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Economies of scope and scale in the Norwegian electricity industry

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ABSTRACT

An important issue for multi-product firms to consider is economies of scope, i.e., whether there is any benefit from producing two or more products, or whether specializing in producing only one product would be less costly. We examined the economies of scope for Norwegian electricity companies because policy makers have decided to force companies that both generates and distributes electricity to split their operations into two companies, one engaged in generation only and the other in distribution only. We set out to test the validity of the policy makers decision on unbundling generation and distribution. Using data from Norwegian electricity companies for the period 2004–2014, we found evidence of economies of scope, meaning that policy makers' insistence on separating generation and distribution companies will have increased costs. We also found evidence of economies of scale, meaning that there are cost savings in expanding outputs. Our findings provide important information to consider in future policy decisions in the Norwegian electricity industry, probably with implications for other countries.

1. Introduction

The electricity industry in Norway, and in many other countries, consist of market-oriented competitive entities in generation and power trading, and, on the other side, natural monopolies within transmission and distribution. Traditionally, most electric utilities worldwide have performed all services from generation to distribution in the electricity supply chain. However, electricity industries worldwide have undergone profound changes involving strict separation of these services (Fetz and Filippini, 2010).

In Norway, accounting unbundling was introduced in the electricity industry in the 1990s. The European Union's Second Energy Package was adopted in Norway in 2007. It imposes rules on legal unbundling for firms with more than 100,000 customers. In 2016, the Norwegian parliament amended the Energy Act, with the changes taking effect from 2021. The amended legislation will introduce legal and functional unbundling for all firms involved in electricity distribution. 'Functional unbundling' means that the distribution company shall have its own board, separate from the boards of other companies in the group.

The main motivation for the unbundling of services has been to increase competition in the electricity industry, avoid cross-subsidization between generation and distribution, and to ensure that the distribution system operators (DSOs) focus on network operations only, and in that way may better exploit potential economies of scale within the electricity distribution sector.

Unbundling might reduce the potential for cost savings from economies of scope (product diversification).[1] However, the policy assumption is that society will benefit from economies of scale through merging distribution companies and increased competition in the power market. These gains might be greater than the loss from not utilizing economies of scope. We believe that this view is held by Norwegian policy makers because the unbundling was implemented without referring to any economies of scope studies for Norway or any other country.

Baumol et al. (1982) pointed out that economies of scope can exist because of synergies in the joint utilization of labor and capital. The type of labor required in the distribution and generation of electricity might be quite similar. Furthermore, combining all elements of electricity supply into one value chain from electricity generation to distribution may lower production costs. Examples of positive synergies are advertising and billing costs, and what Waldman and Jensen (2001) called

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[1] A formal definition of economies of scope is given in Section 3.

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"massed reserves," meaning that multioutput firms can exploit the same reserve capacity during emergency repairs and maintenance. Furthermore, as multioutput firms are bigger, one major benefit would be savings in procurement costs.

In this study, we ask: "What are the costs or benefits from separating electricity distribution firms that also have generation of electricity into two specialized firms?" and "What potential exist regarding economies of scale among electricity generation and distribution firms?" The first question relates to benefit (cost) of product diversification or economies of scope. The second question relates to decrease (increase) in average cost from expansion of output, meaning scale economies (diseconomies). To do this, we estimate a cost model using data from 212 Norwegian electricity firms observed over a period of 11 years. In particular, we estimate a quadratic cost function using the flexible technology approach of Triebs et al. (2016). The flexible technology approach is useful because it allows the technologies of integrated and separated firms to be different and gives a plausible estimate of the effect of unbundling (product separation). For the scope and scale measures, we do not follow the standard practice of presenting the results at the mean or median values of output. In our analysis, we seek to identify the costs and benefits of separating an integrated firm into two specialized firms to see how the new legislation will affect production cost of the Norwegian electricity industry. We present scope and scale estimates for all combinations of output values for all 42 integrated firms in our dataset, instead for reporting their mean values (or values evaluated at the mean values of data).

The remainder of the paper is organized as follows. Section 2 presents a brief survey of the literature. Section 3 describes the model specification and method. Section 4 describes the data and Section 5 presents the results. In Section 6, we present our concluding remarks.

2. Literature review

It is somewhat surprising that, considering its policy importance, there is little research on economies of scope in the electricity industry in Norway. We are aware of only one recent report from the Norwegian Water Resources and Energy Directorate (NVE) that briefly addresses the topic. Nevertheless, in 2015, NVE reported that the operational costs of vertically integrated companies were 15% lower than those of other companies.

