Efficiency Analysis Working Papers

WP-EA-18

Quo vadis efficiency analysis of water distribution? A comparative literature review

Christian von Hirschhausen, Astrid Cullmann, Matthias Walter, Robert Wand und Michael Zschille

October 2008

Submitted to *Utilities Policy*

Dresden University of Technology

Chair of Energy Economics and Public Sector Management

Quo vadis efficiency analysis of water distribution? A comparative literature review

Christian von Hirschhausen[a,b,*], Astrid Cullmann[a], Matthias Walter[b], Robert Wand[b], Michael Zschille[b]

Paper submitted to "Utilities Policy"

[a]DIW Berlin (German Institute for Economic Research), Department of International Economics, Mohrenstraße 58, 10117 Berlin, Germany, acullmann@diw.de, chirschhausen@diw.de
[b]Dresden University of Technology, Faculty of Business and Economics, Chair of Energy Economics and Public Sector Management, 01062 Dresden, Germany, cvh@mailbox.tu-dresden.de, matthias.walter@tu-dresden.de, robert.wand@mailbox.tu-dresden.de, michael.zschille@mailbox.tu-dresden.de

Abstract

Recognizing the growing importance of scientific benchmarking in water distribution, we provide a comprehensive survey of the available literature by analyzing 43 studies. We begin with a discussion about the use of benchmarking in the regulation of UK water utilities. We find that the role of ownership (private, public) is ambiguous; quality and structural variables are significant parameters; and water losses and population density are the most important drivers. Analysis reveals that economies of scale only exist in fragmented water industries, whereas economies of density are omnipresent. Finally, we summarize recent methodological developments.

Keywords: water distribution, efficiency analysis, literature review

JEL classification: L95, Q25, C13, C14

**Corresponding author: Tel.: +49-351-463-39770; Fax: +49-351-463-39763*

1 Introduction

Water distribution is increasingly coming under scrutiny by regulators, policymakers, business, and the research community. While early applications of benchmarking techniques have been practiced in the UK, in this decade we observe global uses of water benchmarking. The indisputable natural monopoly character of water distribution, the need for fair prices, and the generally large number of observations have favored the diffusion of efficiency analysis. As applied methods grow more sophisticated, technical issues now dominate. Recognizing the growing role of scientific benchmarking in water distribution, this paper provides a comprehensive survey of the available literature and studies. Figure 1 shows that benchmarking of water distribution is now practiced throughout the world, even in less-regulated Africa and Asia.[1] The majority of the 43 studies we selected from an extensive search were published during the last ten years, and focus primarily on water distribution companies (integrated energy and water utilities and sewerage[2] companies were excluded whenever possible). All of the reviewed studies are frontier studies evaluating efficiency differences.

The paper is structured as follows: Section 2 concerns the use of water benchmarking in regulation. Section 3 compares the studies with respect to the role of public and private ownership. Section 4 reports on the results of studies using structural variables and quality indicators. Section 5 presents the findings related to economies of scale and density in water benchmarking, and Section 6 reports on recent methodological trends. Section 7 concludes.

[1] Many studies originate from the UK (primarily England and Wales) and other Western European countries (France, Italy and Spain). Australia, North America and South America (particularly Peru) were also identified as regions with relevant studies. We note a scarcity of studies in Russia, Northern and Eastern Europe, and in the Middle East.

[2] Sewerage and mixed (water and sewerage) companies are excluded in the comparison of economies of scale and density because they may heavily influence estimates due to their different water and sewerage activities (Saal and Parker, 2006).

Figure 1: Considered countries in the literature review (source: own illustration)

2 Benchmarking for regulatory purposes

One of the prime functions of quantitative benchmarking is to assist regulators to define the appropriate policy instruments for the water distribution sector, as well as for individual companies.[3] Efficiency analysis and benchmarking was first applied to the price reviews of the UK water industry.

