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## Cost structure and economies of scale in German water supply

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# Cost structure and economies of scale in German water supply\*

Michael Zschille †

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## Abstract

Potable water supply in Germany is highly fragmented. A consolidation of the industry could, therefore, lead to lower cost of water supply and price savings for the customers. In this paper we estimate a total cost function for potable water supply based on a unique sample of German water utilities observed between 2004 and 2010. Newly available data allows for a detailed cost modeling approach. Capital stocks are estimated using the Perpetual Inventory Method, while capital costs are estimated using a weighted cost of capital approach. Local water suppliers are found to have strong cost advantages compared to regional suppliers. While the results indicate strong density effects, economies of scale are only found for the smallest water utilities. Thus, the results argue against a consolidation of the industry.

*JEL-Codes:* C14, L22, L95, Q25

*Keywords:* Water supply, cost function, economies of scale, seemingly unrelated regression

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# 1 Introduction

As the stable and safe provision of potable water is of vital importance for society, it is a major network infrastructure service. In general, the value-added chain of potable water supply consists of three steps: raw water abstraction and treatment, the transmission of treated potable water, and the distribution of potable water to final customers. Different vertical arrangements along the value-added chain are possible, with partially or fully integrated water production and distribution utilities as well as disintegrated bulk water suppliers and potable water distribution companies. In Germany, water utilities can also be horizontally integrated into larger utilities that also provide other services, including electricity, natural gas, and district heating.<sup>1</sup>

In Germany, groundwater is the most important raw water resource and accounts for 61.1% of total raw water abstraction for potable water supply purposes. Surface water resources like river and dam water account for 30.4%, while wells and springs account for 8.5% of raw water abstraction (Statistisches Bundesamt, 2013).<sup>2</sup> In order to obtain potable water quality, the raw water is treated in water treatment plants, then transmitted and distributed to final customers or other water utilities over water transmission and distribution networks. In Germany, residential customers account for around 80% of potable water demand; businesses and other customers account for around 20% (Bundesverband der Energie- und Wasserwirtschaft, 2011).

Since potable water supply requires considerable infrastructure, including water abstraction and treatment plants as well as water transmission and distribution networks, the potable water industry faces a high share of fixed cost in total cost. In German potable water supply, fixed cost represent around 70% of total cost (Bundesverband der Energie- und Wasserwirtschaft, 2011). Based on year 2008 information, the cost of German potable water provision consists of 18.5% personnel costs, 18.3% depreciation, 16.6% energy purchases, 15.5% supply of services and 31.1% of other costs (Bundesverband der Energie- und Wasserwirtschaft, 2011).<sup>3</sup>

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<sup>1</sup>Such multi-output utilities also exist in other countries like Italy and Switzerland, see e.g. Farsi et al. (2008) or Fraquelli et al. (2004).

<sup>2</sup>In addition to river and dam water, shore filtrate and enriched groundwater are also considered as surface water (Bundesverband der Energie- und Wasserwirtschaft, 2011; Statistisches Bundesamt, 2013).

<sup>3</sup>Other costs include tax and interest payments for debt, concession fees, material costs

By German constitution, the provision of potable water supply is a municipal responsibility. The municipalities can decide about how to organize the provision of potable water. The local responsibility for potable water supply in Germany has led to a high fragmentation of the industry with 6,065 water utilities in 2010. Compared to 6,560 utilities in 2001, the water industry therefore shows a slow consolidation process, but remains fragmented. The distribution of water utilities over Germany shows strong disparities: based on 2010 numbers, 2,299 water utilities are located in the federal state of Bavaria and 1,334 in Baden-Wuerttemberg (Statistisches Bundesamt, 2013). Both states therefore account for almost 60% of the number of German water utilities, but only for around 28% of the population. In an international context, potable water supply is similarly fragmented in other countries, like Japan with 16,178 water utilities (Ministry of Health, Labor and Welfare, 2012) or Portugal with about 300 water utilities (De Witte and Marques, 2011; Marques and De Witte, 2011).<sup>4</sup> On the other hand, potable water supply is highly consolidated e.g. in England and Wales with 22 water utilities (Bottasso and Conti, 2009) or the Netherlands with 13 water utilities (De Witte and Marques, 2010).<sup>5</sup>

From a consumer perspective, the major interest is in the tariffs to be paid for potable water supply. The water tariffs vary widely across Germany (Rüster and Zschille, 2010). However, the extent to which tariffs differ can not only be explained by different service area characteristics leading to cost and thus to tariff differences, but also by inefficient service provision (Haucap et al., 2010). Therefore, the German Monopolies Commission recommended the introduction of an incentive regulation scheme in German water supply (Haucap et al., 2010). In addition to improving the cost efficiency of service provision in German water supply, the German Monopolies Commission repeatedly criticized the industry structure and recommended a consolidation of the industry (Haucap et al., 2010, 2012, 2013; Zimmer et al., 2014), arguing that larger utilities might benefit from scale advantages based on the idea of economies of scale, reduce the cost of potable water supply and, therefore, and other expenditures (Bundesverband der Energie- und Wasserwirtschaft, 2011).

<sup>4</sup>The Japanese potable water supply industry consists of 1,443 large water supply systems, 6,687 small water supply systems, 98 bulk water supply systems and 7,950 small private water supply systems (Ministry of Health, Labor and Welfare, 2012).

<sup>5</sup>The potable water industry in England and Wales consists of 12 water-only companies and 10 integrated water and sewerage companies (Bottasso and Conti, 2009).

reduce the tariffs for potable water supply charged to final customers.<sup>6</sup> Furthermore, it is arguable that larger water utilities might be better able to face the future challenges of water supply, like ensuring the availability of good quality raw water in sufficient quantities under changing climate conditions, fulfilling increasing quality standards for potable water supply or ensuring future investments in water treatment plants and network infrastructure. However, contrary to the recommendations of the German Monopolies Commission, the German Federal Government (Bundesregierung, 2010) decided against an incentive regulation scheme and against a consolidation of the industry.

