School of Finance & Law
Working Paper Series

Economies of scale, economies of capital utilisation and capital utilisation in the English and Welsh water industry

by

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No. 17

1999

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Published 1999 by the School of Finance and Law, Bournemouth University, Talbot Campus, Fern Barrow, Poole, Dorset, BH12 5BB.

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Email: jashton@bournemouth.ac.uk
ISBN 1-85899-090-4

A catalogue record for this publication is available from the British Library.

Acknowledgements

I would like to thank P. Hardwick his insightful comments on an earlier draft of the paper. The usual disclaimer applies.

For further information on the series, contact K. Howell,

School of Finance & Law,
Bournemouth University.

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Abstract

This study estimates a variable cost model of the UK water industry. From this variable cost function, estimates of economies of scale and economies of capital utilisation and capacity utilisation are made. The data used in the study consists of 20 English and Welsh water companies. The results suggest that only slight, albeit, significant dis-economies of scale and substantial dis-economies of capital utilisation exist in the industry. These estimates indicate that if output increases, with or without holding capital constant, variable costs would increase at a level above the proportional increase in output. Both these results indicate that if the water industry has not been in long-term equilibrium (in terms of capital) both merger and acquisition amongst water companies (a process that is occurring) is not justified in terms of cost efficiency. A low level of capital utilisation is indicated for the water industry. It is shown that the level of capital utilisation does increase over the sample period to approximately 30 per cent in 1996, indicating dis-equilibrium, in terms of capital, is present in this sector.

1. *Introduction*

Capital utilisation refers to the ratio of actual output to some measure of potential output and is a central feature of the efficient organisation of resources within a firm and an industry. The water industry is subject to both very long-term investments in capital projects such as water mains and reservoirs and changing demand both over the year (higher demands for water in the summer) and over the medium term with the migration of people to, from and throughout England and Wales. These two features make long-term planning in the water industry both uncertain and problematic. Additionally, significant political pressure is applied when peak demand is not reached. This study will aim to quantify the existence of economies of scale and economies of capital utilisation with a sample of 20 water only companies within England and Wales.

The water supply industry is generally acknowledged as possessing many characteristics of natural monopoly, such as economies of scale and high fixed costs associated with distribution. Prior to the privatisation of the water and sewerage industry in 1989, water supply in England and Wales was provided by a combination of 28 private companies and 10 state-owned water and sewerage authorities. The responsibilities of the regulator, (the Office of Water Regulation or OFWAT), include ensuring that reasonable demands for services are met, that licensees are able to finance the provision of services, that the interests of consumers in terms of prices levied and the quality of services provided are protected and that competition is promoted.

This study will fill a gap in the present literature by providing empirical evidence as to whether economies of scale, economies of capitalisation and the level of capital utilisation are significant factors in policy terms. The implications of positive or negative economies of scale, economies of capital utilisation and the level of capital utilisation are significant for both the regulation of the industry and in assessment of the substantial investment plans of the industry.

The study is organised as follows: a review of previous empirical studies of the English and Welsh water industry is presented in section 2. Section 3 discusses the data employed, and section 4 outlines the model form and estimation procedure used in the study. Section 5 considers the results of the analysis, with a summary of the paper and conclusions presented in section 6.

2. Previous studies of the UK water supply industry

A number of studies of the English and Welsh water industry have been undertaken in the last decade. These studies have included descriptive studies of the industry in which issues, such as competition, regulation and efficiency are considered[1], a number of qualitative assessments of organisational and economic characteristics of the industry and empirical studies quantifying a range of economic attributes of the industry, including efficiency, economies of scope and productivity. It is the last group of studies that this literature review will consider in most depth. A broader literature review concerning studies both on the English and Welsh water and sewerage and the privatisation movement in the UK is provided by Crafts (1998).

The empirical studies consist of studies sponsored and published by OFWAT as well as studies published in the wider academic literature. The empirical studies sponsored and published by OFWAT have mostly emphasised measurement of the relative efficiencies or the productivity of water and sewerage service provision.

Bosworth *et al* (1994) consider the underlying movement of real unit operating costs and productivity in the water and sewerage industries and contrast their findings with a number of 'comparator' industries. In all five, industries are defined as the most relevant for comparison, including extraction of sand and gravel, extraction of miscellaneous materials, pharmaceuticals, brewing and malting and miscellaneous manufacturing. Comparable estimates of the water industry are calculated using Census of Production data.