These price reviews are conducted by the Water Service Regulation Authority (Ofwat) every 5 years (1994, 1999, 2004, 2009). The approach used by Ofwat in the 1994 review was extensively described by Thanassoulis (2000a, 2000b). Ofwat applied Data Envelopment Analysis (DEA) on a company-function level in order to facilitate discrimination in the model (i.e. fewer output variables; Ofwat recognized the potential problems resulting from limiting observations, but chose not to use panel data). The

[3] We will focus in the following on established benchmarking for regulatory purposes. For benchmarking proposals and suggestions, see e.g., García-Valinas and Muniz (2007) for Spain; Corton (2003) for Peru; and in a broader context, see Anwandter and Ozuna (2002) for Mexico.

clean water operations were identified by "distribution", "resources & treat" and "business activities". The five potential output sets shown in Table 1 have the corresponding input *operating expenditure* in common. The first output set, "number of connections, length of main and water delivered" was chosen as relevant for the final calculations. The efficiency results were then compared to regression results, and entered into the price determination with the exact usage being confidential to Ofwat. Therefore, price caps are not automatically determined by Ofwat (Stern, 2005).

The 1994 output set includes three dimensions of water distribution: number of customers served, geographical dispersion and consumption; other studies (e.g. Bhattacharyya et al., 1995) have used water sales as the single output. Ofwat appears to have recognized that the objective of water distributors is not to deliver as much water as possible, but rather to connect as many households as possible at minimum cost and maximum quality.

Although Ofwat still used econometric techniques for the determination of price caps in 1999, DEA was no longer employed (Dassler et al., 2006). For the 2004 price review, Ofwat commissioned studies comparing the results of Ordinary Least Squares (OLS) with DEA and Stochastic Frontier Analysis (SFA). However, the regulator was criticized for overstatement in interpreting 90% of the water model residuals as inefficiency (Cubbin, 2005). At the time this literature review was written, Ofwat had not announced their plans of using either DEA or SFA in the 2009 price review.

Other examples of efficiency analysis used for regulation are found in Italy and Colombia. Zoric (2006) and Antonioli and Filippini (2001) report on a yardstick competition with tariff approval by the Italian regulator in which the approval decision is based on a parametric one-year benchmarking of variable costs. Marques and

Contreras (2007) report on a new rate structure in the Colombian Water and Sewerage sector based on DEA calculations. The DEA model is run separately for companies with less than and more than 25,000 customers. However, the large number of variables is criticized by Marques and Contreras (2007).

Table 1: Output sets on the distribution level for the use of DEA in the 1994 Ofwat price review (source: own illustration)

Set	Outputs
1	*Number of connections, length of main and water delivered (measured and delivered)*
2	Number of connections and length of main
3	Length of main and water delivered
4	Number of connections, length of main and bursts
5	Number of connections, length of main, measured water delivered and estimated water delivered

In italics: Selected output set for final calculations

3 Public vs. private ownership

A large number of studies address the role of public and private ownership for the efficiency of water distribution companies in industrialized and less-developed countries. Table 2 provides the results of a selection of the here mentioned studies (some of which also include sewerage activities).

For industrialized countries, no clear picture emerges. Bhattacharyya et al. (1995) suggest that in the US, publicly owned water utilities are more efficient.. They apply a translog variable cost function to data of 221 US water utilities in 1992.

Shih et al. (2004) find that public utilities have lower costs than private utilities. They apply DEA to two datasets, each with more than 1,000 observations of water suppliers obtained through the Community Water System Survey conducted by the US Environmental Protection Agency. No clear results are obtained by Saal et al. (2007) who apply SFA with panel data from 1985 to 2000 to ten British and Welsh private water and sewerage companies. Similar results are obtained by García-Sánchez (2006) using DEA with data for 24 Spanish water utilities.

Total Factor Productivity (TFP) studies are also sometimes used to assess the effect of privatization on the cost structure and TFP-levels. Thus Saal and Parker (2000, 2001) apply TFP-analysis to a panel of ten UK private companies from 1985 to 1999. They suggest that during the period labor input was reduced and at least partially substituted for by capital. However, privatization appears to have no impact on TFP growth. The latter result is in contrast to Estache and Trujillo (2003), who find an increase in TFP growth rates for four Argentinean water utilities after privatization, using panel data from 1992 to 2001.

In developing countries there is a slight positive impact of private ownership on company efficiency. Kirkpatrick et al. (2006) use DEA and SFA to determine the impact of ownership structure on efficiency performance in African countries. Using the DEA approach, higher relative efficiency is shown for privately owned utilities. This result coincides with Estache and Kouassi (2002), who estimate a Cobb-Douglas production function for 21 African water utilities using panel data from 1995 to 1997. They obtain significant results for the ownership structure, indicating that private ownership decreases inefficiency slightly. Using the SFA approach, Kirkpatrick et al. (2006) obtain no statistically significant results for the impact of ownership. No significant differences between efficiency under public and private ownership are observed by Estache and Rossi (2002), who estimate a Cobb-Douglas variable cost function using data from 50 water utilities in developing and transition countries in the Asian and Pacific region in 1995.