One reason for the lack of studies in this area may be that it is difficult to obtain data suitable for analyzing economies of scope.

Although many scope studies have been conducted within energy markets in other countries, including the markets for electricity, gas, water, and coal,[2] only a few have focused on economies of scope and scale in the electricity industry.[3]

Based on our knowledge, there have been five scope studies of US electricity markets. Using cross-sectional data examining US electric utilities, Kaserman and Mayo (1991), Kwoka (2002), and Arocena et al. (2012) used data from 1981, 1989, and 2001, respectively. Meyer (2012a) and Triebs et al. (2016) both examined the US electricity market with panel data covering the periods 2001–2008 and 2000–2003, respectively. These studies provide empirical evidence for the existence of significant economies of vertical integration between generation and transmission/distribution in electricity supply companies. The estimates of scope economies ranged from 4% to 27%. Both Arocena et al. (2012) and Triebs et al. (2016) reported evidence of economies of scale, with returns to scale (RTS) estimates ranging from 1.01 to 1.13[4]

We found four studies of economies of scope of the European electricity industry, all of them used panel data. Jara-Díaz et al. (2004) analyzed Spanish electricity generation and distribution companies for the period 1985–1996. Piacenza and Vannoni (2009) examined the Italian electricity market for the years 1994–2000, while Fetz and Filippini (2010) investigated Swiss generation and distribution companies for the period 1997–2005. Gugler et al. (2017) studied 28 electricity generation and transmission firms from 16 European countries for the period 2000–2010. These European studies reported evidence of economies of scope, ranging from 6.5% to 60%, which are higher than the estimates for the US. Both Jara-Díaz et al. (2004) and Fetz and Filippini (2010) found evidence of economies of scale, with estimates of RTS at 1.07 and 1.4–1.7, respectively. As this brief review shows, no scientific published economies of scope studies of the electricity market exist for Norway or Scandinavia.

While there exist several nonparametric approaches, in this study, we focus on parametric estimation to measure economies of scope. Examples of theoretical contributions within the nonparametric approach include Cherchye et al. (2008), Ferrier et al. (1993) and Grosskopf et al. (1992). Examples of empirical work include Marques and Witte (2011), Morita (2003) and Prior and Solà (2000).

3. Model specification and method

In this section, we describe the specifications of our model and the estimation method used in this study. Before introducing the model, we provide definitions of scope and scale economies. For economies of scope, we measure the difference between the cost of one firm producing two outputs and the costs (sum) of two specialized firms producing the same outputs (see Baumol et al., 1982; Panzar and Willig, 1981).[5] Economies of scope are measured as:

$$Scope = \frac{(C_D(D) + C_G(G)) - C_I(D,G)}{C_I(D,G)}, \tag{1}$$

where $C_D(D)$ is the cost for the specialized firms in *distribution* and is usually obtained by setting the output of *generation* (G) to zero in $C(D,G)$, i.e., $C_D(D) = C(D,0)$. Likewise for the specialized firms in *generation*, the cost is $C_G(G) = C(0,G)$, and for the *integrated* firms with positive outputs in both *distribution* and *generation*, the estimated costs are $C_I(D,G) = C(D,G)$. If the scope measure is positive (or negative), economies (or diseconomies) of scope exist.,[6,7] Thus the presence of scope economies

[2] Among scope studies of the energy markets, we mention a few. Mayo (1984) and Chappell and Wilder (1986) found evidence of economies of scope in the US electricity and gas markets. Fraquelli et al. (2004) and Piacenza and Vannoni (2004) examined the Italian electricity, gas, and water distribution markets, while Farsi et al. (2008) examined the corresponding Swiss markets. Garcia et al. (2007) studied North American water utilities, and Carvalho and Marques (2014, 2015, 2016) studied Portuguese water utilities.

[3] Carvalho and Marques (2016) used a Bayesian approach to estimate size and scope economics in the Portuguese water sector. In our case, we use a simple model, and find no good reason to use the Bayesian approach. Zellner (1971) showed that, under uninformative priors, the classical regression and the Bayesian results are identical. Furthermore, Carvalho and Marques (2016) accounted for different types of service provisions by including dummies (intercept) for each service type, which, as opposite of the Triebs et al. (2016) flexible technology approach used in our study, does not allow technologies to be completely different for different services.

