The Performance of German Water Utilities: A First Non-Parametric Analysis

Jörn Guder[a], Barnabas Kittlaus[b,c], Robert Moll[a], Matthias Walter[b], Michael Zschille[b]

[a]*Dresden University of Technology, 01062 Dresden, Germany*
[b]*Dresden University of Technology, Faculty of Business and Economics, Chair of Energy Economics and Public Sector Management, 01062 Dresden, Germany*
[c]*Corresponding author: barnabas.kittlaus@mailbox.tu-dresden.de*

This version of 2/27/2009

Abstract

The German water supply industry is characterized by a multitude of water utilities and a high variety in prices, possibly arising due to structural differences outside the control of the management but also due to inefficiency. In this paper we determine technical efficiency scores of water utilities in Germany based on cross sectional data from 373 water utilities in 2006 using Data Envelopment Analysis. A bootstrapped truncated regression is applied in order to determine the structural variables with significant impact on performance. We find high differences in technical efficiency scores even after inclusion of significant structural variables.

Keywords: Water Supply, Technical Efficiency, Data Envelopment Analysis, Structural Variables, Bootstrapped Truncated Regression

JEL-Codes: L95, C14, Q25

1. Introduction

Water supply industries are heavily bound to cost-intensive network structures and therefore, by implication, candidates for natural monopoly. To ensure an efficient production and distribution of water in good quality, some countries like England and Wales, Australia and Slovenia established a regulation based on yardstick competition in the water supply industry. In Germany, active price regulation is still at its beginning. In the federal state of Hesse with its economic heart Frankfurt, a number of trials to decrease prices administered by the federal cartel office have been observed. One of their main incentives originates from the vast price differences. The prices for residential water customers in Germany differ between 0.52 Euro and 3.95 Euro per cubic meter (Bundesverband der Energie- und Wasserwirtschaft, 2008a). In order to analyze the high variety in prices and therefore to check if this variety is mainly caused by structural differences or due to inefficiency, different methods of Data Envelopment Analysis (DEA) are applied in this paper. The aim of this study is to check if different prices in the German water sector are justifiable by conducting a three stage non-parametric efficiency measurement approach. In the first stage, after determining the returns to scale technology by a test proposed by Simar and Wilson (2002), DEA efficiency scores are calculated. In the second stage, these efficiency scores are explained by structural variables in a bootstrapped truncated regression (Simar and Wilson, 2007). In the third stage, technical efficiency scores based on a standard DEA model are calculated after inclusion of structural circumstances.

The paper’s objective is inter alia to initiate further studies about efficiency analysis and a possible regulation in this industry. For the implementation of an efficient and fair regulation, a robust and representative measurement of efficiency is necessary. To lay the foundation for that, we also give an overview of the German water supply sector. As the companies we look at not only deliver water, but also extract and treat water, we will talk about water supply.

In 2006, total water production for public water supply in Germany was about 5.3 billion cubic meters, which was more than 20% less than in 1990. Groundwater is the most important resource for water production in Germany with a share of 66.5% in total water production, followed by 25.7% surface water (including reservoir water) and 7.8% of well-spring sources. Like the water production, the per capita consumption declined, from 147 liters per day and person in 1990 to 126 liters per day and person in 2006. Especially in East Germany the water consumption has declined significantly from 142 to 99 liters per day and person.

To ensure a stable and satisfying drinking water quality, about 42 billion Euros have been invested into the water supply infrastructure since 1990. About 60% of total investments were used for network infrastructure.[1] The cost structure in Germany's water supply industry can be described as followed: 21.5% depreciation, 20.6% personnel costs, 15.4% supply of services, 13.7% administration, 9.6% cost of water purchase and 40.7% other costs[2] (Bundesverband der Energie- und Wasserwirtschaft, 2008b). Additionally, dependent on the federal state there might be some license fees which have to be paid to the municipality.

The variety in German water supply companies consists of municipal utilities (Stadtwerke) as well as regional and over-regional acting special purpose associations (Zweckverbände). Municipal utilities in Germany in the vast majority are privately organized while being under full public control. They often cover services like water supply, sewerage handling, local public transport, bathes, electricity and natural gas supply. To benefit from economies of scale, especially in areas of low population density, so called special purpose associations were founded. This is a merger of municipal utilities to benefit from fewer labor input requirements, higher amounts of water sold and possibly from lower wholesale prices for water input, if supply by third parties is necessary. This is the most common form of inter-municipal cooperation. Most of the special purpose associations are large-sized and often do not deliver drinking water to the end customer but organize the production or the purchase of water. The comparison of such companies with different cost structures and wholesale prices not delivering water to end customers can lead to inconsistencies in efficiency analysis. For

[1] This could explain both the low average leak ratio of 6.8% in 2004 in comparison to other countries as well as the high drinking water quality with only a few cases of measurements not meeting necessary requirements (see Deutsche Vereinigung des Gas- und Wasserfaches e.V., 2006).

[2] Other costs include interest payment for debt and material costs as well as taxes.

this reason, special purpose associations not delivering drinking water to end customers are not considered within this study. Nevertheless, there are some special purpose associations which only supply very few communities, and deliver drinking water to the end customer, so that these companies can be included in the dataset.

Due to the liberalization of the energy delivery and the incentive based regulation of the electricity and gas distribution networks in Germany (see the ordinance for the incentive regulation, *Anreizregulierungsverordnung* (ARegV)), most of the municipal utilities' services are legally separated and keep separate accounts. Thus, a regulator could easily get information about the companies' financials and technical capabilities. Such a regulation could also be possible in the water sector, especially if research in this sector can confirm that differences in prices are not only due to structural differences but also due to inefficiency or excessive profit generation.

The paper is structured as follows. Section 2 reviews relevant literature with respect to the applied methodology. Section 3 explains the methodology of this paper, and Section 4 discusses the data used for this efficiency analysis. Results are presented within Section 5, and Section 6 concludes.

