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The Efficiency of Rural Infrastructure - Water Supply in Rural Areas of Transition

43rd Congress of the European Regional Science Association: "Peripheries, Centres, and Spatial Development in the New Europe", 27th - 30th August 2003, Jyväskylä, Finland

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ERSA 2003 CONGRESS

PAPER FOR EPAINOS-AWARD:

**'The Efficiency of Rural Infrastructure
- Water Supply in Rural Areas of Transition'**

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'The Efficiency of Rural Infrastructure - Water Supply in Rural Areas of Transition'

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Keywords: Water Supplying Industry, Rural Development, Economies of Transition, Stochastic Frontier Analysis, Probit-Model, Separability Hypothesis

JEL-Classifications : C49, H41, O12, Q25, R53, R58

Summary / Abstract :

This research is focused on the efficiency of water supplying infrastructure in rural areas. A cross-sectional data set was collected with respect to water firms in rural areas of East and West Germany. After formulating partial performance indicators, the relative cost efficiency is being estimated by a stochastic frontier analysis. Due to this analysis first (preliminary) results show that the technical efficiency in the (rural) water sector can be improved by up to 45 % with the same technology and the same hydrological and supplying characteristics. No significant effect on suppliers' inefficiency by regional location was found. Economies of scale are verified for the sample suggesting the realisation of efficiency gains by the expansion of the average supplying area. Assumed explicit negative effects on firms' efficiency by the existing legal framework of the water sector are hence empirically confirmed. The analysis of the determinants of public funding reveals that there is no significant influence of operational efficiency on the decision about funding by public institutions. Finally it is shown that firms in East Germany enjoy a more easier access to public funds, regardless how efficient their operations are.

I) Introduction

The sustainable use of the global water resources is of highest priority on the agenda of international development activities. This was recently shown by the 3rd World Water Forum at Kyoto/Japan in March 2003. Here it was again stressed that public and private management – both on the level of the urban or rural supplier as well as the water sector – have to be oriented at economic principles. This holds also with respect to transition economies in Central and Eastern Europe (see SAUER 2001 and 2002).

Furthermore the provision of adequate infrastructure capital is crucial for the economic development and transition of rural areas in these former command economies. In economic theory water supplying services are regarded as a fundamental part of the regional ‘core infrastructure’. Nevertheless, the commonly held perception of water and sewerage companies in economies of transition is, that the operational and financial performance is poor, revenue generation is inadequate and services are not provided in an efficient and cost-effective way (see e.g. EBRD, 1999 and WORLDBANK, 2000).

The objectives of this research project are therefore:

- the analysis of the relative efficiency of rural water suppliers in economies of transition and the identification and evaluation of the relevant cost factors,
- the analysis of the effects of institutional infrastructure funding on the individual firm’s efficiency and the implications for the national as well as EU-structural policy,
- suggestions for the design of an optimal infrastructure policy with respect to rural water supply in EU-accession countries.

Finally this research is also a contribution to the growing literature on the estimation and use of efficiency frontiers with respect to the liberalisation as well as regulation of infrastructure services.¹

¹ See e.g. recently Estache (1999, 2002) on the water supplying services and Coelli (2001).

II) Sampling, Questionnaire and Data

The focus of this project is on water suppliers in rural areas of transition economies. Due to still severe constraints in the former socialist economies with respect to data availability (as well as comparability and reliability), in a first step technical, financial as well as institutional data on suppliers in rural areas of the East German Bundesländer (the territories of the former GDR) as well as the West German Bundesländer have been collected. Therefore the category ‘rural area’ had to be defined referring to valid definitions used by economic policy decision units.

As the European Commission (1997) stresses, EU member states generally developed their own definitions of rural areas based on socio-economic criteria (such as agricultural patterns, density of inhabitants per square kilometer or population decline). “At EU level, there is no common definition.” (EC, 1997) There are basically two methods – one by the OECD and the other by EUROSTAT – which are often employed to describe the different situations existing in the Union’s rural areas.

The OECD definition distinguishes two hierarchical levels of territorial unit: local and regional. At the local community level (corresponding to the *Nomenclature of Territorial Units for Statistics: NUTS 5*²), the OECD identifies rural areas as communities with a population density below 150 inhabitants per square kilometer. At the regional level (NUTS 3), larger functional or administrative units are distinguished by their degree of rurality depending on what share of the region’s population lives in rural communities. The EUROSTAT approach is based on the degree of urbanisation.³

The DG VI of the European Commission has re-worked the OECD methodology, adjusting the population density threshold used to determine the municipality’s type at 100 inhabitants per km² (OECD: 150 inhabitants per km², see EC, 1997). According to this parameter the regions can be grouped into three types:

- predominantly rural regions: > 50 % of the population living in rural communities,

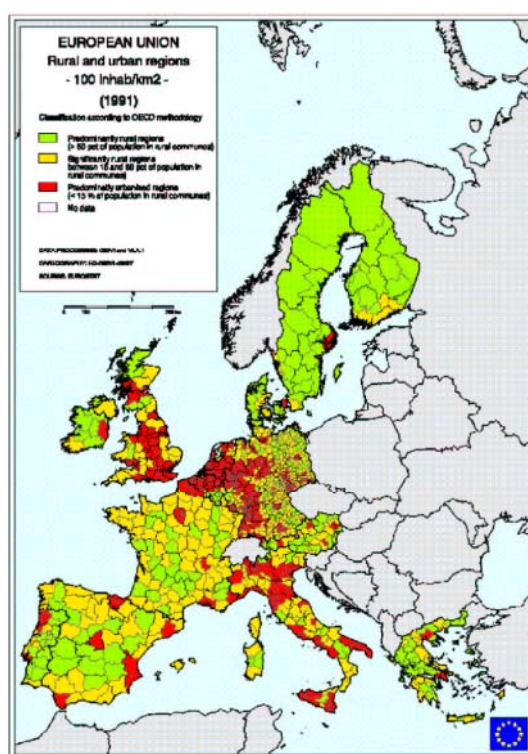
² Regional data are based on the NUTS classification comprising five levels of territorial units (see EUROSTAT, 1999).

³ An algorithm was developed to classify every European region according to one of the three classes: densely populated zones, intermediate zones and sparsely populated zones.

- significantly rural regions: 15 to 50% of the population living in rural communities;
- predominantly urban regions: < 15% of the population living in rural communities.

On the basis of this re-worked OECD methodology (see OECD, 1994) nearly 15% of the EU15 population is living in rural communities, covering appr. 80% of the EU territory. With respect to the EU territory the following pattern emerges (see *map 1*). By applying this methodology on Germany and by using the NUTS classification, 60 'predominantly rural regions' were identified (corresponding to NUTS 3 level). These rural areas consist of 3632 communities.

Map 1: 'Rural and Urban Regions in the European Union (Re-worked OECD methodology)'

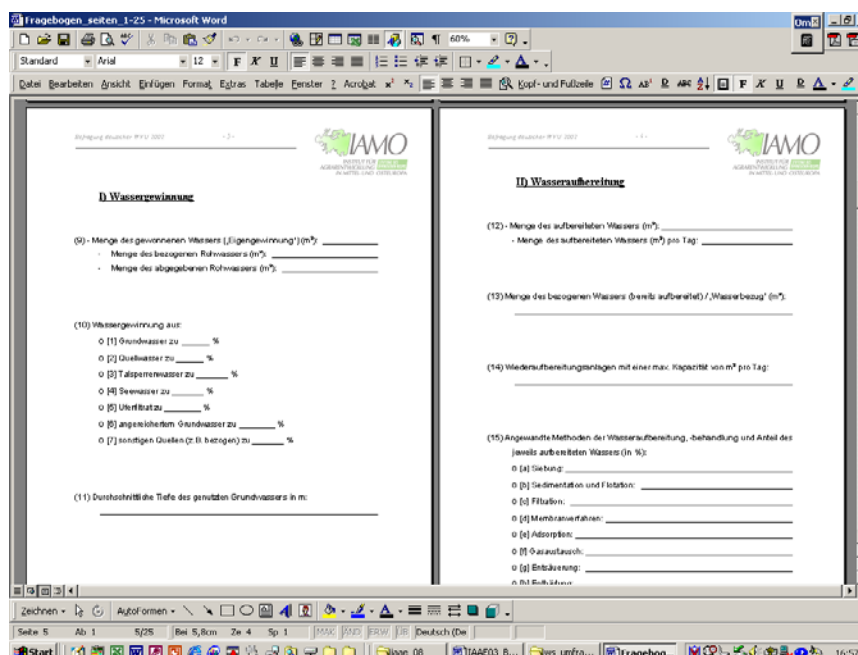


Rural communities (less than 100 inhabitants/km²) operate their own water supplying system, are part of a water association supplying a group of communities in a certain region or are supplied by a nearby municipal utility. Private operation of such forms of water supplying companies is rare due to the legal framework and the liberalisation efforts which are still at an early stage. Hence a total population of 632 water suppliers in rural regions was identified.

With respect to this target population a comprehensive questionnaire was developed in order to collect valid technical, financial and institutional data on the different stages of rural water production and provision⁴. This was sent to all suppliers of the described total population in November 2002. Till end of March 2003 about 32% of the suppliers answered positive or negative, ending up with about 60 – 65 nearly complete data sets. Finally the collection of such data on about 150 rural water suppliers in Poland has been started in March 2003.

Being far from representative, the analyses as well as conclusions drawn on the basis of this sample on rural water suppliers can be regarded as more than a first hint where the journey 'efficiency discussion in the water sector' should be directed in the future. This even more, if one takes into account that there is rarely any valid data set on rural water suppliers available in East Germany and other transition countries.

Picture 1: 'Questionnaire Excerpt: Data on Rural Water Suppliers 2000'



⁴ Due to the financial year 2000 or 2001.

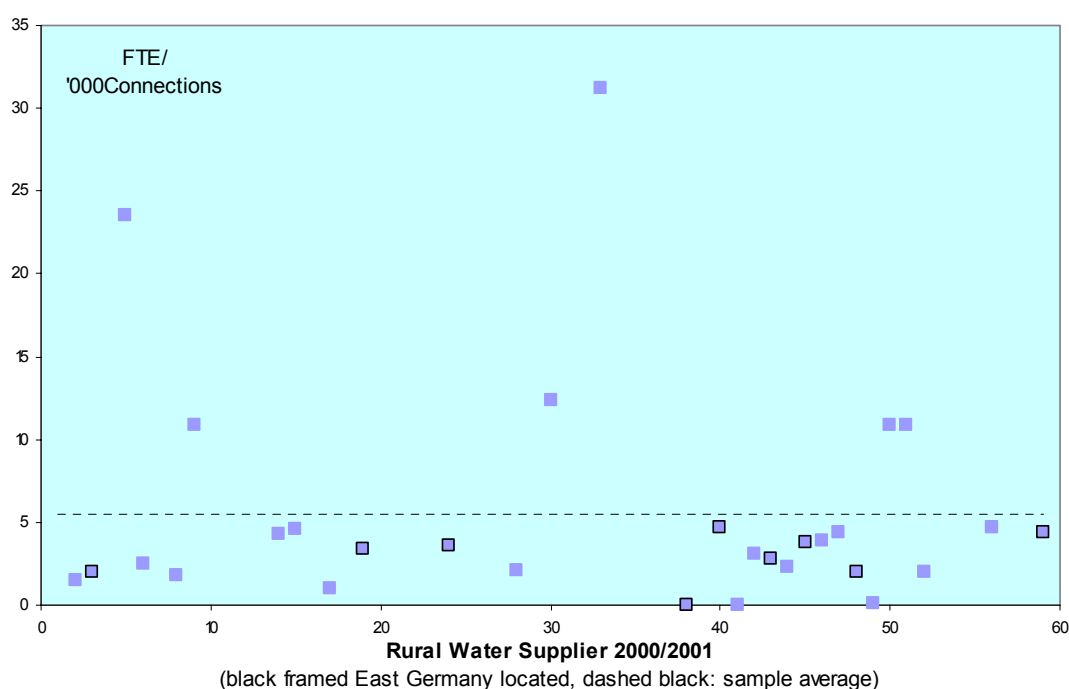
III) Preliminary Performance Indicators – *First Evidence of Firm Specific Inefficiency ?*

In a first step the relative productivity of water suppliers in rural areas of economies in transition can be analysed by valid performance indicators in the form of partial input-output ratios. These are formulated on the basis of the recent recommendations of the International Water Association (IWA 1. Level Performance Indicators; see *Alegre et al, 2000*) and applied on a preliminary sample of rural water suppliers in East and West Germany for the year 2000 resp. 2001. The 'personnel indicator' – beside others recommended for the productivity measurement by the IWA – :

$$\text{number of full time employees of the water undertaking / number of service connections} \quad (2.1.)$$

varies for the same cross-sectional data between 0.06 and 31.2 full time employees per supplied connection (see *figure 1*). This means that the 'lowest performer' of the sample used more than 500 times (!) more labour input per connection than the 'best performer' in the year 2000/2001.

Figure 1: 'Personnel Indicator (IWA 2000 – Indicator)'



With respect to average labour productivity:

$$\frac{\text{total water supplied (in '000 m}^3\text{)}}{\text{number of full time employees of the water undertaking}} \quad (2.2.)$$

it is to say, that the most productive rural water supplier in the sample produced and provided about 40 times more water than the least productive rural supplier per full time employee in 2000/2001 (see *figure 2* and *Appendix 1, figure A8*). The same holds with respect to the comparison of the average productivity of capital (see *figure 3*):

$$\text{total water supplied (in m}^3\text{) / fixed assets (in Euro)} \tag{2.3.}$$

where the most productive rural supplier produced 0.82 m³, the least productive supplier about 0.04 m³ water per used Euro of capital (fixed assets):

Figure 2: 'Average Labour Productivity'

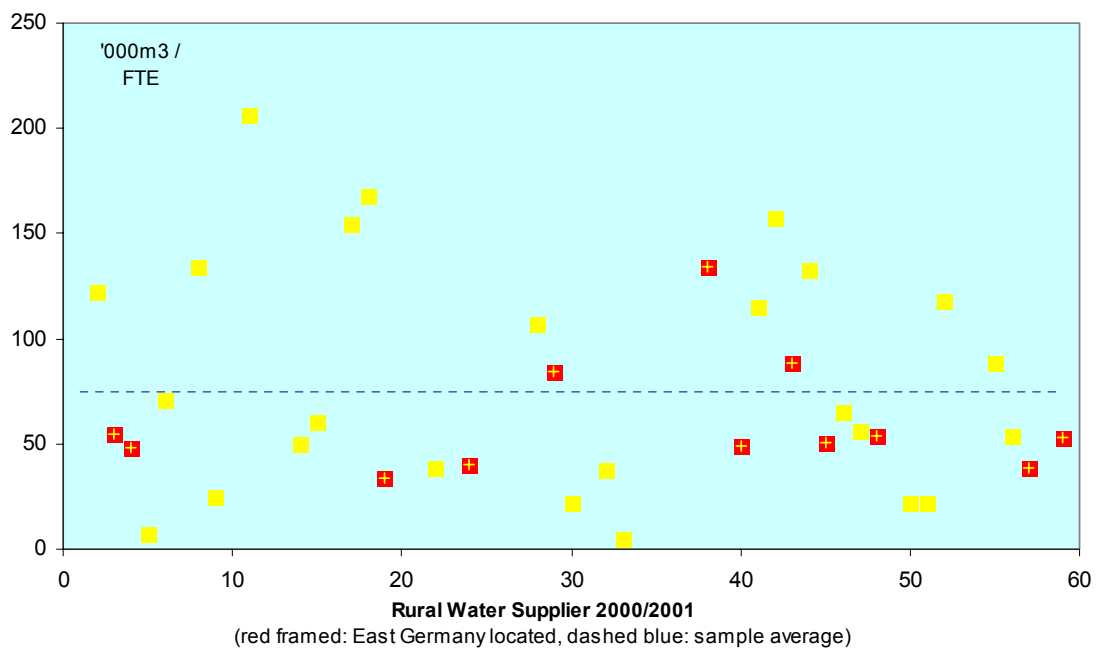
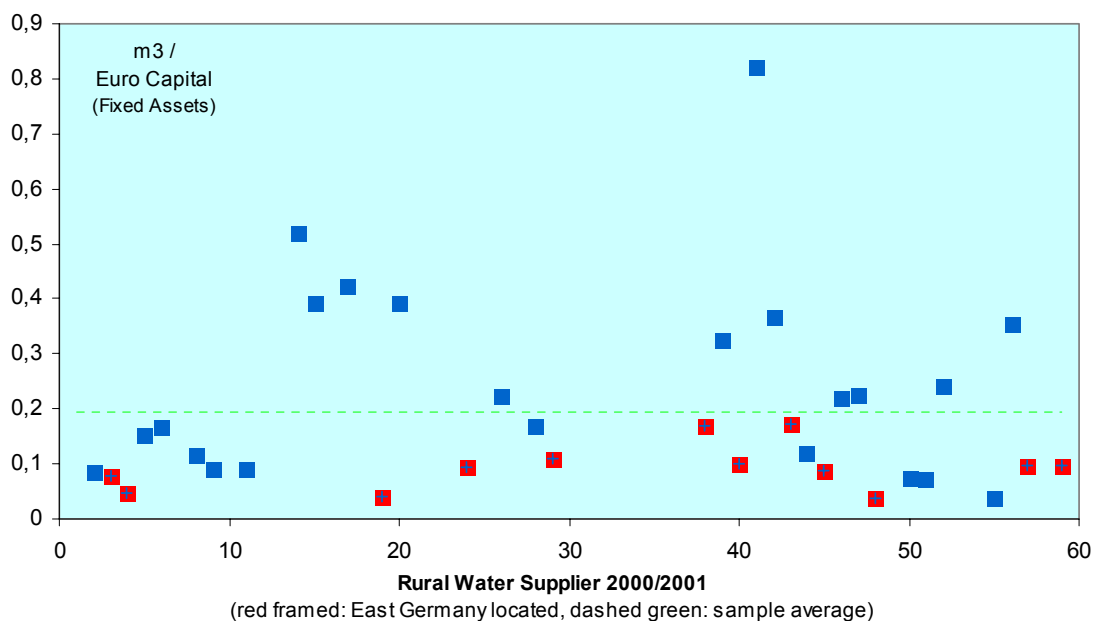


Figure 3: 'Average Capital Productivity'

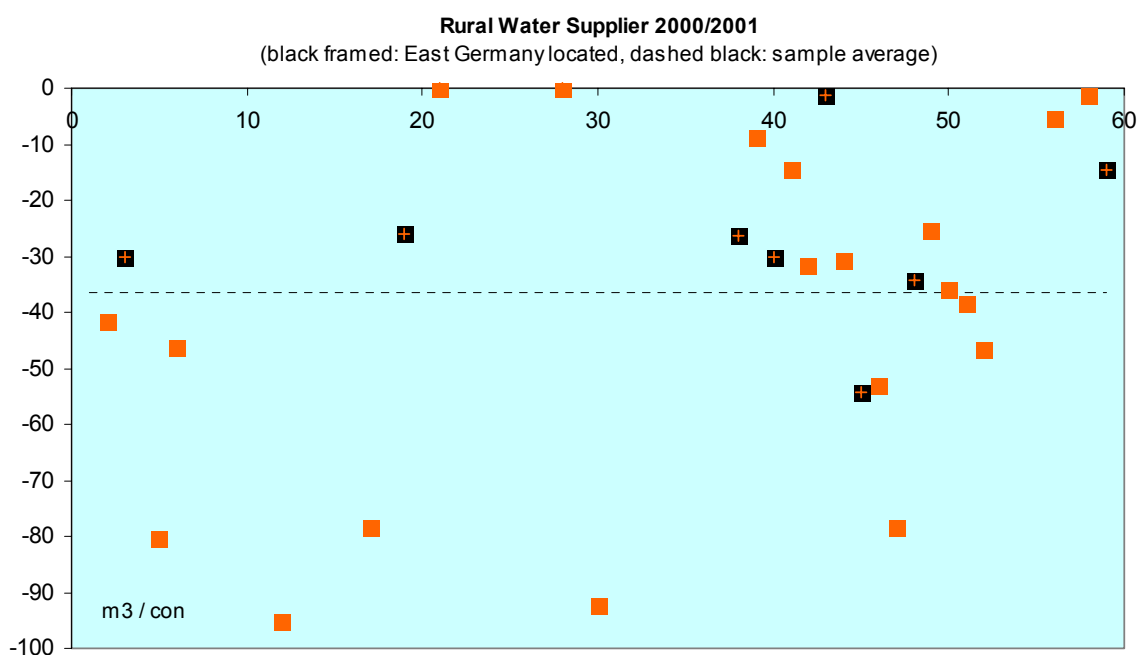


The IWA indicator 'water loss' (see *figure 4*):

$$\frac{\text{water billed} - \text{water produced and supplied (in m}^3\text{)}}{\text{total number of served connections}} \quad (2.4.)$$

finally shows a very high range of m³-water lost during production and provision for the sample of rural water suppliers. The 'lowest performer' lost about 95 m³ per connection, the 'best performer' only about 0.006 m³ per connection.