Table 2: Selected studies evaluating the impact of ownership (source: own illustration)

Author(s)	Data sample	(Functional form and) Specification	Model (and method of estimation)	Results for ownership
Bhattacharyya et al. (1995)	221 US water utilities in 1992	Translog VC function	SFA (SUR and two-step estimation)	Publicly owned water utilities are more efficient
Saal et al. (2007)	10 UK water utilities from 1985-2000	Translog input distance function: capital stock, operating costs, total staff ⇨ connections with water customers, connections with sewerage customers, physical water supply, physical sewerage treatment load	OLS, FE	Privatization has positive impact on minimum efficiency levels but no positive impact on overall efficiency scores
García-Sánchez (2006)	24 Spanish water utilities	Total staff, treatment plants, net kilometers, total costs ⇨ water delivered, number of connections, analyses performed	DEA input orientation with CRS and VRS	Ownership does not influence level of efficiency
Estache and Trujillo (2003)	4 Argentinean provinces from 1992-2001	Labor, energy ⇨ water production	Tornqvist TFP index	TFP appears to increase after privatization
Kirkpatrick et al. (2006)	66 African firms in 2000	Labor price, material price, number of water treatment works ⇨ water delivered, hours of piped water available per day	DEA input orientation with VRS	Evidence for higher relative efficiency in the private sector
	76 African firms in 2000	Cobb-Douglas VC function	Error components (OLS,ML), Battese & Coelli (1995; OLS, ML)	No statistically significant result obtained for ownership
Estache and Kouassi (2002)	21 African water utilities from 1995-1997	Cobb-Douglas production function: labor costs, material costs, hours of work, energy costs, number of connections ⇨ water production	Within group estimator, GLS, GMM, instrumental variables	Privately owned water utilities tend to be more efficient

VC = Variable cost

4 Structural and quality variables

Structural variables (like population density) and quality have been identified as essential for objective efficiency analysis, but there is still room for methodological improvements.

Table 3 summarizes four DEA studies that explicitly address structural and quality variables.[4] Renzetti and Dupont (2008), García-Sánchez (2006) and Tupper and

[4] Some of the studies include sewerage activities.

Resende (2004) all conduct a second stage Tobit regression to determine if the efficiency levels calculated by DEA significantly depend on structural and quality variables. Picazo-Tadeo et al. (2008) on the other hand directly compare DEA efficiency levels with/ without the inclusion of a quality variable. The quality variable water losses, has a significant impact on efficiency levels in Brazil (Tupper and Resende, 2004) and Spain (Picazo-Tadeo et al., 2008), but in the latter the efficiency ranking of utilities is not influenced by the different efficiencies. In a study of Peruvian water utilities using SFA, Lin (2005) finds a high correlation of utilities between models with accounted-for water as quality variable and models absent this variable. Lin however points to strong rank differentiations between specific utilities where water loss appears to be a more serious problem than elsewhere. In an analysis of time varying efficiency models (based on Battese and Coelli, 1995; Caudill et al., 1995; Coelli et al., 2003 and Estache et al., 2004) Lin also finds that a positive rate of chlorine tests, service coverage and service continuity should be included as output variables.

Other SFA studies simply incorporate structural and quality variables in the estimated function rather than comparing results with/ without the inclusion of these additional explanatory variables. For example, the significant impact of water losses on efficiencies and costs appears in a study by Antonioli and Filippini (2001), evaluating 32 Italian water utilities from 1991-1995 with SFA panel data models. They also find that chemical treatment is an influential variable. This contrasts with a study by Fabbri and Fraquelli (2000) concerning the costs and the structure of technology in the Italian water industry. Fabbri and Fraquelli (2000) also identify the positive impact of the population density on costs, a result confirmed with the DEA studies by Tupper and Resende (2004), García-Sánchez (2006) and Renzetti and Dupont (2008) as shown in

Table 3. An analysis of Canada by Renzetti and Dupont (2008) suggests adding elevation differences and the ratio of residential water consumption as structural variables.

Another variable outside the scope of management is analyzed by Saal and Reid (2004) for England and Wales: they find that productivity growth is unaffected by improved water and environmental quality standards.