2. Literature Review

The relevant literature dealing with efficiency of water supply can best be categorized into four main areas: First in Stochastic Frontier studies estimating economies of scale, density or scope. A wide variety of methodical issues and results are given by Saal and Parker (2000, 2005), Sauer (2003, 2004a, 2006) or Filippini, Hrovatin and Zoric (2008). Second in studies determining whether private or public services are more efficient. Prevalent examples therefore are Bhattacharyya et al. (1995), Saal and Parker (2001) or Saal, Parker and Weyman-Jones (2007). Third, there are studies using DEA and regression analysis in order to check whether structural variables influence individual efficiency scores. Fourth, more methodological studies can be considered, see Saal and Reid (2004) or Sauer (2004b). In this section we focus on a review of the third group given by the similar approach of our paper. A more detailed analysis of the results of the other groups can be found in Hirschhausen et al. (2008, see also Hirschhausen et al. (2009a) for a reference focus on Germany).

So far, to our knowledge there is no efficiency analysis considering the whole German water supply industry. First results for rural water supply in Germany were so far only drawn by Cantner and Hanusch (1991), determining technical inefficiencies of 13 rural water utilities using a corrected ordinary least square (COLS) approach for stochastic frontier production functions. Furthermore Sauer and Frohberg (2007) applied a Stochastic Frontier Analysis (SFA) approach for a relatively small sample of 47 water utilities for East and West Germany. Basically using a symmetric generalized McFadden function, they have compared technical efficiency levels of different groups of German water suppliers.

Referring to the third group of literature, Table 1 shows four recent DEA studies evaluating the impact of structural and quality variables with the resulting significant variables. Renzetti and Dupont (2008) use the multistage procedure recommended by Fried et al. (1999), focusing on the relative efficiency of 64 municipal water suppliers in Ontario, Canada. The utilities' inputs and outputs are involved in an application of a variable returns to scale DEA procedure passing through first stage. The second stage examines the role of six external factors upon water agencies by regressing the total input slack values on a vector of variables that are expected to influence efficiency but are outside the control of water agency managers. Explicitly, these are differences in elevation between each city's highest point and its water treatment facility as well as the maximum weekly summer temperature in 1996 in each city and the total precipitation in each city to consider topographical and climatic issues. Furthermore, each city's population density, the ratio of residential water use to total water agency output, and the number of private dwellings are considered. Due to the censored normal distribution of the error term a Tobit regression is used, but in order to undertake valid hypothesis testing, a bootstrapped truncated regression algorithm as described in Simar and Wilson (2007) is additionally adopted. In the third stage another DEA procedure with original output and adjusted input measures is conducted to establish a base equal to the least favorable external conditions. Carrying out this adjustment removes the differences in external operating environments that may distort efforts to assess the utilities' relative technical efficiency. DEA mean efficiency scores are absolutely 6.6% (Tobit adjustment) respectively 28.4% (truncated regression adjustment) higher in the third stage than in the first stage.

García-Sánchez (2006) also uses a multistage approach to estimate the technical and scale efficiency of 24 Spanish municipal water supply agencies. Inputs are staff, treatment plants and network length. Outputs are defined by the amount of water delivered, the number of properties connected and analyses performed. Four stages are executed to perform the analysis. The first stage is the statistical selection of inputs and outputs. Here Pearson's correlation coefficient is used to eliminate improper correlated inputs and/or outputs. Following Roll et al. (1989), the DEA model with the best discriminating characteristics is chosen. With the aim of accomplishing a homogeneous analysis as to the particular external conditions of each municipality, in the second stage a three-step process is used to detect the influence of external circumstances on the estimation of levels of efficiency by a Tobit model. These ten circumstances called social variables are population and population density, average income and temperature as well as the municipal area, the tourist index and square meters of greenbelts. Further social variables are economic activity, number of houses and average people per house. In the third stage, constant returns to scale (CRS) efficiency scores according to Charnes et al. (1978) and variable returns to scale (VRS) efficiency scores according to Banker et al. (1984) are estimated. Finally, in the fourth stage, it is contrasted whether the differences in efficiency indexes were caused by the type of ownership (public and private) using the Mann-Whitney-Test. This methodology leads to three best-discriminating DEA models with nearly identical efficiency scores, showing that only population density has a statistical significant impact on inefficiencies. Furthermore, García-Sánchez shows that efficiency scores do not depend on the type of ownership.

Tupper and Resende (2004) determine if calculated efficiency levels in the Brazilian water sector depend on structural and quality variables by using a second stage Tobit regression. Their results suggest that only water losses have a significant impact on efficiency levels.

Directly comparing DEA efficiency levels with and without the inclusion of quality variables, Picazo-Tadeo et al. (2008) also conclude that water losses have a significant impact on efficiency levels of 38 Spanish water utilities, but that the ranking of utilities is not influenced by the different efficiencies. The mean efficiency score is 0.773 respectively 0.851. In both studies unaccounted-for water is seen as an endogenous variable and as an indicator for water quality.

Table 1: Studies evaluating the impact of structural and quality variables with focus on DEA (Hirschhausen et al., 2008)

Author(s)	Data Sample	DEA Specification	Inputs	Outputs	Results for structural and quality variables
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
Picazo-Tadeo et al. (2008)	38 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

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

3. Methodology

3.1 DEA approaches

For our efficiency analysis, the method of Data Envelopment Analysis is chosen because of the following two reasons: first, the absence of panel data restricts the applicability of stochastic frontier models and second, Data Envelopment Analysis is able to discriminate best between different outputs like in our case between household and industrial demand, which are not under the control of the management. DEA puts individual weights on the outputs of each firm. Hence firms with e.g. low industrial demand are not punished in the model.

Data Envelopment Analysis uses linear programming methods to obtain measures of technical efficiency. A piece-wise surface (frontier) over the data, consisting of input and output variables, for a sample of firms can be constructed. The efficiency of each firm is measured through calculating the distance between each data point and the point on the frontier, and lies between 0 and 1. The frontier represents the most efficient firms with technical efficiency equal to one, the so-called peer firms. Under input orientation, those firms produce the same output with fewer inputs. The Banker, Charnes and Cooper (BCC) formulation of Data Envelopment Analysis can be expressed by the following linear programming problem (see Banker et al., 1984):

$$
\begin{aligned}
&\min_{\theta,\lambda}\ \theta \\
&s.t.\quad -q_i + Q\lambda \geq 0 \\
&\qquad\ \ \theta x_i - X\lambda \geq 0 \\
&\qquad\ \ I1'\lambda = 1 \\
&\qquad\ \ \lambda \geq 0
\end{aligned}
$$

with θ as a scalar, X as $N*I$ input matrix for N inputs and I firms, Q as $M*I$ output matrix for M outputs and I1 as a $I*1$ vector of ones. Inputs and outputs for the i-th firm are represented by the column vectors x_i and q_i, λ represents a $I*1$ vector of constants. Using the BCC formulation, a convex hull enveloping the data points is constructed. The BCC formulation is often referred to as a variable returns to scale (VRS) formulation. This formulation allows for differences in firm sizes.