Figure 4: 'Water Loss (IWA 2000 – Indicator)'



By applying partial performance or productivity indicators on (preliminary) data it became clear, that the relative performance of rural water suppliers varies due to different individual as well as systematic factors (see also additional indicators in *Appendix I*). This is further illustrated by the ranking of rural water suppliers with respect to different performance ratios given in *table 1*:

Table 1: 'Performance Ranking by Partial Indicator'

Rural Supplier No.	I) Average Output per Labour	II) Average Output per Capital	III) Average Output per Net	IV) Average Labour per Net
1	nda	nda	16	nda
2	8	28	40	5
3	19	29	43	11
4	26	32	34	17
5	36	17	nda	nda
6	15	16	30	14
7	nda	nda	42	nda
8	6	19	32	6
9	32	25	39	22
10	nda	nda	31	nda
11	1	26	35	4
12	nda	nda	18	nda
13	nda	nda	nda	nda
14	24	2	23	21
15	17	5	10	24
16	nda	nda	37	nda
17	4	3	45	2
18	2	nda	nda	nda
19	31	33	41	18
20	nda	4	13	nda
21	nda	nda	nda	nda
22	29	nda	49	10
23	nda	nda	48	nda
24	27	24	38	16
25	nda	nda	22	nda
26	nda	11	47	nda
27	nda	nda	44	nda
28	11	14	33	8
29	14	20	26	12
30	33	nda	9	32
31	nda	nda	nda	nda
32	30	nda	36	20
33	37	nda	4	nda
34	nda	nda	14	nda
35	nda	nda	nda	nda
36	nda	nda	20	nda
37	nda	nda	46	nda
38	5	15	25	9
39	nda	8	27	nda
40	25	21	12	27
41	10	1	21	13
42	3	6	5	15
43	12	13	3	26
44	7	18	2	19
45	23	27	15	25
46	16	12	1	30
47	18	10	7	28
48	21	36	17	23
49	nda	nda	6	1
50	35	30	11	33
51	34	31	24	31
52	9	9	29	7
53	nda	nda	19	nda
54	nda	nda	nda	nda
55	13	35	50	3
56	20	7	nda	nda
57	28	23	nda	nda
58	nda	nda	28	nda
59	22	22	8	29

('nda': no data available; 1: if no ranking was possible due to nda, the average value was taken)

The individual ranking of the rural water suppliers varies largely with respect to the performance indicators (see *table 1: I) – IV)* and *appendix 3*). Supplier 41 e.g. shows a very high capital productivity (ranked 1) but a very low average revenue (ranked 44). Supplier 2 shows high cost coverage ratios (ranked 5 and 13) but on the other side a very low output per net ratio (ranked 40). As these results may be consistent considered as a multi-faceted picture of the supplier’s efficiency, they do not recognise the more complex nature of interactions between inputs and outputs.⁵

Especially with respect to the specific and largely differing conditions of water extraction and treatment (e.g. hydrological conditions, quality of raw water sources) as well as water transport and distribution (e.g. connection and consumer density, need for pumping), the analysis of the efficiency of water supplying firms in rural areas of transition has to take these factors with respect to its – both direct and indirect – effects on output and costs into account. This is adequately done by applying multiple regression analysis in the form of the estimation of stochastic efficiency frontiers⁶. Here the cost frontier show the (operational or total) costs of a rural water undertaking as a function of the level of water output and the prices of inputs. Finally decisions on public funding for water suppliers have to be based on such complete efficiency comparisons (see also *VII. First Results*).

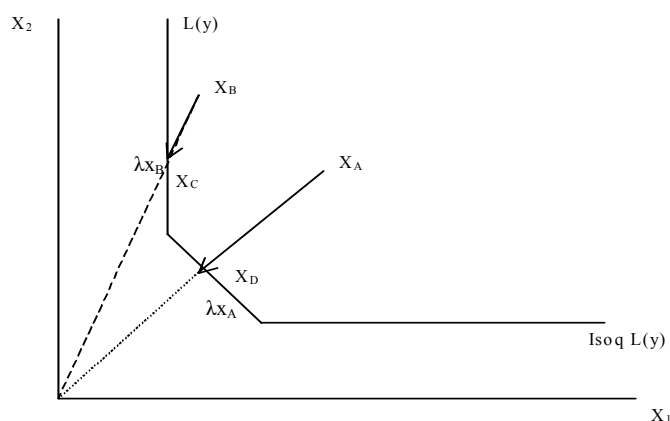
⁵ Nevertheless, as e.g. also Estache et al. (1999) note, data limitations in most countries make partial indicators the only usable method to compare firms’ efficiency. Therefore they tend to be used in conjunction with various types of quality indicators to obtain a multi-dimensional snapshot of a water supplier’s performance.

⁶ See initially Aigner, D./Lovell, C.A./Schmidt, P.; *Formulation and Estimation of Stochastic Frontier Production Function Models*, in: *Journal of Econometrics*, 6, 1977, pp. 21 - 37.

IV) Method – Stochastic Frontier Approach (SFA)

The empirical measurement of economic efficiency in a given organisation or industry focuses on determining the extent of either allocative and/or technical efficiency. The measure of technical efficiency is defined as one minus the maximum equiproportionate reduction in all inputs (denoted as θ in 4.3.) that still allows continued production of given outputs⁷. A score of unity indicates technical efficiency because no equiproportionate input reduction is feasible (corresponding to a position on $L(y)$ in figure 5), and a score less than unity indicates the severity of technical efficiency (estimated e.g. at point x_A or x_B in figure 5):

Figure 5: 'Debreu-Farrell Technical Efficiency Measurement (Input-Oriented)'



with :

$$DF_1(y, x_C) = DF_1(y, x_D) = 1 > \max \{DF_1(y, x_A), DF_1(y, x_B)\} \quad (4.1.)$$

$$DF_1(y, \lambda x_A) = DF_1(y, \lambda x_B) = 1 \quad (4.2.)$$

$$DF_1(y, \theta x_A) = DF_1(y, \theta x_B) = 1 \quad (4.3.)$$

Different frontier approaches⁸ have been developed to assess firms' performance relative to some empirically defined best-practice standard. The SFM approach uses statistical techniques (the classical linear regression model) to estimate a production or cost function and to estimate efficiency relative to this frontier. It assumes the presence of some noise or error in the variables and hence that not all deviation from the efficiency frontier can be attributed to inefficiency (see AIGNER et al. (1977), MEEUSEN et al. (1977) and JONDROW et al. (1982)). As the regulated water supplier minimises a total cost function subject to a target

⁷ I.e. 'input-oriented' efficiency measurement.

⁸ The most important ones are the non-parametric linear programming approach or data envelopment analysis (DEA), the stochastic frontier approach (SFA), the thick frontier approach (TFA), and the distribution-free approach (DFA).

output constraint it appears necessary to focus on cost minimisation rather than profit maximisation: since output is exogenous, the regulated firm maximizes benefits simply by minimizing its costs of producing a given level of output subject to pre-set water tariffs.

The traditional cost function is modified to the extent that a cost-minimising firm may not be able to produce a given level of output (with given input prices) at a minimum possible cost (the cost frontier) if technical and allocative inefficiencies are present. Technical efficiency can arise due to poor management, low quality of inputs, etc., while allocative inefficiency is due to optimisation error, i.e., failure to use inputs by equating the ratio of input prices to their marginal products. Thus the sources of errors in production and cost are: (i) technical inefficiency, resulting from the failure to produce a given output by a minimum set of inputs, (ii) allocative inefficiency, arising out of the choice of sub-optimal input-proportions, given input prices, and (iii) white noise – representing exogenous shocks, etc. which are not in the control of the supplier. Hence control variables are included in the specification of the estimated functional relations to ensure that the various rural water suppliers are effectively comparable. Hence by confronting the ‘best’ supplier(s) in the industry (the sample) with the same constraining factors of a specific rural water utility, the relative efficiency of that supplier can be assessed.

The general theoretical specification (see also 5.3.) of the rural water supplier’s cost function could be described as:

$$C_{ws} = f(Y_{ws}, W_i, Z_j, T_l) \quad (4.4.)$$

with C_{ws} as total costs, Y_{ws} as total output of the rural water supplier, W as I-dimensional vector of relevant input prices, Z as j-dimensional vector of exogenous control variables with respect to extraction, treatment, transport and distribution and T as l-dimensional vector of exogenous control variables with respect to the institutional setting as well as the process of transition.

With respect to the functional form a Cobb-Douglas-type function can be applied (4.5. showing the logarithmic version):

$$\ln C_{ws} = \alpha_0 + \beta_y \ln y_{ws} + \sum_{i=1}^n \beta_i \ln W_i + \sum_{j=1}^m \gamma_j \ln Z_j + \sum_{l=1}^o \omega_l \ln T_l + \epsilon \quad (4.5)$$

further a Translogarithmic⁹ (or other flexible forms) can be tested:

$$\begin{aligned} \ln C_{ws} = & \alpha_0 + \beta_y \ln y_{ws} + \sum_{i=1}^n \beta_i \ln W_i + \sum_{j=1}^m \gamma_j \ln Z_j + \sum_{l=1}^o \omega_l \ln T_l + 1/2 \{ \sum_{i=1}^n \sum_{q=1}^n \delta_{iq} \ln W_i \ln W_q \\ & + \sum_{j=1}^m \sum_{s=1}^m \delta_{js} \ln Z_j \ln Z_s + \sum_{l=1}^o \sum_{u=1}^o \delta_{lu} \ln T_l \ln T_u + \delta_{yy} \{ \ln y_{ws} \}^2 \} + \sum_{i=1}^n \sum_{j=1}^m \delta_{ij} \ln W_i \ln Z_j \\ & + \sum_{i=1}^n \sum_{l=1}^o \delta_{il} \ln W_i \ln T_l + \sum_{i=1}^n \delta_{iy} \ln W_i \ln y_{ws} + \sum_{j=1}^m \sum_{l=1}^o \delta_{jl} \ln Z_j \ln T_l + \sum_{j=1}^m \delta_{jy} \ln Z_j \ln y_{ws} \\ & + \sum_{l=1}^o \delta_{ly} \ln T_l \ln y_{ws} + \epsilon \end{aligned} \quad (4.6)$$

with C_{ws} as the (total or operational) costs of the rural water undertaking, y_{ws} as the total water output, $W_i = [W_M, W_L, W_E]$ defines vectors with respect to the prices for the variable inputs material, labour and energy ($X = [X_M, X_L, X_E]$). The vector Z defines a number of control variables as e.g. the fix input capital (Z_K), the amount of treated water (Z_{WT}) or the total length of transport and distribution net (Z_{WTDL}). T denotes a number of institutional and transition related control variables as e.g. the form of ownership (T_{OWN}) or the granting of public funding (T_{PFU}).

This systematic part of the model determines the minimum cost (maximum output in the case of a production frontier) that can be obtained with a given set of inputs and control variables. This set is labelled ‘cost (production) frontier’. The minimum cost function (maximum output function) defines this frontier showing the technically possible costs (output) associated with the supplier specific level of inputs and control variables. The two-sided random error term ϵ captures the effects of noise, measurement error and exogenous shocks beyond the control of the water supplier.¹⁰ It is decomposed in the following way:

$$\epsilon_{wsi} = u_{wsi} + v_{wsi} \quad (u_{wsi} \geq 0) \quad (4.7.)$$

where v_{wsi} captures the effects of stochastic noise for the I -th rural water supplier. It is assumed to be iid by following $N(0, \sigma^2_v)$. u_{wsi} represents the cost inefficiency for the I -th rural water supplier, which is assumed to be independent from v_{wsi} and the regressors.¹¹ In a first step the parameters of the cost or production function are estimated. Further the error term is decomposed following the form presented by JONDROW et al. (1982). The efficiency of the I -th rural water supplier is finally obtained by (4.8.):

$$\text{efficiency } I\text{-th rws}_i = \exp(-u_{wsi}) \quad (4.8.)$$

⁹ Symmetry and homogeneity of degree zero in inputs are imposed.

¹⁰ As e.g. FUSS ET AL. (1978: 249) puts it: “Relations between measured production variables will in general contain stochastic components introduced at four levels: (1) the technology of the production unit, (2) the environment of each firm, particularly the market environment, (3) the behaviour of the production unit, and (4) the process of observation, which often involves aggregation over commodities, production units, and time; direct errors in measurement; and incomplete observation.”

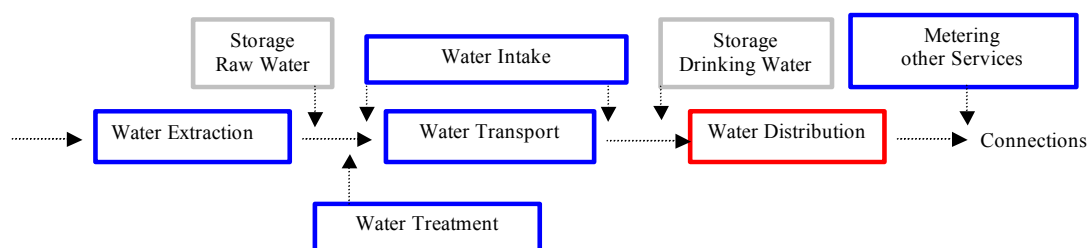
¹¹ Various distributions have been suggested for this error component: half normal, truncated normal and exponential. The half normal distribution implies that the majority of suppliers are almost quasi efficient. Nevertheless, it has to be noted that the estimation results for u_i depend also on the applied distribution. This problem can be addressed by using the consistency condition approach (see GREENE, 1990).

V) Production Stages and Modelling

5.1. The Structure of Production

In order to formulate a theoretically valid model for the estimation of the relative efficiency of rural water suppliers, the basic stages of water production can be described by *figure 6*:

Figure 6: ‘Water Production Stages (Cost-Oriented)’



Water storage is normally not regarded as an integral part of the production process. The water intake is delivered by other firms. Metering and other services are mostly done by the supplier itself, nevertheless can be ‘contracted-out’. The process of water treatment is regarded as a central part of the rural water undertaking, but is – compared to other stages – not very cost intensive. The highest costs are generated by the transport of water as well as the distribution of drinking water to the consumers. The costs of water extraction depend on the hydrological setting (ground, spring or surface water). Only the stage of water distribution can be regarded as a natural monopoly.

Assuming the realisation of economies of vertical integration, the majority of rural water suppliers in Germany are organised by following the principle of total vertical integration.¹²

5.2. The Problem of Separability

However, with respect to the estimation of an efficiency frontier for rural water production the real nature of interdependencies between the different sub-stages of production have to be discussed. If there are no such interdependencies in the ‘sub-cost functions’ for water generation or extraction (C_E), water treatment (C_T), water storage (C_S) water transport (C_{TP}) and water distribution (C_D), ‘separability’ of the production stages can be assumed and therefore the different production processes can be independently modelled. With respect to the cost function ‘strong separability’ implies that the cost function is additive with respect to these sub-cost functions:¹³

$$C(W, Q) = C(C_E(W_E, Q_E) + C_T(W_T, Q_T) + C_S(W_S, Q_S) + C_{TP}(W_{TP}, Q_{TP}) + C_D(W_D, Q_D)) \quad (5.1.)$$

¹² See SAUER 2003b for a detailed discussion of the organisation of the water supplying industry.

¹³ With respect to the production function: $Q(W, C) = Q(Q_E(W_E, C_E) + Q_T(W_T, C_T) + Q_S(W_S, C_S) + Q_D(W_D, C_D))$. See e.g. CHAMBERS (1988) or GOLDMAN/UZAWA (1964).

subject to the strong separability condition¹⁴:

$$\partial/\partial W_x [(\partial C(W,Q)/\partial W_i)/(\partial C(W,Q)/\partial W_j)] = 0, \quad W_i \in W^1, W_j \in W^2, W_x \in W^1 \cup W^2 \quad (5.2.)$$

with W_i , W_j and W_x as the prices of input I, input j and the price of the intermediate good x respectively. Thus, a sub-cost function excluding intermediate inputs can be estimated (and optimised) separately. This implies that a two-stage cost minimization process can be applied: first each sub-cost function is minimized by using its relevant input prices and output, and second the derived intermediate input prices are used to minimize the overall cost function subject to the output constraint.

If strong separability holds with respect to the rural water industry this implies, that the cost function of water production and provision can be separated in up to five sub-cost functions. The production decisions in each stage would be independent of each other and therefore vertical disintegrated production would be as efficient as integrated production. No commonly assumed technological economies of vertical integration would exist and hence no reason for the integrated rural utility model. To shed empirical light on the discussions about the technological boundaries of water industry liberalisation the separability of rural water production and provision should be tested subject to the availability of valid data on the different production stages (see SAUER 2003b).

5.3. Explanatory Variables and Estimation Model(s)

On the basis of the outlined production structure a comprehensive set of explanatory variables can be formulated. (4.4.) defines Z as j-dimensional vector of exogenous control variables with respect to extraction, treatment, transport and distribution: amount of water treated (Z_{WT}), amount of water purchased (Z_{WTP}), capital (Z_K), change in capital stock ($Z_{\Delta K}$), share of general and administrative labor (Z_{LA}), share of technical labor (Z_{LT}), length of internal transport system (Z_{TS}), amount of water pumped (Z_{WP}), share of water from groundwater sources (Z_{WG}), share of water from surface water sources (Z_{WS}), share of water from spring water sources (Z_{WSP}), depth of groundwater sources (Z_{DWG}), share of water treated by filtration (Z_{WTF}), share of water treated by disinfection (Z_{WTD}), share of water treated by oxidation (Z_{WTO}), share of water treated by other techniques (Z_{WTT}), index for raw water pollution (Z_{RWP}), index for treated water pollution (Z_{TWP}), share of water stored in underground facilities (Z_{WSU}), share of water stored in above ground facilities (Z_{WSA}), altitude meters pumped for above ground storage (Z_{WSM}), number of connections (Z_{WC}), share of household connections (Z_{WHC}), share of

¹⁴ $(\partial C(W,Q)/\partial W_i) / (\partial C(W,Q)/\partial W_j)$ as the marginal rate of substitution between W_i and W_j .

commercial connections (Z_{WCC}), share of industrial connections (Z_{WIC}), share of public connections (Z_{WPC}), amount/share of water loss (Z_{WL}), length/share of water distribution system made of different materials (Z_{WDM}), total length of water distribution system (Z_{WDL}), amount/share of water consumed by average household (Z_{WCH}), amount/share of water consumed by average commercial consumer (Z_{WCCC}), amount/share of water consumed by average industrial consumer (Z_{WCI}), amount/share of water consumed by average public connection (Z_{WCP}), total amount of water consumed by average consumer (Z_{WTC}).

