Scale and scope economies of German electricity and gas distribution networks

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Abstract

The German electricity and gas distribution sectors are characterized by an exceptionally fragmented structure. There are currently 1076 network operators distributing electricity or gas in Germany. This number contrasts sharply with other European countries which feature a significantly smaller number of network operators. The question arises whether or not this highly fragmented structure with a lot of of small distributors is cost efficient. A suboptimal, and therefore cost inefficient sector structure induces welfare losses in the form of too high network charges for end consumers. It is therefore the aim of this paper to analyze the cost structure of German electricity and gas distribution. The focus lies on the estimation of scale and scope economies as these determine the cost efficient configuration of the industry.

Keywords: electricity distribution, gas distribution, cost efficiency, economies of scale, economies of scope

JEL classification: D22, L10, L97

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1. Introduction

As a result of federalism and regional monopolies from the time before liberalization, the German electricity and gas distribution sector is characterized by an exceptionally fragmented structure. According to the German regulator, the Bundesnetzagentur, there are 1076 electricity and gas distributors in Germany in the year 2016 from which 537 are integrated electricity and gas distributors and 539 specialized network operators only active in electricity or gas distribution (Bundesnetzagentur, 2016). These numbers contrast sharply with other European countries that feature a significantly smaller number of network operators: For example, Great Britain has only 14 electricity and 8 gas distribution networks (Office of Gas and Electricity Markets, 2017*a*,*b*), while in the Netherlands there are eight integrated electricity and gas distributors Also France, which is comparable in its energy consumption to Germany, has 160 electricity and 25 gas distribution network operators .

Even though the structure of the electricity and gas distribution sector in Germany was shaped in the times before liberalization, one could not observe a structural change in the last years. One possible reason for this is that small network operators take on a special role in the incentive regulation regime of the Bundesnetzagentur. According to the Incentive Regulation Ordinance (ARegV), network operators with less than 30.000 customers connected to their electricity grid or with less than 15.000 customers connected to their gas grid do not have to participate in the efficiency benchmarking of the Bundesnetzagentur. Instead, they can choose to participate in the 'simplified procedure' and accordingly face the weighted average of all efficiency levels of the network operators that participate in the national efficiency benchmarking (§ 24 ARegV). In addition, small network operators that are taking part in the efficiency benchmarking are not penalized for being too small because of the assumption of non-decreasing returns to scale in the utilized Data Envelopment Analysis (DEA) benchmarking model. Yet, from the next regulatory period on, beginning 2018 for gas and 2019 for electricity, the assumption of non-decreasing returns to scale will be released and instead constant returns to scale will be assumed for the DEA efficiency benchmarking. This way, the efficiency pressure applies to all network operators taking part in the efficiency benchmarking no matter their size (Anlage 3 zu § 12 Absatz 4 ARegV).

As network industries are subject to scale economies due to their high capital intensity, the question arises whether this highly fragmented structure in Germany is cost efficient. A cost inefficient sector structure induces welfare losses in the form of too high network charges for end consumers. It is therefore the aim of this paper to analyze the cost structure of the German electricity and gas distribution sector. The focus lies on the estimation of scale and scope economies as these determine the cost efficient configuration of the industry. The analysis is based on a data set of German electricity and gas distributors covering 1099 observations for the years 2011 until 2014. The data set consists of publicly available data from the annual statements of the network operators as well as technical data provided by ene't. The data set is unique in its size and scope for Germany and thus allows for the first analysis of scale and scope economies in the liberalized German electricity and gas distribution sector.

The rest of the paper is organized as follows. Section 2 gives an overview of the literature already published in this field, while Section 3 specifies the model that will be used for the analysis and provides the theoretical background for calculating scale and scope economies. Section 4 describes the econometric model and the data. Section 5 presents and discusses the results and Section 6 concludes.

2. Literature

The analysis of the cost structure of energy suppliers has been of high political importance since the liberalization of the energy sector, as the exact knowledge of the cost structure is an important prerequisite for identifying the cost efficient industry structure and thus a corresponding regulatory design. In this context, the literature has dealt with the analysis of scale and scope economies of vertically integrated energy generation and distribution as well as of horizontally integrated distribution networks. For example, Farsi et al. (2007) estimated a quadratic cost function for a sample of 87 electricity, gas and water distribution utilities in Switzerland using panel data, whereas Fetz and Filippini (2010) estimated a quadratic multi-stage cost function for a sample of 74 Swiss electricity distribution and generation companies. Both studies estimated a random effect panel data model and a random-coefficient model and, thereby confirm the existence of significant economies of scale and scope. Moreover, these studies indicate that economies of vertical integration are largest for those companies operating below the median output. Kaserman and Mayo (1991) and Kwoka (2002) estimated a quadratic multi-stage cost function for a cross section of 74 and 147 electricity generation and distribution companies in the United States, respectively. Both studies found that economies of vertical integration exist for firms producing the median output, while smaller and larger companies at times show diseconomies of scope.