The scientific literature provides a large number of studies on economies of scale in water supply across different countries around the world. Saal et al. (2013), Abbott and Cohen (2009) and Walter et al. (2009) provide extensive reviews of the empirical literature on the analysis of economies of scale in water supply. In countries with fragmented potable water supply industries, researchers usually find economies of scale, e.g. for France (Garcia and Thomas, 2001), Italy (Fraquelli et al., 2004), Japan (Urakami and Parker, 2011), and Portugal (Martins et al., 2012). However, the extent of the economies of scale estimates strongly differs between the countries and studies. For highly consolidated potable water industries like England and Wales (Saal and Parker, 2000, 2004; Saal et al., 2007) or the Netherlands (De Witte and Dijkgraaf, 2010), researchers usually confirm diseconomies of scale.<sup>7</sup> While the international evidence on economies of scale in potable water supply is mixed depending on the analyzed country and data sample, results usually indicate economies of scale for smallest water utilities. For output levels above a certain threshold value, results usually indicate diseconomies of scale. Few studies are available for Germany, e.g. by Sauer (2005) and Zschille (2014). These studies, however, have several drawbacks. The analysis of Sauer (2005) relies on a very small sample of only 47 rural

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<sup>6</sup>Economies of scale describe the relative change in the total cost of production based on a relative increase in outputs. If total cost relatively increase less than proportional to the relative change in outputs, a water utility is characterized by economies of scale and could benefit from an increase in output levels. If total cost relatively increase more than proportional to a relative change in output levels, a water utility could benefit from reducing output levels (Hanoch, 1970; Panzar and Willig, 1977).

<sup>7</sup>The evidence on economies in English and Welsh water supply differs for water-only companies and integrated water and sewerage companies, see Saal et al. (2013) for an overview.

water utilities. Zschille (2014), on the other hand, analyzes returns to scale in a production function framework and is, therefore, not able to analyze economies of scale in a cost analysis framework.

Therefore, in contrast to previous studies on German water supply, in this paper we provide a detailed cost function analysis of a larger sample of German water utilities, yielding empirical evidence on the economies of scale characteristics of the industry and potential cost savings from a restructuring of the industry, which might also lead to savings potentials for the customers. Newly available data provided by the German Federal Statistical Office and the statistical offices of the German *Länder* allows for the construction of a unique data sample on German potable water supply. Detailed cost and structural information allow for the modeling of the cost of water supply, including the estimation of capital stocks and capital costs. The data also allows for accounting for the impact of different operating characteristics and regional differences on the cost of water supply.

## 2 Methodology

The aim of this paper is to analyze German potable water supply in a cost function framework. The cost function represents the minimum cost of producing an output bundle  $y$  given input prices  $w$  and a production technology  $T$  and has the form (Chambers, 1988; Bogetoft and Otto, 2011):

$$c(w, y) = \min_{x \geq 0} [wx : (x, y) \in T] \quad (1)$$

The input prices are assumed to be strictly positive and exogenously given, i.e. the water utilities are price takers in the input markets. The output vector is assumed to be positive and fixed. Therefore, in order to minimize the cost of producing outputs  $y$  given input prices  $w$ , the inputs have to be chosen accordingly. Following Chambers (1988), costs are assumed to be non-negative. The cost function is further assumed to be non-decreasing, concave and continuous in input prices  $w$ , positive linearly homogeneous and non-decreasing in outputs  $y$ .

The econometric estimation of a cost function requires an assumption about the underlying functional form. While it is possible to assume a Cobb-Douglas functional form for the cost function estimation, it does not allow economies of scale estimates to vary with firm size and only yields an estimate of economies of scale at the approximation point of the cost func-



tion. Economies of scale estimates are, thus, constant across all firm sizes. Therefore, in line with the majority of analyses of economies of scale in the empirical literature, we assume a translog functional form for the total cost function to be estimated.<sup>8</sup>

The translog cost function has the form

$$\begin{aligned} \ln TC = & \alpha_0 + \sum_{k=1}^K \beta_k \ln y_k + \sum_{m=1}^M \gamma_m \ln w_m \\ & + \frac{1}{2} \sum_{k=1}^K \sum_{l=1}^K \delta_{kl} \ln y_k \ln y_l + \frac{1}{2} \sum_{m=1}^M \sum_{n=1}^M \zeta_{mn} \ln w_m \ln w_n \\ & + \sum_{k=1}^K \sum_{m=1}^M \eta_{km} \ln y_k \ln w_m + \sum_{r=1}^R \theta_r z_r + \lambda t + \epsilon \end{aligned} \quad (2)$$

with  $TC$  denoting total cost,  $y_k$  a set of  $k = 1, \dots, K$  outputs,  $w_m$  a set of factor prices of  $m = 1, \dots, M$  inputs,  $z_r$  a set of  $r = 1, \dots, R$  environmental factors,  $t$  a linear time trend,  $\beta_k$ ,  $\gamma_m$ ,  $\delta_{kl}$ ,  $\zeta_{mn}$ ,  $\eta_{km}$ ,  $\theta_r$  the parameters to be estimated, and  $\epsilon$  the error term. The model fulfills further symmetry conditions on the parameter estimates:

$$\delta_{kl} = \delta_{lk}, \quad \zeta_{mn} = \zeta_{nm} \quad (3)$$

Applying Shephard's Lemma (Shephard, 1953), the input share equations are obtained as

$$s_m = \gamma_m + \sum_{n=1}^M \zeta_{mn} \ln w_n + \sum_{k=1}^K \eta_{km} \ln y_k \quad (4)$$

with  $s_m$  denoting the share of input  $m$  in total cost.

Linear homogeneity in input prices is imposed through additional parameter restrictions:

$$\sum_{m=1}^M \gamma_m = 1, \quad \sum_{k=1}^K \sum_{m=1}^M \eta_{km} = 0, \quad \sum_{m=1}^M \sum_{n=1}^M \zeta_{mn} = 0 \quad (5)$$

For linear homogeneity in input prices, we further drop the input share equation of a chosen input factor, in our case the price of other inputs. The

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<sup>8</sup>See Saal et al. (2013) for an overview.

translog cost function satisfies the general properties of a cost function of being non-negative and continuous (Henningsen, 2014). After estimating the translog cost function, we can further test if the estimated cost function fulfills the general cost function properties of being non-decreasing in input prices  $w$  and outputs  $y$  as well as of being concave in input prices. Following Henningsen (2014), a cost function is non-decreasing in input prices if the predicted cost share equations are non-negative. The cost function is non-decreasing in outputs if the cost flexibility, i.e. the sum of the derivatives of the cost function with respect to outputs, is non-negative. In order to check for the concavity of the cost function with respect to input prices, we check for the negative semi-definiteness of the Hessian matrix of the cost function (Henningsen, 2014).

The system of the total cost function and the input share equations is estimated using the iterated Seemingly Unrelated Regression Estimation (SURE) approach proposed by Zellner (1962).

