TECHNISCHE UNIVERSITÄT DRESDEN

Efficiency Analysis of German Water Utilities

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Chair of Energy Economics and Public Sector Management

Agenda

1. Introduction
2. The German Water Supply Industry
3. Review of Relevant Literature
4. Methodology
5. Data Description
6. Results
    1. Efficiency Scores and Regression on Structural Variables
    2. Final Efficiency Scores and Interpretation
    3. Comparing East and West Germany
7. Conclusions

1. Introduction

- First efficiency analysis of German water sector
- Evaluation of differences between East and West Germany
- Ascription of price disparities to structural differences or to inefficiencies
- High price differences for the end customer
- Regulations in other countries

Implementation in Germany?

Trials for regulation of water prices in the federal state of Hesse

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2. The German Water Supply Industry

- **Characteristic of German water supply industry**
  - **67% Groundwater, 26% Surface Water, 8% Well-Spring Sources**
  - **Decline of demand for water from 147 liters pro person and day (in 1990) to 126 liters (in 2006)**
  - **High investments in network infrastructure since 1990 (42 bn. €)**
    - High supply security, high drinking water quality
    - Low leak ratio

  - **Industry consists of municipal utilities and special purpose associations**
  - **Consideration not only of water distribution but also production and treatment**
  - **Higher per capita consumption in West Germany**

- **Regulation seems possible/reasonable when**
  - **Research shows that prices differ not only due to structural differences**
  - **All prices are too high (not considered in this study)**

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3. Review of Literature

- **Separation of literature in four main areas**

1. Economies of scale, scope and density – Stochastic Frontier Studies	2. Comparison of private and public services
3. DEA combined with regression analyses to explain structural differences	4. Further more methodological studies

➢ **Focus on review of the third group**

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3. Studies evaluating the impact of structural and quality variables with focus on DEA

Authors	Data sample	DEA specifi-cation	Inputs	Outputs	Results for structural and quality variables
• Renzetti and Dupont (2008)	• 64 Canadian water utilities in 1996	• Input orientation • VRS	• Labor costs • Material costs • Delivery network	• Water delivered	• Elevation differences • Population density • Ratio of residential water • Number of private dwellings with significant impact on efficiency
• García-Sánchez (2006)	• 24 Spanish water utilities in 1999	• Input orientation • CRS	• Staff • Treatment plants • Delivery network	• Water delivered • Number of connections • Chemical analyses performed	• Network density with significant influence on efficiency
• Tupper and Resende (2004)	• 20 Brazilian water and sewerage utilities from 1996 - 2000	• Output orientation • VRS	• Labor costs • Operational costs • Capital costs	• Water produced • Treated sewage • Population served-water • Population served-treated sewage	• Network densities and accounted-for water ratio with significant influence on efficiency
• Picazo-Tadeo et al. (2008)	• 38 Spanish water utilities (with 20 also providing sewerage services) in 2001	• Output orientation • CRS	• Delivery network • Sewer network • Labor • Operational costs	• Population served • Water delivered • Treated sewage	• Accounted-for water does not influence the ranking of utilities

Source: Hirschhausen et al. (2008)

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4. Methodology

4.1 Choose of approach and outlier detection

4.1.1 Choose of efficiency analysis method

4.1.2 Choose of orientation

4.1.3 Choose of returns to scale approach

4.2 Standard DEA efficiency scores

4.3 Regression on structural variables

4.4 Calculation of DEA efficiency scores with adjusted inputs

(4.2–4.4: **Three step approach**)

4.5 DEA model specification

4.1 Choose of approach and outlier detection

4.1.1 Choose of efficiency analysis method

- DEA because
  - Absence of panel data → restricts applicability of SFA
  - Discriminate best between different outputs (household and industrial demand)
  - Puts individual weights on individual output of each firm

4.1.2 Choose of orientation

- Input orientation (common practice in network industries and natural monopolies) because of fixed output vector:
  - Fixed geographical area
  - Demand not under management control

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4.1 Choose of approach and outlier detection

4.1.3 Choose of returns to scale

- **Assumption of variable returns to scale with BCC formulation**
  - **Different sizes of suppliers in the dataset**

- **Returns to scale test (Simar and Wilson, 2002):**
  - **Two-step test**

Test 1: H_0: the production frontier is globally CRS

H_1: the production frontier is globally VRS

Test 2: H_0: the production frontier is globally NIRS

H_1: the production frontier is globally VRS

➢ **Result of the test: variable returns to scale (p-value < 1%)**

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4.2 Standard DEA efficiency scores