Triebs et al. (2016) estimated a firm type flexible translog function for a pooled sample of 436 local government owned electricity generation and distribution utilities operating in the US. They find evidence for both economies of scale and scope at the sample mean. Gilsdorf (1994) estimated a standard translog cost function for a sample of 77 electricity generation, transmission and distribution companies in the United Sates. He estimated the cost function using SUR for cross sectional data and found no evidence of cost complementarity between electricity generation, transmission and distribution. Nevertheless, his results suggest the existence of product-specific scale economies for each stage at the sample mean. Martinez-Budria et al. (2003) estimated a quadratic cost function for a pooled sample of 106 companies operating in electricity generation and distribution in Spain. They estimated the cost function using the SUR estimation procedure. Jara-Diaz et al. (2004) estimated a multistage-multiproduct quadratic cost function for an unbalanced panel of 106 Spanish electricity generation and distribution companies. They estimated a fixed effects model using SUR. Both studies indicate the existence of economies of scope for all output ranges, while increasing returns to scale are only observed at the mean of the production levels and decreasing returns are observed thereafter. Piacenza and Vannoni (2009) and Fraquelli et al. (2004) compared the composite cost function to the Standard Translog, Generalized Translog, and the Separable Quadratic for a pooled sample of 90 and 270 Italian gas and water distribution companies and vertically integrated electricity companies, respectively. Both studies used the non-linear counterpart of Zellner s SUR estimation and confirm the existence of global and product-specific economies of scope, as well as of global returns to scale. Fraquelli et al. (2004), however, only found this to be true for multi-utilities with output levels lower than the ones characterizing the median firm.

3. Model specification

The most general specification of the production process of multi-utilities is given by the transformation function $T(X, Y)$, where X is an n-dimensional vector of input levels and Y is an m-dimensional vector of output levels (Kaserman and Mayo, 1991). Provided that certain regularity conditions are satisfied, there exist cost and transformation functions which are dual to each other, meaning they contain the same information about the production frontier. Total cost of production for a firm can be expressed as $C(Y, P)$, where P is an n-dimensional vector of input prices. The regularity conditions on the cost function are that it be non-negative, real-valued, non-decreasing, strictly positive for nonzero Y and linearly homogenous and concave in P for each Y (Diewert, 1982; and (Baumol et al., 1982). Direct estimation of the production function is suitable in the case of endogenous outputs. As the estimation of scale and scope economies of utility companies is dealing with exogenous outputs, the estimation of the cost function is more appropriate (Christensen and Greene, 1976).

Before the estimation, one needs to choose a functional form of the cost function that appropriately represents the technology of the firms. Baumol et al. (1982) defined four desiderata for multiproduct cost functions which need to be fulfilled in order to correctly estimate scale and scope economies. The first property of flexibility requires that the cost function should not impose any restrictions on the first and second order partial derivatives. Second, properness presupposes that the cost function is non-negative, linearly homogeneous in input prices, concave in output, monotonic with respect to input prices, and has positive marginal costs. The third property, tractability, demands that the cost function is properly defined in the range of zero values. The last requirement is that the estimation of the cost function necessitates as least parameters as possible.

In the empirical literature the translog cost function is one of most popular functional forms as it is flexible in the sense that it makes no a priori assumptions on its first and second order derivatives; that is, it also does not assume constant elasticities and scale economies such as the Cobb-Douglas cost function. Yet, one drawback of the classic translog cost function is that it is unable to accommodate observations which contain zero values for some outputs. As we aim to estimate a cost function for both integrated and specialized distributors, this automatically involves observations with zero values for some of the outputs of the specialized firms. In order to overcome this problem, we use a flexible translog cost function that allows integrating type-specific technologies as proposed by Triebs et al. (2016). With $M(m = 1, ..., M)$ electricity distribution outputs and $K(k = 1, ..., K)$ gas distribution outputs the total cost function can be written as:

$$
\begin{aligned}
ln\,TC_{it} = I * [\alpha_0^I + \sum_{m=1}^{M} \alpha_m^I\, ln\,QE_{mit} + \sum_{k=1}^{K} \alpha_k^I\, ln\,QG_{kit} + \alpha_z^I\, ln\,ND_{it} \\
+ \frac{1}{2} \sum_{m=1}^{M} \sum_{n=1}^{M} \alpha_{nm}^I\, ln\,QE_{mit}\, ln\,QE_{nit} + \frac{1}{2} \sum_{k=1}^{K} \sum_{l=1}^{K} \alpha_{kl}^I\, ln\,QG_{kit}\, ln\,QG_{lit} \\
+ \sum_{m=1}^{M} \sum_{k=1}^{K} \alpha_{mk}^I\, ln\,QE_{mit}\, ln\,QG_{kit} + \sum_{t=2}^{T} \alpha_t^I\, DT_t] \\
+ E * [\alpha_0^E + \sum_{m=1}^{M} \alpha_m^E\, ln\,QE_{mit} + \alpha_z^E\, ln\,ND_{it} \\
+ \frac{1}{2} \sum_{m=1}^{M} \sum_{n=1}^{M} \alpha_{nm}^E\, ln\,QE_{mit}\, ln\,QE_{nit} + \sum_{t=2}^{T} \alpha_t^E\, DT_t] \\
+ G * [\alpha_0^G + \sum_{k=1}^{K} \alpha_k^E\, ln\,QG_{kit} + \alpha_z^G\, ln\,ND_{it} \\
+ \frac{1}{2} \sum_{k=1}^{K} \sum_{l=1}^{K} \alpha_{kl}^G\, ln\,QG_{kit}\, ln\,QG_{lit} + \sum_{t=2}^{T} \alpha_t^G\, DT_t] + u_{it}
\end{aligned} \tag{1}
$$