Based on the estimated total cost function it is possible to derive an estimate of economies of scale. Economies of scale represent the relative change in the total cost of water supply relative to a proportional change in all  $k = 1, \dots, K$  outputs. Formally, economies of scale (*EOS*) are defined as

$$EOS = \left( \sum_{k=1}^K \frac{\partial \ln TC}{\partial \ln y_k} \right)^{-1} \quad (6)$$

For a value of  $EOS > 1$ , a company is characterized by economies of scale and could thus benefit from an increase in firm size since the cost of service provision would increase less than proportional to a relative increase in all outputs. For  $EOS < 1$ , a company is characterized by diseconomies of scale and is too large compared to optimal firm size and would thus benefit from reducing output levels (Hanoch, 1970; Panzar and Willig, 1977).

### 3 Data

The analysis is based on data provided by the Research Data Centers of the German Federal Statistical Office (*Statistisches Bundesamt*) and the Statistical Offices of the German *Länder*.<sup>9</sup>

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<sup>9</sup>Zschille (2016) describes the data in more detail and provides information on the construction of each variable used in the analysis. For data protection, we only have

The data sample is constructed by combining statistics on the cost structure of energy and water utilities (*Kostenstrukturerhebung der Unternehmen der Energie- und Wasserversorgung*) and annual report statistics of public enterprises (*Statistik der Jahresabschlüsse öffentlicher Fonds, Einrichtungen und Unternehmen*), containing the companies' profit and loss accounts and balance sheets.<sup>10</sup> Furthermore, the supply structures of the water utilities (*Erhebung über die öffentliche Wasserversorgung*) are combined with the cost data over individual company identifiers. The data also contains the official municipal identification number of each individual service area the water utilities are operating in. This allows us to combine the cost and structural data on the water utilities with additional municipal data to characterize the service areas based on municipal data surveys (*Statistik lokal*) provided by the German Federal Statistical Office. While many water utilities only supply water in one service area, as defined by the official municipal identification number, some water utilities also supply water in more than one service area, i.e. in more than one municipality. It is possible that two or more water utilities supply water to different areas in one municipality, which, thusly, have the same official municipal identification number. Since the municipal data is only available on the level of these official municipal identification numbers, it is not possible to further differentiate the service areas in such situations. Considering such service areas in the analysis would thus lead to biased variable definitions.<sup>11</sup> Consequently, we ignore municipalities with more than one water utility and, therefore, water utilities operating in service areas with more than one operator.<sup>12</sup>

Financial data and information about the municipalities are available for the years 2003-2012. However, the physical data on water utilities, including

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remote access to the data. Furthermore, we are not allowed to report numbers or other information that could facilitate the identification of individual companies in the data. We can therefore only report 1%- and 99%-quantiles instead of minimum and maximum values.

<sup>10</sup>The annual report statistics of public enterprises contain information on public enterprises with a share of private shareholders of less than 50%.

<sup>11</sup>Since the available information does not allow to e.g. split up the area size of a municipality in case two or more water utilities are supplying potable water in the municipality, the full area size would be used for every water utility and would thus lead to biased results.

<sup>12</sup>To ensure the full representation of all service areas belonging to a water utility, we further ignore all water utilities for which the information about individual service areas are incomplete.

characteristics of their supply structures and water volumes, are only published every three years and are available for 2004, 2007 and 2010. Therefore, after combining the financial data with the information about water volumes and supply structures, we obtain panel data for the years 2004, 2007 and 2010. In order to ensure for the comparability of the water utilities in the sample, we focus on the analysis of water utilities only supplying potable water. Utilities supplying other services like electricity or natural gas besides water supply are neglected. The analysis of integrated utilities with the joint provision, e.g. of water and electricity supply services, might distort the results of the analysis through potential scope effects.<sup>13</sup> Ensuring the comparability of the water utilities in the sample, we ignore bulk water suppliers without water deliveries to final customers and with water deliveries to other water utilities only. Further deleting observations with missing or erroneous data, the final sample contains 665 observations with 247 observations in 2004, 221 observations in 2007 and 197 observations in 2010.<sup>14</sup>

Table 1 provides summary statistics of the input and output variables as well as environmental variables used in the analysis. Table 2 provides summary statistics of the considered dummy variables.

### 3.1 Total cost and input price measures

The aim of the analysis is to estimate a total cost function for the sample of water utilities. Total cost  $TC$  are defined as the sum of expenses for labor, capital and other inputs. The price of labor  $wL$  is calculated as the cost of labor divided by labor input  $xL$ . Labor input is measured as the number of full time equivalents in the water utility. The cost of labor contains salaries as well as mandatory and other social security payments as reported in the companies' profit and loss accounts.

The price of capital  $wC$  to be included in the total cost function estimation is calculated as the ratio between estimated capital cost and the

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<sup>13</sup>Furthermore, the data does not allow for a clear division of costs and inputs between the different services. Since water utilities in Germany are often integrated with other services, the number of observations for the analysis reduces significantly. However, in order to ensure the comparability of the water utilities in the sample, it is necessary to focus on utilities with water supply services only.

<sup>14</sup>In addition to guaranteeing the comparability of the water utilities in the sample, the assumed translog functional form does not allow for the consideration of zero outputs. While the number of observations only represents a small share of German water utilities, the use of the restricted sample is necessary for an appropriate analysis.

Table 1: Descriptive statistics of input, output and environmental variables

	Q1	Median	Mean	Q99	Std. dev.
Total cost					
TC [1000 Eur]	259.15	880.88	1,285.36	9,685.29	1,660.43
<i>Input quantities</i>					
Number of Employees					
xL [FTE]	0.10	3.00	4.79	47.92	8.20
Capital stock					
xC [1000 Eur]	1,021.23	4,454.47	7,034.33	38,550.95	9,078.00
Water input					
xO [1000 m <sup>3</sup> ]	243.56	581.00	775.25	5,465.72	873.35
<i>Input prices</i>					
Labor					
wL [Eur]	435.74	45,334.29	43,931.94	90,656.56	21,184.35
Capital					
wC [Eur]	0.05	0.09	0.10	0.16	0.02
Other inputs					
wO [Eur]	107.07	521.66	570.11	1,531.14	305.21
<i>Output variables</i>					
Final water deliveries					
yWdel [1000 m <sup>3</sup> ]	243.56	581.00	775.25	5,465.72	873.35
Population served					
yPop [number]	3,836.88	10,122.00	13,282.21	102,597.00	15,101.06
Service area size					
yArea [ha]	162.28	558.00	872.20	7,855.24	1,277.62
<i>Environmental variables</i>					
Water losses					
zWL [ratio]	0.0022	0.0922	0.1058	0.3549	0.0786
Purchased water input					
zWP [ratio]	0.0000	0.3364	0.4433	1.0000	0.4192
Groundwater usage					
zWG [ratio]	0.0000	0.5530	0.5049	1.0000	0.4498
Bulk water supplies					
zBW [ratio]	0.0000	0.0000	0.0149	0.3214	0.0564
Residential water deliveries					
zHH [ratio]	0.4734	0.8707	0.8533	1.0000	0.1146
Settlement density					
zSR [ratio]	0.0588	0.1526	0.1623	0.3470	0.0656