(4.4.) defines T as 1-dimensional vector of exogenous control variables with respect to the institutional setting as well as the process of transition: structure/form of ownership (T_O), share of private stakeholders (T_{PS}), amount/share of public funding/grants (T_F), structure of the relevant decision unit (T_{DU}), number of different decision fractions (T_{DF}), number of board members also member of another decision unit (T_{BM}), water sector experience of the members of the decision unit (T_{DEX}), per capita income of supplied inhabitants (T_{PCI}).

Due to the availability of only limited data on water suppliers in rural areas of Germany the following explanatory variables (see *table 2*) as well as various ratios (see *table 3*) will be tested:

Table 2: ‘Explanatory Variables’

<i>PL</i>	<i>Price of Labour</i>
<i>PE</i>	<i>Price of Energy</i>
<i>CAP</i>	<i>Capital</i>
<i>MAT</i>	<i>Material</i>
<i>L</i>	<i>Labour</i>
<i>E</i>	<i>Energy</i>
<i>REV</i>	<i>Total Revenue</i>
<i>OUT</i>	<i>Total Water Output</i>
<i>CON</i>	<i>Number of Connections Supplied</i>
<i>CUST</i>	<i>Number of Consumers / Inhabitants Supplied</i>
<i>NET</i>	<i>Length of Transport and Distribution Net</i>
<i>OUTHH</i>	<i>Water Output Household Consumers</i>
<i>OUTIND</i>	<i>Water Output Industry Consumers</i>
<i>IN</i>	<i>Water Input</i>
<i>I</i>	<i>Water Intake from Groundwater Sources</i>
<i>SOU</i>	<i>Water Intake from Spring Sources</i>
<i>SHOP</i>	<i>Share of Own Water Produced</i>
<i>INVO</i>	<i>Investment per Water Output in 2000 (2001)</i>
<i>INVO05</i>	<i>Investment per Water Output in last 5 Years</i>
<i>INVO10</i>	<i>Investment per Water Output in last 10 Years</i>
<i>BREG</i>	<i>Binary Variabel for Regional Location</i>
<i>BY</i>	<i>Binary Variable for Year</i>
<i>BFU</i>	<i>Binary Variable for Public Funding</i>
<i>BOWN</i>	<i>Binary Variable for Ownership</i>
<i>BSEW</i>	<i>Binary Variable for Combination with Sewerage</i>

Table 3: 'Explanatory Ratios'

ENL	Energy per Labour (E / L)
MATL	Material per Labour (MAT / L)
CAPL	Capital per Labour (CAP / L)
AVE	Average Energy per Water Output (E / OUT)
AVL	Average Labour per Water Output (L / OUT)
AVCAP	Average Capital per Water Output (CAP / OUT)
OUTL	Labour Productivity (OUT / L)
OUTCAP	Capital Productivity (OUT / CAP)
AVREV	Average Revenue per Water Output (REV / OUT)
AVNETO	Average Net per Water Output (NET / OUT)
AVLNET	Average Labour per Net (L / NET)
AVCONET	Average Connections per Net ('Density' : CON / NET)
MSTR	Market Structure (OUTHH / OUTIND)
AVGRWO	Average Groundwater per Water Output (GROW / OUT)
AVINO	Average Water Intake per Water Output (IN / OUT)
LOSS	Water Billed / Water Produced

The testing of a translog cost function requires a relatively large data set to maintain adequate degrees of freedom as a consequence of the inclusion of the second-order and cross terms. The following estimation model(s) are therefore based on the specification of a Cobb-Douglas functional form:

$$\ln(y) = \ln(X)^\beta \tag{5.3.}$$

and with reference to the duality theorem¹⁵ the indirect cost function:

$$\ln(C) = \ln(X)^\beta \tag{5.4.}$$

Using a Cobb-Douglas type of function with a rather simple algebraic form further allows the compliance with curvature requirements, as e.g. LAU (1978: 410) states: "(...) estimated Cobb-Douglas production functions are automatically quasi-concave if they satisfy the monotonicity conditions."¹⁶ In addition to the CD-models specified above, functional forms

¹⁵ See in detail e.g. SHEPHARD 1953 and DIEWERT 1973.

¹⁶ The properties of production functions can be shortly described as follows:

Let \mathbf{v} , \mathbf{y} be vectors of inputs and outputs, respectively. Suppose that \mathbf{y} (occurring in some input-output vector in \mathbf{Y} denoting the production possibility set) is restricted to a single element y , then by using the notion of an input requirement set $V(y)$ containing all the input bundles which can produce y i.e. $V(y) = \{\mathbf{v} : (\mathbf{v}, y) \in \mathbf{Y}\}$ the production function with respect to y can be defined as: $f(\mathbf{v}) = \max_y \{y : \mathbf{v} \in V(y)\}$. When $V(y)$ has the properties *location*, *closure*, *monotonicity* and *convexity* (see in detail e.g. DIEWERT, 1971 or FUSS, 1978) $f(\mathbf{v})$ has the following properties:

- (1) *domain*: $f(\mathbf{v})$ is a real-valued function of \mathbf{v} defined for every $\mathbf{v} \in \Omega_n$ and it is finite if \mathbf{v} is finite; $f(\mathbf{0}) = 0$;
- (2) *monotonicity*: an increase in inputs cannot decrease production: $\mathbf{v} \geq \mathbf{v}' \rightarrow f(\mathbf{v}) \geq f(\mathbf{v}')$;
- (3) *continuity*: f is continuous from above: every sequence $\{\mathbf{v}^n\} \subset \Omega_n$ such that $f(\mathbf{v}^n) \geq y^0$, $y^0 = f(\mathbf{v}^0)$ and $\mathbf{v}^n \rightarrow \mathbf{v}^0$ implies $\lim_{n \rightarrow \infty} f(\mathbf{v}^n) = y^0$;
- (4) *concavity*: f is quasi-concave over Ω_n : the set $\{\mathbf{v} : f(\mathbf{v}) \geq y, \mathbf{v} \in \Omega_n\}$ is convex for every $y \geq 0$ which implies diminishing marginal rates of substitution.

out of the class of functional forms with global curvature properties – as e.g. the Quadratic (e.g. LAU 1979), the Generalized McFadden or the Generalized Barnett (e.g. DIEWERT ET AL. 1984) – will be tested.

The initial models for the estimation are as follows:¹⁷

$$\begin{aligned} \ln\text{AVOC} = & \alpha + \beta\ln\text{PL} + \beta\ln\text{PE} + \gamma\ln\text{AVCAP} + \gamma\ln\text{CAPL} + \gamma\ln\text{MATL} \\ & + \gamma\ln\text{AVCONET} + \gamma\ln\text{AVNETO} + \gamma\ln\text{NET} + \gamma\ln\text{AVGRWO} + \gamma\ln\text{MSTR} \\ & + \gamma\ln\text{SOU} + \gamma\ln\text{SHOP} + \gamma\ln\text{LOSS} + \gamma\ln\text{INVO10} + \omega\text{BREG} + \omega\text{BY} + \omega\text{BFU} \\ & + \omega\text{BOWN} + \omega\text{BSEW} + \epsilon \end{aligned} \quad (5.5.)$$

$$\begin{aligned} \ln\text{TC} = & \alpha + \beta\ln\text{PL} + \beta\ln\text{PE} + \gamma\ln\text{OUT} + \gamma\ln\text{CAP} + \gamma\ln\text{L} + \gamma\ln\text{MAT} + \gamma\ln\text{CAPL} \\ & + \gamma\ln\text{MATL} + \gamma\ln\text{AVCONET} + \gamma\ln\text{NET} + \gamma\ln\text{MSTR} + \gamma\ln\text{GRWO} + \gamma\ln\text{SOU} \\ & + \gamma\ln\text{SHOP} + \gamma\ln\text{LOSS} + \gamma\ln\text{INVO} + \omega\text{BREG} + \omega\text{BY} + \omega\text{BFU} + \omega\text{BOWN} \\ & + \omega\text{BSEW} + \epsilon \end{aligned} \quad (5.6.)$$

As due to public accounting standards the expenses for energy are part of the overall expenses for material, for the purpose of estimation either the latter (MAT) or the variable energy (E) were solely chosen. In (5.5.) the variable INVO10 were chosen to test for the state of technology in the form of volume and date of past investment. This is substituted by INVO in (5.6.) to test for the costs of capital investment in the same period. Further most of the control variables are indexed by total water output.

In addition, twice *differentiability* of f is commonly imposed for empirical work. The selection of the optimal input mix for some $\mathbf{y} \in \mathbf{Y}$ and some set of exogenous input prices \mathbf{r} further normally assumes cost minimizing behaviour. Cost minimization for all $\mathbf{r} \in \Omega_n^*$, where Ω_n^* is the strict positive orthant, and $\mathbf{y} \in \mathbf{Y}$ is described by the cost function $C(\mathbf{y}, \mathbf{r}) = \min \{\mathbf{r} \cdot \mathbf{v} : \mathbf{v} \in \mathbf{V}(\mathbf{y})\}$. If $\mathbf{V}(\mathbf{y})$ has the properties (1) through (4) then $C(\mathbf{y}, \mathbf{r})$ has the following properties:

- (5) *domain*: $C(\mathbf{y}, \mathbf{r})$ is a positive real-valued function defined for all positive prices \mathbf{r} and all positive producible outputs; $C(\mathbf{0}, \mathbf{r}) = 0$;
- (6) *monotonicity*: $C(\mathbf{y}, \mathbf{r})$ is a non-decreasing function in output and tends to infinity. It is also non-decreasing in price;
- (7) *continuity*: $C(\mathbf{y}, \mathbf{r})$ is continuous from below in \mathbf{y} and continuous in \mathbf{r} ;
- (8) *concavity*: $C(\mathbf{y}, \mathbf{r})$ is a concave function in \mathbf{r} ;
- (9) *homogeneity*: $C(\mathbf{y}, \mathbf{r})$ is linear homogeneous in \mathbf{r} .

Finally empirical applications usually assume in addition:

differentiability: $C(\mathbf{y}, \mathbf{r})$ is to be twice differentiable in \mathbf{r} and then $C(\mathbf{y}, \mathbf{r})$ possesses the derivative property (a) $dC / dr_i = v_i$ describing the ‘Shephard’s Lemma’ from which follows the ‘Symmetry’ of: $d^2C / dr_i dr_j = d^2C / dr_j dr_i$ resp. $dv_i / dr_j = dv_j / dr_i$.

¹⁷ Average Operational Costs (AVOC) are the average variable costs of water extraction, treatment, storage, transport and distribution (AVVC). The Average Total Costs (AVTC) are therefore the sum of average variable costs and average fix costs (AFC) of water production and provision expressed as average operational costs and average capital plus other costs as e.g. taxes and concession fees (AVRC). Hence: $\text{AVTC} = \text{AVVC} + \text{AFC} = \text{AVOC} + (\text{AVCAP} + \text{AVRC})$, and as AVRC are ignored due to lack of comparable data : $\text{AVTC} = \text{AVOC} + \text{AVCAP}$.

VI) Empirical Cost Frontiers

STEWART (1993)

By preparing a report for the UK office of water regulation (OFWAT) *Stewart* estimated a cost function for the UK water sector by focusing on operational costs. As explanatory variables he considered: the size of the distribution network, the volume of water sold, the volume of water put through the distribution network, the number of properties rented, the volume of water sold to non-residential users. Further the sources of raw water, the nature of demand (peak vs. average), the need for rehabilitation of pipes in poor state – are included:

<i>Dependent Variable</i>	-Total Operational Costs (COSTS)
<i>Explanatory Variables</i>	-Volume of Water Sold (SALES) -Length of the Network (NETWORK) -Volume of Water Sold on Average to Non-Residential Clients / Total Volume of Water Sold (STRUC) -Average Water Pumping Needed (PUMP)
<i>Sample</i>	Privatised Water Companies in the UK in 1992/93
<i>Frontier</i> (parenthesis = prob-values)	$LnCOSTS = 3.34 (0.39) + 0.57 (0.08) lnSALES + 0.38 (0.08) lnNETWORK - 0.62 (0.27) STRUC + 0.13 (0.06) lnPUMP$ ($R^2 = 0.99$)

PRICE (1993)

Another study prepared for OFWAT (PRICE, 1993) estimated the operational costs per unit of water distributed:

<i>Dependent Variable</i>	-Average Operational Costs (AVOPEX)
<i>Explanatory Variables</i>	-Proportion of Ground Water Subject to More Than Simple Disinfection and Derived from Treatment Generating less Than 25 Mill l/d (WSZ) -Share of Surface Water Subject to More Than Primary Treatment + Share of Ground Water Subject to More Than Disinfection only (TT) -Average Pumping / Water Delivered (PH) -Average Size of Wells * Water Delivered From Wells (BHSZ) -Share of Total Water Distributed to Non-Residential Users (MNHH) -Share Derived From Wells Only Subject to Disinfection (BHDIS)
<i>Sample</i>	UK Water Suppliers for the Period 1992/93
<i>Frontier</i>	$AVOPEX = 17.4 + 1.8 WSZ + 10.3 TT + 0.1 PH - 1.9 BHSZ - 12.1 MNHH + 21.4 BHDIS$ ($R^2 = 0.851$)

BHATTACHARYYA ET AL. (1995a)

Bhattacharayya et al. based their stochastic efficiency measurement on the estimation of a translog cost function for more than 200 urban water suppliers in the USA in 1992.¹⁸ The data for this study were originally collected by a survey of the water industry conducted by the American Water Works Association (AWWA) in 1992. The estimation of the cost frontier uses the total costs as dependent variable and energy, labour, capital, total production, system loss, net output, materials, surface source, combined surface and ground source as explanatory variables (see *appendix 3*). They reported a very good fit of the chosen model ($R^2_g = 0.99$).

CRAMPES ET AL (1997)

Crampes et. Al. estimated a water cost function for Brazil including among others the explanatory variables of volume of water produced, the relation between the volume of water billed and the volume of water produced and the number of connections per employee:

<i>Dependent Variable</i>	-Total Costs (COSTS)
<i>Explanatory Variables</i>	-Volume of Water Produced (PROD) -Operational Expenditure / Revenues (PROPI) -Average Salary (SALAR) -Number of Connections / Number of Employees (PROP2) -Number of Connections (CONE) -Volume of Water Billed / Volume of Water Produced (PROP3)
<i>Sample</i>	Brazilian Water Suppliers
<i>Frontier</i> (parenthesis = t-ratios)	$COSTS = 5.599 (8.36) + 0.380 (4.18) PROD - 0.01 (-10.0) PROPI$ $+ 0.590 (8.94) SALAR - 0.712 (-3.77) PROP2 + 0.689 (6.04) CONE$ $- 0.004 (-4.0) PROP3$ ($R^2 = 0.844$)

Further a additional average cost function was estimated including a additional explanatory variable:

<i>Dependent Variable</i>	-Average Costs (COSTAVER)
<i>Explanatory Variables</i>	-Volume of Water Produced (PROD) -Operational Expenditure / Revenues (PROPI) -Average Salary (SALAR) -Number of Connections / Number of Employees (PROP2) -Number of Connections (CONE) -Volume of Water Billed / Volume of Water Produced (PROP3) -Water Produced / Number of Connections (PROP4)
<i>Sample</i>	Brazilian Water Suppliers
<i>Frontier</i>	$COSTAVER = 13.954 (18.15) - 0.674 (-5.57) PROP4 - 0.01 (-10.0) PROPI +$

¹⁸ *Bhattacharayya et al.* estimated also a production frontier on 26 rural water suppliers of Nevada/USA in 1992. See *Bhattacharayya et al. (1995b)*.

(parenthesis = t-ratios)	$0.598 (8.67) SALAR - 0.907 (-5.85) PROP2 - 0.005 (-5.0) PROP3$ $(R^2 = 0.46)$
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CUBBIN ET AL (1998)

Cubbin et al. applied regression analysis on 1993/1994 data with respect to the regulated water industry in England and Wales. In this estimation operating costs were regressed on a number of potentially important explanatory variables and the final model were as follows:

<i>Dependent Variable</i>	-Total Operational Costs (OPEX)
<i>Explanatory Variables</i>	-Volume of Water Delivered (WDEL), -Length of Water Main (LEN), -Proportion of Distribution to Non-Households (PMNH)
<i>Sample</i>	29 Water Suppliers in England and Wales in 1993/1994
<i>Frontier</i> (parenthesis = t-ratios)	$LnCOST = 4.02 (10.54) + 0.67 (6.17) lnWDEL + 0.29 (2.67) lnLEN -$ $1.04 (-2.84) PMNH$ $(R^2 = 0.988)$

ESTACHE/ROSSI (1999)

Estache and Rossi estimated a cost function for 50 Asian water companies (in 1995) on the base of data published by the Asian Development Bank in 1997. These include data on operational and maintenance costs, number of clients, the daily water production, the population density in the area served, the number of connections, the percentage of water from surface sources, the treatment capacity, the market structure represented by the relation between residential sales and total sales, the number of hours where water is available, the number of employees and the salary. Further a set of qualitative variables with respect to the way of treatment are used (conventional, rapid sand filters, slow sand filters, chlorification, desalination).

The first function estimated by *Estache and Rossi* is similar to the ones estimated by *Stewart (1993)* and *Crampes et.al. (1997)* but includes certain control variables: GDP/capita and a quality indicator (number of hours where water is available). Further dummy variables were tested reflecting ownership and possible concessioning. The final model used to calculate the efficiency measures was:

<i>Dependent Variable</i>	-Total Operational and Maintenance Costs (COST)
<i>Explanatory Variables</i>	-Number of Clients (CLIEN) -Daily Production (PROD) -Population Density in the Area Served (DENS) -Number of Connections (CONE) -Percentage of Water from Surface Sources (ASUP) -Treatment Capacity (CAPAC) -Market Structure: Residential Sales / Total Sales (STRU) -Number of Hours of Water Availability (QUALI) -Staff (PERS) -Salary (SAL) -Conventional Treatment (DUMCONV) -Rapid Sand Filters (DUMFRAP) -Slow Sand Filters (DUMFLEN) -Chlorification (DUMCLO) -Desalination (DUMDES) -Ownership (DUMPUB) -Concession (DUMCON)
<i>Sample</i>	50 Asian Water Suppliers in 1995
<i>Frontier</i> <i>(parenthesis = prob-values)</i>	$LnCOST = -0.56 (0.91) + 0.43 (0.05) lnSALAR + 0.72 (0.08) lnCLIEN - 0.19 (0.08) lnDENS + 0.32 (0.05) lnCONE - 0.56 (0.19) lnSTRU + 0.32 (0.16) lnQUALI - 0.82 (0.47) DUMCON$ $(R^2 = 0.947)$

ESTACHE/ROSSI (2002)

Estache and Rossi conducted further a cost efficiency frontier in order to determine the effect of ownership on the supplier's efficiency. This concluded in the following frontier estimation:

<i>Dependent Variable</i>	-Total Operational Costs (COST)
<i>Explanatory Variables</i>	-Salary (SALAR) -Number of Clients (CLIEN) -Number of Connections (CONE) -Daily Production (PROD) -Population Density in the Area Served (DENS) -Percentage of Water from Surface Sources (ASUP) -Number of Hours of Water Availability (QUALI) -Proportion of Metered Clients (METER) -Desalination (DUMDES) -Chlorification (DUMCLO) -Concession (DUMCON) -Administration (DUMBC) -Private Sector Participation (DUMOP)
<i>Sample</i>	50 Asian Water Suppliers in 1995
<i>Frontier</i> <i>(parenthesis = prob-values)</i>	$LnCOST = 0.49 (0.53) + 0.29 (6.06) lnSALAR + 0.67 (3.63) lnCLIEN + 0.27 (3.95) lnCONE + 0.08 (0.45) lnPROD - 0.14 (-1.65) lnDENS + 0.12 (0.46) ASUP + 0.03 (1.99) QUALI + 0.32 (1.51) METER + 0.58 (0.81) DUMDES + 0.21 (1.01) DUMCLO + 0.01 (0.01) DUMCON + 0.09 (-0.49) DUMBC + 0.19 (1.01) DUMOP$ $(R^2 = ?)$

VII) First Empirical Results – Cost Efficiency and Public Funding

After this brief review of the ‘history of cost efficiency studies on water suppliers’, first preliminary estimation results for the generated sample of water suppliers in rural areas of Germany are reported:

7.1. Summary Statistics

The data set used was collected by a written survey of 59 rural water supplying firms in East and West Germany for the year 2001 (or 2000 if data on 2001 was not available). The rural water suppliers differ considerably in size, composition and service diversity, but can be regarded as similar with respect to water-input accessibility, ownership (only a few show private ownership participation) and the form of energy (mostly electricity) used. *Table 4* reports the descriptive statistics of the key variables used.