where TC represents total costs, QE electricity distribution outputs, QG gas distribution outputs, ND network density and DT time dummies which capture changes over time. The dummy variables I, E and G take the value one if the firm is integrated or specializes in electricity or gas distribution, respectively. The subscripts i and t denote the firm and year, respectively, and the αs and u are unknown parameters to be estimated.

Based on the estimated cost function, it is possible to derive an estimate of economies of scale and scope. In contrast to the single output case, multiproduct cost functions possess no natural scalar quantity over which costs can be averaged. Borrmann and Finsinger (1999) propose an approaches in order to generalize the concept of economies of scale: scale economies along a ray. Scale economies along a ray correspond to the case where an output bundle is considered that can only vary in fixed proportions. By means of the concept of ray average costs, one can generalize the definition of scale economies to the case of multiple products. The degree of scale economies defined over the entire product set is given by the ratio of total costs to the marginal cost of each product weighted with the contribution of the specific product to total output:

$$S_n(y) = \frac{C(y)}{\sum_{i=1,n} y_i \frac{\partial C(y)}{\partial y_i}} \tag{2}$$

Scale economies are said to be increasing, constant, or decreasing as $S_n(y)$ is greater than, equal to, or less than unity.

In addition to economies deriving from the scale of a firm s production, cost savings may result from the simultaneous production of multiple outputs compared to their production in isolation in specialized firms. Accordingly, scope economies are present if it is cheaper to jointly produce two or more products in one firm than it is to produce them separately in multiple firms (Mafoua and

Hossain, 2001). Thereby, all possible partitions of specialized production need to be considered. Scope economies can be defined for the n-product case which however necessitates a rather formal definition. Following Baumol et al. (1982) a nontrivial partition $P = \{T_1, ..., T_k\}$ (with $k > 1$) of $S \subseteq N$ is considered. That is,

$$\cup_i T_i = S \tag{3}$$

$$T_i \cap T_j = \emptyset \qquad \forall i \neq j \quad and \quad \forall T_i \neq \emptyset \tag{4}$$

Economies of scope exist at y_S with respect to the partition P if

$$\sum_{i=1}^{k} C(y_{T_i}) > C(y_S) \tag{5}$$

There are said to be weak economies of scope if the inequality in Equation 5 is weak rather than strict and diseconomies of scope if the inequality is reversed.

Following Triebs et al. (2016) for a measure of economies of scope with two outputs (in our case electricity and gas distribution), two subsets are considered, $E \in N$ and $G \in N$ such that $E \cup G = N$ and $E \cap G = \emptyset$. Let y_E denote the vector whose elements are equal to those of y for $i \in E$ and y_G denote the vector whose elements are set equal to those of y for $i \in G$. Similarly, $C(y_E)$ and $C(y_G)$ denote the cost of producing only the products in the subsets E and G, respectively. The degree of economies of scope between $y_E$and y_G is defined as

$$SC_{E,G}(y) = \frac{C(y_E) + C(y_G) - C(y)}{C(y)} \tag{6}$$

Scope economies are present if the separation of production increases, decreases or leaves unchanged the cost of production and thus if $SC_{E,G}(y)$ is greater than, less than, or equal to zero, respectively.

4. Data

The estimation is based on an unbalanced sample of German electricity and gas distributors for the years 2011 until 2014. The dataset consists of publicly available data from the annual statements of the network operators (profit and loss account and balance sheets) as well as technical data provided by ene't. German regulation prescribes financial unbundling of vertically integrated electricity and gas distributors (EnWG, 2005, ï¿ 6b). Since 2011, these are obliged to disclose separate balance sheets and profit and loss accounts for their activities in electricity and gas distribution, respectively. This allows an exact allocation of costs to the activity of distribution. The dataset comprises 1098 observations in total with 661 observations of integrated electricity and gas distributors, 283 observations of specialized electricity distributors and 154 observations of specialized gas distributors. The number of observations broken down into the type of firm as well as on the year is shown in Table 1. According to the Bundesnetzagentur, there are 537 integrated electricity and gas distributors, 344 specialized electricity distributors and 195 gas distributors in Germany in the year 2016.[1] Our sample thus corresponds to approximately one third of the German electricity and gas distribution sector in terms of the number of network operators in the years 2011 until 2013. The year 2014 shows fewer observations as only some of the network operators had already published their annual statements of the year 2014 by the time of data collection.