[4] A summary of the most important previous empirical economies of scope and scale studies within the electricity sector is presented in Table A1 in the appendix. Meyer (2012b) provided a review of the theoretical and empirical literature within the field of vertical economies and the costs of separating electricity supply.

[5] In some previous studies the term "economies of vertical and horizontal integration" was used instead of "economies of scope and scale." We believe these terms are synonymous.

[6] Note that in our analysis we focus on the economies of scope concept based on the cost function. However, as pointed out by one referee, economies of scope can also be studied by focusing on the production technology alone, see e.g., Chavas and Kim (2007).

[7] In our study we measure economies of scope by comparing integrated firms and "fully specialized" firms. Chavas and Kim (2007, 2010) demonstrated how to measure different levels of specialization.

means joint production of D and G is cost-effective. That is, it is cheaper to produce both jointly instead of producing them separately.

Following Baumol et al. (1982), global economies of scale in a multioutput setting are defined as:

$$Scale = \frac{C(D,G)}{D\,\frac{\partial C(D,G)}{\partial D} + G\,\frac{\partial C(D,G)}{\partial G}} \tag{2}$$

If the scale measures are greater than, equal to, or less than unity, RTS are increasing, constant, or decreasing, respectively. That is, cost is increased by less than 1% for a simultaneous increase in G and D by 1% if RTS>1. In this case, there is scale economies meaning that average cost is decreased when outputs are expanded (i.e., expansion is cost-effective).

In estimating a single cost function that includes multiple firm types jointly, a common technology among firm types is assumed. The question is whether the technology used by the specialized utilities is identical to that used by the utilities providing more than one service. If the technologies are different, and one assumes a common technology, the results are likely to be wrong. For instance, results suggesting the presence of economies of scope may actually be a result of scale economies. One way to get around this issue is to perform separate estimations for each firm type. This allows the technology to be different between the firm types. Triebs et al. (2016) introduced a method that allows us to test for differences in technology.

In our analysis, we use panel data, but, to simplify the notation, we drop the subscripts i and t, where i denotes the firm, $i = 1, \ldots$,n and t denotes time, $t = 1, \ldots$,t. We use a quadratic cost function and add flexibility to it by allowing the technology to vary across specialized and integrated firms. We do so by following the approach in Triebs et al. (2016) whereby we use dummies for specialized and integrated firms and write the cost function as:

$$\begin{aligned} C = Idum\Big(&\alpha_0 + \beta_1 L + \beta_2 Q + \frac{1}{2}\beta_{11}L^2 + \frac{1}{2}\beta_{22}Q^2 + \beta_3 E + \beta_4 N + \frac{1}{2}\beta_{33}E^2 \\ &+ \frac{1}{2}\beta_{44}N^2 + \frac{1}{2}\beta_{12}L{*}Q + \frac{1}{2}\beta_{13}L{*}E + \frac{1}{2}\beta_{14}L{*}N + \frac{1}{2}\beta_{23}Q{*}E + \frac{1}{2}\beta_{24}Q{*}N \\ &+ \frac{1}{2}\beta_{34}E{*}N\Big) + Ddum\left(\alpha_D + \delta_1 L + \delta_2 Q + \frac{1}{2}\delta_{11}L^2 + \frac{1}{2}\delta_{22}Q^2 + \frac{1}{2}\delta_{12}L{*}Q\right) \\ &+ Gdum\left(\alpha_G + \gamma_1 E + \gamma_2 N + \frac{1}{2}\gamma_{11}E^2 + \frac{1}{2}\gamma_{22}N^2 + \frac{1}{2}\gamma_{12}E{*}N\right). \end{aligned} \tag{3}$$

where C is total operational cost, and $Ddum$ and $Gdum$ are dummy variables representing the distribution and generation companies, respectively. $Idum$ represents the integrated companies that have both generation of electricity and distribution of electricity. The cost function for each firm-type is obtained from eq. (3) by turning the appropriate dummy on. For example, $Ddum = 1$ ($Gdum = 0$, $Idum = 0$) gives the cost function for the distribution companies. Similarly, we can get the cost functions for the generation and integrated companies. Kilometers of high-voltage network (L) and number of customers (Q) represent outputs of distribution companies. Megawatt hours of produced electricity (E) and number of generators (N) are the outputs of the electricity generation companies. We do not use input prices in our cost model because there is no input price variation cross-sectionally in our data and the temporal variation can be captured in the time dummies or the time trend variable in the model. In Norway, union agreements regarding wages and social benefits are centralized at the national level. Thus, the assumption of constant input prices across firms is reasonable in a small country such as Norway.[8] As a result, homogeneity in input prices violation, as discussed in Farsi et al. (2008) and Triebs et al. (2016), is not a problem in our model.