The three central findings of the study include the identification of the key features of the industry, such as its capital-intensive form, the identification of appropriate comparative industries and analysis of different cost ratios between the water industry and the comparable industries. This analysis has been criticised due to the " … possible arbitrariness of the cost ratios", where this method " … seems inadequate to reflect either the relative importance of the different industries as 'comparators' or the relative importance of the different ratios" (Crafts, 1998, p. 28). Overall, it is indicated that the real unit operating costs of the water and sewerage industry have been increasing faster than those in the manufacturing sector in general.

Crafts (1998) extended the work of Bosworth *et al* (1994) by considering the level of efficiency and total factor productivity growth within the water and sewerage sector. The study emphasises the comparison of the water industry with other comparable industries which have a similar function or ‘nature of work’ and a comparable history (i.e. they have also been a public sector corporation in the past). Comparable industries by ‘nature of work’ are associated with specific functions of the water and sewerage companies. The functions of the industry are divided into a number of distinct categories including the water supply services incorporating water resource management and treatment and water distribution. Similarly, sewerage services are deemed to consist of sewerage distribution, sewerage treatment and sludge treatment and disposal. Water and sewerage companies are also seen to be involved with other business activities such as customer services, scientific services and regulatory services which are deemed to be associated with service industries and financial services companies.

Crafts (1998) estimates of total factor productivity growth are made for both the water and sewerage industry and the ‘comparator’ industries. It is indicated through comparison that substantial efficiency gains have been made by the water and sewerage industry in relation to the ‘comparator’ industries.

In addition to the range of models proposed by OFWAT there is also a body of literature produced by the academic community relating a broad range of issues relevant to the water supply industry. Hunt and Lynk (1995) considered the cost structure of the English and Welsh water and sewerage industry. Data for this study is taken from the annual accounts of the water and sewerage companies for the period 1979/80 to 1987/88 and from CIPFA (1989). The model employed is a translog cost function consisting of costs, input prices and output quantities. Three outputs are defined including a water output, a sewerage output and an environmental services output. The water output is defined as the quantity of water (megalitres put into supply everyday). The sewerage output is measured as the volume of trade effluent taken per day (data on trade effluent is used because data for domestic effluent quantity was unavailable to the authors for time period assessed). The third output is environmental services which includes functions such as " … quality, regulation, pollution alleviation, recreation and amenity, navigation, fisheries and charges for environmental services" (p.378).

The cost variable is defined as annual operating expenditure, including labour costs and other running costs. Depreciation and charges for infrastructure are not used in the study as serious doubts are raised about their validity in the pre-privatisation period. One input price is therefore defined (labour price) as total labour costs divided by the number of employees. A number of other variables are incorporated in the model, including a time-trend variable, which is included to identify technical change, and a firm specific dummy which is incorporated to account for the distinct operating areas of the water and sewerage companies. The central finding of the study is the substantial economies of scope for the joint production of water and sewerage services with environmental services[2]. Hunt and Lynk suggest the " … evidence contained in this paper suggests that these (*the efficiency gains from privatisation*)[3] need to be considerable to compensate for the lost benefits which were available under joint production" (p.386).

Cubbin and Tzanidakis (1998) present a comparison of DEA and econometric regression techniques for measuring the relative efficiency of water supply for the water and sewerage and water only companies for 1994-95. Following Stuart (1993), operating expenditure regressed on a number of potential cost drivers (cost drivers deemed to be statistically insignificant are dropped from the analysis). It is concluded that the main cost drivers are the proportion of water delivered to non-households, the amount of water delivered, and the length of water mains. A number of findings are reported including the presence of scale economies, the substantial discrepancies reported between regression analysis and DEA efficiency rankings and the strong influence that model form has on the efficiency ranking of water supply companies.

Lynk (1993) used a stochastic frontier analysis to assess the efficiency of water only and water and sewerage companies. Data used for water and sewerage companies for 1980 to 1987-88 and water only companies for the years 1984/85 and 1987/88 was taken from the annual reports of water companies. Separate models are estimated for water and sewerage companies and water only companies due to difficulties in pooling data sets. The model employed for the water and sewerage companies considers costs as annual operating costs. The price of labour is defined as the total labour costs divided by total employment. Output variables include the water supply measured as supply per day (in megalitres), the sewerage output is measured as the trade effluent output per day (excluding domestic sewerage) and the third output, environmental services, is the turnover value of this sector of the industry. Dummy variables used in the estimation of the cost function include a time dummy and a region dummy.