Table 1: Number of observations

	2011	2012	2013	2014	Total
Integrated	185	233	223	20	661
Electricity distribution	108	80	80	15	283
Gas distribution	35	58	55	6	154
Total	328	371	359	41	1098

The total amount of electricity and gas supplied by the network operators in the sample as well as the total number of connection points is shown in Table 2. Regarding the number of connection points, the electricity network operators in the sample correspond to almost one half of the connection points in Germany (approximately 49 million), while the gas distributors in the sample only cover 10 percent of the total number of gas connection points in Germany (approximately 38 million).

Table 2: Sample overview

	2011	2012	2013	2014
Electricity supplied (GWh)	414 484	483 809	694 166	65 273
Electricity connection points (number)	18 711 560	24 050 580	26 368 334	3 666 239
Gas supplied (GWh)	342 413	476 654	326 287	41 057
Gas connection points (number)	3 017 549	4 591 958	4 150 395	603 296

The structure of the electricity distributors in the sample is given in Figure 1. The figure shows the frequency distribution of electricity supplied and the number of connection points.[2] The figure illustrates that the sample mainly consists of relatively small electricity distributors. The largest electricity distributor in terms of both the amount of distributed electricity and the number of connected customers is Netze BW (formerly known as EnBW Regional) with a total of 243 TWh of distributed electricity and more than six million connected customers in the year 2013. Netze BW is a wholly-owned subsidiary of EnBW Energie Baden-Wï¿ rttemberg AG and is, next to electricity distribution, also active in gas distribution.

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[1] ï¿ bersicht Strom-und Gasnetzbetreiber; Status: 23.06.2016

[2] For reasons of clarity, the x-axis is cut off at 2 000 GWh of electricity supplied and 100 000 connection points. The network operators in the figure correspond to more than 90 percent of the network operators in the sample.

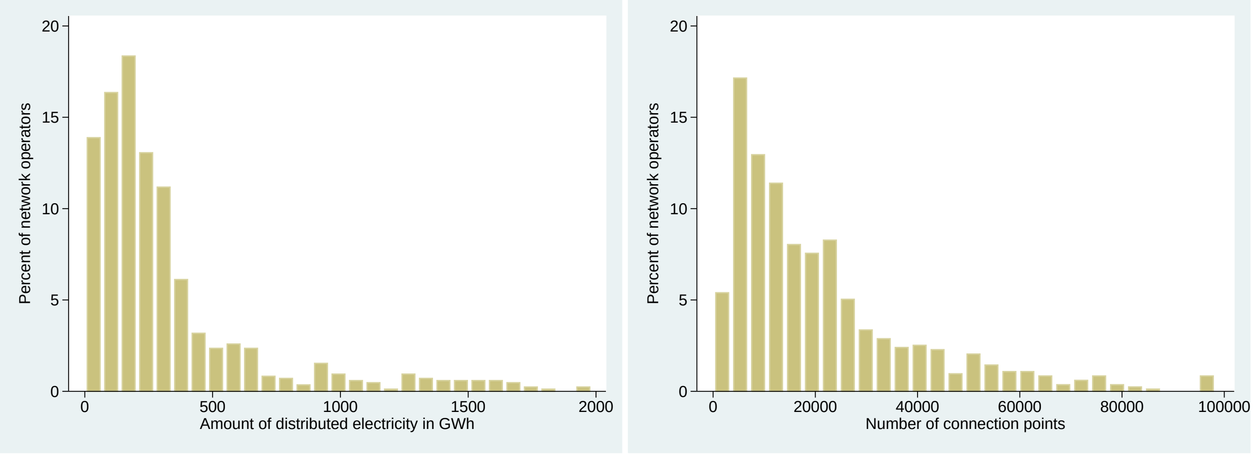

Figure 1: Amount of distributed electricity (left) and number of connection points (right) of electricity distribution

The structure of the gas distributors in the sample is given in Figure 2.[3] The figure illustrates a similar picture to the electricity distributors: the sample mainly consists of relatively small gas distributors, while there are only a few relatively large network operators in the sample. The largest gas distributor in terms of the amount of distributed gas is the Versorgungsbetriebe Hoyerswerda GmbH in Saxony with 110 TWh of distributed gas and 6 201 connected consumers in the year 2012. The Versorgungsbetriebe Hoyerswerda GmbH is a mixed public-private company with a majority stake held by the municipally owned SWH Stï¿ dtische Wirtschaftsbetriebe Hoyerswerda GmbH. The largest gas distributor in terms of connected customers is the NBB Netzgesellschaft Berlin-Brandenburg mbH & Co. KG with 319 402 connected customers and 40.5 TWh of distributed gas in the year 2013. While the NBB Netzgesellschaft Berlin-Brandenburg mbH & Co. KG is a specialized gas distributor, the Versorgungsbetriebe Hoyerswerda GmbH is also active in electricity distribution.

