data Approach. *Journal of Productivity Analysis* 8.

[9] Beck, N.J., Katz, J., 1995. What to Do (and Not to Do) with Time -Series-Cross-Section Data in Comparative Politics. *American Political Science Review* 89.

[10] Bernstein, J.I., Sappington D.M., 1999. Setting the X-factor in Price Cap Regulation Plans. *Journal of Regulatory Economics* 16, 5-25.

[11] Bottasso, A., Conti, M., 2006. Efficiency Incentives for a Regulated Monopoly: Some Lessons from the English and Welsh Water Industry. Forthcoming in *Rivista di Politica Economica.*

[12] Caves, D.W., Christensen L.R., Swanson, J.A., 1981. Productivity Growth, Scale Economies and Capacity Utilization in US Railroads, 1955-74. *American Economic Review* 71, 5.

[13] Caves, D.W., Christensen L.R., Diewert, W.E., 1982. Multilateral Comparisons of Output, Input and Productivity Using Superlative Index Numbers. *The Economic Journal* 92.

[14] Coelli, T., Prasada Rao, D.S, Battese, G.E. *An Introduction to Efficiency and Productivity Analysis.* Kluwer Academic Publishers.

[15] Cohen J.P., Morrison Paul, C., 2007. The Impact of Transportation Infrastructure on Property Values: A Higher Order Spatial Econometrics Approach. *Journal of Regional Science* 47, 3.

[16] Cowing, T.G., Holtmann, A.G., 1983. Multiproduct Short Run Hospital Cost functions: Empirical Evidence and Policy Implications from Cross Section Data. *Southern Economic Journal* 49, 3.

[17] Cubbin, J. 2005., Efficiency in the Water Industry. *Utilities Policy* 13, 4.

[18] Davidson R., MacKinnon, J.G., 2004. *Econometric Theory and Methods.* Oxford: Oxford University Press.

[19] Fabbri, P., Fraquelli, G., 2000. Costs and Structure of Technology in the Italian Water Industry. *Empirica* 27, 1.

[20] Farsi, M., Filippini, M., Kuenzle, M., 2007. Cost Efficiency in the Swiss Gas Distribution Sector. *Energy Economics* 29.

[21] Farsi, M., Fetz, A., Filippini. M., 2006. Economies of Scale and Scope in Local Public Transportation. *CEPE* working Paper 48.

[22] Filippini, M., 1996. Economies of Scale and Utilization in the Swiss Electric Power Distribution Industry. *Applied Economics* 28, 543–550.

[23] 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.

[24] Hunt, L., Lynk, E. 1995. Privatization and Efficiency in the UK Water Industry: an Empirical Analysis. *Oxford Bulletin of Economics and Statistics* 57, 3.

[25] Kelejian, H., Robinson, D., 1992. Spatial Autocorrelation: A New Computationally Simple Test With an Application to Per Capita County Police Expenditure. *Regional Science and Urban Economics* 22.

[26] Kim, H.Y., Clark, R.M., 1988. Economies of Scale and Scope in Water Supply. *Regional Science and Urban Economics* 18.

[27] Kmenta, J., 1986. *Elements of Econometrics.* New York, MacMillan.

[28] Mizutani, F., Urakami, T., 2001. Identifying Network Density and Scale Economies for Japanese Water Supply Organizations. *Papers in Regionl Science* 80.

[29] Roberts, M., 1986. Economies of Density and Size in the Production and Delivery of Electricity Power. *Land Economics.*

[30] Saal, D., D. Parker., 2001. 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.

[31] Saal, D., Parker, D., 2005. Assessing the Performance of the Water Operations in the English and Welsh Water Industry: A Panel Input Distance Function Approach. *Aston Business School Working Paper* 0502.