The water only companies model specification considers costs as total operating costs. (including water purchased, abstraction licences, pumping and boosting, treatment and examination, distribution, chargeable services, local rates, administrative expenses and services). The price of labour is defined as the cost of labour divided by the average number of employees. The output variable is the quantity of daily water supply (megalitres/per day); time and regional dummies are also used.

Both models employ econometric stochastic frontier models where efficiency is assumed to have a half-normal distribution. The study provides strong evidence that efficiencies are gained though joint production of water and sewerage services and environmental services. It is reported that the average level of inefficiency of private (water only) firms is far higher than for public (water and sewerage firms) firms, indicating either further evidence of economies of scope or a higher level of efficiency associated with public ownership.

A number of other studies have considered a range of features of the water and sewerage industry, such as organisation behaviour, accounting and regulation. For example, Sawkins (1995a) used an event study to consider the influence of regulatory events and declarations by OFWAT (the water regulator) on the stock prices of the English and Welsh privatised water and sewerage companies between 1989 and 1994. The results of the study indicate that the water regulator did not influence the stock prices of water and sewerage companies in a predictable way and therefore suggests that the water regulator has not been 'captured' by the water and sewerage companies. It is concluded that the regulator both balances the demands of companies and consumers. Sawkins (1995b) presents a field work analysis of yardstick competition or comparative competition in the English and Welsh water industry. Shaoul (1997) provided an accounting assessment of the cost and output data of the water and sewerage industry and Ogden and Anderson (1999) present an analysis of the organisation theory employed in the water and sewerage industry.

3. Data

Data is taken from annual reports, the CRI report on water costs and from OFWAT. The sample consists of 20 water only water companies between 1991 and 1996. The data is deflated by the retail price index (RPI) where appropriate. Water services are also provided by the 10 water authorities that were privatised in 1989. These companies produce both water and sewerage supply and treatment services. Due to the potential for economies of scope to distort the results and the far greater size of the water authorities, the water only companies are considered in isolation in this study. Summary statistics are displayed in Table 1 both overall and over two time periods.

Table 1 *Summary Statistics of the English and Welsh water supply industry*

Period	Average	*Standard deviation*	Average	*Standard deviation*	Average	*Standard deviation*
	Population served (000's)		Number of Employees		Water Delivered (ML)	
1991-93	691.00	*716.95*	340.98	*274.98*	57184.48	*50804.34*
1994-96	630.83	*585.72*	314.28	*247.54*	57886.53	*53213.66*
1991-96	660.91	*655.32*	327.63	*261.96*	57535.51	*52024.13*
	Turnover (£m)		Staff Costs (£m)		Length of Water Mains (Km)	
1991-93	28.761	25.431	5.8667	*4.8965*	3503.73	*2797.18*
1994-96	34.713	29.903	7.1167	*5.7952*	3947.85	*4088.74*
1991-96	31.737	27.916	6.4917	*5.4010*	3725.79	*3510.03*
	Total variable costs (£m)		Operational Assets (£m)		Other non-staff variable costs (£m)	
1991-93	17.282	15.068	520.41	423.94	11.4153	*10.2655*
1994-96	18.853	16.415	574.86	501.27	11.7367	*11.1371*
1991-96	18.068	15.776	547.63	465.01	11.5760	*10.711*

The summary statistics display a number of trends that have occurred in the water only sector. Whilst the average number of employees has consistently fallen, the overall average variable costs and the constituents of variable costs have all increased over time. The average amount of water delivered has slightly increased reflecting an increase in the level of demand during the sample period. The average level of turnover, providing an indication of the viability of the sector, has increased consistently over the sample period. The slight decline in the average population served by the water-only companies may reflect the migration of customers between areas served by water-only companies and areas served by the water authorities.

4. Model Form

The techniques employed in this study to quantify economies of scale and capital utilisation are drawn from cost and production economics. Such economic techniques are favoured in that they are grounded in a theoretical conception of the firm. The approach employed broadly follows the methods used by Nelson (1989) and Caves and Christensen (1988) and the techniques employed in a number of studies of capital utilisation in the power generation sector (see, for example, Burney, 1998 and Filippini, 1996). The methodology rests on the assumption that over the short-term firms may not be in equilibrium with respect to the stock of capital. It may therefore be suggested that if this is case long-run estimates of economies of scale may be flawed.