7.2. Sample Pooling

As the data set is a cross sectional one consisting of technical and financial data on the firm level for the year 2000 ($n=16$) or 2001 ($n=43$), the pooling of the data sets (i.e. using the data as one sample) has to be tested for by determining the significance of a binary dummy variable (BY : 0 for 2000, 1 for 2001) with respect to the dependent variable(s) operational costs ($\ln AVOC$) or total costs ($\ln TC$). This was done by including the binary variable BY in the estimated multiple regression models (see 7.3.) as well as correlation analysis showing the following results:

Table 4: ‘Testing the Significance of BY ’

Dependent Variable	$P T > t$	$\rho_{BY, C}$	N
$\ln AVOC$	0.6257	-0.1386	45
$\ln TC$	0.5503	-0.4485	37

As can be seen from *table 4* the variable BY is not significant at the 50%-level of significance ($P|T|>t$) with respect to average operational costs as well as total costs. The coefficient of correlation ($\rho_{BY, C}$) shows a relatively low correlation between costs and the year of data recording. This suggests that the two data sets (2000 and 2001) can be pooled into one cross-sectional data set for the subsequent analysis.

Table 5: ‘Summary Statistics of the Key Variables’

Variable / Ratio	Unit	Sample Size (n)	Mean	Std. Deviation	Minimum	Maximum
PL	EURO / FTE	37	24840	16074	511	49675
L	FTE	38	27,58	65,21	0,35	391
PE	EURO / kWh	28	0,088	0,031	0,050	0,186
E	kWh	30	752186	1131018	0	4180993
MAT	EURO	42	768871	2298131	1278	14532947
CAP	EURO	37	16561396	38119327	10832	223291813
OUT	m ³	58	1094907	2720745	2000	19655000
REV	EURO	44	2597788	7199126	10226	46574089
OUTHH	m ³	39	944282	2005064	2000	11594000
OUTIND	m ³	37	222219	686125	0	3984000
IN	m ³	57	1715429	4596186	2000	25236000
GRWO	m ³	56	804009	1226156	0	5325000
SOU	m ³	56	36510	73637	0	332000
SHOP	%	56	93,8	16,6	15,5	100
CON	'000	45	6,4	15,9	0,002	102,7
CUST	n	57	35901	167355	6	1265000
NET	km	51	257,80	533,81	0,35	3545,00
INVO	EURO / m ³	46	0,895	1,453	0	7,158
INVO05	EURO / m ³	23	3,162	2,816	0	9,487
INVO10	EURO / m ³	23	10,093	17,970	0	80,847
ENL	kWh / FTE	26	44208	35457	0	120881
MATL	EURO / FTE	36	29827	42092	426	254635
CAPL	EURO / FTE	32	630288	565114	6391	2343672
AVE	kWh / m ³	28	0,723	0,316	0,069	1,221
AVL	FTE / '000 m ³	38	0,0257	0,0364	0,00023	0,2000
AVCAP	EURO / m ³	37	8,36	6,90	0,06	26,56
OUTL	m ³ / FTE	38	187400	695601	5000	4352137
OUTCAP	m ³ / EURO	38	1,742	7,057	0,061	43,666
AVREV	EURO / m ³	44	1,318	0,695	0,081	2,893
AVINO	%	56	113,9	23,8	77,5	204,6
AVGRWO	%	56	72,2	49,2	0	133,9
AVLNET	FTE / km	34	0,1384	0,3358	0,0017	2,0000
AVNETO	km / '000 m ³	50	0,3006	0,1816	0,0902	0,8468
AVCONET	Consumer / km	50	329,22	1760,61	0,11	12524,75
MSTR	%	37	12,76	21,80	0	85,30
LOSS	%	56	89,24	13,02	48,87	100
BREG	1 = East 0 = West	15 44				
BYEAR	1 = 2001 0 = 2000	43 16				
BFU	1 = Funding 0 = No Funding	13 28				
BOWN	1 = Cooperative Forms 0 = Other Forms	22 32				
BSEW	1 = Sewerage Services 0 = No Sewerage Services	22 34				
Total Number of Rural Water Suppliers		59				

7.3. OLS – Analysis

Prior to the estimation of a efficiency frontier ordinary least square models were estimated to test for the significance of the selected variables and ratios with respect to the costs of rural water production and provision. This was done by following the so-called ‘general-to-specific’ econometric methodology (see e.g. GRUBER 1997). It was started by regressing the models (5.5.) and (5.6.). By dropping the statistically insignificant variables¹⁹ and ensuring that the model passed a number of diagnostic tests on functional form, normality and heteroscedasticity the following specifications were finally chosen:²⁰

Model CD I:

$$\begin{aligned} \ln AVOC = & 1.05_{(1.16)} + 1.01_{(0.07)} \ln AVCAP - 0.82_{(0.11)} \ln CAPL + 0.69_{(0.09)} \ln MATL \\ & - 0.02_{(0.006)} \ln SOU + 0.13_{(0.05)} \ln NET - 0.43_{(0.12)} BOWN \end{aligned} \quad (7.1.)$$

To test for the assumed Cobb Douglas specification ($\ln(y) = \ln(X)' \beta$) the linear restriction ($\sum_k \beta_k = 1$) for constant returns to scale (homogeneity of degree 1) (5.6.) was further imposed on model *CD I*.²¹

$$\gamma_{\ln AVCAP} + \gamma_{\ln CAPL} + \gamma_{\ln MATL} + \gamma_{\ln SOU} + \gamma_{\ln NET} + \omega_{BOWN} = 1 \quad (7.2.)$$

The model statistics²² are given in *table 6*. As the F-statistic for the model fit indicates, the model seems to be well specified. The assumption of a CD-production function for the sample of rural water suppliers is further justified by the F-statistic for imposing the linear restriction of constant returns to scale. The Durbin-Watson statistic states no autocorrelation at the level of 1%-significance, all explanatory variables are significant at the 1%-level of significance.

The signs of the coefficients for the explanatory variables are those expected by theory, except for the ratio *MATL* (material used per labour). As *MAT* contains expenses for all kinds of materials with respect to extraction, treatment, storage, transport and distribution (including energy) no clear theoretical deductions can be made so far. The ratio *AVCAP* (capital per water output) shows a positive influence on average operational costs. Capital intensity is estimated by *CAPL* (capital per labour): the higher the capital intensity the lower the costs of

¹⁹ Oriented at keeping sufficient degrees of freedom, the least significant variable (any variable with a less than 10%-level of significance) were eliminated and reintroduced at the next stage to ensure that it is still insignificant (otherwise it was kept in the model).

²⁰ Asymptotic standard errors are in parentheses. The given coefficients can be interpreted as the elasticity of average operational costs with respect to the specific input or control variable.

²¹ A BoxCox test on functional form is further planned to be applied.

²² For the descriptive statistics for the variables in ln-fom see *appendix 4*.

water production. This is in line with the observation that the water industry – especially in rural areas – is subject to a relatively high capital intensity with respect to water treatment and transport as well as distribution. The negative significance of the ratio *SOU* (as the share of spring water with respect to water input) should be subject to the comparatively low costs of extracting such water. As the natural slope can be used in most cases water pumping is not required reducing the costs share for energy and materials. The larger the distance the water has to be pumped as a consequence of a low consumer density (number of consumers per km net) the higher the operational costs. This is shown by the positive coefficient of the variable *NET*. The binary variabel *BOWN* (1 for cooperative and 0 for other forms of ownership) is significant with a negative coefficient indicating a cost decreasing influence of the cooperative form of ownership. As water suppliers run by such cooperative forms produce and provide mostly a relatively high volume of water output, this should be also due to economies of scale (see 7.4.)

Other variables as *MSTR* for the market structure (relatively few industrial customers in rural areas), *LOSS* for the share of lost water during transport and distribution (relatively low level of water loss in Germany due to high technical standard of transport and distribution net) and *GRW* for the share of groundwater intake with respect to water input (the effect of this variable is obviously included in the coefficient of the variable *SOU*) were not significant at the 10%-level.

Table 6: 'OLS Model CD I Statistics'

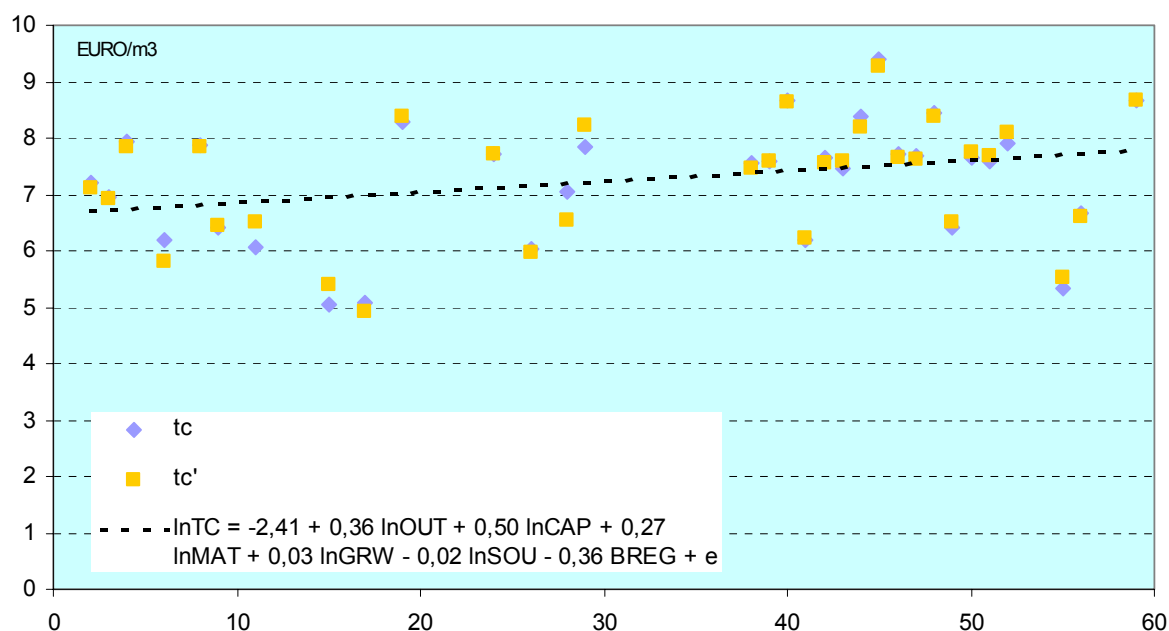
Explanatory Variable x	t - Ratio	P T > t	$\rho_{x,y}$
Constant	0.906	0.3764	-
lnAVCAP	14.090	0.0000	0.6819
lnCAPL	-7.430	0.0000	0.1347
lnMATL	7.836	0.0000	-0.0678
lnSOU	-3.848	0.0011	-0.4170
lnNET	2.892	0.0093	0.4699
BOWN	-3.519	0.0023	0.2649
<hr/>			
N	26		
DoF	19		
R ²	0,95		
F-statistic	54.83	0.0000	
<hr/>			
Log-L	-33.58		
DW-statistic	1.53		
<hr/>			
Restriction:			
	$b(2) + b(3) + b(4) + b(5) + b(6) + b(7) = 1$		
F-statistic	11.12	0.0035	

Model CD II:²³

$$\begin{aligned} \ln TC = & -2.41_{(1.03)} + 0.36_{(0.14)} \ln OUT + 0.50_{(0.08)} \ln CAP + 0.27_{(0.11)} \ln MAT \\ & + 0.03_{(0.01)} \ln GRW - 0.02_{(0.009)} \ln SOU - 0.36_{(0.22)} BREG \end{aligned} \quad (7.3.)$$

Table 7 reports the essential statistics with respect to model CD II (see 5.9.) Here the linear restriction of $(\sum_k \beta_k = 1)$ for constant returns to scale (homogeneity of degree 1) was rejected at the 5%-level of significance. A significant model fit is indicated by the F-statistic, the Durbin-Watson statistic states no autocorrelation at the level of 5%-significance, with exception of the binary variable BREG all explanatory variables are significant at the 5%-level of significance. The estimated elasticities are again consistent with theory in sign, other tested variables and ratios were not significant at the 10%-level.

Figure 7: 'Model CD II – Observations and Predictions'



The negative coefficient of the dummy variable BREG (0 for a location of the I-th rural supplier in the West, 1 for a location in the East) indicates lower total costs of water production and provision for water suppliers in rural areas of East Germany. This is somewhat surprising with respect to commonly held perceptions in the financial and political sector that water supplying firms in the new 'Länder' are comparatively less efficient due to lacking technology and management expertise. But as indicated by the (preliminary) results of the

²³ Asymptotic standard errors are in parentheses. The given coefficients can be interpreted as the elasticity of average operational costs with respect to the specific input or control variable.

stochastic frontier analysis (see 7.5.) relatively low total costs are necessary but not sufficient for efficiency on the firm level.

Table 7: ‘OLS Model CD II – Statistics’

Explanatory Variable x	t - Ratio	P T > t	$\rho_{x,y}$
Constant	-2.344	0.0273	-
lnOUT	2.675	0.0130	0.9190
lnCAP	6.132	0.0000	0.9158
lnMAT	2.427	0.0228	0.9338
lnGRW	2.519	0.0186	0.6372
lnSOU	-2.447	0.0218	-0.3672
BREG	-1.681	0.1051	0.5587
N	32		
DoF	25		
R ²	0,97		
F-statistic	124.13	0.0000	
Log-L	-68.55		
DW-statistic	1.88		
Restriction:			
	$b(2) + b(3) + b(4) + b(5) + b(6) + b(7) = 1$		
F-statistic	1.14	0.2951	

By an additional OLS model the effect of the variable INVO10 (invested EURO in the last 10 years) on average variable costs for a small subsample of 11 rural suppliers was tested showing a significance at the 1%-level (see *appendix 5*). However, the positive sign of the coefficient is somewhat surprising as one would expect due to a high volume of investment a high standard of technology and therefore significant input savings and finally low average variable costs of water production and provision. This could probably be due to the small sample size (only 5 degrees of freedom) but nevertheless further technical expertise on this question has to be collected.

7.4. Economies of Scale and Subadditivity

Most studies on the estimation of a water supply cost function agree on the existence of economies of scale in water supply (see e.g. KIM ET AL. 1988, BHATTACHARAYYA ET AL. 1995a). But there is considerable disagreement among economists with respect to the range over which such economies exist. Engineerial studies on the other side point to practically unexhausted economies in water treatment. Plant size with respect to extraction and treatment might nevertheless be limited by diseconomies in transport and distribution: “The problem then involves a tradeoff of scale economies in production versus diseconomies in distribution, which affects the choice of the optimal size, location, and distribution patterns of one or more plants.” (KIM ET AL. 1988, p. 480). This points to highly relevant policy implications with respect to the ongoing discussion about market liberalisation and the linked matters of determining an optimal service area as well as an optimal firm size and organisation (see also SAUER 2003b).

Economies of scale reflect the properties of the underlying production technology.²⁴ Increasing (decreasing) economies of scale imply decreasing (increasing) average costs. Nevertheless economies of scale can vary with respect to different quantities of output. BAUMOL ET AL. (1982) define the measure of overall (or production stage specific) scale economies $S(q)$ as the ratio of average to marginal costs and as a local property of the cost function:

$$S(q) = AC(q) / C'(q) \quad (7.4.)$$

with: $S(q) < 1$ indicating decreasing, $S(q) = 1$ constant and $S(q) > 1$ increasing scale economies.

This local measure can also be defined as the scale elasticity of cost:

$$S(q) = 1 / \epsilon_{CY} \quad (7.5.)$$

The local scale economies at the sample mean and the average of the individual suppliers’ local scale economies²⁵ on the base of total costs (tc) as well as variable costs (vc) are shown in *table 8*:

²⁴ Economies of scale in the water industry are mainly due to the comparatively high fix (and to a large extent sunk) costs of the transport and distribution net (about 65% in 2000, see SAUER 2003). Further due to technological and stochastic effects.

²⁵ The measurement at the suppliers’ level delivered mixed results with respect to the existence of economies of scale (total cost basis): 9 rural suppliers showed diseconomies, 21 showed economies of scale. Only one firm seems to produce with constant returns to scale.

Table 8: 'Overall Scale Economies'

Estimates of Overall Scale Economies			
	average water supplied ('000 m3)	overall scale elasticity	N
sample mean	1282.95	1.289	31
utility average (tc)	1282.95	1.768	31
utility average (vc)	1369.23	1.071	45

As other infrastructure sectors water industry – the overall production process or at least individual production stages as e.g. water distribution – is regarded as a natural monopoly. An industry can be characterised as such if I cost function $C (\bullet)$ is sub-additive with respect to the relevant output quantity (see e.g. BAUMOL ET AL. 1982, FRITSCH ET AL. 2001):

$$C (\sum_{i=1}^n q_i) < \sum_{i=1}^n C (q_i) \tag{7.6.}$$

with: $q_i > 0, I = 1, \dots, n$ as the output quantity of a homogenous product (see BAUMOL, 1982, p. 170).