By introducing the dummy variables $Idum$, $Ddum$, and $Gdum$ for the integrated firms and the two specialized comanies in distribution and generation, respectively, the model in eq. (3) combines three separate cost functions, one for each firm type, into one function. Use of the dummy variables makes it possible to estimate the three separate cost functions from eq. (3) simultaneously.

Our model is made stochastic by introducing the error term u_i. To control for firm heterogeneity, we include random effects. Thus, in our estimation, we replace the constant terms α_0, α_D, and α_G in eq. (3) with $\varepsilon_\tau = (\alpha_\tau + w_i)$, where the subscript $\tau = 0, D$, or G. The term w_i is a time-invariant, firm-specific random term that controls for firm heterogeneity.,[9,10]

In scope studies, one or several outputs are zero for specialized firms. There might be a problem with zero values when using a quadratic function. If the number of zero values represents a large proportion of the total number of sample observations, the parameter estimates may be biased (Battese, 1997). This potential problem does not arise in Triebs et al. (2016) approach because the zero values are eliminated when estimating the model. E.g., if one estimates the technologies separately, then no output data on electricity generation (E = N = 0, meaning that the firm is a distribution utility) will be used to estimate the technology for the distribution utilities. These zero values will then be eliminated when multiplied by $Ddum$, and the model reduces to one, for which only the output data on the distribution utilities are used; the same applies for the generation utilities. Furthermore, this approach is suitable for any kind of functional form specified, including a translog cost function specification.[11] For further details, see Triebs et al. (2016).

In eq. (1) we presented the general definition of scope. From our model specification in eq. (3) we obtain: $\frac{(C_{Ddum}(D)+C_{Gdum}(G))-C_{Idum}(D,G)}{C_{Idum}(D,G)}$. See Fuss and Waverman (1981) for more on this.

The dummy variable specifications of the quadratic cost function make it possible to test whether a common technology assumption is appropriate. We can do this by performing a joint likelihood ratio test with the following restrictions on our model:

$$\begin{aligned} &\beta_1 = \delta_1,\ \beta_2 = \gamma_2,\ \beta_3 = \gamma_1,\ \beta_4 = \gamma_2,\ \beta_{11} = \delta_{11}, \\ &\qquad \beta_{22} = \delta_{22},\ \beta_{33} = \gamma_{11},\ \beta_{44} = \gamma_{22} \end{aligned} \tag{4}$$

Note that the technology, e.g., for the generation companies, is obtained by imposing the above restriction together with $Gdum = 1$, which also implies $Ddum = 0$ and $Idum = 0$. Failure to reject the null hypothesis with the above restrictions indicates the presence of a shared technology for all firm types.

8 For fixed input (factor) prices, the cost function is written as a function of outputs. See Färe et al. (1990) and Varian (1992: p. 67). Temporal variations in input prices are captured by the time dummies or time trend included in the cost function.

9 The Breusch and Pagan Lagrange multiplier test for random effects (against a standard OLS regression) rejects the null hypothesis. The p value of the test is 0.000.

10 We have low temporal variation in some variables in our data. Thus, we are more interested in between variation than within variation. In addition, we use an unbalanced panel where a portion of the sample has four or fewer observations per firm (i.e., panel data with a short time-series component). In cases such as this, based on Clark and Linzer (2015), a fixed effect model exacerbates measurement error bias and the random effect model is preferable. The fixed effect model is therefore not be appropriate in our case.

11 Zero values are a problem also in the translog function specification because the logarithm of zero is not defined (missing values will be created). Previous studies have shown that the common approach by replacing zero values by some arbitrary small number can influence the results (e.g., see Pulley and Humphrey, 1993). However, the flexible technology approach introduced by Triebs et al. (2016) avoids the zero-value problem by allowing the technologies of the specialized firms to be different from the integrated firms.

Table 1
Descriptive statistics.