In this study a restricted variable cost function is used to model the production structure of the water supply industry. Central to the definition of this cost function is the presence of both variable and quasi-fixed inputs (capital) where quasi-fixed inputs may not be adjusted to achieve minimum cost in the sample period. It is assumed the technology employed in this sector is fairly homogeneous. The variable cost function is assumed to be concave, linearly homogeneous in input prices, non-decreasing in input prices and outputs and decreasing in the quasi-fixed inputs. The total variable cost function may therefore be derived from a production function (*1*),

$$Y = F(V, X, t) \qquad (1)$$

where V is a vector of variable inputs, X is a vector of quasi fixed inputs, Y represents output and t denotes time. Subject to regularity condition (i.e. costs are minimised with respect to variable inputs conditional on the level of quasi-inputs and output), a dual variable cost function may be defined. The total variable cost function may be written as:

$$VC = VC(Y, w_l, w_r, K, D, t) \qquad (2)$$

where VC represents total variable costs and Y is output (measured as the amount of water supplied to households over the year in mega litres). w_l represents price of the labour input (defined as the total labour cost derived by the number of full time equivalent employees) and w_r represents the price of other variable costs including rents, materials and power costs. This is defined as all non-labour variable costs divided by total assets to provide a measure of other variable costs for every pound of total assets. K represents the stock of capital, which is defined as the total of operational assets and t represents time. D represents the population density of the area served by the company; this variable is defined as the total number of households served by the water company divided by the total length of water mains used by the company. This variable is incorporated in the model to account for exogenous differences in operating environment experienced by individual firms.

It is assumed that a twice-differentiable production function exists in the supply of water. The dual of this production function may be approximated a translog variable cost function. The variable cost function is estimated in translog form for the period 1991-96.

A generalised least squares (*GLS*), iterative, seemingly unrelated regression (*SUR*) estimator is used for all estimations, following a procedure suggested in Greene (1993). It is assumed the variable cost function is non-neutral in terms of technical change. This may be written as:

$$\begin{aligned} LnVC &= a_o + b\ LnY + c\ LnD + v\ LnK + \sum_j a_j Ln w_j + 1/2(g\ LnY\ LnY) + \\ & 1/2(y\ LnK\ LnK) + 1/2(t\ LnD\ LnD) + 1/2(\sum_j \sum_k w_{jk} Ln w_j\, Ln w_k) + \\ & \sum \sum_j d_j LnY\ Ln w_j + \sum \sum_j q_j LnD\ Ln P_j + \sum \sum_j u_j LnK\ Ln w_j + \\ & z\, t + r\ LnD\ LnY + k\ LnK\ LnY + h\ LnK\ LnD + e \qquad (3) \end{aligned}$$

for j, k =1, 2.

Following Nelson (1988) a number of restrictions are imposed on the translog model to ensure linear homogeneity in input prices. These may be written as:

1) $\sum_j a_j = 1$, 2) $\sum_j u_j = 0$, 3) $\sum_j q_j = 0$, 4) $\sum_j d_j = 0$.

Following Shephard’s Lemma, cost share equations are obtained and are used to complete the system to be estimated, where:

$$S_j = \partial LnVC / \partial Ln w_j = a_j + \sum_j w_{jk} Ln w_j + d_j LnY + u_j LnK + q_j LnD + e \qquad (4)$$

As the cost shares must add up to one, one equation is deleted to make the system operational[4].

Following the approach proposed by Nelson (1989) and Cave and Christensen (1988), economies of capital utilisation (EU_{VC}) are derived as unity divided by a proportional increase in total variable costs resulting from a proportional increase in output, holding capital stock constant. That is:

$$EU_{VC} = 1/\partial \ln VC/\partial \ln Y \qquad (5)$$

Economies of utilisation occur when EU_{VC} is greater than 1 and diseconomies of utilisation occur when EU_{VC} is less than 1. EU_{VC} = 1 denotes constant economies of utilisation. The presence of economies of capital utilisation, estimated from a variable cost function, would suggest that if the level of output was increased, while holding capacity constant, variable costs would increase at a lower rate than the increase in output.

Scale economies may also be defined as the proportional increase in total variable cost resulting from a proportional increase in output. Again following the approach forwarded by Caves and Christensen (1988), this may be written as:

$$ES_{VC} = [1-(\partial \ln VC/\partial \ln k)]/(\partial \ln VC/\partial \ln y) \qquad (6)$$

Economies of scale are denoted by values greater than one while dis-economies of scale are denoted by values less than one. One denotes constant costs. The presence of economies of scale, estimated from a variable cost function would suggest that if output increased, variable cost would increase at a lower rate than output, when capacity or the level of capital is not held constant.