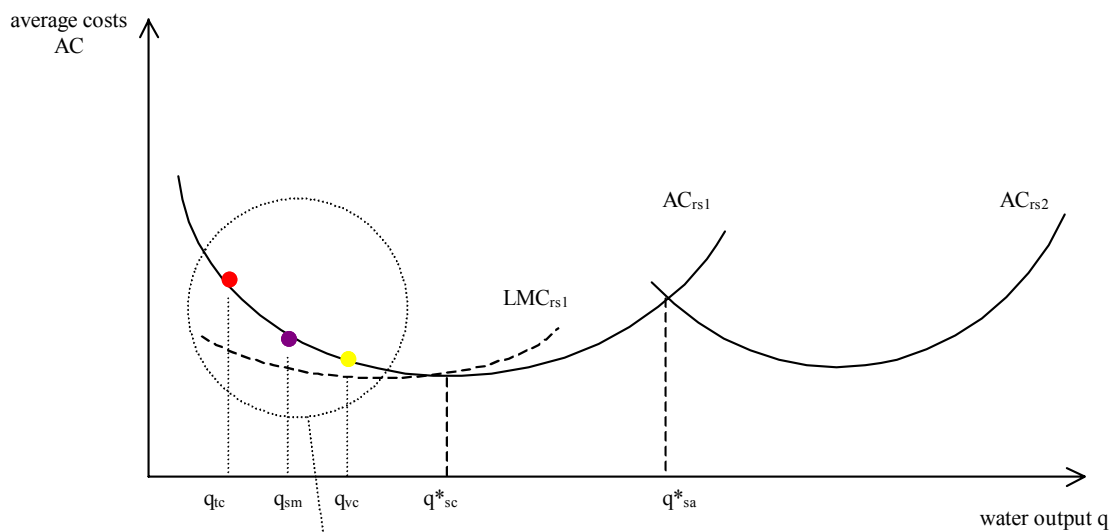
Hence the production of the quantity q_i of water by n suppliers results in higher costs than the production of q_i by only one water supplier. Further with respect to a single product industry²⁶ decreasing average costs (and therefore decreasing economies of scale) are regarded as sufficient – but not necessary as TIROLE 1988 showed (see also PANZAR 1989 or TAKAYAMA 1994) – for subadditivity. Furthermore a water supplier can show increasing average costs (and therefore increasing economies of scale) over a certain range of I cost curve. Bringing this piece of economic theory together with the preceeding findings of increasing economies of scale for the rural water industry the following conclusions can be drawn:

As *figure 8* shows, a rural water supplier rws_1 produces on the average cost curve AC_{rws1} . I average costs decrease till the quantity q^*_{SC} is reached (coming from the left side). Due to the definition of a natural monopoly oriented at scale economies this is the optimal supplier size, the range on the left side of the AC-curve up to q^*_{SC} is therefore considered as being characteristic for a natural monopoly. At q^*_{SA} the condition of decreasing average costs is not fulfilled, but nevertheless up to this point the monopolist enjoys lower costs of production than a second producer producing on AC_{rws2} . Hence due to the concept of subadditivity a natural monopoly can also produce on this range of AC_{rws1} . Thus in the range from q^*_{SC} up to

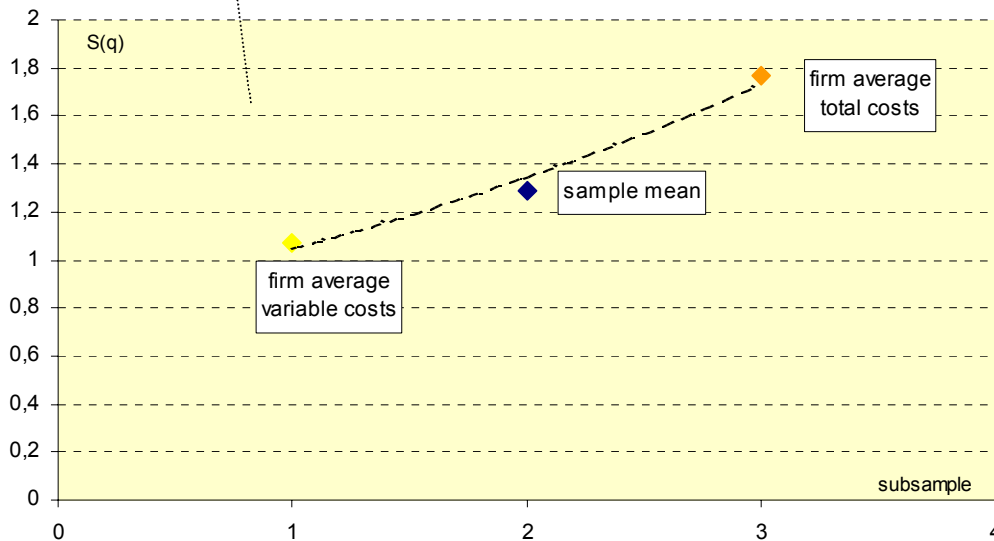
²⁶ For the sake of simplicity this is assumed for the water industry.

q^*_{SA} economies of scale decrease and according to the measured overall scale elasticity a rural water supplier at the sample mean produces at the velvet point (q_{sm}) on AC_{rws1} . Measured at the basis of total costs (resp. variable costs) the average of the suppliers produce at q_{tc} (red point) resp. q_{vc} (yellow point). Finally the average rural water supplier would enjoy cost advantages and efficiency gains by expanding the output quantity up to q^*_{SA} . Producing at the right range of q^*_{SA} would mean increasing average costs and finally diseconomies of scale.

Figure 8: 'Subadditivity, Scale Economies and Rural Water Supply'



Overall Scale Economies



with AC_{rsi} as the average costs for the i -th rural water supplier, LMC_{rs1} as the long-run marginal costs of rural supplier 1, q^*_{sc} as the optimal quantity of water output due to economies of scale considerations, q^*_{sa} as the optimal quantity of water output due to subadditivity considerations, q_{sm} as the quantity of water output with respect to the sample mean, q_{tc} as the quantity of water output with respect to the average rural water supplier (total cost basis) and q_{vc} as the quantity of water output with respect to the average rural water supplier (variable cost basis).

This points finally to the following policy implications: As BAUMOL ET AL. (1982) note, the simultaneous existence of overall economies of scale and economies of scope can be regarded as being sufficient for the empirical ‘guarantee’ of natural monopoly.²⁷ The preceding analysis showed overall scale economies for a sample of rural water suppliers.²⁸ Nevertheless adequate data is lacking to test for economies of scope (see SAUER 2003b). Hence a final empirical judgement whether the political treatment of water suppliers in rural areas as natural monopolies²⁹ is justified or not can not be made at this stage.

It can be concluded from the preceding analysis that additional efficiency gains are realised by increasing the output of rural water suppliers (with respect to customers and produced water). This would be in line with the reported negative effect of the cooperative form of ownership (Zweckverband, Wasserbeschaffungsverband) on average variable costs. As rural water suppliers organised in this way usually supply a larger total amount of water and customers compared to other forms of ownership, these findings recommend the expansion of the existing – and legally guaranteed (see ‘kommunale Selbstverwaltung’, ‘kommunales Örtlichkeitsprinzip’) – supplying areas.³⁰ Even if economies of scope could be empirically verified, it seems to be unrealistic that the individual supplying area prescribed by legal considerations is congruent with the most efficient one derived by economic analysis.

²⁷ Others regard the existence of economies of scale as sufficient for a natural monopoly (see e.g. BÜHLER ET AL. 2002).

²⁸ These findings are contradictionary to earlier ones showing constant returns to scale for most of the utilities (see e.g. KIM ET AL. 1988). However, no such investigations exist with respect to rural water suppliers in Europe producing far less water output and supplying far less customers than their complements in the USA as well as municipal utilities.

²⁹ Legally guaranteed by the classification as ‘kartellrechtlicher Ausnahmbereich’ (§§103) and the ‘Preisaufsicht der Länder’.

³⁰ By taking into account the basic hydrological settings of the rural area.

7.5. Stochastic Frontier Analysis – First Efficiency Measures

As one result of a study tour to Germany by water and sewerage professionals of the World Bank in 1995 the chief of the water and sanitation division *Briscoe* noted that there is no incentive as well as study for German water suppliers to compare their cost efficiency with the ‘international frontier’ of water supplying firms (see BRISCOE 1995). Due to severe problems of data collection as well as data validity (e.g. with respect to different national financial accounting standards) the accurate estimation of such a efficiency frontier seems to be largely unrealistic at present state of national and international statistics. As no such frontier estimation for the German (urban as well as rural) water sector was done so far this study on the efficiency of rural water suppliers aims to shed some empirical light on the technical and financial situation of the German water sector. Beside the use for the national sector as well as for policy makers in transition countries the results are at least a first step to include German suppliers’ efficiency in a international comparative perspective.

Based on the estimated OLS models³¹ (see 7.3.) and the (in-)significance of the selected variables and ratios and by applying the described methodology of ‘general-to-specific’ the (preliminary³²) maximum likelihood estimates of the stochastic frontier cost function are reported by *table 8*. For the average operational cost model (*CD I*) 27 observations, for the average total cost model (*CD II*) 31 observations could be used. The estimates of the half-normal specifications differ not dramatically from those of the truncated-normal model specification. $E(u)$ takes the values 0,2116 and 0,1417 for the regression on $\ln AVOC$ and 0,4554 and 0,3844 for the regression on $\ln AVTC$. The estimation results for the individual rural water supplier are given in *table 9*.

³¹ As mentioned in (5.5.) the testing of a translog cost function requires a relatively large data set to maintain adequate degrees of freedom as a consequence of the inclusion of the second-order and cross terms. As in the case of the OLS-models the following frontier model(s) are therefore based on the specification of a Cobb-Douglas functional form.

³² The following estimates and efficiency measures are first results as they have to be critically discussed internally.

Table 9: 'MLE Estimates SF Cost Functions'

MODEL CD I				
Dependent Variable		lnAVOC		
Observations		27		
	<i>Half-Normal Model</i>		<i>Truncated-Normal Model</i>	
Variable	Coefficient	SE	Coefficient	SE
Constant	-0,4835	2,1377	-0,4369	2,3633
lnAVCAP	0,9934	0,1186	1,0000	0,1227
lnCAPL	-0,8059	0,1603	-0,8143	0,1666
lnMATL	0,6727	0,1447	0,6787	0,1444
lnSOU	-0,1735	0,0073	-0,0170	0,0073
lnAVNETO	-0,2380	0,1632	-0,2393	0,1621
λ	1,3289	1,0393	1,4234	2,2452
σ	0,3329	0,1293	0,3588	0,5596
σ_u	0,0707		0,0862	
σ_v	0,0401		0,0425	
E(u)	0,2116		0,1417	

MODEL CD II				
Dependent Variable		lnAVC		
Observations		31		
	<i>Half-Normal Model</i>		<i>Truncated-Normal Model</i>	
Variable	Coefficient	SE	Coefficient	SE
Constant	-1,1585	0,7935	-0,8988	1,3412
lnAVCAP	0,4107	0,1834	0,3878	0,1735
lnAVMAT	0,3589	0,1117	0,4268	0,1919
lnAVGRWO	0,0392	0,0158	0,0370	0,0163
lnNET	0,1597	0,1083	0,1397	0,1047
λ	1,5518	0,9321	2,7394 ^a	26,6299 ^a
σ	0,6876	0,2024	1,0599 ^a	9,6563 ^a
σ_u	0,3340		0,9913	
σ_v	0,1387		0,1321	
E(u)	0,4554		0,3844	

(^a : this estimation was subject to abnormal iteration exit)

Table 10: 'Estimated Technical (Cost) Efficiency'

rws no.	SF MODEL CD I AVOC		SF MODEL CD II AVTC	
	h-n	t-n	h-n	t-n
2	0,9193	0,9392	0,6992	0,7553
3	0,8146	0,8765	0,7427	0,8095
4	0,7326	0,8175	0,6516	0,7117
6	0,7759	0,8520	0,4851	0,5764
8	0,8642	0,9055	0,5177	0,5721
9	0,9277	0,9442	0,6527	0,7235
11	0,8188	0,8779	0,8738	0,8964
15	-	-	0,8178	0,8566
17	0,7929	0,8598	0,6112	0,6695
19	0,8781	0,9144	0,7690	0,8104
24	0,8726	0,9113	0,5732	0,6312
26	-	-	0,6050	0,6604
28	-	-	0,2744	0,2220
29	-	-	0,8542	0,8827
32	0,8110	0,8744	-	-
38	0,8020	0,8671	0,6715	0,7354
39	-	-	0,6324	0,6954
40	0,8468	0,8965	0,7052	0,7672
41	0,8736	0,9118	0,7507	0,7989
42	0,9027	0,9294	0,7433	0,8052
43	0,8496	0,8968	0,6298	0,6872
44	0,7756	0,8518	0,6081	0,6785
45	0,6619	0,7596	0,7682	0,8179
46	0,8695	0,9100	0,5598	0,6441
47	0,8364	0,8902	0,5746	0,6551
48	0,8804	0,9159	0,6506	0,7109
49	0,8427	0,8910	0,7267	0,7811
50	0,8245	0,8822	0,6462	0,7132
51	0,7042	0,7930	0,7248	0,6921
52	0,5673	0,6511	0,7248	0,7684
55	0,7814	0,8523	0,7712	0,8162
59	0,7390	0,8237	0,2771	0,2708
Average TE	0,8135	0,8702	0,6546	0,7037
Maximum TE	0,9277	0,9442	0,8738	0,8964
Minimum TE	0,5673	0,6511	0,2744	0,2220

('AVOC' : average operational costs

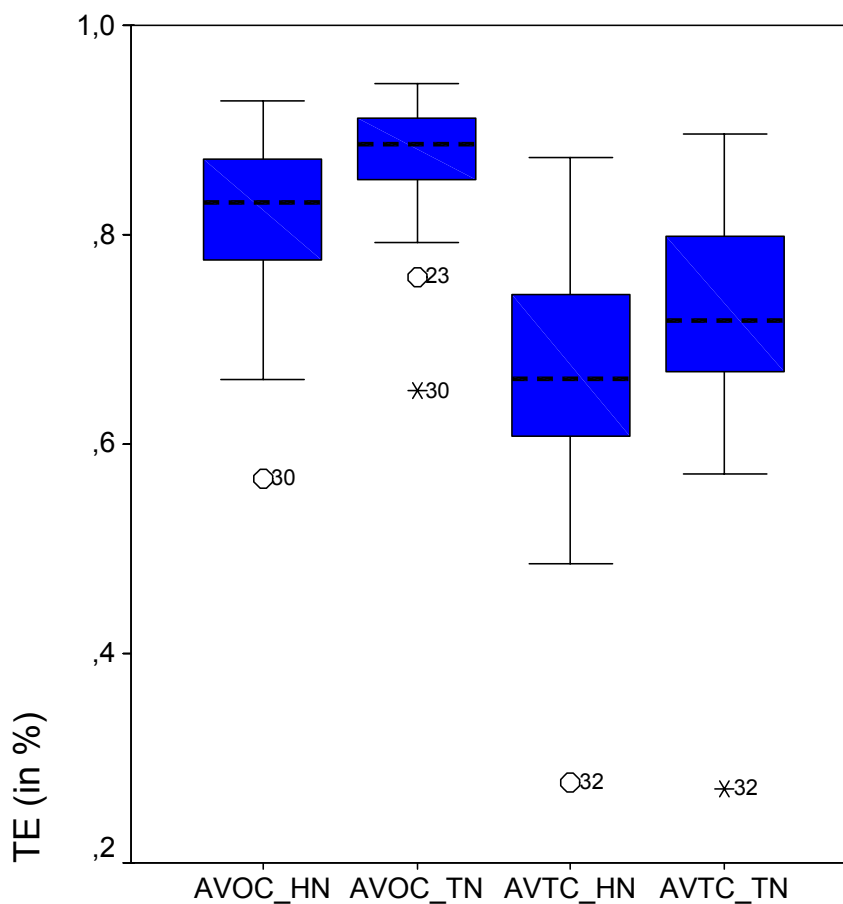
'AVTC' : average total costs)

('-' : no data available)

As can be seen from *table 10* the cost efficiency of rural water suppliers in Germany with respect to operational costs for the year 2000/2001 varied between 57 and 94 %. This means

that (*ceteris paribus*³³) the average supplier could produce the same output (produced water or supplied customers) with up to 19 % less operational costs. The cost efficiency with respect to total costs varied between 22 and 89 %. Here the average supplier (*ceteris paribus*) could produce the same output with up to 35 % less total costs. Thus improving technical efficiency with respect to costs will result in significant suppliers' profit gains which can be finally result in gains for the consumer via decreasing water prices. These results are illustrated by *figure 9*:

Figure 9: 'Average Deviation of Technical Cost Efficiency'



with the blue boxes indicating the estimated efficiency values between the 25% and 75% - quartiles with the median as the dotted line, the thin lines indicate the 95%-interval and O marks an outlier³⁴ and * an extreme value³⁵ of the sample. *AVOC* and *AVTC* denote average operational costs and average total costs as the dependent variables, *hn* resp. *tn* denote the applied frontier assumptions of a half-normal or truncated-normal distribution.

³³ Holding constant the parameters for the state of technology and input use as well as environmental control variables.

³⁴ Cases with values between 1.5 and 3 box lengths from the upper or lower edge of the box. The box length is the interquartile range.

³⁵ Cases with values more than 3 box lengths from the upper or lower edge of the box.

The variance of the inefficiency results ranges with respect to the different models between 0,01 and 0,08 whereas the suppliers’ inefficiency scores for total costs vary to a larger extent. *Table 11* gives a statistical overview of the results of efficiency frontier studies for water supplying firms in different countries (see also *VI*):

Table 11: ‘Relative Cost Efficiency of Water Suppliers in Different Countries’

Study			Efficiency Estimates					
Country (level)	Author, Year	Indep. Variable	Mean	SD	Variance	Min	Max	N
USA (urban)	<i>Bhattacharayya et al., 1995</i>	Variable Costs	0,8895	0,1727	0,0281 ^a	0,4308 ^a	0,9844 ^a	221
UK (regional)	<i>Cubbin et al., 1998</i>	Variable Costs	0,7780	0,1040	0,0108	0,5720	1,0000	29
Asia (urban, rural)	<i>Estache et al., 1999</i>	Total Costs	0,6393	0,2467	0,0609	0,1500	1,0000	44
Germany (rural)	<i>Sauer, 2003</i>	Variable Costs	0,8135	0,0793	0,0063	0,5673	0,9277	27
		Total Costs	0,6546	0,1348	0,0182	0,2744	0,8738	31

(^a: calculated on the basis of sub-samples averages)

There is no relevance in comparing the individual as well as minimum, maximum and mean efficiency estimates of the different studies due to unsystematic data (e.g. different national accounting standards) and measurement errors as well as applied explanatory variables in the individual estimation. On the other side by comparing the different values for variances of the samples it became clear that the variation of technical efficiency on the firm level with respect to variable costs is the lowest for the German sample which could be due to different factors (see second stage regression on inefficiency estimates). With respect to total costs the computed variance for the German rural suppliers is lower than that for the Asian sample of urban and rural water suppliers. This is exactly what would be expected as the Asian sample makes no differences with respect to different national settings (e.g. by testing explanatory variables for regional location or national resp. sub-national per capita income).

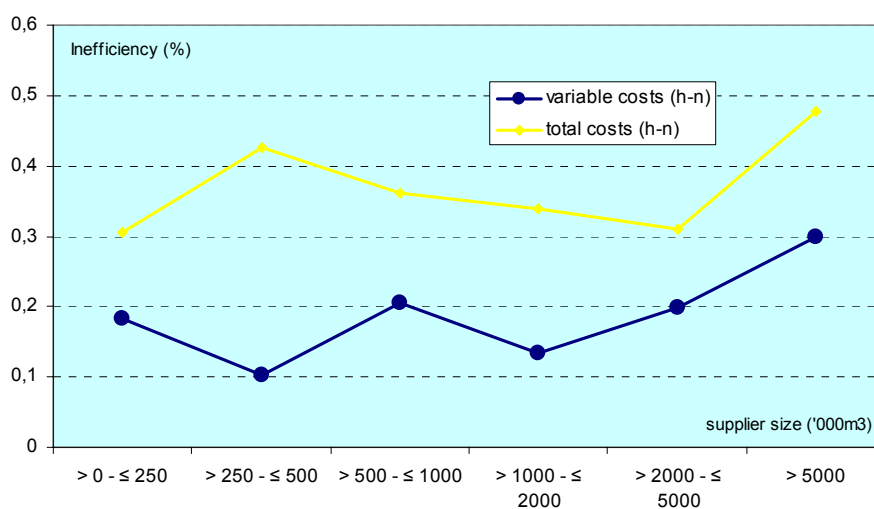
Comparing the mean cost inefficiency for different firm sizes (measured by average output per year) *table 12* shows, that cost-minimizing behaviour of the supplier’s management is not related to the size of the supplier, which is further illustrated by *figure 10*. The correlation coefficients of water output and inefficiency in the individual categories show for variable cost inefficiency values between – 1,00 - + 1,00 and for total cost inefficiency values between – 1,00 - + 0,59. It can be concluded that there is negative correlation between total cost inefficiency and firm size (output oriented). This effect should be due to the high investment costs of the transport and distribution net: as water output increases, average total costs

decreases. On the other side with respect to variable cost inefficiency a clear negative correlation between inefficiency and firm size exists for the sample up to a size of about 2 Mio. m³ water output.