DEA models can be input or output oriented. Under input orientation the efficiency scores relate to the largest feasible proportional reduction in inputs for fixed outputs, while under output orientation, the efficiency scores correspond to the largest feasible proportional expansion in outputs for fixed inputs. It is common practice to apply input orientation for the analysis of network utilities because the firms are generally required to supply services to a fixed geographical area, and hence the output vector is essentially fixed.

In order to determine the returns-to-scale technology, we conduct a returns to scale test as proposed by Simar and Wilson (2002). This returns to scale test consists of two different tests. In test 1, the null hypothesis that the production frontier exhibits global constant returns to scale (CRS) is tested against the alternative test hypothesis that the production frontier exhibits variable returns to scale (VRS). If the null hypothesis is rejected, an additional test is conducted. During the second test, the null hypothesis whether the production frontier exhibits globally non-increasing returns to scale (NIRS) is tested against the alternative hypothesis of variable returns to scale. Hence, following Simar and Wilson (2002), the returns to scale test has the form:

Test 1: H_0: the production frontier is globally CRS

H_1: the production frontier is VRS

Test 2: H_0: the production frontier is globally NIRS

H_1: the production frontier is VRS

The ratio of means defined by

$$\hat{S}_n^{CRS} = \sum_{i=1}^{n} \hat{D}_n^{CRS}(x_i, y_i) \Big/ \sum_{i=1}^{n} \hat{D}_n^{VRS}(x_i, y_i)$$

for test 1 is used as a reasonable test statistic and measures the distance between the CRS and the VRS frontier. Similarly, for test 2 the distance between the NIRS and the VRS frontier is measured using this test statistic. For both tests, the null hypothesis is not rejected when the distance between both frontiers is small.

Within a bootstrap procedure, pseudo samples S_{bn}^* with $b = 1,...,B$ bootstrap replications are generated according to the original sample S_n in order to derive bootstrap estimates $\hat{\omega}_b^*$, with ω denoting a univariate parameter for each testing problem and $\hat{\omega}$ as a consistent estimator of ω. With $\hat{\omega}_{obs}$ denoting the observed value of the test statistic mentioned above, p-values can be derived according to the approximation $\hat{p} = \Pr(\hat{\omega}^* \leq \hat{\omega}_{obs} \mid H_0, S_n)$. For both tests, p-values higher than the significance level of 5% lead to the rejection of the null hypothesis.

3.2 A three-step approach including bootstrapping

In this paper a three-step approach is applied in order to obtain valid results for technical efficiency scores. The first step includes the outlier detection. In the first place, the partial indicator *revenues divided by total water output* is used to detect extreme observations. Afterwards the super-efficiency approach proposed by Banker and Gifford (1988) is applied for outlier detection as well. Using super-efficiency, some observations may have efficiency scores greater than one, i.e. lie above the constructed frontier. That is to say that within super-efficiency reference observations for the evaluation of an observation *i* are constructed only using all observations other than *i*. For further information see Banker and Gifford (1988) or Banker and Chang (2006). The super-efficiency criterion is applied repeatedly until there are no clear outliers left. Therefore, we set maximum attainable efficiency score on a level of 1.2 due to a dense distribution of technical efficiency scores up to this level. [3] Above the level of 1.2, technical efficiency scores are less densely distributed and show higher dispersion. Afterwards, a standard DEA approach is used in order to obtain first technical efficiency scores.[4]

[3] With this approach we follow a suggestion by Banker and Chang (2006).
[4] We applied Standard DEA instead of Bias-corrections (Bootstrapping), because significant results for the regressions could only be obtained with Standard DEA efficiency scores. The reason for that may lie in the characteristic that Bootstrapping can create close ranks.

Within step 2, the efficiency scores obtained by the standard DEA approach are regressed on several explanatory variables like for example output density or the location of the utility under consideration in East or West Germany. Studies calculating efficiency scores using the non-parametric DEA approach often conduct a regression analysis for the inclusion of parametric components. Most often, a Tobit regression is applied therefore. However, Simar and Wilson (2007) argue that the use of a Tobit regression in a two-stage analysis is inappropriate because serial correlation in DEA efficiency estimates is not taken into account. Hence, the results of a Tobit regression analysis can be invalid and thus lead to incorrect inference. Regarding this controversial discussion about the use of Tobit regression for the purpose of determining factors influencing efficiency estimates, we apply a bootstrapped truncated regression as proposed by Simar and Wilson (2007). Simar and Wilson mention two different algorithms for the bootstrapped truncated regression. While algorithm #1 is aimed only to improve on inference, algorithm #2 also takes bias correction into account. Unfortunately, the application of bias correction can introduce additional noise into calculations, which was also the case for our analysis, so that we will focus on algorithm #1 without bias correction for further considerations. In a first step, coefficient estimates $\hat{\beta}$ and an estimate of the standard deviation of the error term $\hat{\sigma}_\varepsilon$ are derived from the truncated regression of the efficiency values $\hat{\theta}_i > 1$ on the explanatory variables using the maximum likelihood method. The reciprocal values of the DEA technical efficiency scores resulting from stage 1 are used therefore. Afterwards, a bootstrap algorithm with *B* bootstrap replications is conducted based on those coefficient estimates and on the estimated standard deviation of the error term.

Within the bootstrap algorithm, the error term ε_i for each observation *i* is drawn from a $N(0, \hat{\sigma}_\varepsilon^2)$ distribution, for which a left-truncation at $(1 - z_i \hat{\beta})$ is assumed. Based on the error terms ε_i, new efficiency estimates $\theta_i^* = z_i \hat{\beta} + \varepsilon_i$ are calculated. Those new efficiency estimates can then again be regressed on explanatory variables using maximum likelihood estimation with left truncation at one. As follows, the bootstrap algorithm yields *B* estimates for each coefficient. Using this set of coefficient estimates, confidence intervals can be constructed as described by Simar and Wilson (2000). For more details on how to estimate the bootstrapped truncated regression, see Simar and Wilson (2007).