A number of methods have been developed to quantify the level of capital utilisation including peak to peak measures, survey analysis and cost and production economics techniques. Peak to peak measures attempt to quantify capital utilisation through examining the level of output over time. From a time series, the relative periodic peaks in output may be determined, which are employed to form a relative measure of maximum output over time through extrapolating a line through the identified peaks. This method, whilst simple in both conception and practice, is based on the arbitrary assumption that a peak in output is associated with maximum output. Additionally, to undertake this form of analysis data must be available on a frequent basis such as monthly or at least seasonally (to the authors knowledge data is only produced annually for the English and Welsh water industry). Finally, this measure may require reassessment whenever a new peak in output is identified.

Survey analysis has also been employed to assess capital utilisation. This technique involves the questioning of industry representatives about their opinions on the level of capital utilisation. As well as problems with the sampling and interpretation of results, there may be bias in the respondents' perception of capital utilisation (see Kenny, 1996 for further discussion of alternative methods of quantifying capital utilisation).

The technique employed in this study to quantify capital utilisation relies on cost and production economics. In common with the peak to peak measures, economic approaches may attempt to quantify the maximum level of output if all available inputs are fully utilised and compare the present level of output with this derived maximum level. To quantify this maximum level of output requires the specification and estimation of a production function. These functions provide a relationship between the inputs, outputs and the productive technology prevalent in the industry considered.

In this study the level of capital utilisation is derived from the variable cost function. As the cost function is dual to the production function, the actual level output is compared with the level of output produced when cost is minimised. The technique used in this study is outlined in Nelson (1989). This technique defines capital utilisation in relation to short-run average total costs (*SRATC*) (which may be defined as variable costs in addition to fixed costs divided by the quantity of output produced i.e. *SRATC* = variable costs (*VC*) + fixed costs *FC*) / output (*Y*)). By estimating the level of output (Y^*) that minimises costs on the *SRATC* curve and comparing this level of output with actual output (*Y*) the level of capital utilisation may be derived as (Y/Y^*).

This level of output (Y^*) may be estimated by considering the minimum point (first order condition) on the SRATC curve. Following Nelson (1989) this may be defined as:

$$1/Y^{*} \cdot \partial VC/\partial Y^{*} - VC/Y^{*2} - FC/Y^{*2} = 0 \qquad (7)$$

As $\partial VC/\partial Y^{*} = (VC/Y^{*})(\partial LnVC/\partial LN\, Y^{*}))$ and $(\partial LnVC/\partial LN\, Y^{*})$ may be derived as $(\partial LnVC/\partial LN\, Y^{*}) = b + gLn\, Y^{*} + \sum_{j} w_{j}\, Ln\, w_{j} + kLnK + rLnD$, the minimum point on the SRATC curve (Y^{*}) may be estimated by substitution. Iteration[5] methods were used for this purpose.

4. Results

The parameter estimates and diagnostic statistics for the translog cost function model are displayed in Table 2. The majority of parameter estimates are significant at the 5 per cent level. The adjusted R^2 and F statistics both provide a measure of model fit; both statistics experience high and statistically significant levels of model fit. The Wald test for restrictions provides a test of the restrictions imposed on the translog model; the restrictions cannot be rejected. The log-likelihood statistic is significant indicating that a linear form of the cost models is rejected.

Positive partial elasticities of variable cost with respect to input prices are found, in accordance with expectation for the model. The partial derivative with respect to population density (*D*) is positive and insignificant. The estimates of economies of utilisation, economies of scale and capital utilisation are displayed in Table 3.

Table 2 Parameter estimates and diagnostic statistics

Parameter	Coefficient	Standard Error	Parameter	Coefficient	Standard Error	Parameter	Coefficient	Standard Error
α_o	0.1550	(0.0187)*	ω_{12}	-0.0110	(0.0018)*	ω_{12}	-0.0110	(0.0018)*
β	-1.9167	(0.0881)*	δ_1	-0.0006	(0.0015)	δ_1	-0.0006	(0.0015)
χ	0.8006	(0.1354)*	δ_2	0.0006	(0.0015)	δ_2	0.0006	(0.0015)
ϖ	2.2821	(0.1321)*	θ_1	-0.0002	(0.0009)	θ_1	-0.0002	(0.0009)
α_1	0.0475	(0.0114)*	θ_2	0.0002	(0.0009)	θ_2	0.0002	(0.0009)
α_2	0.9525	(0.0114)*	υ_1	-0.0052	(0.0016)*	υ_1	-0.0052	(0.0016)*
γ	0.2572	(0.0298)*	υ_2	0.0052	(0.0016)*	υ_2	0.0052	(0.0016)*
ψ	0.1173	(0.0402)*	ξ	0.0016	(0.0010)	ξ	0.0016	(0.0010)
τ	0.0108	(0.0103)	ρ	0.1110	(0.0264)*	ρ	0.1110	(0.0264)*
ω_{11}	0.0217	(0.0029)*	κ	-0.1734	(0.0348)*	κ	-0.1734	(0.0348)*
ω_{22}	-0.0107	(0.0025)*	η	-0.1393	(0.0247)*	η	-0.1393	(0.0247)*