[32] Saal, D., Parker D., Weyman-Jones, T., 2007. Determining the Contribution of Technical, Efficiency, and Scale Change to Productivity Growth in the Privatized English and Welsh Water and Sewerage Industry: 1985-2000. Forthcoming in *Journal of Productivity Analysis.*

[33] Saal, D., Reid, S., 2004. Estimating Opex Productivity Growth in English and Welsh Water and Sewerage Companies: 1993-2003. *Aston Business School Working Paper.*

[34] Stone & Webster Consultants, 2004a. Investigation into Evidence for Economies of Scale in the Water and Sewerage Industry in England and Wales. *Report for Ofwat.*

[35] Stone & Webster Consultants, 2004b. An Investigation into Opex Productivity trends and causes in the Water Industry in England and Wales. *Report for Ofwat.*

[36] Torres, M., Morrison Paul, C., 2006. Driving Forces for Consolidation or Fragmentation in the US Water Utility Industry: A Cost Function Approach with Endogenous Output. *Journal of Urban Economics* 59, 1.

6 Appendix

Tab. 1: Panel Structure

Years of obs.	No.of firms	Obs.
10	10	100
8	2	16
5	4	20
2	4	8
Total Observations		144

Tab. 2: Descriptive Statistics

Variable	Mean	SD	Min	Max
Properties	317.53	286.84	38.87	1237.36
Volume	185.71	175.01	24.66	800.79
Area	1418	1060.2	90	3700
Total costs	108.37	97.07	15.60	416.41
Variable costs	22.21	20.33	3.11	93.86
Price labour	24.40	3.45	15.96	34.96
Price other costs	0.003	0.0008	0.001	0.006
Price capital	0.109	0.014	0.088	0.161
Capital stock	917.19	844.51	122.56	3421.98
APH	127.97	39.38	56.1	213.87
Density	0.168	0.029	0.107	0.218
Nh	0.290	0.071	0.173	0.484
Riv	0.35	0.32	0	1
Q_1	96.52	4.09	77.5	100
Q_2	99.65	0.85	93.72	100
Q_3	99.92	0.19	98.49	100

1) Properties (thousands of connected properties)
2) Volume: water distributed (Megalitres/day)
3) Area: Service area size (squared Kms)
4) Total costs (millions of GB £)
5) Variable costs (millions of GB £)
6) Price labour (thousands of GB £)
7) Price other costs (million of GB pounds/000Km of water mains)
8) Price capital (rate of return)
9) Capital stock (Millions of GB £)
10) Aph: average pumping head (m.hd)
11) Nh (water delivered to non households/water delivered)
12) Riv: Fraction of distribution input which is abstracted from river sources
13) Q1: quality index 1 (see Data section)
14) Q2: quality index 2 (see Data section)
15) Q3: quality index 3 (see Data section)

Tab. 3: Variable cost function estimates

	RE	PCSE	SURE
β_{vol}	0.154 (0.149)	0.165 (0.105)	0.253(0.074)
β_{prop}	0.304 (0.166)	0.308 (0.116)	0.434(0.078)
$\beta_{\sup}$	0.208 (0.054)	0.188 (0.045)	0.150(0.025)
β_{w}	0.447 (0.060)	0.457 (0.055)	0.399(0006)
β_{k}	0.247 (0.111)	0.250 (0.073)	0.038(005)
β_{volsq}	-0.08 (0.398)	-0.182 (0.380)	-1.063(0.208)
β_{propsq}	-1.733 (1.188)	-1.765 (0.678)	-0.769(0.535)
β_{wsq}	0.404 (0.142)	0.473 (0.149)	0.193(0.008)
β_{ksq}	-2.041 (0.782)	-2.129 (0.504)	-0.423(0.315)
β_{wvol}	0.150 (0.149)	0.177 (0.122)	0.006(0.020)
β_{wprop}	-0.080 (0.188)	-0.122 (0.160)	0.087(0.024)
β_{wk}	-0.037 (0.197)	0.010 (0.146)	-0.096(0.021)
$\beta_{volprop}$	0.218 (0.596)	0.309 (0.434)	1.129(0.302)
β_{volk}	0.288 (0.552)	0.400 (0.325)	0.759(0.248)
β_{propk}	1.368 (0.786)	1.285 (0.457)	-0.650(0.336)
$\beta_{\sup sq}$	0.148 (0.115)	0.176 (0.077)	0.399(0.037)
$\beta_{w \sup}$	-0.067 (0.090)	-0.090 (0.087)	-0.029(0.009)
$\beta_{vol \sup}$	-0.287 (0.224)	-0.357 (0.219)	-0.546(0.087)
$\beta_{prop \sup}$	-0.100 (0.105)	-0.129 (0.112)	-0.148(0.058)
$\beta_{k \sup}$	0.366 (0.271)	0.439 (0.198)	0.360(0.104)
β_{trend}	-0.003 (0.009)	-0.001 (0.009)	0.007(0.004)
$\beta_{trendsq}$	-0.001 (0.001)	-0.002 (0.001)	-0.003(0.0007)
$\beta_{trend \sup}$	0.002 (0.007)	0.002 (0.008)	0.001(0.002)
β_{trendk}	0.013 (0.017)	0.014 (0.014)	0.020(0.006)
β_{trendw}	-0.003 (0.008)	-0004 (0.008)	-0.005(0.001)
$\beta_{trendprop}$	-0.023 (0.021)	-0.025 (0.013)	-0.011(0.009)
$\beta_{trendvol}$	0.013 (0.015)	0.013 (0.011)	-0.005(0.006)
β_{aphead}	0.070 (0.042)	0.081 (0.028)	0.093(0.019)
β_{riv}	-0.010 (0.031)	-0.014 (0.021)	-0.006(0.012)
β_{nh}	-0.141 (0.251)	-0.123 (0.188)	-0.122(0.132)
β_{q1}	0.0007 (0.001)	0.0007 (0.001)	-0.0001(0.0009)
β_{q2}	0.015 (0.010)	0.012 (0.010)	-0.011(0.004)
β_{q3}	0.001 (0.016)	0.001 (0.013)	0.004(0.011)
R^2	0.99	0.99	0.99