For the inclusion of regression results within the calculation of new DEA efficiency scores in stage three, we adjust inputs for the influence of exogenous variables following a methodology proposed by Fried et al. (1999). They recommend regressing total input slacks on explanatory variables in order to derive coefficient estimates and an estimate of the error term.[5] Afterwards, input slacks are predicted based on the estimated coefficients. The predicted input slacks are then used to adjust inputs according to

$$x_j^{adj} = x_j + [Max\{I\hat{T}S_j\} - I\hat{T}S_j]$$

for the one-input case with $I\hat{T}S_j$ denoting the predicted input slacks. For all observations $j = 1,...,N$ input x is proportionally adjusted by the difference between the maximum predicted input slack $Max\{I\hat{T}S_j\}$ of all observations and the predicted input slack. For example, a difference of 0.2 leads to an increase in total input of 20%. Following, for the unit operating under least favourable circumstances and thus exhibiting the highest input slack, the difference in parentheses is equal to zero und inputs are not increased. For all other observations, the difference is positive and thus, inputs are increased while output is held constant so that efficiency scores are adjusted for external influences. Thus, having adjusted inputs for the operating environment, remaining inefficiency can be considered as being caused by the management.

4. Data Description

The study is based on cross sectional data from the year 2006 with an original data set including 1096 water utilities. Full data availability was given for 373 observations. The data has been gathered from the statistical publication for German water utilities published by the German Association for Energy and Water Industries (Bundesverband der Energie- und

[5] We focus on the radial part of total input slacks only, hence on the pure inefficiency, because we want to evaluate purely the impact of structural differences on efficiency scores.

Wasserwirtschaft, 2008c) and annual financial statements of the water utilities. Additionally, elevation differences have been gathered from topographical maps. Private water utilities are taken into account as well as public utilities even like those with mixed ownership structures. The descriptive statistics for the variables are shown in Table 2 and the correlation matrix is shown in Table 3. The utilities included in our dataset deliver drinking water to about 32 million people, what is around 39% of total German population, so that our dataset is quite representative.

The water utilities included in the dataset are located all over Germany and cover all federal states except Bremen. Most water utilities included in the analysis are located in North Rhine-Westphalia, Bavaria and Baden-Wuerttemberg. These federal states do not only represent about one half of Germany's population, most of Germany's water utilities are also located there.

Total deliveries of the water utilities consist of deliveries to private households and deliveries to all other costumers, i.e. deliveries to industrial costumers and public utilities as well as re-distributors. This differentiation seems necessary since the utilities in our dataset have quite different characteristics. On the one hand there are utilities mainly serving private costumers with higher costs due to the need of more water connections. On the other hand, utilities with significantly higher shares of industrial costumers or additional water deliveries to re-distributors are included in the dataset with lower costs of serving these costumers due to a higher amount of water deliveries using only few connections. To consider these facts, we consider the private consumption and the industrial and other consumption as two different outputs. In sum, total water deliveries of the water utilities included into our analysis add up to 1.98 billion cubic meters. Looking at total water production in Germany in 2006, our dataset covers around 36% of German water supply. The number of water meters also gives information about the firm size and the number of costumers. The number of water meters is included into the analysis as output variable to ensure not discriminating utilities serving costumers with low consumption. Total revenues arising from water supply in 2006 are taken into account as proxy for total costs, since no better data or proxy is available. We assume revenues to be equal to the costs of water supply following the European water framework directive (Directive 2000/60/EC, Article 9), stating that all costs incurred by the water utility should be covered by revenues. This principle of cost recovery for water supply is also included into the legislation for local public authorities within the several federal states of Germany. Using this approach, we can assure our model to cover all costs arising within water supply, that is to say material costs, depreciation and labor costs. In addition, efficiency can also be measured by how much customers have to pay for water supply, so that the assumption of revenues being equal to total costs appears quite realistic. This approach to use revenues as input variable and several cost drivers as output variables within DEA has also been recommended by Brunner and Riechmann (2004) in order to find out if tariffs for water deliveries are reasonable and if this is not the case, by how much tariffs could be reduced. Despite the use of monetary data, only technical efficiency and no allocative efficiency is considered in our study.

The variable network length shows high differences in firm and area sizes. Network is not included as input variable, because costs for network infrastructure and investments are already included within the total cost block representing total revenues. Later on, the network length will be included into the analysis to calculate the structural variable output density.

Different explanatory variables can be taken into account within the second stage represented by the regression analysis and the following third stage. The total number of inhabitants as well as output density are candidates for including possible disadvantages of water utilities in rural areas in contrast to urban regions following the assumption that higher density increases the efficiency of the utility. This assumption has already been confirmed by several efficiency analyses, e.g. Renzetti and Dupont (2008) or García-Sánchez (2006). However, the population is not included in the regression analysis due to a very high correlation with the output variable *water delivered to households*. Output density is computed as total amount of water delivered to households and non-households per kilometer of network length (*Metermengenwert*). This variable serves as a key indicator in the regulation of the Hessian federal cartel office (Hirschhausen et al., 2009b). Higher density may lead to efficiency increases, but a very high density may cause extra cost when considering the complexity of pipe laying in densely settled downtowns. The leak ratio, defined as water losses between extraction and end-user consumption divided by total water extraction is included as quality variable for the network conditions. The share of groundwater used by the utility is also under consideration because the need for water treatment is lower for groundwater in comparison to surface water. On the other hand, pumping costs tend to be higher for groundwater (see for example Filippini et al., 2008; Garcia and Thomas, 2001), while capital costs are normally lower than for the use of storage water (see Coelli and Walding, 2006). Hence, utilities using higher shares of groundwater may tend to reach higher efficiency scores. We assume that the type of water extracted is given exogenously, because in the service area of a utility, only available water sources can be used.