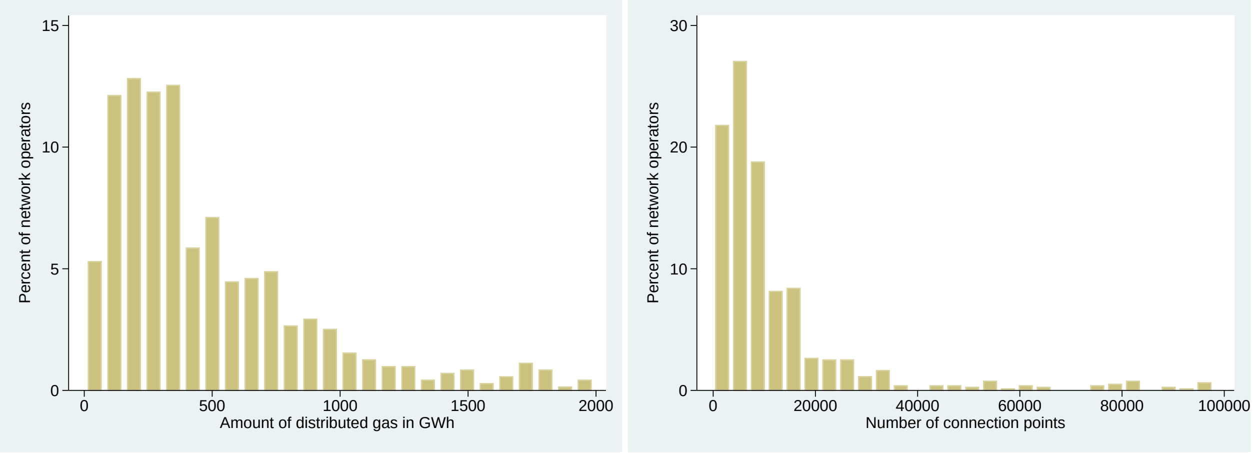

Figure 2: Amount of distributed gas (left) and number of connection points (right) of gas distribution

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[3] For reasons of clarity, the x-axis is cut off at 2 000 GWh of gas supplied and 100 000 connection points. The network operators in the figure correspond to more than 90 percent of the network operators in the sample.

We define the following variables for the estimation of the cost function. Our dependent variable, total costs C, is measured in Euros and consists of capital costs, labor costs and costs of other inputs. The capital costs are defined as the sum of depreciation and the opportunity cost of capital. The opportunity cost of capital is calculated as the capital stock multiplied by the interest rate paid on long-term debt. The capital stock is the written down accounting value of fixed assets. Labor costs are measured by the personnel expenses, while the cost of other inputs is defined as the sum of material expenses and other operating expenses.

Furthermore, the estimation of a cost function requires the specification of suitable output variables. In a liberalized energy market, consumers can freely choose their energy supplier. In order to receive the energy, the consumer requires a network operator that delivers the energy. The services of network operators can accordingly be described by three output dimensions: energy transportation, provision of capacity and customer connection (service). According to the final report of the efficiency benchmarking by the BNetzA, an appropriate cost function should adequately represent all these output dimensions. The output dimension of energy transportation can be represented by the amount of energy delivered, while the provision of capacity can be described by the simultaneous annual peak load of the grid and the output dimension of customer connection by the number of connection points. As the data set provides no information on the annual peak load of the network operators, only the amount of distributed energy and the number of connection points are included in the cost function. The amount of distributed electricity, QE, is measured by the amount of electricity delivered by all voltage levels per year in kWh. The amount of gas distributed, QG, is measured by the amount of gas delivered per year in kWh. The number of connection points, QGC and QEC respectively, corresponds to the sum of the connection points on all voltage levels. Furthermore, the consumer density is included in the cost function as a structural variable in order to take into account different conditions in which distribution networks are operating. Network operators with a high consumer density are expected to have relatively lower costs than network operators with a low consumer density. The consumer density, CD, corresponds to the ratio of the number of connection points and the network length in kilometers. As the dataset provides no information to derive consistent factor prices for capital, labor and other inputs of the network operators, input prices are not included in the cost function. The estimation is thus based on the assumption that input prices do not vary systematically between network operators. In our opinion, this is not a strong assumption as we are only considering German network operators. The summary statistics of the variables are shown in Table 3.

Table 3: Descriptive statistics

	Mean	Std. dev.	Minimum	Maximum
Integrated (291 firms, 661 observations)				
Total cost (million 2010€)	71.60	315.09	2.08	3 847.56
Electricity supplied (GWh)	2 007.82	12 524.87	17.23	242 906.50
Electricity connection points (number)	87 699.30	376 724.60	330.00	6 024 244.00
Gas supplied (GWh)	1 394.44	6 333.22	2.72	110 017.70
Gas connection points (number)	14 008.87	23 369.80	3.00	193 352.00
Network density (connection points/line km)	34.52	18.27	0.22	234.37
Electricity distribution (164 firms, 283 observations)				
Total cost (million 2010€)	40.89	112.05	0.14	1 446.51
Electricity supplied (GWh)	1 168.08	3 694.15	0.61	31 492.64
Electricity connection points (number)	52 393.92	119 910.20	21.00	1 154 150.00
Network density (connection points/line km)	34.49	28.55	0.16	241.92
Gas distribution (83 firms, 154 observations)				
Total cost (million 2010€)	18.65	48.06	0.36	350.68
Gas supplied (GWh)	1 718.76	5 570.74	24.16	40 524.56
Gas connection points (number)	20 151.52	44 659.52	723.00	319 402.00
Network density (connection points/line km)	30.48	9.32	10.69	57.79

5. Econometric Results

The estimated coefficients for the translog cost function defined in Equation 1 are given in Table 4. Since total cost and the regressors are in logarithmic form and the regressors are normalized at their sample median, the coefficients can be interpreted as cost elasticities evaluated at the sample median.