In the absence of detailed information about structural variables, one can follow the approach of Filippini et al. (2008) and apply a true random or a true fixed effects SFA panel data model proposed by Greene (2005a and 2005b) controlling for unobserved heterogeneity.

Table 3: Studies evaluating the impact of structural and quality variables with focus on DEA (source: own illustration)

Author(s)	Data sample	DEA specification	Inputs	Outputs	Results for structural and quality variables
Picazo-Tadeo et al. (2008)	40 Spanish water utilities (with 20 also providing sewerage services) in 2001	Output orientation; CRS	delivery network, sewer network, labor, operational costs	population served, water delivered, treated sewage	accounted-for water does not influence the ranking of utilities
Renzetti and Dupont (2008)	64 Canadian water utilities in 1996	Input orientation; VRS	labor costs, materials costs, delivery network	water delivered	elevation differences, population density, ratio of residential water and number of private dwellings with significant impact on efficiency
García-Sánchez (2006)	24 Spanish water utilities in 1999	Input orientation; CRS	staff, treatment plants, delivery network	water delivered, number of connections, chemical analyses performed	network density with significant influence on efficiency
Tupper and Resende (2004)	20 Brazilian water and sewerage utilities from 1996-2000	Output orientation; VRS	labor costs, operational costs, capital costs	water produced, treated sewage, population served-water, population served-treated sewage	network densities and accounted-for water ratio with significant influence on efficiency

CRS = constant returns to scale, VRS = variable returns to scale

5 Estimates of economies of scale and density

Our review of the literature shows that water distribution is characterized by economies of scale ("big is beautiful") and density. Therefore we confirm the results of previous surveys, such as Filippini et al. (2008) and Mizutani and Urakami (2001)[5]. Since there is now a general consensus that economies of scale and density can vary considerably with the output level and data set, we suggest presenting the estimates of economies in conjunction with the corresponding output levels.Table 4 shows the results of a representative selection of studies in ascending order of the mean output level.

However, economies of scale appear to exist only to a certain level of output. Studies by Garcia and Thomas (2001) for France, Garcia et al. (2007) for the US and Filippini et al. (2008) for Slovenia show economies of scale with a maximum mean output level of 2.30 m m^3. These economies of scale indicate that water utilities should expand their firm size if they wish to profit from economies of scale. Fabbri and Fraquelli (2000) find weak economies/ diseconomies of scale for a mean output level of 18.86 m m^3 in Italy, depending on the functional form chosen. We suggest this is an approximate threshold.

Saal and Parker (2005) for the UK and Mizutani and Urakami (2001) for Japan find diseconomies of scale using data sets with similarly high average output levels. In addition, Saal and Parker (2005) use a Malmquist productivity index to show that the scale efficiency of UK water utilities decreases between 1993 and 2003, indicating that mergers within the period of observation create water utilities that are too large.

There are several types of economies of density. Economies of customer density measures the cost savings resulting from a proportional increase in the number of

[5] These older surveys include Antonioli and Filippini (2001) and Kim and Clark (1988)

customers and total output, holding all other variables constant. Economies of network density measures the relative increase in output when all inputs are proportionally increased, except for network conditions, which are held constant. Economies of output or production density (only differing in water losses) measure changes in costs when output or production increase, holding all other variables constant. All studies that have estimated economies of density show positive results, an indication of possible cost savings. This suggests the explanation is that water collection and connections are less costly than capital-intensive pipe-laying. Garcia and Thomas (2001) and Garcia et al. (2007) who report some diseconomies of density do not offer details, but congestion costs in the short-run or investment needs in the long-run appear to be plausible explanations for these exceptions.

Table 4: Studies estimating economies of scale and density (source: own illustration)