With respect to different development paths we also want to determine differences between water utilities in the eastern and western part of Germany. After the German reunification, high investments have been made for modernization of East German water networks and treatment plants. While those differences can already be observed in prices, we also want to check for differences in efficiency scores obtained by utilities in both parts of Germany. Therefore, we include a dummy variable with value one if the utility is situated in the eastern part of Germany. It is also recommendable to include elevation differences within the service areas into analysis. Utilities distributing water in flatter regions may have more preferable circumstances than utilities in hilly or mountainous regions, where higher pumping costs could be necessary for water distribution. Therefore, we include a variable for elevation differences into analysis. The variable measures the difference between the highest settlement in a service area and the lowest point.[6] We assume that higher elevation differences have a negative impact on the performance of water utilities.

---

[6] It is not guaranteed that there is water demand on the highest or lowest point within a service area, but at least the variable should serve as a good proxy.

Table 2: Descriptive statistics

Variable Description	Abbr.	Classification	Sum	Min.	Mean	Median	Max.	Std. Dev.
Revenues [1000 €]	cost	Input	3,563,312	466	9,843	3,382	424,000	27,878
Water meters [number]	meters	Output	6,850,857	1,653	18,925	9,073	1,008,732	57,151
Water delivered to households [1000 m³]	wdelhh	Output	1,490,046	199	4,116	1,520	142,700	10,872
Water delivered to non-households [1000 m³]	wdelnh	Output	487,598	0.00	1,346	353	58,800	4,000
Network length [km]	net	-*	156,834	39	433	224	7,858	675
Population [1000]	pop	-**	32,373	5	89	35	3,400	233
Output density [1000 m³ per km of network]	dens	Structural var.	-	1.02	10.46	9.25	52.94	5.61
Leak ratio	leak	Structural var.	-	0.01	0.10	0.09	0.30	0.06
Groundwater ratio	ground	Structural var.	-	0.00	0.57	0.71	1.00	0.42
Elevation difference [m]	elev	Structural var.	-	0.00	53.82	40.00	240.00	47.36
Dummy for East Germany	deast	Structural var.	65	0.00	0.18	0.00	1.00	0.38

*Used to calculate the structural variable *output density*, **Omitted for correlation reasons (see correlation matrix)

Table 3: Correlation matrix

	cost	meters	net	wdelhh	wdelnh	pop	dens	leak	ground	elev	deast
cost	1.000										
meters	0.644	1.000									
net	0.883	0.704	1.000								
wdelhh	0.976	0.753	0.883	1.000							
wdelnh	0.907	0.456	0.812	0.845	1.000						
pop	0.991	0.716	0.900	0.988	0.875	1.000					
dens	0.410	0.247	0.246	0.435	0.438	0.393	1.000				
leak	0.000	-0.011	0.069	-0.018	-0.045	-0.002	-0.210	1.000			
ground	-0.050	0.011	-0.027	-0.041	-0.012	-0.038	-0.187	-0.030	1.000		
elev	0.178	0.134	0.188	0.178	0.148	0.169	0.216	0.260	-0.324	1.000	
deast	-0.017	-0.013	0.107	-0.044	-0.004	-0.004	-0.217	0.235	-0.015	-0.031	1.000

5. Results

5.1 Efficiency scores and regression on structural variables

We apply a three-stage procedure to obtain valid results for technical efficiency (TE) scores. In a first stage, the ratio of revenues and total water output is used as partial indicator for outlier detection. Here, 11 observations are deleted. For the application of the super-efficiency approach[7] variable returns to scale and input orientation are assumed. The assumption of VRS is confirmed by the returns to scale test at a low significance level of 1% conducting 1000 bootstrap replications. In the following application of the super-efficiency criterion, 22 additional observations were deleted due to technical efficiency scores higher than the critical value of 1.2.

A summary of efficiency scores obtained in stage 1 is given in Table 4. Efficiency scores show high dispersion and a relatively low mean level of 64.24%, possibly arising due to the large difference in German water prices and hence revenue disparities.

[7] Data Envelopment Analysis and the bootstrapped truncated regression are conducted using Software R with the package FEAR.

Table 4: Descriptive statistics for technical efficiency scores and input slacks

		Mean	Median	Std. Dev.	Min.	Max.
Stage 1	TE score	0.6424	0.6050	0.1833	0.3000	1.0000
	Inefficiency	0.3576	0.3950	0.1833	0.0000	0.7000
Stage 3						
Lower bound	TE score	0.6428	0.6042	0.1839	0.2834	1.0000
	Inefficiency	0.3572	0.3958	0.1839	0.0000	0.7166
Expected value	TE score	0.6459	0.6094	0.1836	0.2909	1.0000
	Inefficiency	0.3541	0.3906	0.1836	0.0000	0.7091
Upper bound	TE score	0.6451	0.6044	0.1835	0.2952	1.0000
	Inefficiency	0.3549	0.3956	0.1835	0.0000	0.7048

In the second stage the inefficiency values are regressed on several explanatory variables. We apply a bootstrapped truncated regression with 2000 replications as proposed by Simar and Wilson (2007) to check for structural reasons of efficiency differences. The estimated coefficients and significance levels are shown in Table 5. The signs of the coefficients show that a higher density, a higher share of groundwater input and the location in East Germany have a negative impact on inefficiency, that is to say they a positive impact on efficiency, while higher elevation differences and higher leak ratios have a positive impact on inefficiency. The magnitude of leak ratio is by far the highest, showing the direct effect of network leakages into inefficiency and corresponding higher prices.

Table 5: Results for regression analysis #1 of inefficiencies

Variable	Coefficient estimates	Confidence Interval [95%]	
dens	-0.0085** (0.0022)	-0.0129	-0.0042
leak	0.3220* (0.1677)	-0.0067	0.6506
ground	-0.0796** (0.0254)	-0.1293	-0.0299
deast	-0.0379 (0.0273)	-0.0914	0.0157
elev	0.0001 (0.0002)	-0.0003	0.0005
constant	0.4746** (0.0378)	0.4005	0.5488

* significant at 5%, ** significant at 1%. Standard errors in parentheses.

In order to include the explanatory variables into the calculation of technical efficiency scores using the input adjustments approach proposed by Fried et al. (1999), inefficiencies have to be predicted from regression analysis. The results from regression analysis #1 are not appropriate therefore because the variable leak ratio is assumed to be influenceable by the management while the aim of this approach is to adjust only for the operating environment.