Variable	Mean	St. Dev.	Min	Median	Max
Total operating costs (1000 NOK):					
Distribution firms	30,773	37,364	4126	16,117	274,822
Generation firms	19,065	20,054	255	12,272	146,887
Integrated firms (distribution and generation)	30,754	21,213	2485	22,952	91,701
Outputs of distribution firms:					
Km of network	479	520	0 (37)	269	2909
Number of customers	13,943	22,315	0 (178)	6646	134,854
Outputs of generation firms:					
Electricity MWh	276,804	296,476	0 (2391)	134,428	1,081,649
Number of generators	8.07	9.73	2	5	68
Outputs of integrated firms:					
Km of network	486	337	31	368	1185
Number of customers	7939	6236	391	6335	25,748
Electricity MWh	91,430	108,907	3861	14,640	535,554
Number of generators	4.35	2.73	2	3	15
Time			2004		2014
Firm type observations:					
Integrated firms (distribution and generation)	316 observations, 42 firms				
Specialized firms (distribution)	671 observations, 77 firms				
Specialized firms (generation)	507 observations, 93 firms				
Total firms	1494 observations, 212 firms				

Note: Numbers in parentheses are the minimum positive outputs for distribution and generation.

4. Data

The data comprise economic and technical information on Norwegian electricity companies from 2004 to 2014 and were collected by the NVE.[12] In total, there are 1494 firm-year observations constituting an unbalanced panel of 212 Norwegian electricity companies. Table 1 presents the descriptive statistics of the variables used in our analysis.

Total operational cost for each firm consists of the sum of material costs, salaries, and other personnel costs (including pension costs), other operating expenses, losses on receivables, losses on disposal of fixed assets, internally priced services, and allocated overhead costs. All costs are adjusted for inflation by an industry commodity price index, where wages are the main component.[13] The output variables for electricity distribution are kilometers of high-voltage network (km of network) and number of customers. We also considered including the number of network stations as a proxy for electricity delivered. However, this would have caused multicollinearity between the output variables. The ratio of the number of customers and the number of network stations, and that between the number of customers and the km of network, capture the same effect. In urban areas, the number of customers is high compared with the number of network stations and km of network, while in rural areas, the situation is the exact opposite.

The output variables for electricity generation are electricity production in megawatt hours (electricity MWh) and number of generators. In a scope study, the minimum value of the output variables will naturally equal zero because by definition, specialized firms do not produce some outputs. The minimum values for distribution and generation outputs in parentheses are the minimum output values, given that the outputs are not zero.

[12] The data used in this study are confidential. Readers who wish to gain access to the data must apply to the NVE for permission; see www.nve.no for details.
[13] The price index was retrieved from Statistics Norway, Table 03363. http://www.ssb.no/en.

Table 2
Marginal costs.

	Integrated firms	Specialized firms, distribution	Specialized firms, generation
Km of network (L)	30.00** (10.06)	27.71** (5.11)	
Number of customers (Q)	1.24* (0.57)	1.17** (0.15)	
Electricity MWh (E)	0.06* (0.03)		0.04** (0.01)
Number of generators (N)	400.90 (897.95)		999.57** (139.17)
Observations	316	671	507

Notes: Standard error in parentheses. ** and * indicate significance at 0.01 and 0.05 levels respectively.

To control for time effects, we also include a time trend variable in our estimation. Note that, because the cost function does not include input prices, which only change over time, the time trend variable captures input price effects as well as other effects (technical change) that shift the cost function. In other words, technical change cannot be separated from any temporal changes in input prices.

Our data consist of three types of firms: integrated firms with positive outputs for both distribution and generation, and specialized firms that have positive output only for distribution or generation. There are large variations in firm size in our data. For example, the lowest total operational cost is 255,000 Norwegian kroner (NOK), while the highest total operational cost is about 275 million NOK. Large variation also exists in the outputs.

5. Results

Using the estimated parameters from the model, we report the marginal costs at the mean values of our data for each of the four outputs (Table 2). These are the derivatives of the estimated cost function with respect to each output and are observation-specific.[14] They tell us how the costs are affected by changes in each of the outputs. Note that, even though the cost elasticities for each firm type are presented in different columns, the three cost functions are estimated simultaneously. All of the marginal costs have positive signs as expected, and all but *Number of generators* for the integrated firms are significant at the 5% level. The results show that for the integrated firms, increasing *Km of network* by 1 km will increase cost by 30.00 (1000 NOK), ceteris paribus.