Author(s)	Data sample	Functional form and cost specification	Model and method of estimation	Estimated economies of scale *at mean output levels*	Estimated economies of density *at mean output levels*	Corres-ponding mean output level
Garcia and Thomas (2001)	55 French water utilities from 1995-1997	Translog VC function	GMM (IV method), SUR method	1.002	EPD: 1.142 (SR) 1.209 (LR) ECD: 1.050 (SR) 0.872 (LR)	0.41 m m³
Garcia et al. (2007)	233 US water utilities (includes 15 distributors) from 1997-2000	Translog VC function	RE (GMM (IV method)), SUR method	1.185 (SR) 1.191 (LR)	EPD: 0.914 (SR)	1.59 m m^3
Filippini et al. (2008)	332 observations for 52 Slovenian water utilities from 1997-2003	Translog total distribution cost function	Pooled, RE, True Fixed Effects (ML, GLS)	1.030-1.088 (for the median, depending on the model)	EOD: 3.042-3.874 ECD: 1.286-1.344 (each for the median, depending on the model)	2.30 m m³
Fabbri and Fraquelli (2000)	173 Italian water utilities in 1991	Cobb-Douglas TC function, Translog TC function	Pooled (OLS)	0.986-1.009 (depending on the functional form)	EOD: 1.470-1.580 (depending on the functional form)	18.86 m m³
Saal and Parker (2005)	30 UK water utilities from 1993-2003	Translog input distance function Malmquist and generalized Malmquist productivity index	Time-varying inefficiency	From 1.108 in 1993 decreasing to 0.978 in 2003 Small negative scale effects for WoCs	-	62.89 m m³
Mizutani and Urakami (2001)	112 Japanese water utilities in 1994	Translog TC function	SUR method	0.921	END: 1.103	66.62 m m³

ECD = Economies of customer density, END = Economies of network density, EOD = Economies of output density, EPD = Economies of production density, LR = Long-run, SR = Short-run

6 Other methodological issues

Many authors also address other methodological issues. In a study on Australian water supply, Coelli and Walding (2006) emphasize data quality. Differences in the valuation methods of capital and price deflators will affect the measures of monetary data. Thus it is preferable to use a price deflator that corresponds directly to the water industry. We note that unequivocal statements about the data origin and the considered part of the value chain are necessary in empirical studies.

Cubbin and Tzanidakis (1998) for England and Wales and Berg and Lin (2007) for Peru compare the results of parametric and non-parametric methods. Cubbin and Tzanidakis (1998) find that regression analysis and DEA produce variations in firm ranking, and recommend bearing in mind that parametric methods assign common weights to the variables while DEA calculates individual weights for each and every firm. The rankings of Berg and Lin for SFA and DEA are similar, however, and the best and worst performers are likewise identified.

An alternative approach regarding the functional form of SFA models is given by Sauer and Frohberg (2007) who apply a non-radial measure with a symmetric generalized McFadden functional. This overcomes the restrictive assumption of standard DEA and SFA models that inputs can be proportionally reduced in order to appear on the efficiency frontier.[6] Sauer and Frohberg compare efficiency levels for groups of German water suppliers clustered by size, state, legal form, sewerage, type of utility and public funding, but their results are based on a relatively small sample. Another methodologically interesting study has been conducted by Bottasso and Conti (2003) who apply a heteroscedastic SFA model to the English and Welsh water industry and discover large firms' size variation in their data. To avoid biases in both estimates of parameter and inefficiency, they model heteroscedasticity in the noise and the inefficiency components.

---

[6] This holds for the case of input orientation for DEA; in the case of output orientation, the outputs are proportionally expanded.

7 Conclusions

The global water sector is commonly subject to the application of efficiency analysis, and further refinements of models and methodological developments are in process. This paper provides a comprehensive overview of current efficiency analyses of water distribution. While its role in the regulation of water distribution is significant, the direct translation of efficiency values into regulatory objectives, e.g., X-factors or revenue caps, is unlikely to occur. We find that the merits of public versus private ownership cannot be clearly established. Future studies should incorporate both structural variables (population density) and quality variables (accounted-for water) in benchmarking, independent from the examined country, because the differences within countries are outside the scope of the management yet significantly influence costs.

Economies of scale and of density are pervasive in water distribution, at least in the lower and medium range of output. As in other network industries, "bigger is beautiful" and mergers should be politically supported. The high economies of density have implications for settlement structures in regions undergoing spatial and demographic change, such as East Germany or other post-socialist countries. Last but not least, data availability and quality are of utmost importance. Whereas the earlier studies of England and Wales can be regarded as "benchmarks" in terms of data availability and data sets, many countries throughout the world still lack significant progress in this respect.

Acknowledgements

This paper is a product of the research program on efficiency analysis in network industries, administered by the Chair of Energy Economics and Public Sector Management (EE^2) at Dresden University of Technology and the German Institute for Economic Research (DIW) Berlin.

References

Allan, G., 2006. Assessing Capital Efficiency in the Water and Sewerage Industry in England and Wales: Ofwat's Approach. Utilities Policy 14(4), 224-233.