For the correct adjustment of inputs, we conduct two further regression analyses using different model specifications and select the best specification after a comparison of both. For regression #2 all variables but the leak ratio are included. Coefficient estimates therefore are shown in Table 6. Like for regression analysis #1, the variables for the density and for the groundwater ratio exhibit a significant negative impact on inefficiencies, while the dummy for East Germany and also elevation differences are insignificant. The question arises, whether all variables should be used for input adjustment or only the significant ones. Thus, a third regression analysis is conducted only using the significant variables from regression #2. Estimation results for regression analysis #3 are also shown in Table 6.

For model selection, we use the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) as well as a likelihood-ratio test. The results of both the AIC and the BIC indicate that the selection of model #3, only using the variables with significant impact on inefficiencies, seems appropriate. This result is also confirmed by the likelihood-ratio test (LR test). The LR value of 2.29 is lower than the corresponding χ^2 value of 5.99 and thus, the restricted model only using the significant variables is preferred. According to these results, the estimates from regression #3 are used to adjust inputs in stage 3 for the operating environment.

Table 6: Results for regression analyses #2 and #3 of inefficiencies

Variable	Regression #2			Regression #3		
	Coefficient estimates	Confidence Interval [95%]		Coefficient estimates	Confidence Interval [95%]	
dens	-0.0096** (0.0022)	-0.0138	-0.0054	-0.0088** (0.0022)	-0.0132	-0.0045
ground	-0.0775** (0.0253)	-0.1271	-0.0278	-0.0827** (0.0254)	-0.1308	-0.0346
deast	-0.0276 (0.0264)	-0.0793	0.0240	-	-	-
elev	0.0002 (0.0001)	-0.0001	0.0006	-	-	-
constant	0.5084** (0.0353)	0.4393	0.5775	0.5106** (0.0312)	0.4495	0.5717
AIC	-275.2396			-276.9467		
BIC	-252.6673			-261.8985		
Log-Likelihood	143.6198			142.4733		

* significant at 5%, ** significant at 1%. Standard errors in parentheses.

5.2 Final efficiency scores and interpretation

Using the standard DEA approach in stage 3 again, final technical efficiency scores are obtained. Summary statistics therefore are shown in Table 4. In comparison to the results of stage 1, before inclusion of structural variables, the mean efficiency score increases slightly from 0.6424 to 0.6459 after inclusion of structural variables. The minimum efficiency score obtained is still relatively low and is even slightly lower than before input adjustment, indicating that additional influencing exogenous factors like climatic conditions or aspects of economic geography could be taken into account if extended data availability had been given. The only small changes in efficiency scores after input adjustment also underline the robustness of efficiency estimated against environmental circumstances. The only weak differences in efficiency scores before and after the inclusion of explanatory variables are also underlined when using the boundaries given by the confidence intervals of the exogenous variables resulting from regression analysis. The corresponding efficiency scores are also shown in Table 4. This result supports current German legislation. The “competitive market concept” is proposed in §19 IV 2 GWB and assumes utilities to be comparable only if the business objective of the utilities is the same. For water supply, this implies that *all* utilities are comparable because their aim is to supply water to households and to the industry so that the operating environment has not to be considered for comparison.

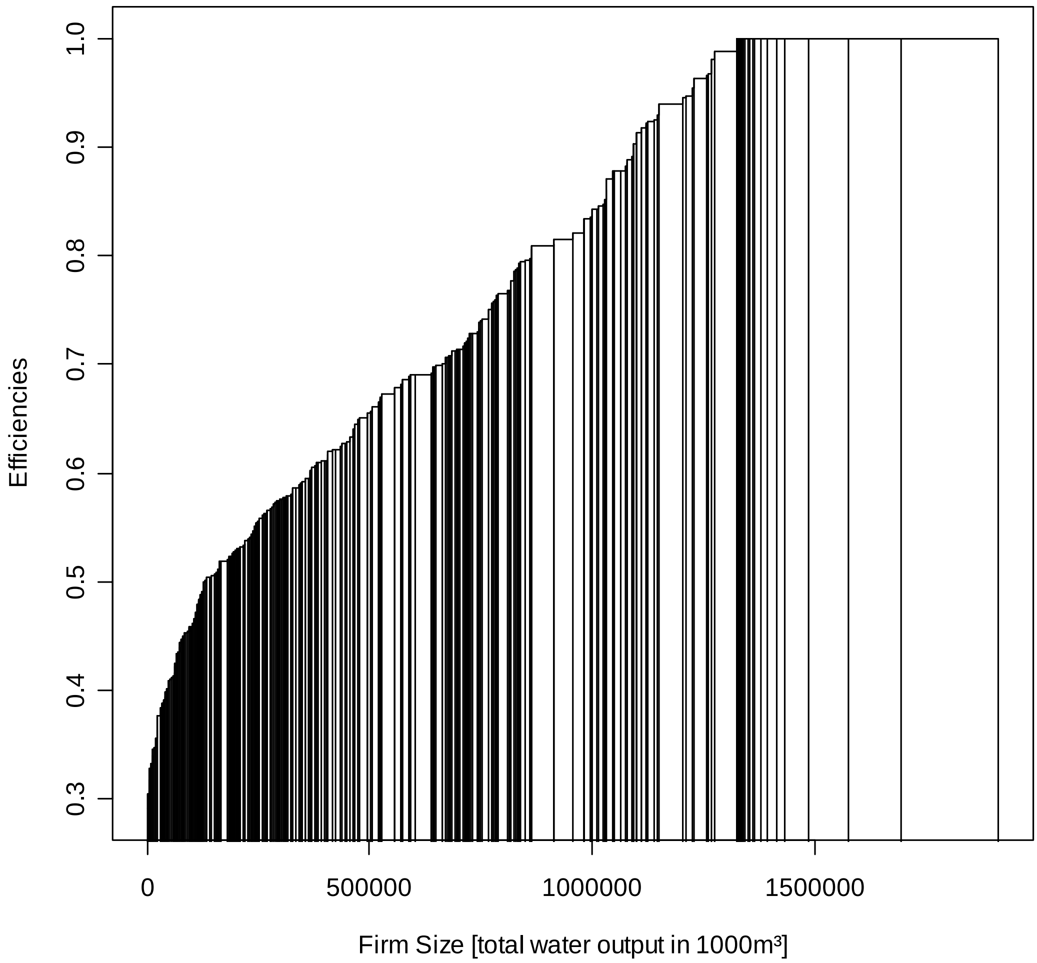
Obviously, there is only weak variation between the lower and the upper bound, the mean technical efficiency for the lower bound with 0.6428 is only slightly lower than for the upper bound with a mean efficiency score of 0.6451, confirming the validity of efficiency scores against exogenous circumstances. Interestingly, the expected mean efficiency score is higher than the mean efficiency score using upper bound. This can be explained by the fact that it remains unclear how efficiency scores change after adjusting inputs because the frontier is completely shifted and some utilities may become more efficient while others will be less efficient than before.