To test the restrictions presented in eq. (4), we performed a joint likelihood ratio test. The test results are presented in Table 3. At the 1% significance level, we reject the null hypothesis of shared technology. Thus, these results support our model specification with the flexible dummy variable approach. Furthermore, several studies have presented evidence that the quadratic representation of the technology is superior to the translog parameterizations (see e.g., Färe et al., 2010, 2016; Chambers et al., 2013).[15]

The policy question to answer from this analysis is: "What are the costs or benefits from separating one integrated firm into two specialized firms?" Alternatively, we could ask what would happen to costs if two specialized firms became one integrated firm. However, this is not relevant for the Norwegian situation. Policy makers have decided to change the Norwegian Energy Act so that all integrated firms within the industry will be strictly separated into specialized firms by 2021.

In previous economies of scope studies, it is normal to use either median or mean values of the data to calculate the scope measures.

[14] For the interested reader, the parameter estimates are available in the appendix (see Table A2).
[15] We have also performed the study using a translog cost function specification, but in this study the results are not totally convincing. However, for the interested reader the modelling and results are available on request.

Table 3
Test for common technology: likelihood ratio test.

H_0:	χ^2	DF	P
$\beta_1 = \delta_1$ $\beta_2 = \delta_2$ $\beta_3 = \gamma_1$ $\beta_4 = \gamma_2$ $\beta_{11} = \delta_{11}$ $\beta_{22} = \delta_{22}$ $\beta_{33} = \gamma_{11}$ $\beta_{44} = \gamma_{22}$	22.83	8	0.005

Table 4
Economies of scope results for integrated firms.

Percentiles	Economies of scope
1%	−0.10
5%	−0.08
10%	−0.05
25%	0.02
50% (median)	0.10
75%	0.21
90%	0.38
95%	0.53
99%	0.92
Mean	0.18
Standard deviation	0.37

Alternatively, a two-by-two table that gives different scope estimates for different combinations of output levels can be constructed. However, these approaches are not always recommended because they are likely to use combinations of output values that do not exist in the actual data set, and which might not be realistic in the real world.[16] To overcome this problem we calculated economies of scope by using the parameter estimates combined with all actual output combinations for the integrated firms in our data set. We retrieved 316 economies of scope estimates from an 11-year period for the 42 integrated firms. The distribution of these 316 estimated economies of scope measures for each model is presented in percentiles in Table 4. The 1% percentile estimate represents the smallest 1% economies of scope estimates from the distribution. We see that the 1% percentile gives diseconomies of scope (−0.10), meaning that, for these integrated firms, costs will be reduced by 10% if they are separated into two specialized firms. We find positive economies of scope at the 25% percentile and above. At the median, the economies of scope estimates are 10%.[17]

Table 4 shows the distribution of scope estimates using all the real output combinations for the integrated firms, providing an overview of economies of scope in the Norwegian electricity industry and showing that there exist economies of scope for several companies in the industry.

In addition, it is interesting to determine what characterizes the firms with diseconomies and economies of scope. In Fig. 1, a plot of the economies of scope estimates by firm size shows that there is a clear relationship between firm size and economies of scope. Fig. 1 uses the scope measures in Table 4, but we have plotted the mean scope measures for each firm against total operational costs (we used total operational cost for each observation as a proxy for firm size for each time period in our data, 42 firms and 316 observations over 11 years). The solid black line is a fitted line between economies of scope and total operational costs to show the trend in the results. The results show an unambiguous relationship between firm size and economies of scope. The largest economies of scope estimates are for the smallest firms, meaning that the costs of separating an integrated firm into two specialized firms are highest for the smallest firms. The bigger the firms, the lower the economies of scope; there are even diseconomies of scope for some of the biggest firms, meaning that the operational costs would be lower if production is separated across two specialized firms.