Table 2: Descriptive statistics of dummy variables

	Q1	Median	Mean	Q99	Std. dev.	Sum
Private governance						
dPV [binary]	0.0000	0.0000	0.0406	1.0000	0.1975	27
Local supplier						
dLoc [binary]	0.0000	1.0000	0.7594	1.0000	0.4278	505
<i>River basins</i>						
Donau						
dWEG1 [binary]	0.0000	0.0000	0.0571	1.0000	0.2323	38
Rhein						
dWEG2 [binary]	0.0000	1.0000	0.8481	1.0000	0.3592	564
Ems						
dWEG3 [binary]	0.0000	0.0000	0.0105	0.3600	0.1021	7
Weser						
dWEG4 [binary]	0.0000	0.0000	0.0466	1.0000	0.2110	31
Elbe						
dWEG5 [binary]	0.0000	0.0000	0.0271	1.0000	0.1624	18
Oder						
dWEG6 [binary]	0.0000	0.0000	0.0000	0.0000	0.0000	0
Küste und Meer						
dWEG9 [binary]	0.0000	0.0000	0.0105	0.3600	0.1021	7

companies' estimated capital stocks  $xC$ . According to Coelli et al. (2003), we define capital cost as the sum of depreciation and interest expenses. For this purpose, we use the information on depreciation reported in the companies' profit and loss accounts including depreciation on tangible and intangible fixed assets as well as on short-term and financial assets. Interest expenses on debt are obtained from the profit and loss accounts. However, for a full interest measure it is further necessary to account for the opportunity cost of equity. In line with other applications in the empirical literature, we apply the weighted average cost of capital (WACC) model for this purpose.<sup>15</sup> Details of the WACC model are presented in Appendix A. We estimate capital stocks using the Perpetual Inventory Method (PIM). Details on this approach are presented in Appendix B.

The price of other inputs  $wO$  is defined as the expenses for raw materials and supplies as reported in the profit and loss accounts, divided by the total amount of water intake  $xO$ . The expenses for raw materials and supplies contain expenses e.g. for electricity and chemicals as well as purchased water, i.e. expenses for own water production and purchasing water. We divide these expenses by the total amount of water intake, defined as sum of own water production and purchased water volumes to define the price for other inputs.

### 3.2 Output measures

We define three variables to characterize the water utilities' distribution outputs: the amount of water delivered to final customers and to other water utilities, the population supplied and the service area size. While the amount of delivered potable water  $yWdel$  is the main output of the water utilities, the transmission and distribution networks as well as connections to the customers are necessary for water output provision and can therefore be considered as additional outputs. Information on the number of connections to customers and on the networks however are not available in the data. Therefore, we use the population served  $yPop$  as a proxy variable for the number of connections and the size of the service areas  $yArea$  as a proxy for network lengths.<sup>16</sup> Similar output specifications were applied e.g. by De Witte

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<sup>15</sup>See e.g. Mosheim (2006) for another application of WACC for the cost analysis of water utilities in the U.S.

<sup>16</sup>While the information on water volumes and the supplied population are included in the statistics on the water utilities' supply structures, the service area size measure

and Marques (2010) and De Witte and Marques (2011) or recommended by Thanassoulis (2000).

### 3.3 Environmental variables

In order to account for the water utilities' operating environments, we further consider a set of different environmental variables. The results by De Witte and Marques (2010) indicate a cost increasing impact of high shares of water losses in water production and distribution. While water losses can be influenced by management to some extent, e.g. through better maintenance of the infrastructure, water losses also depend highly on other factors like topographical conditions and the type of soil. In line with other applications in the literature, we consider the share of water losses  $zWL$ , measured as the share of reported water losses and measurement differences in total water input, in our analysis. The sample average of water losses of around 10.6% is in line with the German average of around 10% (Statistisches Bundesamt, 2009).

The data sample contains different types of water utilities, including integrated water utilities with own water production and distribution, partially integrated water utilities which purchase treated water from other water utilities in addition to own water production and non-integrated distribution companies without own water production. Thus, the consideration of differences on the supply side of the water utilities is necessary. As shown e.g. by Urakami (2007), purchased water input can increase the total cost of water supply compared to own water production. We consider the share of purchased water input,  $zWP$ , in total water input as an additional control variable. We expect a cost increasing impact of the share of purchased water in total water input.<sup>17</sup>

Water utilities with own water production abstract raw water from different types of raw water resources. Raw water from groundwater resources usually is of higher quality and requires less treatment compared to raw water

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is obtained by aggregating the sizes of the individual service areas obtained from the municipal data surveys.

<sup>17</sup>Water utilities without or insufficient own water production usually purchase treated water from bulk water suppliers or other water utilities. Therefore, the cost of water production and treatment are part of the payment to the suppliers. The cost of purchased water input as well as the cost of own water production e.g. for chemicals and electricity are included in the cost measure for other inputs.



from surface water resources like rivers. Furthermore, capital expenditures might be lower than for example for dam water. In order to account for differences in water production technologies and treatment requirements for water utilities with own water production, we consider the share of groundwater input,  $zWG$ , in own water production. We expect a cost reducing impact of a higher share of groundwater input in own water production. On average, about 50% of the raw water for the water utilities in the sample originates from groundwater resources. Groundwater usage is thus lower than the national average of about 61% (Statistisches Bundesamt, 2013).

Some of the considered water utilities in our sample not only supply water to residential and industrial customers, but also to other water utilities. Such bulk water supplies enable the water utilities to sell large amounts of water over the existing network and transmission pipes and increase capacity utilization in water treatment plants. We take into account the share of bulk water supplies,  $zBW$ , in total water deliveries as an additional control variable. We expect cost to decrease with increasing shares of bulk water supplies. Similarly, the mixture of residential and non-residential customers can be assumed to have an impact on the cost of water distribution. For residential customers, the amount of water delivered per connection is usually lower than for industrial or large-scale customers, thus leading to lower capacity utilization rates. We take into account the share of water deliveries to residential customers,  $zHH$ , in overall water deliveries to final customers. We expect a cost increasing impact of a higher share of residential customers. The sample average share of residential water deliveries of 85% is similar to the national average of around 80% (Bundesverband der Energie- und Wasserwirtschaft, 2011).