We estimated three models with varying output specifications. Model 1 is the most comprehensive model as it includes two electricity and two gas outputs: electricity supplied ($QE1$), electricity connections points ($QE2$), gas supplied ($QG1$) and gas connection points ($QG2$). All coefficients have the expected signs. That is for all firm types the cost function is increasing in outputs and decreasing in network density at the approximation point. Furthermore, all output and density coefficients except the one for gas supplied by specialized gas distributors ($GQG2$) are statistically significant at least at the 5% level. In all likelihood the statistically insignificant coefficient for gas supplied by specialized gas distributors is due to the very high correlation of 0.95 between the two gas outputs of the specialized gas distributors.[4] Therefore, we estimated a second model with two electricity and only one gas output (Model 2).

The estimated coefficients of the second model are very similar to the estimated coefficients of the first model. In particular, both models indicate that a 10% increase in network density will decrease total cost of integrated distributors, specialized electricity distributors and specialized gas distributors by about 3%, 4% and 5% at the sample median, respectively. The respective coefficients are statistically significant at least at the 5% level.

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[4] The correlations between the two electricity and two gas outputs of the integrated and the specialized electricity distributors are much lower and vary between 0.77 and 0.86.

Table 4: Total cost function parameter estimates (first-order coefficients)

Variable	Parameter	Model 1		Model 2		Model 3	
I	α_0^I	16.156***	(0.026)	16.186***	(0.027)	16.215***	(0.035)
$ln\,QE1$	$\alpha_{m=1}^I$	0.184***	(0.031)	0.150***	(0.036)	0.423***	(0.055)
$ln\,QE2$	$\alpha_{m=2}^I$	0.460***	(0.052)	0.527***	(0.053)		
$ln\,QG1$	$\alpha_{k=1}^I$	0.075**	(0.032)	0.220***	(0.044)	0.364**	(0.069)
$ln\,QG2$	$\alpha_{k=2}^I$	0.194***	(0.038)				
$ln\,ND$	α_z^I	-0.275^{***}	(0.079)	-0.300^{***}	(0.082)	-0.056	(0.044)
$DT2$	$\alpha_{t=2}^I$	0.036	(0.034)	0.038	(0.037)	0.082*	(0.048)
$DT3$	$\alpha_{t=3}^I$	0.078**	(0.034)	0.083**	(0.036)	0.087*	(0.046)
$DT4$	$\alpha_{t=4}^I$	0.116*	(0.070)	0.127	(0.084)	0.098	(0.103)
E	α_0^E	16.108***	(0.036)	16.108***	(0.036)	16.201***	(0.055)
$ln\,QE1$	$\alpha_{m=1}^E$	0.133***	(0.033)	0.133***	(0.033)	0.754***	(0.023)
$ln\,QE2$	$\alpha_{m=2}^E$	0.799***	(0.038)	0.799***	(0.038)		
$ln\,ND$	α_z^E	-0.439^{***}	(0.056)	-0.439^{***}	(0.055)	0.087***	(0.030)
$DT2$	$\alpha_{t=2}^E$	-0.028	(0.047)	-0.028	(0.047)	-0.042	(0.078)
$DT3$	$\alpha_{t=3}^E$	0.065	(0.051)	0.065	(0.051)	0.050	(0.081)
$DT4$	$\alpha_{t=4}^E$	0.027	(0.115)	0.027	(0.114)	0.289*	(0.149)
G	α_0^G	15.169***	(0.113)	15.115***	(0.116)	15.115***	(0.116)
$ln\,QG1$	$\alpha_{k=1}^G$	0.588**	(0.262)	0.746***	(0.090)	0.746***	(0.089)
$ln\,QG2$	$\alpha_{k=2}^G$	0.162	(0.293)				
$ln\,ND$	α_z^G	-0.571^{***}	(0.203)	-0.492^{**}	(0.205)	-0.492^{**}	(0.205)
$DT2$	$\alpha_{t=2}^G$	0.097	(0.136)	0.174	(0.152)	0.174	(0.151)
$DT3$	$\alpha_{t=3}^G$	0.218	(0.139)	0.283*	(0.151)	0.283*	(0.150)
$DT4$	$\alpha_{t=4}^G$	-0.157	(0.211)	-0.059	(0.234)	-0.059	(0.234)
Observations		1098		1098		1098	

Notes: To conserve space the first-order coefficients are presented only. The second-order and interaction coefficients are available from the authors upon request. Robust standard errors in parentheses. ***, ** and *: Significant at the 1%-, 5%-, and 10%-level. R-squared = 0.99 for all models.