Antonioli, B., Filippini, M., 2001. The Use of Variable Cost Function in the Regulation of the Italian Water Industry. Utilities Policy 10(3-4), 181-187.

Anwandter, L., Ozuna, T. Jr., 2002. Can Public Sector Reforms Improve the Efficiency of Public Water Utilities. Environment and Development Economics 7(4), 687-700.

Battese, G.E., Coelli, T.J., 1995. A Model for Technical Efficiency Effects in a Stochastic Frontier Production Function for Panel Data. Empirical Economics 20(2), 325-332.

Berg, S., Lin, C., 2007. Consistency in Performance Rankings: The Peru Water Sector. Journal of Applied Economics 40(6), 93-805.

Bhattacharyya, A., Harris, T.R., Narayanan, R., Raffiee, K., 1995. Specification and Estimation of the Effect of Ownership on the Economic Efficiency of the Water Utilities. Regional Science and Urban Economics 25(6), 759-784.

Bottasso, A., Conti, M., 2003. Cost Inefficiency in the English and Welsh Water industry: An Heteroskedastic Stochastic Cost Frontier Approach. Economics Discussion papers 573, University of Essex, Department of Economics.

Caudill, S.B., Ford, J.M., Gropper, D.M., 1995. Frontier Estimation and Firm-Specific Inefficiency Measures in the Presence of Heteroscedasticity. Journal of Business and Economics Statistics 13(1), 105-111.

Coelli, T., Walding, S., 2006. Performance Measurement in the Australian Water Supply Industry. In: Coelli T., Lawrence D. (editors): Performance Measurement and Regulation of Network Utilities. Edward Elgar Publishing, Cheltenham.

Coelli, T.J., Estache, A., Perelman, S., Trujillo, L., 2003. A Primer on Efficiency Measurement for Utilities and Transport Regulators. World Bank Publications, Washington, D.C.

Corton, M.L., 2003. Benchmarking in the Latin American Water Sector: The Case of Peru. Utilities Policy 11(3), 133-142.

Cubbin, J., 2005. Efficiency in the Water Industry. Utilities Policy 13(4), 289-293.

Cubbin, J., Tzanidakis, G., 1998. Regression versus Data Envelopment Analysis for Efficiency Measurement: An Application to the England and Wales Regulated Water Industry. Utilities Policy 7(2), 75-85.

Dassler, T., Parker, D., Saal, D.S., 2006. Methods and Trends of Performance Benchmarking in UK Utility Regulation. Utilities Policy 14(3), 166-174.

Estache, A., Kouassi, E., 2002. Sector Organization, Governance and the Inefficiency of African Water Utilities. World Bank Policy Research Working Paper, No. 3374.

Estache, A., Rossi, M., 2002. How Different is the Efficiency of Public and Private Water Companies in Asia. World Bank Economic Review 16(1), 139-148.

Estache, A., Rossi, M.A., Ruzzier, C.A., 2004. The Case for International Coordination of Electricity Regulation: Evidence from the Measurement of Efficiency in South America. Journal of Regulatory Economics 25(3), 271-295.

Estache, A., Trujillo, L., 2003. Efficiency Effects of 'Privatization' in Argentina's Water and Sanitation Services. Water Policy 5(4), 369-380.