Step one: Calculation of standard DEA efficiency scores

1. **Use of the partial indicator** $= \frac{\textit{total revenues}}{\textit{total water output}}$ **for detection of extreme observations**

2. **Use of the super-efficiency approach as proposed by Banker and Gifford (1988)**
   - **Maximum attainable efficiency score is 1.2 following Banker and Chang (2006)**

3. **Standard DEA approach is used to derive <u>first efficiency scores</u>**

1. Standard DEA efficiency → **2. Regression on structural variables** → **3. DEA with input adjustment**

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4.3 Regression on structural variables

Step two: Regression on structural variables

- **Regression of efficiency scores obtained by standard DEA on explanatory variables**
- **Bootstrapped truncated regression as proposed by Simar and Wilson (2007)**
    - **To account for serial correlation in DEA efficiency estimates**
    - **To avoid incorrect inference**

4.4 Calculation DEA efficiency scores with structural variables

Step three: Including explanatory variables into standard DEA calculation

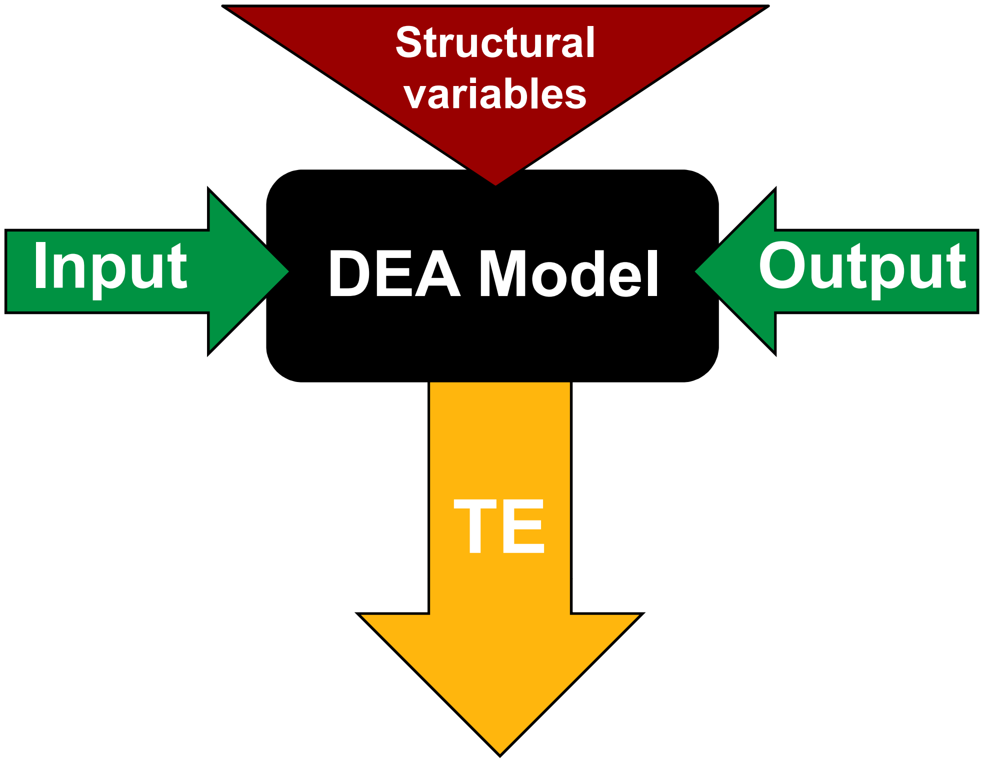
- **Correct efficiency scores by including structural variables**
- **Reason: structural variables describe influences outside of management control**
- **Fried et al. (1999): adjust inputs according to the least favorable operating environment**
  - **The inputs of the utility with the least favorable operating environment remain unchanged**
  - **The inputs of all other utilities are increased**
- **Include adjusted inputs into new DEA calculation**

➢ **<u>Final technical efficiency scores</u>**

1. Standard DEA efficiency → 2. Regression on structural variables → 3. DEA with input adjustment

4.5 DEA model specification

- **Inputs**
  - Total revenues
    - Cost proxy
- **Outputs**
  - Private consumption
  - Industrial and other consumption
  - Number of water meters
- **Observed regression variables**
  - Ratio of groundwater
  - Elevation difference
  - Dummy East/West
  - Output density
  - Leak ratio