Table 4: Long run cost economies

		RE	PCSE	SURE
25^{th}	EOD	6.00	5.84**	5.06***
	ECD	1.43***	1.41***	1.40***
	ESD	2.61**	2.65***	2.49***
	ES	1.09***	1.09***	1.09***
50^{th}	EOD	3.12*	2.94**	3.76***
	ECD	1.70***	1.65***	1.42***
	ESD	1.56*	1.57**	2.23***
	ES	1.10***	1.10***	1.12***
75^{th}	EOD	2.58*	2.25**	1.59***
	ECD	1.89***	1.89***	1.79***
	ESD	1.29	1.20	1.00
	ES	1.09***	1.10***	1.19***

* sign 10%,** sign 5%,*** sign 1%

Table 4b: Long run scale economies

	RE	PCSE	SURE
Small	1.03	1.03	1.01
Medium	1.14***	1.15***	1.14***
Medium-large	1.09***	1.10***	1.21***
Large	1.12***	1.13***	1.24***
Low density	0.97	0.92	1.04**
Medium density	1.03	1.02	1
High density	1.20***	1.20**	1.23**
South East	1.11**	1.16**	1.08***

* sign 10%,** sign 5%,*** sign 1%

Table 5: Long run cost economies

Model with density				
		RE	PCSE	SURE
25^{th}	EOD	6.00*	5.33**	6.35***
	ECD	1.21*	1.21**	1.08***
	ESD	3.72*	3.50	5.90***
	ES	1.08***	1.08***	1.06***
50^{th}	EOD	2.54	2.21*	4.60***
	ECD	1.51*	1.50*	1.05*
	ESD	1.56	1.48	5.03***
	ES	1.10**	1.12***	1.07***
75^{th}	EOD	2.30*	1.92**	1.91***
	ECD	1.79**	1.85**	1.12**
	ESD	1.28	1.15	1.90***
	ES	1.11**	1.12***	1.11***

* sign 10%,** sign 5%,*** sign 1%

Tab. 6: Technical Change

	RE	PCSE	SURE
95/96 - 96/97	0.003	0.002	-0.004
96/97 - 97/98	0.006	0.004	-0.001
97/98 - 98/99	0.008*	0.007*	0.002
98/99 - 99/00	0.01***	0.01***	0.005**
99/00 - 00/01	0.014***	0.014***	0.009***
00/01 - 01/02	0.017***	0.017***	0.012***
01/02 - 02/03	0.019***	0.020***	0.016***
02/03 - 03/04	0.021***	0.022***	0.019***
03/04 - 04/05	0.022***	0.024***	0.022***

* sign 10%,** sign 5%,*** sign 1%