12 iterations before convergence, Sample size: 60 observations	Coefficient	Standard Error
Partial derivative of variable cost with respect to labour price	0.0561	(0.01407)*
Partial derivative of variable cost with respect to capital price	0.9100	(0.01475)*
Partial derivative of variable cost with respect to population density	0.0728	(0.09647)

Adjusted R^2 = 0.9989, F test [21, 98] = 4908.66, prob. = 0.000, Log Likelihood = 604.6389,
Wald test for restrictions = 197.5538, prob. = 0.000, Sum of squared residuals = 0.07456.

* = significant at 10 per cent.

Table 3 *Estimates of economies of scale, economies of capital utilisation and capital utilisation*

Period	Economies of scale		Economies of Utilisation		Capital Utilisation
	Coefficient	Standard Error	Coefficient	Standard Error	
1991	0.9631	(0.00066)*	0.0370	(0.00006)*	0.2989
1992	0.9629	(0.00058)*	0.0370	(0.00006)*	0.2952
1993	0.9642	(0.00056)*	0.0358	(0.00006)*	0.2964
1994	0.9636	(0.00058)*	0.0361	(0.00006)*	0.2876
1995	0.9632	(0.00048)*	0.0364	(0.00006)*	0.2997
1996	0.9630	(0.00046)*	0.0366	(0.00006)*	0.3149
average	0.9633	(0.00054)*	0.0365	(0.00006)*	0.2988

* = significant at 10 per cent.

The estimates for both economies of scale and economies of utilisation are consistent across all years. Slight, albeit statistically significant diseconomies of scale are found in all years. Substantial and significant diseconomies of capital utilisation are indicated, in all years, for the water industry. The level of capital utilisation indicates that on average approximately 30 per cent of the fixed asset of the water companies are employed. This value increases slightly over the sample period from 0.299 in 1991 to 0.315 in 1996. These values are low relative to comparable studies of other utilities, for example, Nelson (1989) indicated that a sample of 22 US privately owned electricity utilities had an average capital utilisation level of 0.667 between 1961 and 1983.

6. Conclusions

The purpose of the study was to estimate measures of economies of scale, economies of capital utilisation and capital utilisation in the English and Welsh water industry for the period 1991-96. Diseconomies of scale and diseconomies of capital utilisation where reported and estimates suggesting low levels of capital utilisation are forwarded.

The presence of slight dis-economies of scale in the water supply industry indicates that if output increased, without holding capital constant, variable costs would increase at a level slightly above any increase in the level of output. The presence of dis-economies of capital utilisation indicates that if the level of capital was held constant, variable cost would increase at a higher level than increase in the level of output. Both results indicate that if the water industry has not been in long-term equilibrium (in terms of capital) both merger and acquisition amongst water companies (a process that is occurring) is not justified in terms of cost efficiency and therefore is not a necessary avenue to achieve greater operating efficiency. The estimates of capital utilisation indicate that the level of utilisation is indeed changing (albeit slowly) and dis-equilibrium (in terms of fixed capital) appears to be present in this sector

The findings of this study are deemed to be of importance for the regulation of this industry. The concept of capital utilisation is not explicitly incorporated in any the econometric models used by the regulator OFWAT. These models are used to ascertain the efficiency of the water supply companies (see, for example, OFWAT, 1998) and are central to their Periodic Review of water and sewerage service pricing. This omission of what may be a substantial determinant of efficiency and productivity could lead to both mis-specification in the determination of operating efficiency and error in the prediction of an acceptable future level of both water supply costs and prices.

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[1] See for example Cowan, (1997)
[2] This finding is of particular note as environmental services were previously performed by the water and sewerage companies until privatisation when the responsibility for environmental services was transferred to the National Rivers Authority.
[3] Explanatory text in italics added by the author,.
[4] By removing one equation from the system a singular covariance matrix is avoided (Nelson, 1989, p.277).
[5] A non-linear maximum likelihood minimisation (see Greene, 1995) was used.

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