Table 12: 'Mean Cost-Inefficiency and Average Firm Size'

total output per supplied person ('000m3)	no. of firms	cost of inefficiency	$\rho_{x,y}$
variable costs (h-n)			
> 0 - ≤ 250	7	0,1825	-0,1386
> 250 - ≤ 500	2	0,1035	-1,0000
> 500 - ≤ 1000	6	0,2051	-0,3255
> 1000 - ≤ 2000	4	0,1331	-0,5352
> 2000 - ≤ 5000	6	0,1979	0,0065
> 5000	2	0,2996	1,0000
total costs (h-n)			
> 0 - ≤ 250	8	0,3051	-0,5163
> 250 - ≤ 500	3	0,4252	-0,5733
> 500 - ≤ 1000	6	0,3619	0,5986
> 1000 - ≤ 2000	5	0,3389	-0,9162
> 2000 - ≤ 5000	7	0,3100	-0,1461
> 5000	2	0,4773	-1,0000

Figure 10: 'Cost-Inefficiency and Firm Size'



7.6. Efficiency Rankings and Consistency

By the following section the efficiency ranking by the frontier estimation is compared with those obtained from the partial productivity indicators in *chapter III*. If the two measurement approaches are consistent, the efficiency results must show a positive correlation (see also BAUER ET AL. 1998, ESTACHE ET AL. 1999). For the comparison of rankings the indicators *labour productivity* (see *figure 2*), *capital productivity* (see *figure 3*), *net productivity* (see *figure A2*) and the IWA indicator *labour per net* (see *figure 1*) are selected. *Table 12* summarizes the different rankings (see also *figure 11*):

Table 13: 'Efficiency Rankings'

supplier no.	ranking					
	cf total costs	cf variable costs	pi labour productivity	pi capital productivity	pi net productivity	IWA labour per net
2	13	2	6	23	27	5
3	7	16	18	24	29	9
4	17	24	23	27	22	-
6	29	21	14	13	19	12
8	28	9	5	15	20	6
9	16	1	27	20	26	23
11	1	15	1	21	23	-
15	3	-	16	3	8	21
17	23	19	3	2	30	4
19	6	5	26	28	28	15
24	26	7	24	19	25	16
26	24	-	-	8	31	-
28	31	-	10	11	21	10
29	2	-	13	16	16	-
32	-	17	25	-	24	-
38	15	18	4	12	15	2
39	20	-	-	5	17	-
40	12	11	22	17	10	22
41	8	6	9	1	13	1
42	9	3	2	4	4	14
43	21	10	11	10	3	13
44	22	22	6	14	2	11
45	5	26	21	22	11	17
46	27	8	15	9	1	18
47	25	13	17	7	6	19
48	18	4	19	30	12	7
49	10	12	-	-	5	3
50	19	14	29	25	9	24
51	14	25	28	26	14	25
52	11	27	8	6	18	8
55	4	20	12	29	32	-
59	30	23	20	18	7	20

To test for the hypothesis that the different rankings are not correlated a *Spearman test*³⁶ of ranking correlation were conducted. As the results in the matrix show (see *table 14*), only between the rankings on the basis of labour productivity and capital productivity (significant at 1%-level), capital productivity and net productivity (at 10%-level), net productivity and labour per net (at 20%-level), capital productivity and labour per net (at 20%-level) and labour per net and labour productivity (at 1%-level) exist a significant correlation. However, the correlation between net productivity and labour per net were shown to be negative and therefore the two rankings are not consistent.

Table 14: 'Spearman Correlations'

Spearman Correlations						
	cf total costs	cf variable costs	pi labour productivity	pi capital productivity	pi net productivity	IWA labour per net
cf total costs	-	0,011	0,053	-0,224	-0,115	0,041
cf variable costs	0,011	-	0,027	0,035	-0,009	0,096
pi labour productivity	0,053	0,027	-	0,547***	0,033	0,761***
pi capital productivity	-0,224	0,035	0,547***	-	0,301**	0,285*
pi net productivity	-0,115	-0,009	0,033	0,301**	-	-0,268*
IWA labour per net	0,041	0,096	0,761***	0,285*	-0,268*	-

(**** : correlation different from 0 is significant at the 1%-level of significance)

(*** : correlation different from 0 is significant at the 10%-level of significance)

(** : correlation different from 0 is significant at the 20%-level of significance)

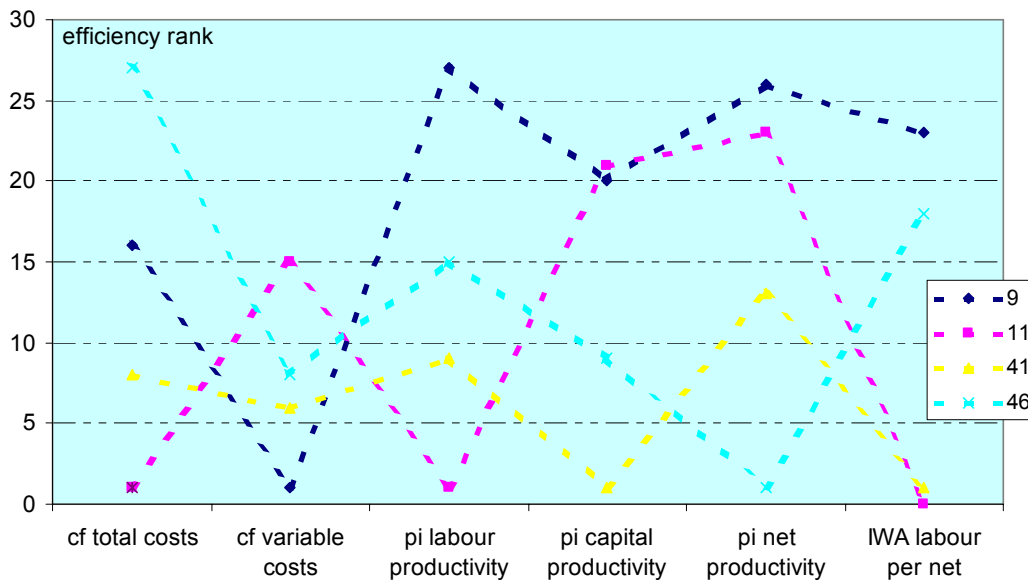
The rankings on the basis of a total cost frontier and capital productivity, total cost frontier and net productivity and variable cost frontier and net productivity are not consistent. Other rankings are at least consistent but largely insignificant. With respect to the use of such efficiency rankings for the regulation of water suppliers this would suggest that regulatory assessments should be based on different efficiency measures.³⁷ This holds particularly with respect to partial indicator rankings. Efficiency rankings on the basis of stochastic frontier models are superior to partial indicators as they use such partial ratios as explanatory variables for the efficiency estimation. Hence this frontier techniques allow for interdependencies in the effects on suppliers' inefficiency on a multi-dimensional basis.

³⁶ Spearman's rho is a measure of association between rank orders.

³⁷ Otherwise it is likely that the regulatory assessment would vary with the specific measurement approach used.

ESTACHE ET AL. (1999, p. 19) note that “(...) there is no real consensus among researchers as to how to measure this frontier. Yet, the choice of method can influence regulatory decisions. The problem stems from the multiplicity of individual efficiency measures available. So a far question is whether efficiency studies are useful at all.” As far as the sub-sectors of rural water infrastructure in Germany and transition economies are concerned, the answer has to be clear positive. Empirical analysis about the real state of efficiency on firm as well as market level point to the economic validity of frequently used arguments about efficiency gains by liberalisation and privatisation. Similar studies on the rural water sectors in these countries do not exist up to now. This nevertheless holds even in the case of still incomplete measurement techniques (see also BAUER ET. AL. 1998).

Figure 11: 'Inconsistency of Different Efficiency Rankings – Examples'



7.7. Inefficiency Effects

In order to explore the sources of efficiency differentials among rural water suppliers the predicted inefficiency results by the stochastic frontiers (h-n models) are now regressed upon a vector of firm-specific factors in a second-stage analysis.³⁸ The obtained inefficiency elasticities and semi-elasticities of significant variables are reported by *table 15*:

Table 15: 'Elasticities and Semi-Elasticities of Inefficiency'

Variable Cost Inefficiency				Total Cost Inefficiency			
Parameter	Estimate	SE	P T > t	Parameter	Estimate	SE	P T > t
γ_{CON}	-0.2386	0,2062	0.2625	γ_{SOU}	-0.0233	-0.0088	0.0134
γ_{NET}	0.4363	0.2405	0.0863	ω_{SEW}	-0.2469	0.1492	0.1100
ω_{BOWN}	-0.5040	0.1927	0.0175	ω_{BOWN}	-0.1735	0.1552	0.2740
ω_{SEW}	0.1744	0.1588	0.2867	γ_{SHOP}	-0.2674	0.2086	0.2112
<hr/> N = 23 R ² = 0.39				<hr/> N = 31 R ² = 0.23			

Due to these OLS-models the variable cost inefficiency decreases by about 24% when the number of supplied consumers would be increased by 100% (see γ_{CON}). If the length of the net is increased by 100% the variable cost inefficiency would increase by 44% (see γ_{NET}). These findings are in line with previous empirical studies and the concept of economics of density: if the water output per net is increased (either by the supply of additional consumers and/or the supply of a smaller area), the efficiency of operations can be raised. Cooperative forms of ownership (e.g. Zweckverband) have a positive effect on both forms of efficiency (see ω_{BOWN}). This could be due to the fact that cooperatives by average supply a higher volume of water output. Rural water suppliers operating also sewerage services show a higher variable cost inefficiency but on the other side a lower total cost inefficiency (see ω_{SEW}). This seems to be rather implausible as the market observers would expect the realisation of economies of scope with respect to operational expenses but high sunk costs with respect to capital investments. The higher the share of spring water intake the higher the total cost efficiency

³⁸ *COELLI ET AL.* (1998) point to the significant problem of inconsistency with the assumptions made for the composed error term with respect to the initial stochastic frontier estimation. In order to apply the approach invented by *JONDROW ET AL.* (1982) for the initial linear regression the efficiency effects are assumed to be independently and identically distributed. The setting of the proposed second stage analysis (inefficiency effects as a function of firm-specific factors) implies that inefficiency is not identically distributed, unless all the coefficients of the factors are simultaneously equal to zero.

(see γ_{SOU}) which could be due to the avoidance of pumping facilities for the extraction of groundwater. The higher finally the share of own water produced, the higher also the total cost efficiency (see γ_{SHOP}) which seems to be implausible as the extraction and treatment of water implies considerable sunk investments.

No significant effect on efficiency could be found with respect to the location of the rural water supplier (East or West Germany). *Table 16* gives the coefficients of correlation with respect to regional location, ownership and inefficiency:

Table 16: 'Inefficiency, Region and Ownership – Correlation Matrix'

		Correlations			
		CF_TC	CF_VC	BREG	BOWN
CF_TC	Pearson Correlation	1	,016	,091	,053
	Sig. (2-tailed)	,	,937	,625	,779
	N	31	26	31	31
CF_VC	Pearson Correlation	,016	1	-,057	,079
	Sig. (2-tailed)	,937	,	,777	,703
	N	26	27	27	26
BREG	Pearson Correlation	,091	-,057	1	,035
	Sig. (2-tailed)	,625	,777	,	,852
	N	31	27	32	31
BOWN	Pearson Correlation	,053	,079	,035	1
	Sig. (2-tailed)	,779	,703	,852	,
	N	31	26	31	31

Figure 12 further illustrates that there is no significant correlation of the binary variable for regional location (BREG) and the estimated variable cost (CF_VC) and total cost (CF_TC) inefficiency. *Figure 13* shows the correlation of the ordinal variable for ownership (BOWN) – is now splitted into 7 different forms – and the estimated inefficiencies: no strong correlation was found. This result is not in line with the negative significance of the dummy variable for ownership at the 5%- and 30%-level of significance obtained by the second stage regression (see *table 15*).

Figure 12: 'Inefficiency and Regional Location'

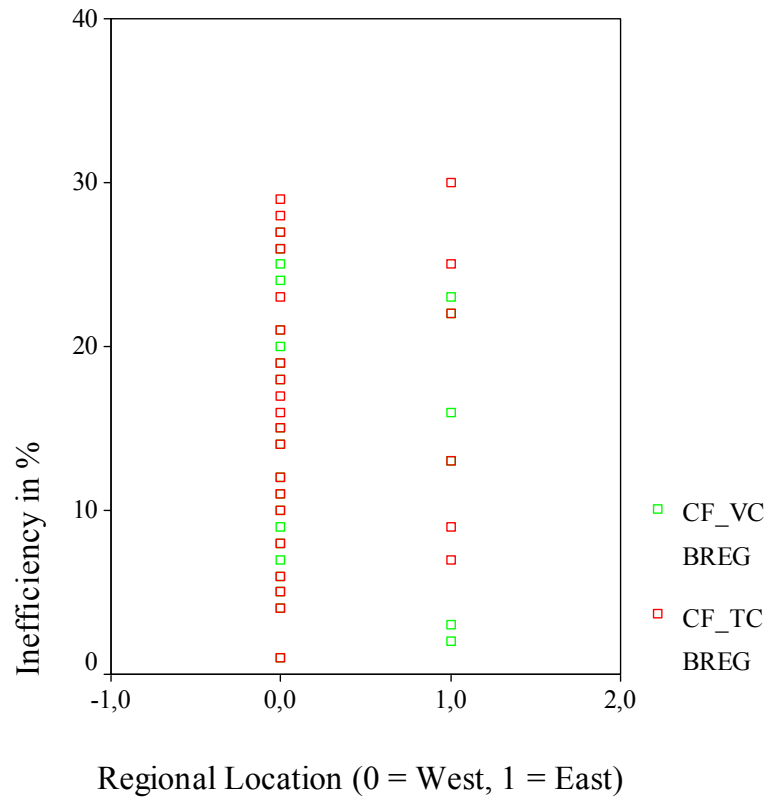
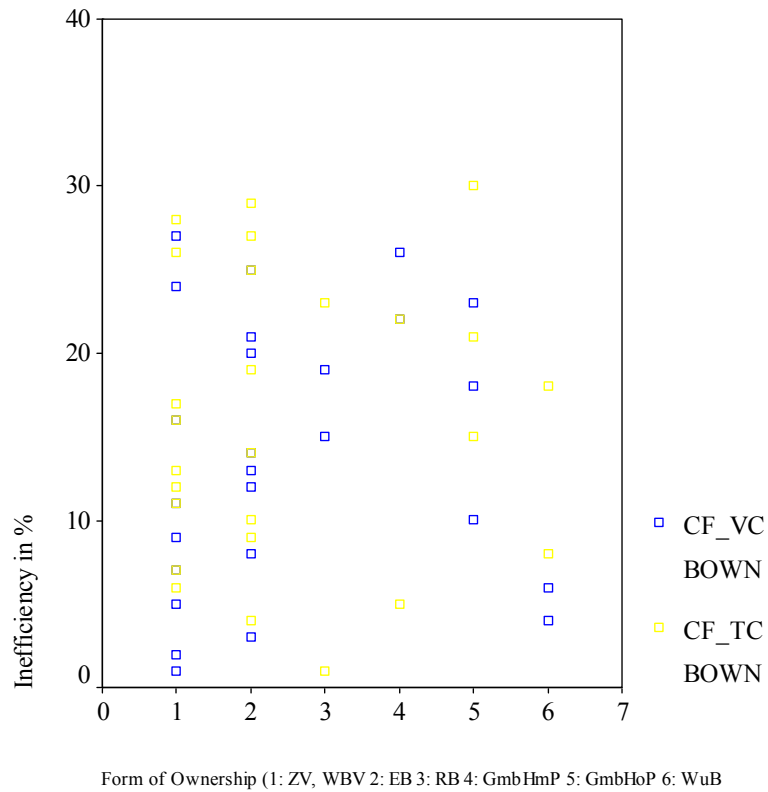
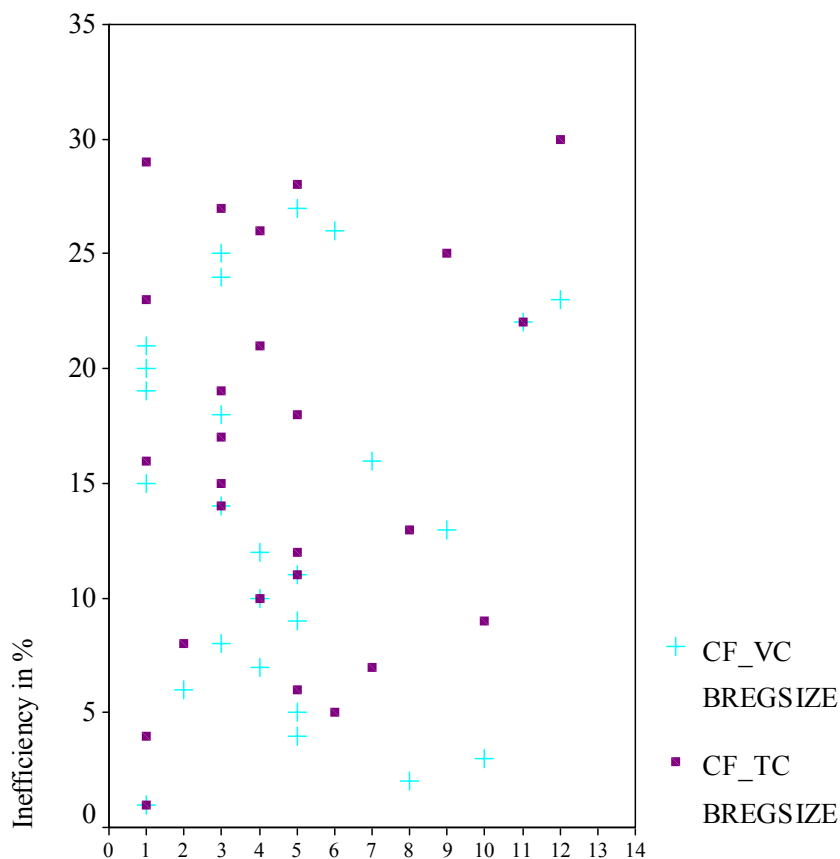


Figure 13: 'Inefficiency and Form of Ownership'



Finally subgroups were formulated with respect to regional location and firm size (oriented at water output). Again no significant correlation between the regional location of the rural water supplier and its (variable or total cost) efficiency could be stated.

Figure 14: 'Inefficiency, Region and Firm Size'



with the categories 1 – 12 as a combination of location and size:

- 1 – West and up to 250 tm^3 water output,
- 2 – West and > 250 to 500 tm^3 water output,
- 3 – West and > 500 to 1000 tm^3 water output,
- 4 – West and > 1000 to 2000 tm^3 water output,
- 5 – West and > 2000 to 5000 tm^3 water output,
- 6 – West and > 5000 tm^3 water output,
- 7 – East and > 250 to 500 tm^3 water output,
- 8 – East and > 250 to 500 tm^3 water output,
- 9 – East and > 500 to 1000 tm^3 water output,
- 10 – East and > 1000 to 2000 tm^3 water output,
- 11 – East and > 2000 to 5000 tm^3 water output,
- 12 – East and > 5000 tm^3 water output.