In addition to the local supply of water within one municipality, water utilities might also deliver water to final customers in multiple municipalities. As shown by De Witte and Marques (2010), the local supply of water increases the efficiency of potable water supply compared to the provision of potable water in multiple municipalities. De Witte and Marques (2010) argue that this is evidence for the lack of economies of scale in potable water supply. In order to account for the possible impact on cost, we therefore define the dummy variable  $dLoc$  with a value of one if a water supplier is supplying water to final customers within one municipality as defined by a single municipal identification number only, and zero otherwise. Water utilities with more than one service area are characterized as regional suppliers. Based on the idea of economies of scale, we expect cost advantages of consolidated,

regional water utilities.

Since we consider the service area size as an output of the water utilities, the consideration of possible differences in service area characteristics is relevant, e.g. based on the amount of agricultural space, forests, lakes or mountains, that are located in a municipal area, but do not require water supply facilities or network infrastructure. Thus, we further consider the settlement density,  $zSR$ , defined as the size of the residentially and non-residentially settled area in the overall municipal area size, as another environmental variable.<sup>18</sup> We expect a cost reducing impact of denser service areas since less network infrastructure is required to supply a larger number of customers. The low settlement densities shown in Table 1 also indicate the dominance of rural areas in the sample.

In order to control for further regional differences between water utilities, e.g. weather conditions or water availability, we include dummy variables  $dWEG1-dWEG9$  for different hydrogeographical regions in our model.<sup>19</sup> For this purpose, we use the seven different river basins in Germany as defined by the EU Water Framework Directive, which differentiates between the *Donau*, *Rhein*, *Ems*, *Weser*, *Elbe*, *Oder*, and *Küste und Meer* areas. Most water utilities are located in the *Rhein* area; our sample contains no observations of water utilities in the *Oder* basin. For all other river basins, the number of observations is found to be low.

The water utilities in the sample are characterized by a range of public and private governance types. Besides the consideration of different ownership types only, fully publicly owned water utilities can also be characterized by a private governance type and are thus not under direct public management.<sup>20</sup>

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<sup>18</sup>The settled area contains residential and non-residential buildings and open areas, leisure areas, cemeteries and traffic areas.

<sup>19</sup>Martins et al. (2012) use a similar classification based on hydrogeographical regions.

<sup>20</sup>The water utilities in the data sample are characterized by different ownership types. In addition to fully publicly owned companies, we also observe mixed public and private ownership with a share of private involvement of up to below 50%. The annual report statistics provided by the Federal Statistical Office are only available for publicly owned companies with a share private shareholders of less than 50% and therefore we must restrict our analysis to such companies. However, beyond the differentiation between different types of ownership, the companies differ in their organizational forms, which might be based either on public or private law. The data does not contain information on fully privately owned water utilities or such with more than 50% of private shares. In total, we only observe very few companies in the sample that are characterized by mixed public and private ownership. Therefore, we decide not to focus on the impact of different ownership

Since public and private governance lead to different legal frameworks for cost calculations, like depreciation rates or the consideration of the cost of equity, a differentiation between these organizational types is meaningful for cost modeling. However, only 27 water utilities in the sample are characterized by private governance modes. We include a dummy variable  $dPV$  with a value of 1 for the water utilities with private governance modes.<sup>21</sup>

## 4 Results

Table 3 presents the coefficient estimates for the translog total cost function. All variables are corrected by their mean values and included in logarithms, so coefficient estimates can be interpreted as elasticities. Following micro-economic theory, a cost function is supposed to be concave in input prices, representing substitution possibilities between inputs when one input becomes relatively more expensive. Checking for the negative semi-definiteness of the Hessian matrix of the estimated cost function, the concavity property is fulfilled for 638 (96%) out of the total of 665 observations in the sample.

The translog cost function is non-negative and continuous in input prices, see Section 2. Linear homogeneity is imposed through parameter restrictions and by dropping the input share equation for other inputs. For 15 observations in the sample, we find the predicted cost share of labor input to be negative. Therefore, the estimated cost function is non-decreasing in input prices in all but 15 observations. The cost flexibility of the estimated cost function is found to be non-negative for all observations and therefore the estimated cost function is non-decreasing in outputs at all observations. The estimated cost function is therefore consistent with all micro-economic properties of a cost function at almost all data points.

### 4.1 Coefficient estimates for output and input price measures

The coefficient estimates for the linear output variables and the input price terms are all found to be positive and statistically significant at the 1%

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types on the water utilities' cost structures.

<sup>21</sup>A higher number of observations with private governance modes would allow for the estimation of separate cost functions for water utilities with a public or a private governance mode.

level. The magnitude of the output coefficient estimates indicate that an increase in the population served or in the service area size have a relatively stronger cost increasing impact than an increase in the amount of water delivered, which indicates the low marginal cost of water compared to the supply infrastructure like networks or connections. The input price coefficient estimates indicate the strong influence of capital on total cost, which is typical for network infrastructure industries. The results further indicate the relatively stronger cost influence of other expenditures, e.g. for electricity for water pumping requirements in raw water abstraction and treated water distribution or for chemical inputs for water treatment, compared to labor input.

## 4.2 Cost impact of the operating environment

In addition to the input and output measures considered in the total cost function, we also include a set of environmental variables and dummy variables for the river basins the water utilities are operating in. For model selection, we perform Likelihood Ratio tests to test the total cost function including all environmental variables and river basin dummy variables against restricted model specifications excluding the environmental variables, river basin dummy variables, or both. All restricted model specifications are rejected at the 1% level of significance in favor of the total cost function including both the set of environmental variables and the set of river basin dummy variables.

Considering the environmental variables included in the cost function, the estimated coefficients indicate a significant cost increasing impact of the share of purchased water input, thus indicating that water utilities purchasing treated water for distribution from other water utilities or bulk water suppliers face higher cost of water provision compared to own water production. This result is in line with our expectations, e.g. due to a possible double marginalization, and confirms similar findings in the literature, e.g. by Urakami (2007). While the purchased water input ratio shows a significant impact on total costs, the share of groundwater input is not found to be significantly different from zero. In order to characterize potable water distribution activities, the share of bulk water supplies and the share of water deliveries to residential customers are not found to have a significant impact on total costs. Furthermore, the share of water losses is not found to have a significant impact on total costs. The coefficient estimate for the dummy