An illustration of efficiency scores obtained in stage 3 is given in the Salter diagram in Figure 1. On the y-axis, the water utilities are sorted according to their efficiency scores. On the x-axis, the width of a bar represents total amount of water deliveries of a utility. Obviously, mainly smaller water utilities with low amounts of total water output obtain the lowest efficiency scores within analysis. The highest efficiency scores are obtained by small as well as larger water utilities representing the VRS approach of our DEA specification. The lowest efficiency scores are obviously represented by the smaller utilities. This fact needs careful interpretation. By using a VRS approach, these inefficiencies cannot be scale diseconomies. However there seem to be cost disadvantages for small utilities. Further research should try to identify the detailed saving potentials through mergers.

Assuming that all residual inefficiency after stage three cannot be assigned to structural differences, the free area in the upper left area of the graph (above the inefficient small utilities) represents the potential for price decreases. The inefficiency is therefore equal to the price decrease whereas the x-axis represents the quantity that could benefit from this price decrease.

Interestingly, the least efficient water utility in our dataset is already under consideration by the Hessian cartel office, which is the precursor in Germany with respect to the regulation of water utilities. With respect to the obtained efficiency scores, one Hessian water utility, against which the price regulation by the Hessian cartel office is most advanced at the moment, is also among the least 10% of the utilities in our dataset.[8]

Figure 1: Salter diagram of technical efficiency scores after inclusion of structural variables



6.3 Comparing East and West Germany

The dummy variable for a location in East or West Germany shows no significant impact in the regressions in stage 2. However, as there is some evidence for different developments, a closer look on efficiency scores seems suitable. Intuitively, lower mean efficiency of water utilities in East Germany would seem to be reasonable due to high investment expenditures for infrastructure modernization. In addition, during investments after the German

[8] The lowest efficiency score of 30% was obtained by Stadtwerke Oberursel, which already had to justify the prices charged for water deliveries. An ordinance to decrease prices is already planned by the Hessian cartel office. The first ordinance to decrease prices was announced against the Stadtwerke Wetzlar, which obtained an efficiency score of 48.5% in our analysis.

reunification, treatment plants and network infrastructure have been built too large. With respect to demographic change and high reductions in population, such plants and networks are only weakly used to date causing negative impacts on performance. Additionally, there is a general tendency especially in East Germany, that people use significantly lower amounts of water. Following the Federal Statistical Office in Germany, water use per day and capita in Saxony was only 88 liters in 2006 (Statistisches Bundesamt, 2008).

As indicated in Table 7, the mean efficiency score for water utilities operating in East Germany is 0.6574. That is even slightly higher than the mean efficiency score obtained by water utilities located in West Germany with a mean efficiency level of 0.6434. This similarity holds for the other statistical indicators. Also the median for water utilities located in East Germany is higher than for water utilities situated in West Germany. In general, the East German water utilities seem to handle the challenges with success as there is no obvious negative impact on the efficiency levels.

Table 7: Comparison of efficiency results between water utilities in East and West Germany

	Efficiency estimates of water utilities in East Germany	Efficiency estimates of water utilities in West Germany
Mean	0.6574	0.6434
Median	0.6128	0.6064
Std. Dev.	0.1852	0.1836
Min.	0.3182	0.2909
Max.	1.0000	1.0000

6. Conclusions

In this paper we provide the first efficiency analysis of water utilities considering Germany as a whole, including utilities of all sizes. In order to avoid distortions in results, the super-efficiency approach was applied for outlier detection. The application of a bootstrapped truncated regression determined factors significantly influencing technical efficiency scores. Output density as well as the groundwater ratio were included into calculation to account for structural differences of water supply. The significance of a density measure is in line with several international studies. The leak ratio showed a significant negative impact on efficiency scores, but is not included in the third stage due to the controllability by the management. The significance points to a possible underinvestment for companies with a high leak ratio. Although the marginal cost of water is relatively low in Germany, the network maintenance should be prioritized in municipal investment. The location in East or West Germany and elevation differences have no significant impact on efficiency levels. Efficiency scores show a relatively small mean level, although a variable returns to scale approach has been chosen based on a returns to scale test. The vast efficiency differences should be caused by price differences. The results indicate a high potential for cost savings and price decreases in water supply. Furthermore, the striking inefficiency of small water utilities raises the question of adequate supply structures.

The inefficiencies show the necessity of an active price regulation of the whole German water supply industry. This upcoming regulation should give the water utilities incentives to reduce costs by setting price caps decreasing over time. Caution is necessary when permitting investment budgets high enough to ensure networks in good condition. The regulation should be based on a profound analysis of performance with careful selection of variables as well as the consideration of exogenous circumstances.

Further research should consider possible additional exogenous factors and also further issues like the use of panel data and an application of stochastic frontier models as well as the determination of economies of scale, scope or density. The issue of ownership structure in German water supply should also be considered analyzing the impact of for example public versus private ownership on technical efficiency.

Acknowledgements

This paper is a joint product of the research programs on efficiency analysis and water economics administered by the Chair of Energy Economics and Public Sector Management (EE²) at Dresden University of Technology. We thank Christian von Hirschhausen for support and criticism, Astrid Cullmann and Maria Nieswand for methodological hints as well as Felix Zschoge for help in the data collection.

References

Anreizregulierungsverordnung as amended on 29. October 2007 (BGBl. I p. 2529), last modification through article 2 section 8 of the ordinance from 17. October 2008 (BGBl. I p. 2006).

Banker, R.D., Chang, H. (2006) The Super-Efficiency Procedure for Outlier Identification, not for Ranking Efficient Units, *European Journal of Operational Research*, **175**, 1311-20.