7.8. Public Funding and Efficiency

One central aim of this research project is to generate empirical evidence on the question about the economic effectiveness of public funding of rural water suppliers in rural areas. Therefore a binomial choice model ('probit model') was formulated with public funding as the dependent variable. The probability of the event 'obtained public funding' – here the binary variable *BFU* with 1 for funding and 0 for non-funding – was tested:

$$E [S_i | X = x_i] = \Pr (S_i = 1 | X = x_i) = F (x_i' b) \quad i = 1, K, N \quad (7.7.)$$

with $X = LNINEFF2$ (estimated total cost inefficiency), $LNAVCAP$ (average capital) and $BREG$ (binary variable for regional location) as well as the constant. N consists of N^1 suppliers which obtained public funding in 2000/2001 and N^0 suppliers without public funding. The endogenous variable follows a Bernoulli distribution taking the value '1' if the rural water supplier obtains funding and '0' if it obtains no funding. B represents the parameter vector which has to be estimated and $F(\cdot)$ denotes a normal distribution.

The probit model was tested on the basis of 26 observations. 13 observations for N^1 and 13 observations for N^0 . The model statistics are summarised by *table 17* including the 2x2-matrix for the predicted and actual values of *BFU*.

Table 17: 'Model Statistics PROBIT – Public Funding'

Explanatory Variable x	Coefficient	P T > t
Constant	-3.0560	0.3711
LNINEFF2	82.635	0.0358
LNAVCAP	3.800	0.0675
BREG	5.7289	0.1063
<hr/>		
N	26	
N ⁰	13	
N ¹	13	
Log-L	-18.02	
Chi ²	26.88	
Sign. Level	0.6231E-05	
R ²	0.6444	
Ben./Lerman	0.8888	
<hr/>		
Predicted		
----- + -----		
Actual	0	1 Total
----- + -----		
0	13	0 13
1	1	12 13
----- + -----		
Total	14	12 26

As most significant explanatory variables INEFF2 for the total cost inefficiency (significant at 5%-level), AVCAP for average capital per output (significant at 10%-level) and the binary variable BREG for the regional location (significant at 10%-level) were found. As the 2x2-matrix shows, only one value was not correctly predicted by the model. The public funded rural water supplier is hence described by the following model :

*Model BC I.*³⁹

$$S_i = -3.06_{(0.37)} + 8.26_{(0.03)} \ln \text{INEFF2} + 3.80_{(0.07)} \ln \text{AVCAP} + 5.73_{(0.22)} \text{BREG} \quad (7.8.)$$

These empirical findings suggest: Public funding for water suppliers in rural areas is positive correlated with total cost inefficiency, average capital per output and the location of the supplier in rural areas of East Germany.

Economically sound public funding (if subsidies are ever economically correct) would be also oriented at the operational inefficiency of rural water suppliers. If a supplier operates profitable with respect to I variable cost efficiency it is likely that this firm is able to compensate total cost inefficiency as a consequence of fix capital investments in the mid- or long-term future. The empirical evidence nevertheless shows that variable cost inefficiency plays no significant role for the funding decision of public institutions. There is no evidence that rural water suppliers with a relatively high total cost inefficiency and a relatively high variable cost inefficiency will have access to public funds. This points to the possibility of a systematic waste of resources by public policy (static perspective) in the form of incorrect funding criteria. This funding policy gives further misleading economic signals for the management of rural water suppliers with respect to investment decisions (dynamic perspective). Finally there is considerable empirical evidence that such economic criteria are contradicted by the orientation of funding policy at the regional location of the rural water supplier: firms in East Germany are more likely to have access to public funds, no matter how efficient their operations are !

The reasons for such a misleded funding policy by public institutions on the various levels of the political system have to be analysed by taking a close look on the selection criteria of the different funding programs in place.

³⁹ Probability values are in parentheses.

VIII) Summary

This research project has the central aim of shedding empirical light on the question of whether rural suppliers in economies of transition are efficient producers and providers of water to rural residential and industrial consumers. Thus on the base of a sample of water utilities in rural areas the relative efficiency and the factors for possible inefficiencies are determined. The data set was collected by a questionnaire as well as based on existing statistics⁴⁰. Further the implications for the institutional infrastructure policy are illuminated: are public funding programmes really focused on the least inefficient water producers and providers and what are the implications of the findings for the national as well as EU-structural policy formulation ?

After the completion of the data set on rural water suppliers in Germany a first analysis was conducted. The major findings so far are summarised by the following conclusions:

- (1) The assessment of rural water suppliers by partial performance indicators varies largely with respect to the applied ratio. Such performance rankings are neither consistent nor do they recognise the complex interactions between inputs, outputs and environmental factors. Stochastic efficiency frontiers more adequately reflect such economic realities.
- (2) With respect to the modelling of water production and provision the hypothesis of functional separability was described. If separability could be empirically verified efficiency gains can be realised by a vertical desintegration of rural water supply.
- (3) Empirical cost frontiers for water supplying firms are either based on a Cobb Douglas – or a Translog – specification. No such frontier estimation exist exclusively for rural water suppliers, the water sector in Germany or economies in transition.
- (4) Estimated regression models on the basis of ordinary least squares more or less confirm expected influences of tested variables. With respect to total costs the regional location of the supplier was found to have a positive effect: rural suppliers in the East (*ceteris paribus*) show lower total costs. Cooperative forms of ownership showed here a negative effect on variable costs.
- (5) Economies of scale could be empirically verified for the sample of rural water suppliers. This suggests to increase the output of the average supplier by expanding the average supplying area to enjoy further efficiency gains. These findings are in line with the negative significance of cooperative forms of ownership on total costs. The specific legal framework (‘municipal self-administration’⁴¹, ‘municipal activities oriented at the municipal borders’⁴²) therefore acts as a barrier for the realisation of efficiency gains.

⁴⁰ Namely the BVGW statistics on 2000 as well as public available accounting statements.

⁴¹ ‘Kommunale Selbstverwaltung’.

⁴² ‘Kommunales Örtlichkeitsprinzip’.

- (6) The relative efficiency of rural water suppliers with respect to operational costs (for 2000/2001) varied between 57 and 94% (average at 84%⁴³), with respect to total costs between 22 and 89% (average at 55%). Hence the technical (cost) efficiency could be improved by up to 45% with the same production technology and in the same environmental setting. A negative correlation between firm size and variable cost inefficiency was found.
- (7) Not all of the efficiency rankings on the basis of partial performance indicators were found to be consistent with the rankings from the stochastic frontiers. With respect to regulation this suggests that regulatory assessments varies with the applied measurement technique and should be therefore based on different measures.⁴⁴
- (8) With respect to inefficiency effects a negative elasticity of production density can be stated. Here no significant effect of the location of the rural supplier on cost inefficiency was found. A more differentiated look on the effect of ownership on inefficiency delivered no significant results.⁴⁵
- (9) The empirical analysis of the ‘average rural water supplier’ with respect to the granting of public funds revealed that the variable cost efficiency of the supplier has no influence on the decision about funding by public institutions. Suppliers with a very low rate of depreciation as a consequence of long dating back capital investments and therefore a relatively low efficiency of operations will have no access to public funds. Finally it could be shown that firms in East Germany enjoy a more easier access to public funds, regardless how efficient their operations are. Hence the selection policy of the different institutions with respect to public funding has to be analysed.

⁴³ The average value of the half-normal and truncated-normal model.

⁴⁴ This confirms the findings of earlier research (see e.g. ESTACHE ET AL. 1999)

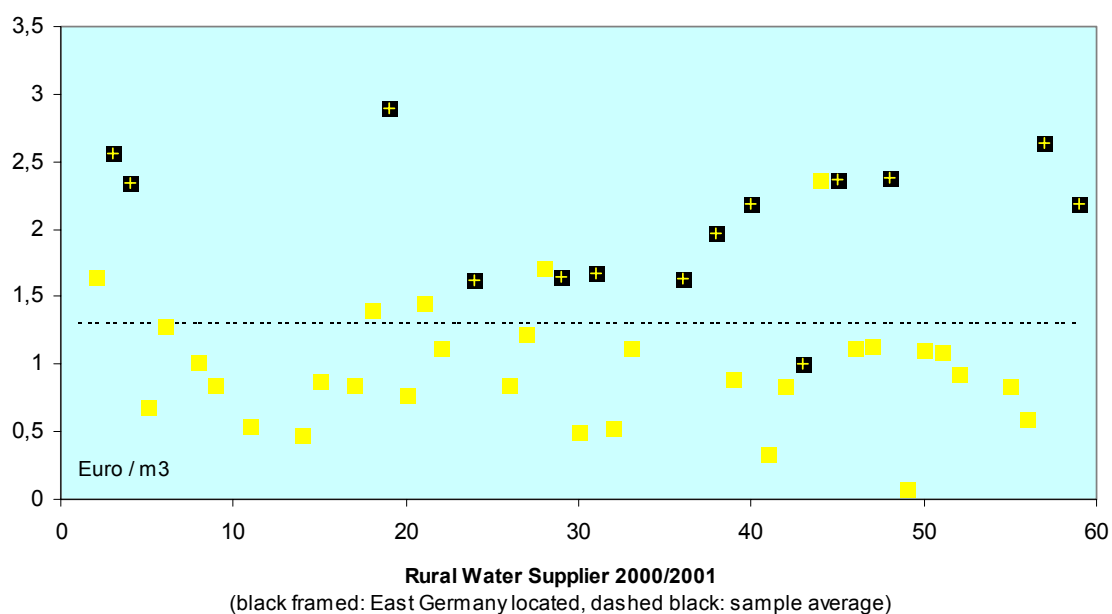
⁴⁵ Due to only 3 rural suppliers with partially private participation, no clear inferences whether public or private forms of ownership are more efficient can be made. These firms showed results at both sides of the estimated efficiency ranges.

IX) Appendix

9.1. Partial Performance Indicators 2000/2001

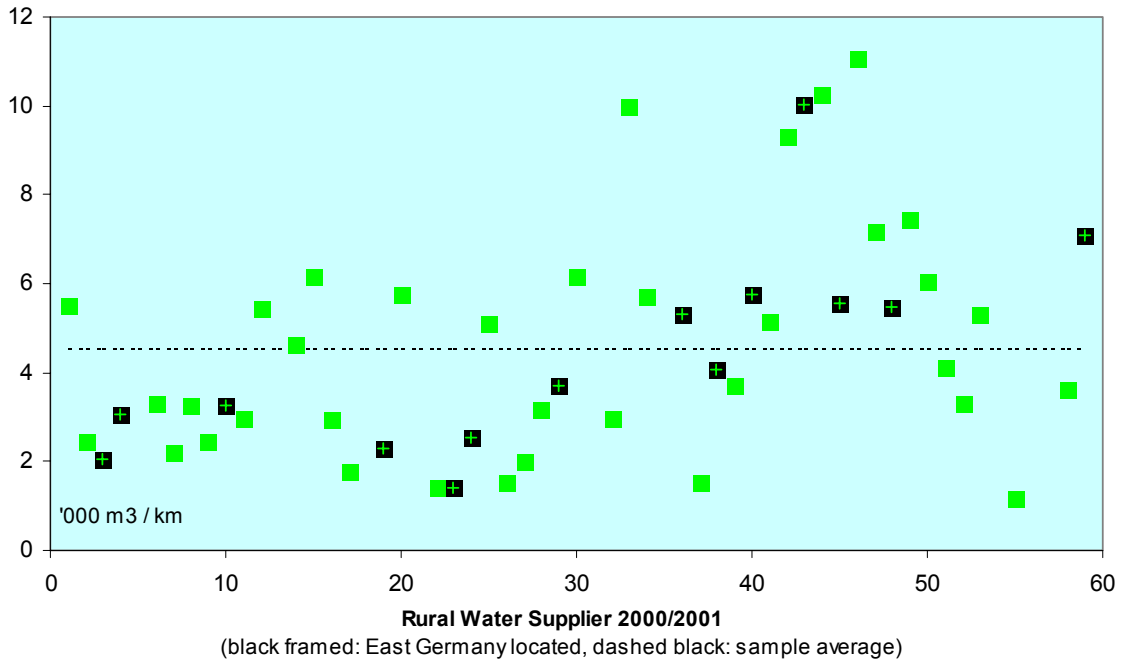
$$\text{Average Revenue} = \frac{\text{Total Revenue Water Supply (Direct and Indirect) (in Euro)}}{\text{Total Water Output (m}^3\text{)}} \quad (\text{A 1.1.})$$

Figure A 1: 'Average Revenue'



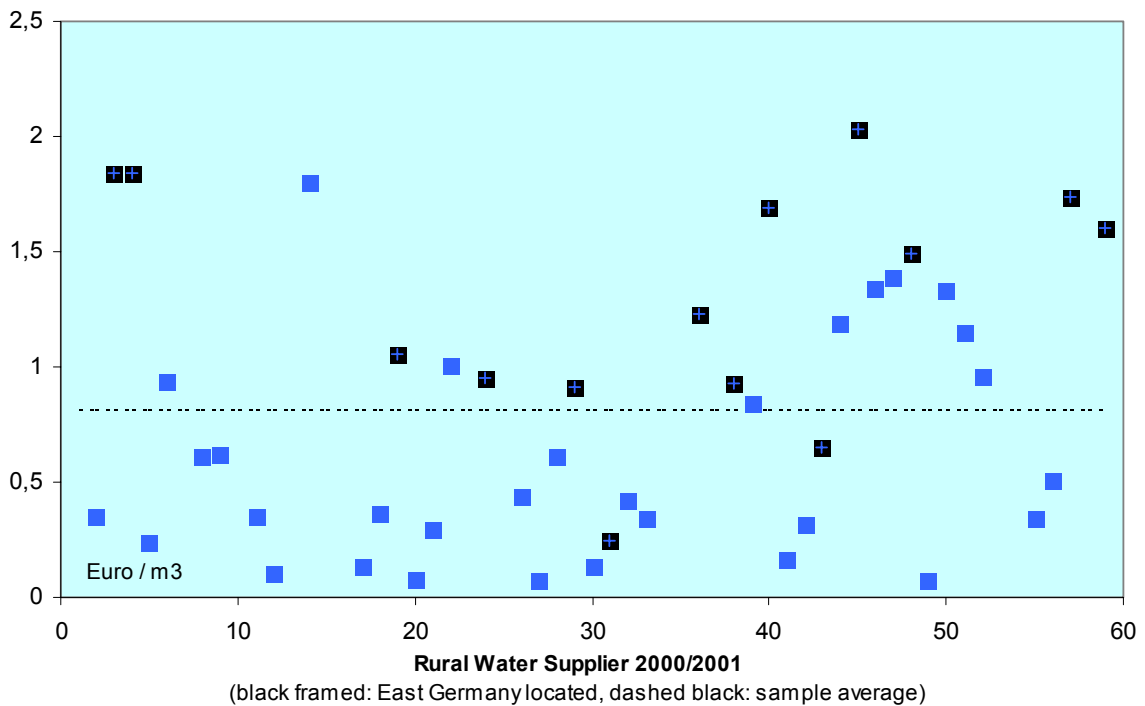
$$\text{Average Output per Net} = \frac{\text{Total Water Output (in '000 m}^3\text{)}}{\text{Total Length of Transport and Distribution Net (in km)}} \quad (\text{A 1.2.})$$

Figure A 2: 'Average Output per Net'



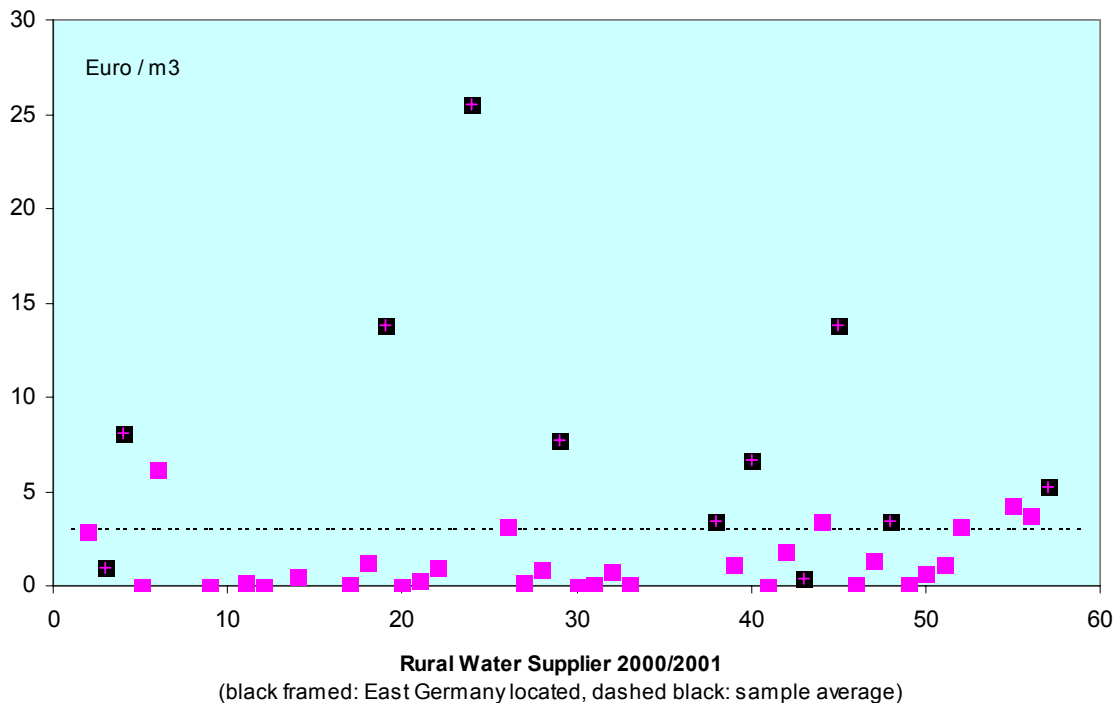
$$\text{Average Operational Costs} = \frac{\text{Total Costs of Operations (in Euro)}}{\text{Total Water Output (m}^3\text{)}} \quad (\text{A 1.3.})$$

Figure A 3: 'Average Operational Costs (IWA 2000 – Indicator)'