Table 3: Regression results

Variable	Parameter	Estimate	Std. error	<i>t</i> -value
<i>intercept</i>	$\alpha_0$	14.276***	0.092	154.413
<i>yWdel</i>	$\beta_{Wdel}$	0.219***	0.072	3.045
<i>yPop</i>	$\beta_{Pop}$	0.516***	0.073	7.041
<i>yArea</i>	$\beta_{Area}$	0.284***	0.031	9.063
<i>wL</i>	$\gamma_L$	0.151***	0.003	47.355
<i>wC</i>	$\gamma_C$	0.478***	0.005	89.588
<i>yWdel*yWdel</i>	$\delta_{Wdel,Wdel}$	1.087***	0.248	4.392
<i>yPop*yPop</i>	$\delta_{Pop,Pop}$	0.744***	0.231	3.227
<i>yArea*yArea</i>	$\delta_{Area,Area}$	0.126*	0.068	1.857
<i>yWdel*yPop</i>	$\delta_{Wdel,Pop}$	-0.735***	0.120	-3.678
<i>yWdel*yArea</i>	$\delta_{Wdel,Area}$	-0.296***	0.103	-2.870
<i>yPop*yArea</i>	$\delta_{Pop,Area}$	0.086	0.098	0.875
<i>wL*wL</i>	$\zeta_{L,L}$	0.037***	0.003	13.809
<i>wC*wC</i>	$\zeta_{C,C}$	0.037***	0.003	13.809
<i>wL*wC</i>	$\zeta_{L,C}$	-0.037***	0.003	-13.809
<i>wL*yWdel</i>	$\eta_{L,Wdel}$	0.022	0.015	1.534
<i>wL*yPop</i>	$\eta_{L,Pop}$	-0.058***	0.014	-4.061
<i>wL*yArea</i>	$\eta_{L,Area}$	0.036***	0.006	5.625
<i>wC*yWdel</i>	$\eta_{C,Wdel}$	-0.099***	0.024	-4.140
<i>wC*yPop</i>	$\eta_{C,Pop}$	0.011	0.024	0.482
<i>wC*yArea</i>	$\eta_{C,Area}$	0.088***	0.011	7.841
<i>zWL</i>	$\theta_{WL}$	-0.025	0.119	-0.210
<i>zWP</i>	$\theta_{WP}$	0.122***	0.026	4.621
<i>zWG</i>	$\theta_{WG}$	-0.013	0.022	-0.592
<i>zBW</i>	$\theta_{BW}$	-0.174	0.168	-1.035
<i>zHH</i>	$\theta_{HH}$	-0.044	0.098	-0.454
<i>zSR</i>	$\theta_{SR}$	-0.664***	0.183	-3.616
<i>dPV</i>	$\theta_{PV}$	0.014	0.047	-0.294
<i>dLOC</i>	$\theta_{LOC}$	-0.151***	0.025	-6.135
<i>dWEG1</i>	$\theta_{WEG1}$	-0.041	0.035	-1.187
<i>dWEG3</i>	$\theta_{WEG3}$	-0.295***	0.087	-3.401
<i>dWEG4</i>	$\theta_{WEG4}$	-0.185***	0.041	-4.545
<i>dWEG5</i>	$\theta_{WEG5}$	0.014	0.058	0.238
<i>dWEG9</i>	$\theta_{WEG9}$	-0.395***	0.081	-4.884
<i>t</i>	$\lambda_t$	0.025**	0.010	2.520

\*\*\*, \*\*, \* indicate significance at 1%, 5% and 10% levels.

Multiple R-squared: 0.887011, adjusted R-squared: 0.881664

variable for water utilities with a private governance mode is not found to be statistically significant and therefore we cannot confirm significant cost differences between water utilities with public and private governance. However, this result might be explained by the low number of observations with a private governance mode. We find the settlement density to have a significant cost reducing impact. In line with our expectations, supplying water in areas with higher density and urbanization rates is thus found to be advantageous from a cost perspective. Furthermore, the significant negative coefficient estimate of the dummy variable for local water suppliers indicates cost advantages of supplying water only within one municipality compared to regional water supply. While this result might indicate stronger cost control abilities of local water utilities compared to larger, more regional entities, this result argues against mergers or cooperation between water utilities in order to realize possible scale or synergy effects and therefore provides strong evidence against economies of scale.

With regards to the consideration of the river basin dummy variables, we drop the dummy variable dWEG2 for the *Rhein* river basin. Coefficient estimates for the dummy variables for the *Ems*, *Weser* and *Oder* river basins are found to be statistically significant and negative, thus indicating significantly lower costs of water supply in these areas. The results indicate no significant impact of the *Donau* and *Elbe* river basins. The coefficient estimate for the linear time trend indicates a significant, but low increase in the total cost of water supply over the sample period.

### 4.3 Economies of scale estimates

As shown in Section 2, firm specific economies of scale estimates can be derived from the estimated cost function. Table 4 presents the summary statistics of the firm specific economies of scale estimates for the 665 observations in our sample. At the mean and median of all observations, economies of scale estimates are marginally lower than one, thus indicating almost constant scale economies. As further shown in Table 4, 407 out of the 665 observations in total are characterized by diseconomies of scale and can thus be considered as being too large compared to optimal scale size. The majority of observations would therefore not benefit from increasing firm sizes or a consolidation of the industry structure. This result confirms the strong cost advantages of local water suppliers, compared to consolidated, regional water utilities supplying potable water in more than one municipality.

Table 4: Economies of scale estimates

	Min	Q25	Median	Mean	Q75	Max
EOS	0.8159	0.9558	0.9870	0.9877	1.0190	1.1390
< 1	407					
= 1	0					
> 1	258					

The economies of scale estimates are further illustrated in Figs. 1-3. The figures illustrate the mostly strong economies of scale estimates for the smallest water utilities in the sample as represented by the amount of water deliveries and the served population. The estimated economies of scale decrease with increasing firm size levels. Diseconomies of scale are found for the majority of the largest water utilities. Unlike the behavior of the economies of scale estimates shown with regard to the amount of water deliveries and the served population, Fig. 3 shows no clear impact of the service area size. Economies and diseconomies of scale are similarly found for all different firm size levels.

Thus, the results indicate density effects based on increasing water output levels and an increase in the served population whereas no clear tendency is found for the service area size. This is in line with the coefficient estimate of the local supplier dummy variable, which indicates cost advantages of supplying water in one municipality instead of regional supply. The coefficient estimate of the share of settlement area in overall municipal area similarly indicates cost saving potentials from a higher settlement density in the existing service areas. Therefore, instead of increasing firm size through service area expansions, e.g. through mergers with neighboring water utilities, the results indicate that an increase in water output and population in existing service areas would be advantageous. However, since most inhabitants in a service area are typically already connected to a water supply system, such growth potentials are restricted and water utilities can not control such exogenous factors.