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5. Data Description

- **Cross sectional data from the year 2006**
  - **All over Germany, all federal states (except Bremen)**
- **Originally, 1096 water utilities**
  - **Full data availability for 373 utilities covering 36% of Germany's water supply**
- **Source: Bundesverband der Energie- und Wasserwirtschaft (2008),**

  118. Wasserstatistik der Bundesrepublik Deutschland
- **Additionally, elevation differences from topographical maps**

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5. Descriptive statistics

Variable Description	Abbr.	Classification	Sum	Min.	Mean	Median	Max.	Std. Dev.
Revenues [1000 €]	cost	Input	3,563,312	466	9,843	3,382	424,000	27,878
Water meters [number]	meters	Output	6,850,857	1,653	18,925	9,073	1,008,732	57,151
Water delivered to households [1000 m³]	wdelhh	Output	1,490,046	199	4,116	1,520	142,700	10,872
Water delivered to non-households [1000 m³]	wdelnh	Output	487,598	0.00	1,346	353	58,800	4,000
Network length [km]	net	-*	156,834	39	433	224	7,858	675
Population [1000]	pop	-**	32,373	5.00	89	35	3,400	233
Output density [1000 m³ per km of network]	dens	Structural var.	-	1.02	10.46	9.25	52.94	5.61
Leak ratio	leak	Structural var.	-	0.01	0.10	0.09	0.30	0.06
Groundwater ratio	ground	Structural var.	-	0.00	0.57	0.71	1.00	0.42
Elevation difference [m]	elev	Structural var.	-	0.00	53.82	40.00	240.00	47.36
Dummy for East Germany	deast	Structural var.	65	0.00	0.18	0.00	1.00	0.38

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

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5. Correlation matrix

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

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6.1 Efficiency scores and regression on structural variables

- **Efficiency scores – Stage 1:**
  - **340 utilities – 33 outliers deleted (critical value: 1.2)**
  - **Mean efficiency score: 0.64**
- **Regression – Stage 2:**
  - **Higher density, groundwater ratio and location in East Germany have a positive impact on efficiency scores**
  - **Leak ratio and higher elevation differences have a negative impact on efficiency scores**

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

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

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6.2 Regression on structural variables

- **Problem: leak ratio can not be included due to endogeneity**
- **Conduct second regression analysis (#2) using all structural variables, except the leak ratio**

- **Next problem: Use all structural variables for input adjustment or only the significant ones?**
- **Conduct third regression analysis (#3), only using the significant variables from regression #2**

- **Selection of most appropriate model specification using**
  - **AIC, BIC, Log-Likelihood value, LR Test**
  - **Model 3 is more appropriate**
  - **LR test: LR value 2.29 is lower than the corresponding χ^2 value (5.99) at a significance level of 5%**

6.2 Regression on structural variables

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

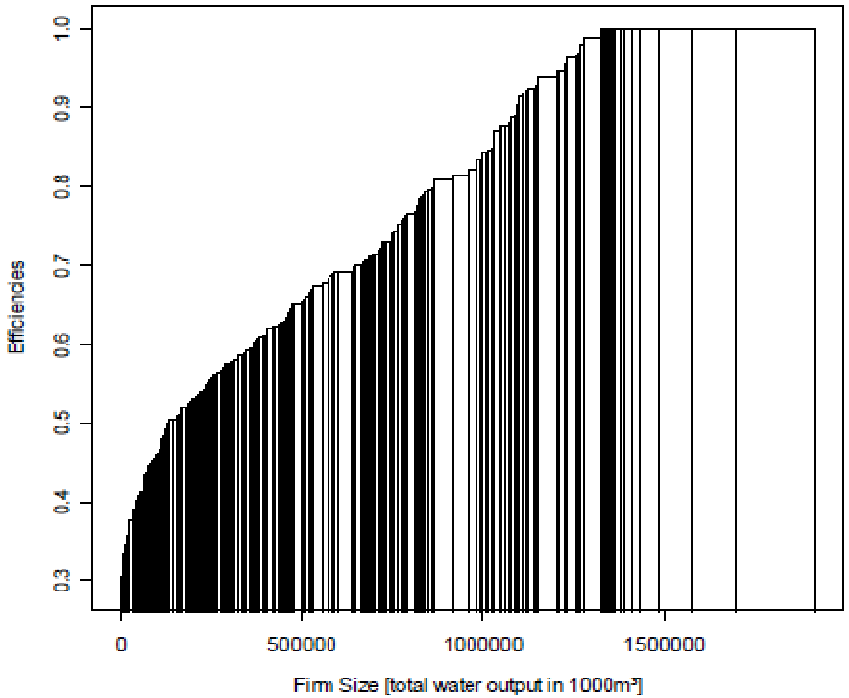
* significant at 5%, ** significant at 1%. Standard errors in parentheses.