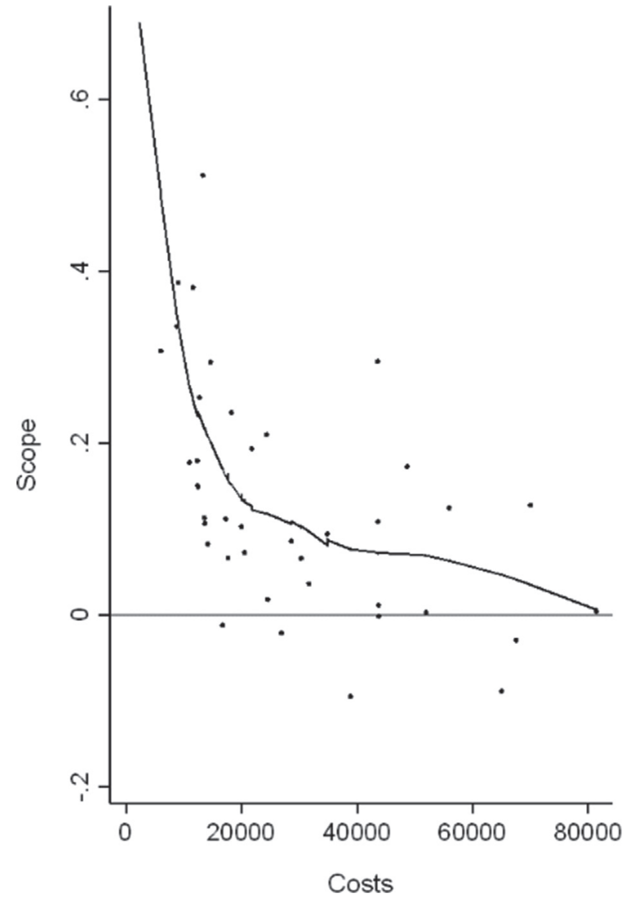

Fig. 1. Economies of scope and firm size using total operational costs as proxy for firm size.
Notes: The solid black line is computed by locally weighted scatterplot smoothing.

To further investigate the firms' characteristics, we examine the

Table 5
Economies of scope and firm output.

		Distribution (*km of network*)					
		200	400	600	800	1000	1200
Generation (*MWh*)	5000	51% (2)	18% (1)	10% (1)	*	*	*
	10000	51% (6)	17% (13)	18% (4)	*	*	*
	20000	36% (13)	14% (22)	10% (9)	*	1% (1)	*
	50000	28% (30)	10% (35)	8% (3)	*	−2% (8)	*
	100000	29% (2)	3% (20)	5% (12)	−0.8% (12)	−8% (10)	−3% (10)
	300000	*	0.7% (19)	9% (6)	4% (11)	11% (7)	7% (27)

Notes: * means no observations.

[16] For the integrated firms in our data set, median L = 383.5 and median E = 53,016. However, a company (with this output combination) does not exist in our data set.

[17] We also estimated our model without random effects, and the scope estimates in the models at median values change from: 0.10 (random effect) to 0.18 (pooled OLS). The economies of scope results increase if we do not control for firm heterogeneity.

Table 6
Economies of scale results for integrated and specialized firms.

Percentiles	Integrated firms	Specialized firms, distribution	Specialized firms, generation
1%	0.82	1.03	1.02
5%	0.92	1.04	1.10
10%	0.94	1.06	1.22
25%	0.99	1.09	1.33
Median	1.07	1.15	1.50
75%	1.21	1.26	1.81
90%	1.79	1.44	2.34
95%	2.67	1.58	2.83
99%	2.99	1.92	4.35
Mean	1.95	1.21	1.80
St. dev.	2.82	0.19	4.38

economies of scope results for different output levels in our sample of Norwegian integrated firms. In Table 5, we present the mean values of the scope estimates for the firms within each output combination. To measure the output value for the distribution of electricity, we use km of network, and for generation of electricity, we use electricity in MWh. We can see the same trend in the results as that in Fig. 1, where we used total costs as a proxy for firm size. We find the highest economies of scope values for the lowest output combination values, suggesting that the smallest firms in terms of output, have the highest economies of scope.

In Table 6, we present the economies of scale results for the integrated and specialized firms in distribution and generation. The economies of scale estimates follow the definition in eq. (2). Except for the smallest percentiles, Table 6 shows increasing RTS across all three firm types. In other words, our results imply that the distribution firms have not exploited scale economies entirely. These findings are consistent with previous scale studies using data from Norwegian electricity distribution firms (see e.g., Mydland et al., 2018; Kumbhakar et al., 2015). An interesting research topic would be to examine how costs in the industry change if separating the integrated firms leads to more mergers among the distribution companies.[18] By doing a merger analysis, one could see whether the cost savings from optimal merges can balance the loss of not utilizing economies of scope. This topic is left for future research.

6. Concluding remarks

We found evidence of scope (benefit form product diversification) and scale economies (benefit from expansion of outputs) in the Norwegian electricity industry. Using a flexible technology approach, we obtained estimates of scope and scale economies. This approach allowed us to test whether specialized and integrated firms share the same technology. We found that the technology differs between firm types. Further, we found a negative relationship between firm size in terms of total costs, and economies of scope in our model. Our results also show that firms characterized by low output values in both the distribution and generation of electricity have the highest economies of scope. These findings suggests that, for the smallest companies in the industry, a policy decision of strict separation between generation and distribution will be costly.