Finally, for comparison reasons we include a third model that only considers one output dimension for both electricity and gas distribution activities. In contrast to Model 1 and 2, the coefficient for network density of the integrated distributors in Model 3 is not statistically significant and the coefficient for network density of specialized electricity distributors indicates a slight positive impact of a higher network density on total cost, that is, a 10% increase in network density will increase total cost by about 0.9%. However, as Model 1 and 2 include more output dimensions we consider estimates from these two models as more reliable.

Furthermore, checking the theoretical assumption that the cost function is non-decreasing in outputs for each observation reveals that in Model 1, 75 of the integrated observations, 3 of the electricity and 39 of the gas observation violate the monotonicity assumption, respectively. In Model 2, these numbers decrease to 20, 3 and 0 observations, respectively, while in Model 3 no violations are present. Taken together, the more comprehensive output definition in Model 2 compared to Model 3 and the relatively low number of monotonicity violations of about 2% (23 out of 1098 observations) in Model 2, suggest Model 2 to be the most trustworthy model. Nevertheless, for comparison reasons we keep on reporting the results of Model 1 and 3 in our further analysis.

Table 5 represents the estimates of scale and scope economies at the sample median. The results suggest scale economies for all firm types indicating that the sample median firm is not operating at an efficient firm size. That is, a proportional increase in all outputs would result in a decrease of ray average costs. Model 1 and 2 give values of 1.10-1.11 and 1.07 for integrated and electricity distribution firms, respectively, while Model 3 provides rather higher values of about 1.27 and 1.33. For gas distribution firms all models suggest a degree of scale economies of about 1.33-1.34. Turning to economies of scope, the estimated values vary between 0.27 and 0.33 among the models. This result suggests that separation of electricity distribution from gas distribution would increase total costs by about 27 to 33%. Overall, these results indicate significant economies of scale and scope at the sample median.

Table 5: Economies of scale and scope at the sample median

	Model 1	Model 2	Model 3
Scale economies integrated firms	1.10	1.11	1.27
Scale economies electricity distribution firms	1.07	1.07	1.33
Scale economies gas distribution firms	1.33	1.34	1.34
Scope economies	0.33	0.27	0.32

Note that the estimates given in Table 5 represent average values evaluated at a hypothetical firm that exhibits sample median values for each variable in the model. Therefore, in order to derive information on the variation of scale and scope economies in our actual sample, we also estimated economies of scale and scope at the individual observation level. The distribution of the estimated observation-specific scale economies is given in Table 6.[5]

Referring to our preferred Model 2, the results show diseconomies of scale for 8 integrated and 27 electricity observations only. Model 3 provides an even lower number with only 10 integrated observations, whereas Model 1 suggest diseconomies of scale for a relatively high number of 53 integrated and 27 electricity observations, respectively. Altogether, all models suggest that the vast majority of all observations exhibit economies of scale, indicating cost advantages of larger firm sizes. Furthermore, for all observation types in all models, except for the gas observations in Model 1, the estimated degrees of scale economies at the 50th percentiles are very similar to the degrees of scale economies evaluated at the sample median. Depending on the model, the 50th percentile values for integrated observations vary between 1.07 and 1.26, for electricity observations between 1.07 and 1.33 and for gas observations between 1.17 and 1.32. In all cases, the lowest value is given by Model 1 and the highest value by Model 3.

Figure 3 depicts the estimated scale economies related to firm size, measured by the number of connection points. All models clearly indicate that larger firms have a lower degree of scale economies. Hence, in particular small and medium-sized firms can create significant cost benefits from altering their scale.

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[5] As observations that violate the monotonicity assumption will provide incorrectly signed elasticities estimates and hence theoretically inconsistent scale economies estimates, we excluded these observations from the observation-specific analysis.

Table 6: Distribution of observation-specific scale economies

	Model 1			Model 2			Model 3		
	Integr.	Elect.	Gas	Integr.	Elect.	Gas	Integr.	Elect.	Gas
5th percentile	0.98	0.98	1.01	1.04	0.98	1.22	1.06	1.17	1.22
25th percentile	1.04	1.04	1.12	1.09	1.04	1.28	1.21	1.28	1.28
50th percentile	1.07	1.07	1.17	1.12	1.07	1.32	1.26	1.33	1.32
75th percentile	1.11	1.10	1.33	1.14	1.10	1.35	1.32	1.37	1.35
95th percentile	1.17	1.15	1.47	1.20	1.15	1.40	1.42	1.43	1.40
Observations	586	280	115	641	280	154	661	283	154
Economies of scale	533	253	111	633	253	154	651	283	154
Diseconomies of scale	53	27	4	8	27	0	10	0	0