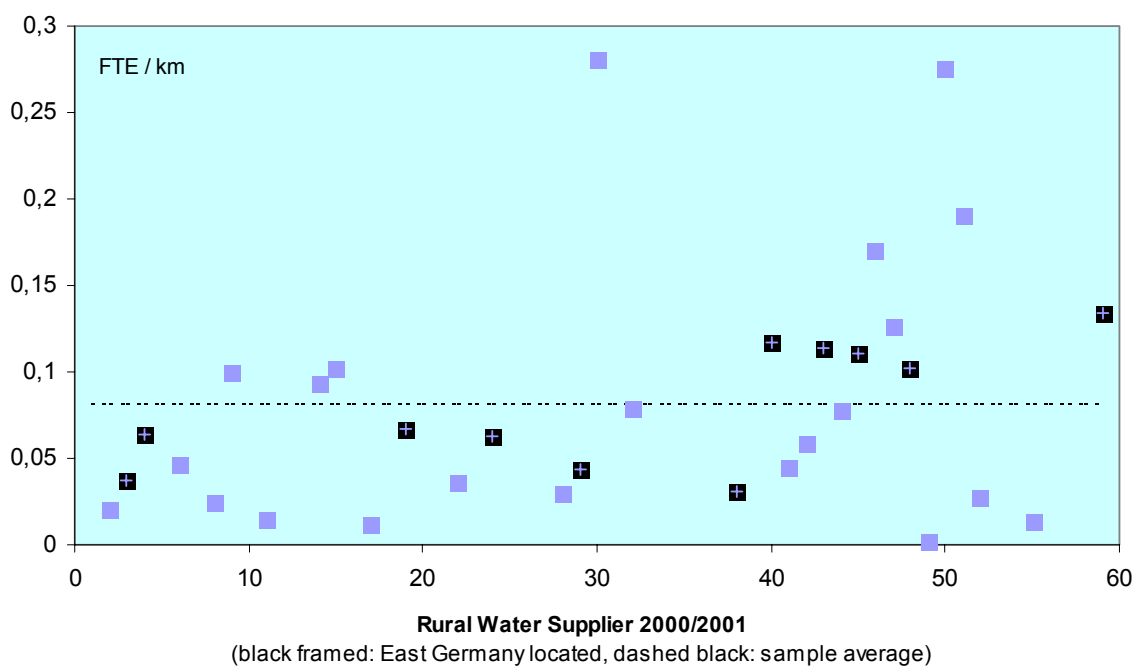
$$\text{Average Total Costs} = \frac{\text{Total Costs of Operations and Investments (in Euro)}}{\text{Total Water Output (m}^3\text{)}} \quad (\text{A 1.4.})$$

Figure A 4: 'Average Total Costs (IWA 2000 – Indicator)'



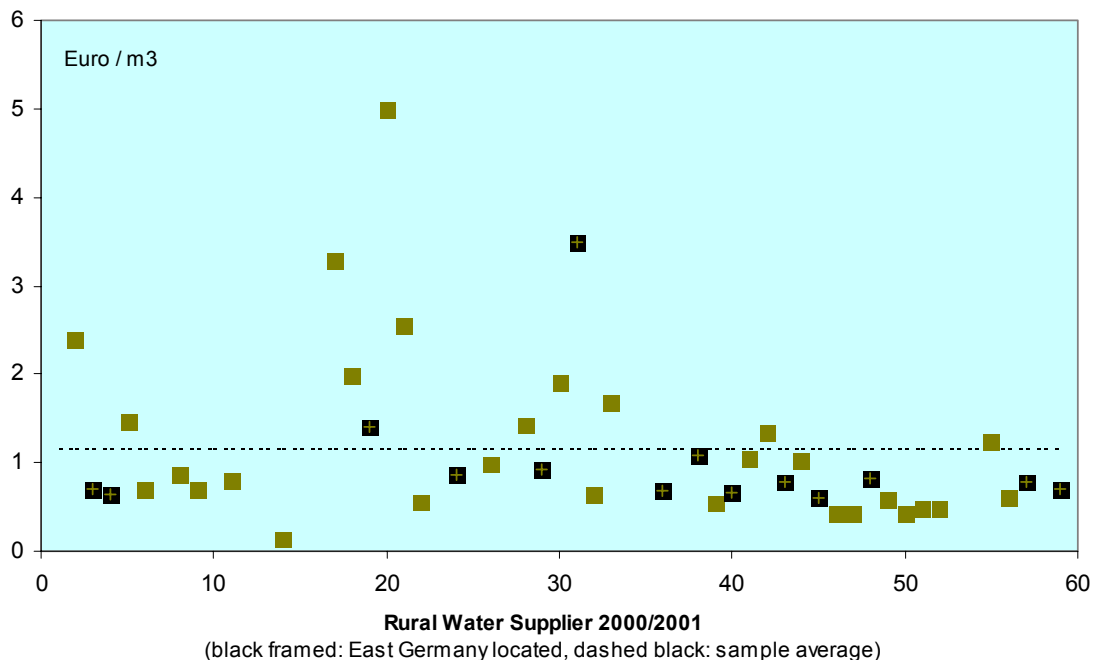
$$\text{Average Labour per Net} = \frac{\text{Full Time Employees}}{\text{Total Length of Transport and Distribution Net (in km)}} \quad (\text{A 1.5.})$$

Figure A 5: 'Average Labour per Net (IWA 2000 – Indicator)'



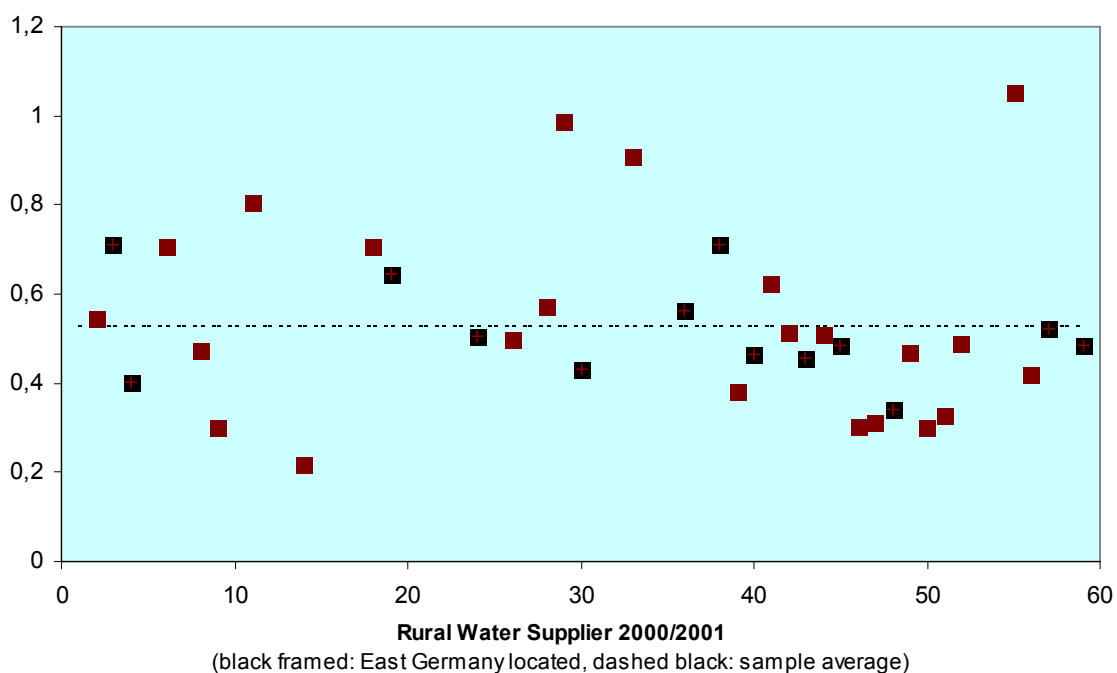
$$\text{Operational Cost Coverage Ratio} = \frac{\text{Total Costs of Operations (in Euro)}}{\text{Total Revenue Water Supply (Direct and Indirect) (in Euro)}} \quad (\text{A 1.6.})$$

Figure A 6: 'Operational Cost Coverage Ratio (IWA 2000 – Indicator)'



$$\text{Total Cost Coverage Ratio} = \frac{\text{Total Costs of Operations and Investments (in Euro)}}{\text{Total Revenue Water Supply (Direct and Indirect) (in Euro)}} \quad (\text{A 1.7.})$$

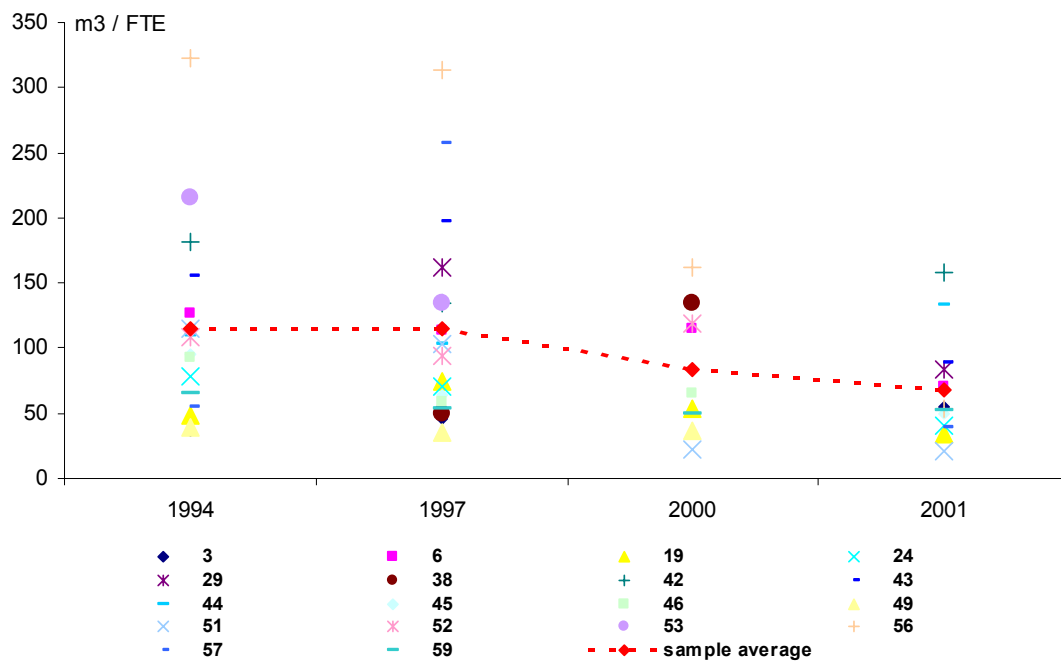
Figure A 7: 'Total Cost Coverage Ratio (IWA 2000 – Indicator)'



9.2. Labour Productivity 1994 – 2001

Figure A 8: 'Decreasing Average Labour Productivity'

$$\text{Average Labour Productivity} = \frac{\text{Total Water Supplied (in '000 m}^3\text{)}}{\text{Number of Full Time Employees of the Water Undertaking}}$$



9.3. Performance Ranking by Partial Indicator

Rural Supplier No.	I) Average Labour per Connection	II) Average Output per Labour	III) Average Output per Capital	IV) Water Loss per Connection	V) Average Revenue per Output	VI) Average Output per Net	VII) Average Operational Costs	VIII) Average Total Costs per Output	IX) Average Labour per Net	X) Operational Cost Coverage	XI) Total Cost Coverage	(Total Ranking)
1	nda	nda	nda	nda	nda	16	nda	nda	nda	nda	nda	22
2	5	8	28	19	14	40	15	27	5	5	13	13
3	9	19	29	12	3	43	43	20	11	25	5	30
4	nda	26	32	nda	7	34	44	39	17	31	28	56
5	29	36	17	26	38	nda	8	1	nda	9	nda	32
6	12	15	16	20	19	30	27	36	14	27	8	33
7	nda	nda	nda	nda	nda	42	nda	nda	nda	nda	nda	35
8	6	6	19	nda	27	32	20	nda	6	20	22	15
9	25	32	25	nda	33	39	22	6	22	26	34	56
10	nda	nda	nda	nda	nda	31	nda	nda	nda	nda	nda	29
11	nda	1	26	nda	40	35	14	12	4	22	4	16
12	nda	nda	nda	28	nda	18	4	5	nda	nda	nda	14
13	nda	nda	nda	nda	nda	nda	nda	nda	nda	nda	nda	25
14	19	24	2	nda	43	23	42	16	21	43	36	57
15	22	17	5	nda	31	10	nda	nda	24	nda	nda	23
16	nda	nda	nda	nda	nda	37	nda	nda	nda	nda	nda	31
17	4	4	3	24	32	45	5	10	2	3	7	3
18	nda	2	nda	nda	18	nda	16	24	nda	6	7	9
19	15	31	33	10	1	41	31	41	18	11	9	45
20	nda	nda	4	nda	37	13	3	2	nda	1	nda	2
21	nda	nda	nda	1	17	nda	10	14	nda	4	nda	6
22	nda	29	nda	nda	24	49	30	21	10	36	nda	51
23	nda	nda	nda	nda	nda	48	nda	nda	nda	nda	nda	40
24	16	27	24	nda	16	38	28	42	16	19	17	48
25	nda	nda	nda	nda	nda	22	nda	nda	nda	nda	nda	24
26	nda	nda	11	nda	34	47	18	29	nda	17	18	42
27	nda	nda	nda	nda	20	44	1	13	nda	nda	nda	17
28	10	11	14	2	11	33	21	19	8	10	11	3
29	nda	14	20	nda	13	26	25	38	12	18	2	18
30	28	33	nda	27	42	3	6	3	32	7	26	39
31	nda	nda	nda	nda	12	nda	9	11	nda	2	nda	7
32	nda	30	nda	nda	41	36	17	18	20	32	nda	49
33	30	37	nda	nda	23	4	12	9	nda	8	3	12
34	nda	nda	nda	nda	nda	14	nda	nda	nda	nda	nda	19
35	nda	nda	nda	nda	nda	nda	nda	nda	nda	nda	nda	25
36	nda	nda	nda	nda	15	20	34	nda	nda	29	12	28
37	nda	nda	nda	nda	nda	46	nda	nda	nda	nda	nda	38
38	2	5	15	11	10	25	26	31	9	14	6	5
39	nda	nda	8	6	30	27	24	22	nda	39	29	41
40	24	25	21	13	8	12	40	37	27	30	24	50
41	1	10	1	8	44	21	7	4	13	15	10	1
42	14	3	6	15	35	5	11	26	15	12	15	7
43	13	12	13	3	28	3	23	15	26	23	25	15
44	11	7	18	14	6	2	33	30	19	16	16	11
45	17	23	27	23	5	15	45	40	25	33	21	53
46	18	16	12	22	22	1	36	8	30	40	33	44
47	20	18	10	25	21	7	37	25	28	42	32	52
48	7	21	36	16	4	17	38	32	23	21	30	46
49	3	nda	nda	9	45	6	2	1	35	23	10	10
50	26	35	30	17	25	11	35	17	33	41	35	58
51	27	34	31	18	26	24	32	23	31	38	31	59
52	8	9	9	21	29	29	29	28	7	37	19	34
53	nda	nda	nda	nda	nda	19	nda	nda	nda	nda	nda	21
54	nda	nda	nda	nda	nda	nda	nda	nda	nda	nda	nda	25
55	nda	13	35	nda	36	50	13	34	3	13	1	35
56	23	20	7	5	39	nda	19	33	nda	34	27	47
57	nda	28	23	nda	2	nda	41	35	nda	24	14	42
58	nda	nda	nda	4	nda	28	nda	nda	nda	nda	nda	20
59	21	22	22	7	9	8	39	nda	29	28	20	36

(nda: no data available; 1: if no ranking was possible due to nda, the average value was taken)

9.4. Empirical Cost Frontier by Bhattacharayya et al. (1995)

<i>Dependent Variable</i>	-Total Costs
<i>Explanatory Variables</i>	-Energy (E), -Labour (L), -Capital (K), -Total Production (P), -System Loss (A), -Net Output (y), -Materials (M), -Surface Source (S1), -Combined Surface and Ground Source (S2)
<i>Sample</i>	221 Urban Suppliers in the USA in 1992
<i>Frontier</i> <i>(parenthesis = prob-values)</i>	$\begin{aligned} \ln \text{COST} = & 0.129 (0.005) \ln E + 0.399 (0.013) \ln L + 0.253 (0.103) \ln K + 0.433 \\ & (0.139) \ln P - 0.180 (0.069) \ln A + 0.226 (0.861) \ln y + 0.472 (0.015) \ln M + \\ & 0.042 (0.015) \ln E \ln E + 0.113 (0.03) \ln L \ln L + 0.537 (0.147) \ln K \ln K + 9.19 \\ & (1.21) \ln P \ln P + 0.144 (0.124) \ln A \ln A + 1.21 (0.43) \ln y \ln y + 0.07 (0.04) \\ & \ln M \ln M - 0.044 (0.014) \ln E \ln L - 0.007 (0.356) \ln E \ln K + 0.032 (0.052) \ln E \ln P \\ & - 0.004 (0.004) \ln E \ln A - 0.028 (0.048) \ln E \ln y + 0.002 (0.021) \ln E \ln M + 0.011 \\ & (0.006) \ln L \ln K - 0.093 (0.032) \ln L \ln P + 0.019 (0.009) \ln L \ln A + 0.079 (0.077) \\ & \ln L \ln y - 0.069 (0.031) \ln L \ln M + 1.823 (0.145) \ln K \ln P - 0.386 (0.084) \ln K \ln A \\ & - 1.975 (0.995) \ln K \ln y - 0.005 (0.002) \ln K \ln M - 3.177 (0.831) \ln P \ln A - 5.145 \\ & (1.056) \ln P \ln y - 0.061 (0.111) \ln P \ln M + 3.328 (1.720) \ln A \ln y - 0.022 (0.009) \end{aligned}$

$\ln A \ln M - 0.051 (0.011) \ln y \ln M - 0.002 (0.001) \ln O \ln E + 0.025 (0.012) \ln O \ln L - 0.004 (0.025) \ln O \ln K - 0.237 (0.106) \ln O \ln y - 0.023 (0.007) \ln O \ln M + 0.019 (0.012) \ln S I - 0.020 (0.010) S I$ $(R^2_g = 0.99)$
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9.5. Descriptive Statistics – Model CD I (LIMDEP output file)

Descriptive Statistics

All results based on nonmissing observations.

Variable	Mean	Std.Dev.	Minimum	Maximum	Cases
All observations in current sample					
LNAVOC	.118480180	.976838830	-2.00867248	1.50363374	45
Skewness=	-.6202	Kurtosis= 2.3735			
LNAVCAP	2.28399772	1.43028721	-2.19508505	3.95027375	37
Skewness=	-1.8278	Kurtosis= 6.1589			
LNCAPL	13.6227776	1.13446264	9.43348408	15.3380404	32
Skewness=	-1.5536	Kurtosis= 6.9718			
LNMATL	10.3854331	1.23244828	6.72543383	13.1183996	36
Skewness=	-.7381	Kurtosis= 4.0754			
LNSOU	-.994430304	9.96128743	-9.21034050	12.7128906	56
Skewness=	.3782	Kurtosis= 1.1490			
LNNET	4.40190044	1.69532124	.405465007	8.17329311	50
Skewness=	-.3235	Kurtosis= 2.7510			
BOWN	.407407407	.495965554	.000000000	1.00000000	54
Skewness=	.3734	Kurtosis= 1.1209			

Correlation Matrix for Listed Variables

	LNAVOC	LNAVCAP	LNCAPL	LNMATL	LNSOU	LNNET	BOWN
LNAVOC	1.00000	.68187	.13470	-.06782	-.41700	.46998	.26496
LNAVCAP	.68187	1.00000	.55400	-.46492	-.05724	.16263	.37423
LNCAPL	.13470	.55400	1.00000	.17564	.23190	.14119	.26516
LNMATL	-.06782	-.46492	.17564	1.00000	.03367	.25342	-.02327
LNSOU	-.41700	-.05724	.23190	.03367	1.00000	-.28328	-.41510
LNNET	.46998	.16263	.14119	.25342	-.28328	1.00000	.35099
BOWN	.26496	.37423	.26516	-.02327	-.41510	.35099	1.00000

9.6. OLS Model CD III - Statistics

Explanatory Variable x	t - Ratio	P T > t	$\rho_{x,y}$
Constant	-5.853	0.0021	-
lnAVCAP	3.450	0.0182	0.2921
lnMATL	6.133	0.0017	0.1950
lnSOU	-7.400	0.0007	-0.7341
lnNET	-4.236	0.0082	0.6205
lnINVO10	4.752	0.001	0.2089
<hr/>			
N	11		
DoF	5		
R ²	0.96		
F-statistic	24.73	0.0015	
<hr/>			
Log-L	-12.71		
DW-statistic	Jul 06		

X) References / Literature

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