## 5 Conclusions

In this paper we analyze the cost structure of potable water supply based on a newly available and unique data sample of German water utilities. Unlike

Figure 1: Economies of scale estimates clustered by the amount of water delivered

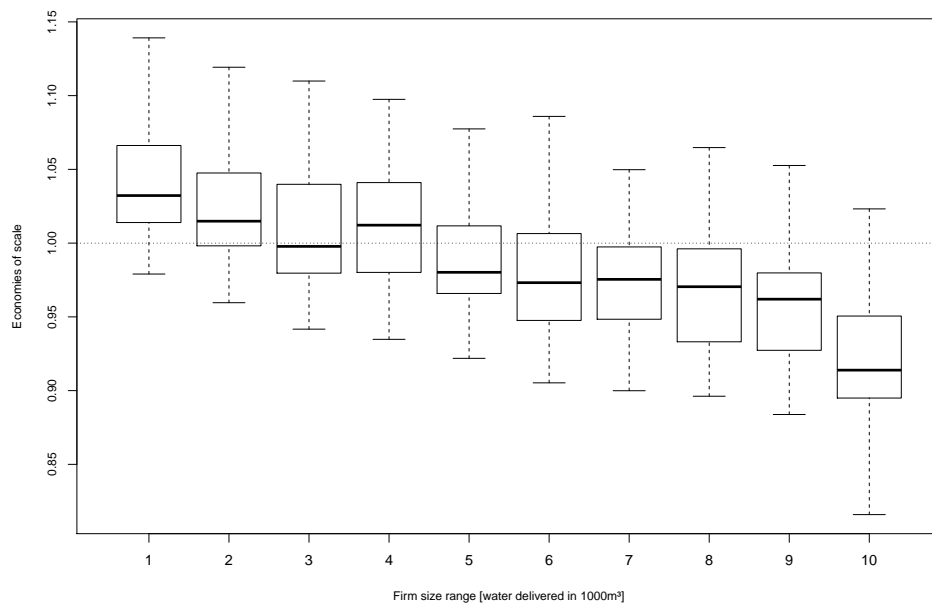




Figure 2: Economies of scale estimates clustered by population numbers

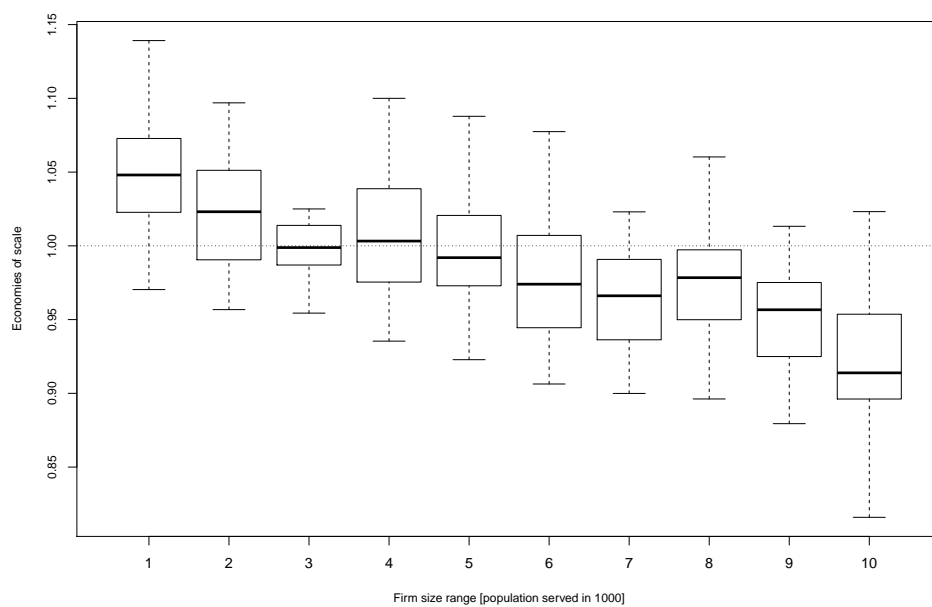
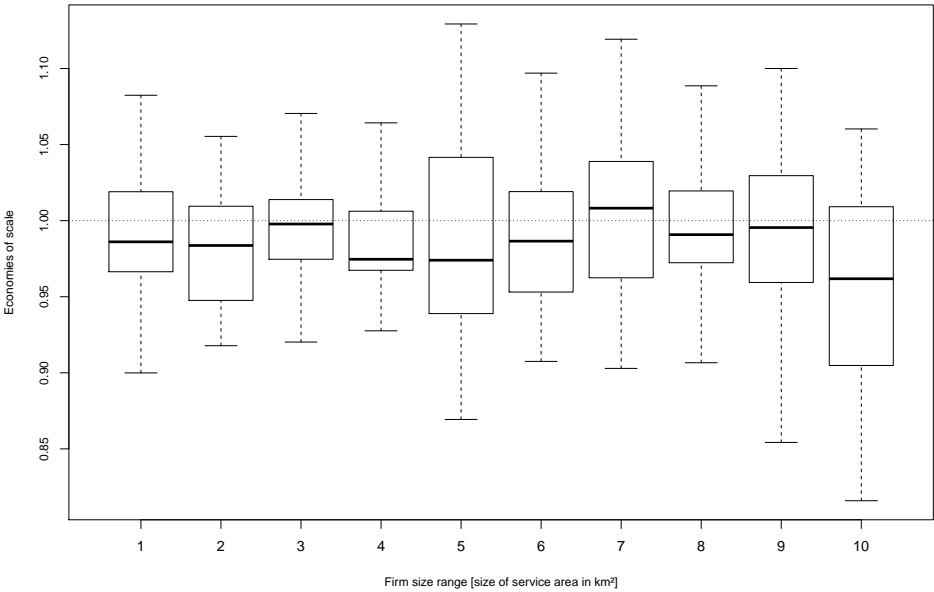


Figure 3: Economies of scale estimates clustered by service area sizes



previous studies on German water supply and most studies in the empirical literature, detailed accounting data allows us to consider a financial capital stock measure based on a Perpetual Inventory Method approach and a weighted average cost of capital measure in the analysis.