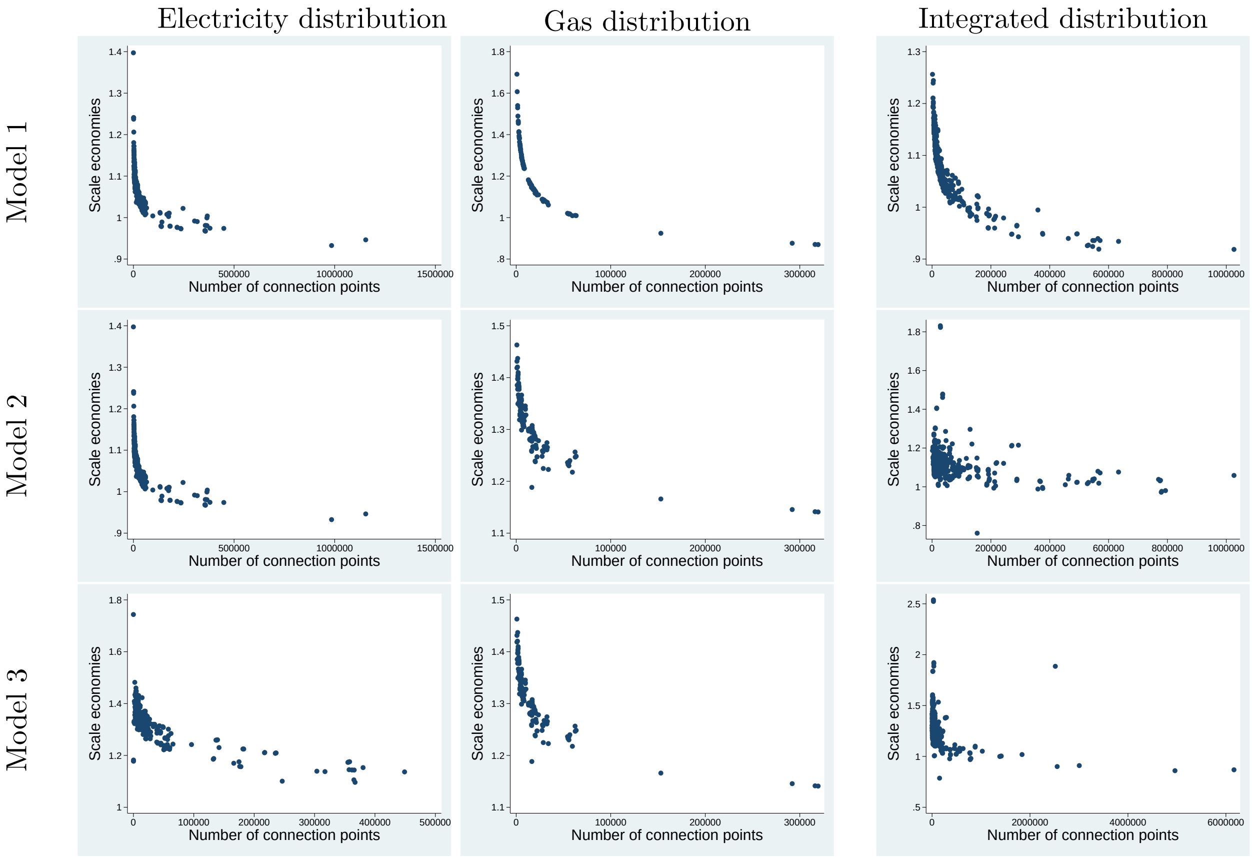

Figure 3: Estimates of scale economies and firm size

Finally, in Table 7 the distribution of observation-specific scope economies is shown. All models provide a rather similar distribution and suggest that a separated production of the outputs of an integrated firm would increase total cost by about 28 to 29% on average. In addition, for the great majority of observations economies of scope are given. In Model 3, only 7 observations exhibit diseconomies of scope, in Model 2 only 13 and in Model 3 only 20. Thus, our results strongly emphasize that significant cost savings occur from the joint provision of electricity and gas distribution services.

Table 7: Distribution of observation-specific scope economies

	Model 1	Model 2	Model 3
5th percentile	0.04	0.08	0.11
25th percentile	0.20	0.21	0.22
50th percentile	0.28	0.29	0.29
75th percentile	0.38	0.37	0.38
95th percentile	0.55	0.58	0.56
Observations	586	641	661
Economies of scope	566	628	654
Diseconomies of scope	20	13	7

6. Conclusions

The purpose of this study was to analyze the cost structure of German electricity and gas distribution firms. A flexible translog total cost function that allows integrating different production technologies was estimated using 1098 observations of integrated and specialized German electricity and gas distribution firms for the period 2011 to 2014. Scale economies were identified for all firm types and in particular indicate that small- and medium-sized firms can realize significant cost benefits from increase their scale of operations. In addition, the estimated scope economies for the majority of the integrated firms suggest that the joint production of electricity and gas distribution services is preferable to a separated production. Overall, the results point to the fact that the highly fragmented structure of the German electricity and gas distribution sector induces too high network access charges and hence results in significant welfare losses. Further developments of the regulatory design should keep this in mind and should at least not cumber in particular small- and medium-sized local utilities in expanding their area of operations both in terms of geography and products.

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