6.2 Final efficiency scores and interpretation

- **Inclusion of significant structural variables output density and groundwater ratio**
- **Mean efficiency scores increase from 0.6424 to 0.6459**
- **Median increases slightly from 0.6050 to 0.6094**

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

6.3 Salter diagram and interpretation



- **Smaller water utilities with low amounts of total water output have lowest efficiency scores**
- **Highest efficiency scores obtained by smaller and larger water utilities**
- **Using VRS approach, inefficiencies can not be caused by scale diseconomies**

- **There seem to be cost disadvantages for smaller utilities**
- **Assuming all residual inefficiencies after stage 3 can not be assigned to structural differences, the upper left area of the graph represents potential for price decreases!**

- ***INEFFICIENCY = PRICE DECREASES***

6.4 Comparing East and West Germany

- **Dummy variable shows no significant impact in regression analysis**
- **Median of efficiency in East Germany is higher (0.613) than in West Germany (0.606)**
- **Also only weak differences in mean efficiency scores (East 0.657 respectively West 0.643)**

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

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7. Conclusions

- **Efficiency scores show a relatively small mean level of 0.65**
  - **High potential for cost savings and price decreases in water supply**
- **Leak ratio significant, but endogenous**
  - **possible underinvestment in companies with high leak ratio**
  - **network maintenance should be prioritized in municipal investment**
- **Striking inefficiency of small water utilities raises question of adequate supply structure**
  - **Solution: mergers?!**
- **Inefficiencies show the necessity of active price regulation**
  - **upcoming regulation: decreasing price caps – incentives to save costs**
  - **careful selection of variables and exogenous circumstances**

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Thank you very much for your attention!

Any questions or comments?

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References

- Banker, R.D., Chang, H. (2006) The Super-Efficiency Procedure for Outlier Identification, not for Ranking Efficient Units, *European Journal of Operational Research*, 175, 1311-20.
- Banker, R.D., Gifford, J.L. (1988) A Relative Efficiency Model for the Evaluation of Public Health Nurse Productivity, Mellon University Mimeo, Carnegie.
- Bundesverband der Energie- und Wasserwirtschaft (2008) 118. Wasserstatistik Bundesrepublik Deutschland 2006, wvgw Wirtschafts- und Verlagsgesellschaft Gas und Wasser mbH, Bonn.
- Fried, H.O., Schmidt, S.S., Yaisawarng, S. (1999) Incorporating the Operating Environment into a Nonparametric Measure of Technical Efficiency, Journal of Productivity Analysis, 12, 249-267.
- García-Sánchez, I.M. (2006) Efficiency Measurement in Spanish Local Government: The Case of Municipal Water Services, *Review of Policy Research*, 23, 355-71.
- Hirschhausen, C.v., Cullmann, A., Walter, M., Wand, R., Zschille, M. (2008) Quo Vadis Efficiency Analysis of Water Distribution? A Comparative Literature Review, *Efficiency Analysis Working Papers WP-EA-18*, Dresden University of Technology.
- Picazo-Tadeo, A.J., Sáez-Fernández, F.J., González-Gómez, F. (2008) Does Service Quality Matter in Measuring the performance of Water Utilities? *Utilities Policy*, 16, 30-38.
- Renzetti, S., Dupont, D. (2008) Measuring the Technical Efficiency of Municipal Water Suppliers: the Role of Environmental Factors, *Working Papers 0802*, Brock University, Department of Economics.
- Simar, L., Wilson, P.W. (2002) Nonparametric Tests of Return to Scale, *European Journal of Operational Research*, 139, 115–132.
- Tupper, H.C., Resende, M. (2004) Efficiency and Regulatory issues in the Brazilian Water and Sewage Sector: An Empirical Study, *Utilities Policy*, 12, 29-40.