Fabbri, P., Fraquelli, G., 2000. Costs and Structure of Technology in the Italian Water Industry. Empirica 27(1), 65-82.
Filippini, M., Hrovatin, N., Zorić, J., 2008. Cost Efficiency of Slovenian Water Distribution Utilities: An Application of Stochastic Frontier Methods. Journal of Productivity Analysis 29(2), 169-182.
Fraquelli, G., Moiso, V., 2005. Cost Efficiency and Economies of Scale in the Italian Water Industry. Paper presented at the Finanziamento del Settore Pubblico conference 2005.
Garcia, S., Moreaux, M., Reynaud, A., 2007. Measuring Economies of Vertical Integration in Network Industries: An Application to the Water Sector. International Journal of Industrial Organization 25(4), 791-820.
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(1), 5-29.
García-Sánchez, I. M., 2006. Efficiency Measurement in Spanish Local Government: The Case of Municipal Water Services. Review of Policy Research 23(2), 355-371.
García-Valinas, M.A., Muniz, M.A., 2007. Is DEA Useful in the Regulation of Water Utilities? A Dynamic Efficiency Evaluation. Applied Economics 39(2), 245-252.
Greene, W., 2005a. Reconsidering Heterogeneity in Panel Data Estimators of the Stochastic Frontier Model. Journal of Econometrics. 126(2), 269-303.
Greene, W., 2005b. Fixed and Random Effects in Stochastic Frontier Models. Journal of Productivity Analysis 23(1), 7-32.
Kim, H.Y., Clark, R.M., 1988. Economies of Scale and Scope in Water Supply. Regional Science and Urban Economics 18(4), 479-502.
Kirkpatrick, C, Parker, D., Zhang, Y.-F., 2006. State versus Private Sector Provision of Water Services in Africa: An Empirical Analysis. The World Bank Economic Review 20(1), 143-163.
Lin, C., 2005. Service Quality and Prospects for Benchmarking: Evidence from the Peru Water Sector. Utilities Policy 13(3), 230-239.
Marques, R.C., Contreras, F.H.G., 2007. Performance-based Potable Water and Sewer Service Regulation. The Regulatory Model. Cuadernos de Administración 20(34), 283-298.
Mizutani, F., Urakami, T., 2001. Identifying Network Density and Scale Economies for Japanese Water Supply Organizations. Papers in Regional Science 80(2), 211-230.
Ofwat, 2008. Setting Price Limits for 2010-15: Framework and Approach. Downloaded on 10. September 2008 from http://www.ofwat.gov.uk/aptrix/ofwat/publish.nsf/AttachmentsByTitle/pap_pos_pr09method080327.pdf/$FILE/pap_pos_pr09method080327.pdf.
Picazo-Tadeo, A.J., Sáez-Fernández, F.J., González-Gómez, F., 2008. Does Service Quality Matter in Measuring the Performance of Water Utilities? Utilities Policy 16(1), 30-38.
Renzetti, S., Dupont, D., 2008. Measuring the Technical Efficiency of Municipal Water Suppliers: the Role of Environmental Factors. Working Papers 0802, Brock University, Department of Economics.

Saal, D.S., Parker, D., Weyman-Jones, T., 2007. Determining the Contribution of Technical Change, Efficiency Change and Scale Change to Productivity Growth in the Privatized English and Welsh Water and Sewerage Industry: 1985-2000. Journal of Productivity Analysis 28(1), 127-139.

Saal, D.S., Parker, D., 2000. The Impact of Privatization and Regulation on the Water and Sewerage Industry in England and Wales: A Translog Cost Function Model. Managerial and Decision Economics 21(6), 253-268.

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

Saal, D.S., Parker, D., 2005. Assessing the Performance of Water Operations in the English and Welsh Water industry: A Panel Input Distance Function Approach. Aston Business School Working Paper RP0502.

Saal D.S., Parker, D., 2006. Assessing the Performance of Water Operations in the English and Welsh Water Industry: A Lesson in the Implications of Inappropriately Assuming a Common Frontier. In: Coelli T., Lawrence D. (editors): Performance Measurement and Regulation of Network Utilities. Edward Elgar Publishing, Cheltenham.

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

Sauer, J., Frohberg, K., 2007. Allocative Efficiency of Rural Water Supply – A Globally Flexible SGM Cost Frontier. Journal of Productivity Analysis 27(1), 31-40.

Shih, J.S., Harrington, W., Pizer, W.A., Gillingham, K., 2004. Economies of Scale and Technical Efficiency in Community Water Systems. Resources for the Future. Discussion Paper 04-15.

Stern, J., 2005. UK Regulatory Price Reviews and the Role of Efficiency Estimates (Editorial). Utilities Policy 13(4), 273-278.

Thanassoulis, E., 2000a. DEA and its Use in the Regulation of Water Companies. European Journal of Operational Research 127(1), 1-13.

Thanassoulis, E., 2000b. The Use of Data Envelopment Analysis in the Regulation of UK Water Utilities: Water Distribution. European Journal of Operational Research 126(2), 436-453.

Tupper, H.C., Resende, M., 2004. Efficiency and Regulatory Issues in the Brazilian Water and Sewage Sector: An Empirical Study. Utilities Policy 12(1), 29-40.

Zoric, J., 2006. Cost Efficiency and Regulation of Slovenian Water Distribution Utilities: An Application of Stochastic Frontier Methods. Dissertation, Lugano.