Banker, R.D., Charnes, A., Cooper, W.W. (1984) Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis, *Management Science*, **30**, 1078-92.

Banker, R.D., Gifford, J.L. (1988) A Relative Efficiency Model for the Evaluation of Public Health Nurse Productivity, Mellon University Mimeo, Carnegie.

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**, 759-84.

Brunner, U., Riechmann, C. (2004) Wettbewerbsgerechte Preisbildung in der Wasserwirtschaft, *Journal for Public and Nonprofit Services*, **27**, 115-30.

Bundesverband der Energie- und Wasserwirtschaft (2008a) Wasserpreise – Fragen & Antworten. BDEW, Berlin.

Bundesverband der Energie- und Wasserwirtschaft (2008b) Branchenbild der Deutschen Wasserwirtschaft, wvgw Wirtschafts- und Verlagsgesellschaft Gas und Wasser mbH, Bonn.

Bundesverband der Energie- und Wasserwirtschaft (2008c) 118. Wasserstatistik Bundesrepublik Deutschland 2006, wvgw Wirtschafts- und Verlagsgesellschaft Gas und Wasser mbH, Bonn.

Charnes, A., Cooper, W.W., Rhodes, E. (1978) Measuring the Efficiency of Decision-Making Units, *European Journal of Operational Research*, **2**, 429-44.

Coelli, T., Walding, S. (2006) Performance Measurement in the Australian Water Supply Industry, in *Performance Measurement and Regulation of Network Utilities* (Eds) T. Coelli and D. Lawrence, Edward Elgar Publishing, Cheltenham, pp. 29-61.

Deutsche Vereinigung des Gas- und Wasserfaches e.V. (2006) Trinkwasserqualität in Deutschland Einwandfrei, *Energie Wasser-Praxis*, **10**, 46.

Directive 2000/60/EC (2000) Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, *Official Journal L 327*, 22/12/2000, 1-73.

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**, 169-82.

Fried, H.O., Schmidt, S.S., Yaisawarng, S. (1999) Incorporating the Operating Environment into a Nonparametric Measure of Technical Efficiency, *Journal of Productivity Analysis*, **12**, 249-67.

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.

García-Sánchez, I.M. (2006) Efficiency Measurement in Spanish Local Government: The Case of Municipal Water Services, *Review of Policy Research*, **23**, 355-71.

Gesetz gegen Wettbewerbsbeschränkungen as amended on 15. July 2005 (BGBl. I p. 2114), last modification through Article 2c from 15. December 2008 (BGBl. I p. 2426).

Hanusch, H., Cantner, U. (1991) Produktion öffentlicher Leistungen – Effizienz und technischer Fortschritt, *Jahrbücher für Nationalökonomie und Statistik*, **208**, 369-84.

Hirschhausen, C.v., Cullmann, A., Walter, M., Wand, R., Zschille, M. (2008) Quo Vadis Efficiency Analysis of Water Distribution? A Comparative Literature Review, Dresden University of Technology, Chair of Energy Economics and Public Sector Management, *Efficiency Analysis Working Papers WP-EA-18*.

Hirschhausen, C.v., Walter, M., Zschille, M. (2009a) Effizienzanalyse in der Wasserversorgung – Internationale Erfahrungen und Schlussfolgerungen für Deutschland, *GWF Wasser und/ Abwasse*r, **Februar/März 2009**, 2-7.

Hirschhausen, C.v., Cullmann, A., Walter, M., Zschille, M. (2009b) Kartellverfahren in der Hessischen Wasserwirtschaft – Auf dem Weg in die Anreizregulierung?, *DIW Wochenbericht*, **10/2009**.

Hollingsworth, B., Smith, P. (2003) Use of Ratios in Data Envelopment Analysis. *Applied Economic Letters*, **10**, 733-35.

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**, 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.

Roll, Y., Golany, B., Seroussy, D. (1989) Measuring the Efficiency of Maintenance Units in the Israeli Air Force, *European Journal of Operational Research*, **43**, 136-42.

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**, 253–68.

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**, 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 Research Papers* ***RP 0502,*** Aston University.

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**, 127–39.

Saal, D.S., Reid, S. (2004) Estimating Opex Productivity Growth in English and Welsh Water and Sewerage Companies: 1993-2003, *Aston Business School Research Papers* ***RP 0434,*** Aston University.

Sauer, J. (2003) The Efficiency of Rural Infrastructure - Water Supply in Rural Areas of Transition, *ERSA 2003 Congress*, **Paper 463**.

Sauer, J. (2004a) Rural Water Suppliers and Efficiency – Empirical Evidence From East and West Germany, *Discussion Paper* ***No. 63***, Institute of Agricultural Development in Central and Eastern Europe.

Sauer, J. (2004b) Die Ökonomie der (ländlichen) Wasserversorgung, *Discussion Paper* ***No. 70***, Institute of Agricultural Development in Central and Eastern Europe.

Sauer, J. (2005) Economies of Scale and Firm Size Optimum in Rural Water Supply, *Water Resources Research*, **41**, W11418, doi:10.1029/2005WR004127.

Sauer, J. (2006) Economic Theory and Econometric Practice: Parametric Efficiency Analysis, *Empirical Economics*, **31**, 1061–87.

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

Simar, L., Wilson, P.W. (1998) Sensitivity Analysis of Efficiency Scores: How to Bootstrap in Nonparametric Frontier Models, *Management Science*, **44**, 49-61.

Simar, L., Wilson, P.W. (2000) Statistical Inference in Nonparametric Frontier Models: The State of the Art, *Journal of Productivity Analysis*, **13**, 49-78.

Simar, L., Wilson, P.W. (2002) Nonparametric Tests of Returns to Scale, *European Journal of Operational Research*, **139**, 115–132.

Simar, L., Wilson, P.W. (2007) Estimation and Inference in Two-Stage, Semi-Parametric Models of Production Processes, *Journal of Econometrics*, **136**, 31-64.

Statistisches Bundesamt (2008) Umwelt: Wasserabgabe der Öffentlichen Wasserversorgung, Tabelle 514-32, Available online under: http://www.statistikportal.de/Statistik-Portal/de_jb10_jahrtabu2.asp, as of 15 December 2008.

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