The considered independent variables indicate strong regional differences of water utilities between the German River Basins as defined by the EU Water Framework Directive. Compared to water utilities located in the *Rhein* river basin, the cost of potable water supply are mostly significantly lower for water utilities located in other river basins. Purchasing treated water from other water utilities is found to increase the total cost of drinking water provision which might be explained by a double marginalization problem. A higher degree of urbanization or settlement density is found to significantly decrease total cost, which can be explained by the lower capital requirements while outputs are higher. Such density effects might contribute to economies of scale and could lead to cost advantages. The results further indicate that local water suppliers operating only within one municipality have significantly lower cost than regional water utilities that supply water in more than one municipality. While the regional supply of water might lead to size advantages, this result indicates that the disadvantages of larger utilities seem to outweigh the advantages. This result therefore argues against the consolidation of the industry through service area expansions. While water utilities could benefit from density effects through increasing population numbers and water output levels, service area expansions are found to be disadvantageous.

The results thus indicate that economies of scale are only found for the smallest water utilities to a varying extent. While some water utilities are characterized by strong economies of scale estimates, for most utilities the estimates are rather low. Thus, only a few water utilities might be able to benefit from cost savings based on firm size increases. Further considering the possible cost disadvantages of larger regional suppliers, adjusting firm size might not be beneficial. These results are therefore in line with previous findings by Sauer (2005), who confirms strong economies of scale for the sample of small rural water utilities and the results by Zschille (2014), who finds similar evidence on the scale characteristics of German water utilities. Furthermore, Zschille (2015) analyzes the potential gains of hypothetical mergers between water utilities located in the same county and finds low overall potential benefits from such mergers and furthermore the scale benefits of such mergers are found to be mostly negligible.

As a result, there is no empirical evidence for major benefits of a consolidation of the German water supply industry as recommended by the German Monopolies Commission. The potential gains from adjusting firm sizes require a careful and profound consideration of the potential advantages and disadvantages from increasing firm size, e.g. through mergers with other water utilities. Potential cost advantages for water utilities are primarily based on higher densities within their service areas, i.e. through higher water output levels and higher population numbers. However, such developments are beyond the control of a water utility. Local authorities might consider such arguments in urban planning.

## A Weighted Average Cost of Capital

The weighted average cost of capital (WACC) are defined as

$$WACC = [(1 - g) * r_e] + (1 - t)[g * r_d] \quad (7)$$

with  $g$  denoting the leverage,  $r_d$  the cost of debt,  $r_e$  the cost of equity and  $t$  the company tax rate (Coelli et al., 2003). The leverage is defined as

$$g = \frac{debt}{(debt + equity)} \quad (8)$$

We obtain information on debt and equity from the companies' balance sheets.

We define the cost of debt as interest payments on debt divided by the total amount of debt of a company. We use the long term average of the cost of debt of each individual company over the sample period 2003-2010 to obtain a more reliable measure of the cost of debt and to balance out annual fluctuations.<sup>22</sup>

We estimate the company tax rate  $t$  as income tax payments divided by the companies' earnings before taxes. We obtain information on both income tax payments and the earnings before taxes from the companies' profit and loss accounts. As for the cost of debt, we use the average tax rate over the period 2003-2010 to balance out annual fluctuations over the sample period.

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<sup>22</sup>Since financial data on the water utilities is available between 2003 and 2010, we use this entire sample period for the determination of the average cost of debt instead of only using information the years 2004, 2007 and 2010, which we have to use for the cost function estimation since technical data on the water utilities is only available for these years.

The cost of equity is estimated based on the Capital Asset Pricing Model (CAPM). The CAPM is defined as

$$CAPM : r_e = r_f + \beta_e * (r_m - r_f) \quad (9)$$

with  $r_e$  denoting the cost of equity to be estimated,  $r_f$  the risk-free return,  $r_m$  the market return and  $\beta_e$  the risk factor (Coelli et al., 2003). The risk-free returns (*Umlaufrenditen inländischer Inhaberschuldverschreibungen*) based on data from Deutsche Bundesbank (2014) are adjusted for inflation using the consumer price index for Germany, provided by Statistisches Bundesamt (2014b). For both the risk-free returns and the consumer price index we use 10 year average values to obtain more reliable estimates.

The risk factor  $\beta$  is based on Hern et al. (2009) with an unleveraged  $\beta = 0.38$ . We assume the equity risk premium  $ERP = r_m - r_f$  with a value of  $ERP = 0.0455$ , which is used by Bundesnetzagentur (2008) for the electricity and natural gas industry. Since the  $ERP$  is not industry specific, we also use this value of the  $ERP$  for our analysis of the water industry.

With the information at hand it is possible to estimate the cost of equity based on the CAPM approach, which is then used for the estimation of the weighted average cost of capital and finally the overall capital cost  $cC$  as follows:

$$cC = \text{depreciation} + WACC * (\text{debt} * \text{equity}) \quad (10)$$

## B Perpetual Inventory Method

Instead of using nominal capital stocks reported in the companies' balance sheets, capital stock values are corrected for inflation for our analysis. We apply the Perpetual Inventory Method (PIM) for this purpose, which has the form

$$K_{t+1} = (1 - \delta) * K_t + \frac{I_t}{PI_t} \quad (11)$$

with  $K_t$  denoting the capital stock value in period  $t$ ,  $\delta$  the depreciation rate of the capital stock,  $I_t$  the investments into the capital stock in period  $t$  and  $PI_t$  a price index to deflate investments.

PIM requires the definition of a base-period capital stock  $K_0$ . Cowing et al. (1981) suggest using a triangularized weighted average of a price index to deflate the first reported capital value in the data to ensure the deflation

of companies' investments before the first year of data in the sample.<sup>23</sup> This approach, however, requires information about the age of the companies, which is not available in our data. Therefore, we assume the first reported capital stock value for each company in the sample to be the base-period capital stock (usually 2003). We calculate the base period capital stocks as the difference between accumulated tangible and intangible fixed assets as well as financial assets and accumulated depreciation on these assets as reported in the companies' summaries of fixed assets.<sup>24</sup> The company specific depreciation rate, annual investments and the price index are then used for the estimation of capital stocks in subsequent years. The company specific depreciation rates in year  $t$  are calculated as the ratio between reported depreciation in year  $t$  and the reported capital values in year  $t$ . As for the cost of debt and company tax rates in the estimation of capital cost, we use the average depreciation rates over the entire sample period, usually 2003-2010. Investments  $I_t$  are defined as the difference between the reported end-of-year and beginning-of-year accumulated capital stock values in the companies' summaries of fixed assets. Investments are deflated by using the investment goods price index (for the water industry) provided by Statistisches Bundesamt (2014a). The base year for deflation is 2010.

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<sup>23</sup>See Gilsdorf (1994) or Nemoto and Goto (2004) for possible applications.

<sup>24</sup>As a result, our capital stock measure contains: intangible fixed assets; land and buildings; machines; technical equipment for water production, purchases, treatment, transmission and distribution; cars and transportation equipment; fixtures and furnishings; financial assets.

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