From a political perspective, it might be desirable to separate generation and distribution companies. Because of natural monopolies in the electricity distribution market, the distribution companies are regulated, whereas the market for electricity generation is competitive (no natural monopoly and thereby no regulation). If unbundling distribution and generation leads to increased competition, less cross-subsidization, and more productive DSOs, this might be beneficial for the electricity industry as a whole. However, as this study shows, the policy decision to enforce strict separation also comes with a cost. Moreover, this cost seems to differ across firms. The overall conclusion of this paper is that, for the larger firms, there are no incentives to keep the firms integrated, but for the smaller firms, distribution and generation should not be unbundled.

Our result corresponds to previous economies of scope studies from Europe and the US within the electricity distribution and generation industry.[19]

In policy making, all pros and cons should be considered before a political action is taken. One of the cons of introducing strict separation between distribution and generation of electricity is the cost of not utilizing economies of scope. In this paper, we provide new insights into this issue, and our results are useful for the formulation of future political strategy within the energy sector.

For future research, it would be interesting to combine the analysis on both economies of scope and merger gains from utilizing economies of scale to determine how we can expect the cost structure in the Norwegian electricity market to evolve. If the policy of separating integrated firms into specialized firms leads to more mergers, the net cost changes might be positive in the long run, provided that the companies utilize unexploited economies of scale. To further investigate the robustness of our results, it would be interesting to measure economies of scope and scale using a nonparametric approach.

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[18] The regulated distribution companies can represent “safe income” for an integrated firm because 40% of the revenue cap is decided by the costs in the distribution company. By unbundling distribution and generation into two totally separated firms, one can avoid any cross subsidizations or anticompetitive behavior. This might lead to an increased interest in merging more distribution companies.

[19] See Table A1 for an overview.

Appendix

Table A1
Summary of previous empirical scope and scale studies of combined generation and transmission/distribution electricity companies.

Author(s)	Data	Functional form	Established method	Economies of scope and scale*
Kaserman and Mayo (1991)	Cross-section (1981, US)	Quadratic cost function	OLS	Economies of scope (EOS) = 0.12 (at mean)
Kwoka (2002)	Cross-section (1989, US)	Quadratic cost function	OLS	EOS = 0.27 (at median). Reports substantial costs of vertical integration and highest for the smallest utilities
Jara-Díaz et al. (2004)	Panel data (1985–1996, Spain)	Quadratic cost function together with cost share equations	Seemingly unrelated regressions (SUR)	EOS = 0.065–0.28. Returns to scale (RTS) = 1.07.
Piacenza and Vannoni (2009)	Panel data (1994–2000, Italy)	Multiproduct & multistage Box–Cox transformed cost function	Nonlinear SUR	EOS = 0.24. RTS = 0.96. Reports findings of both vertical integration gains and horizontal economies of scope
Fetz and Filippini (2010)	Panel data (1997–2005, Switzerland)	Quadratic cost function	Random effects GLS and random coefficient model	EOS = 0.50–0.60 (at median). RTS = 1.40–1.70 (at median). Presence of considerable economies of vertical integration and economies of scale for most companies
Arocena et al. (2012)	Cross-section 2001, US)	Quadratic cost function together with cost share equations	SUR	EOS = 0.04–0.10. RTS = 1.01–1.03. Reports positive sample mean estimates of both vertical and horizontal economies
Meyer (2012a)	Panel data (2001–2008, US)	Quadratic cost function	OLS	EOS = 0.19–0.26, when separating generation from distribution and retail. Reports that if generation and transmission remain integrated but are separated from distribution and retail, EOS = 0.08–0.10.
Triebs et al. (2016)	Panel data (2000–2003, US)	Flexible technology translog cost functions with different specifications	SUR	EOS = 0.04 (0.40 when zeros are replaced by small numbers in the common cost function model). RTS = 1.10–1.13. Reports evidence of economies of scale and vertical economies of scope.
Gugler et al. (2017)	Panel data (2000–2010, 16 European countries)	Multistage quadratic cost function	Nonlinear SUR	EOS = 0.14–0.20. Reports that at the median integrated utilities have EOS = 0.14 while large scale utilities have EOS = 0.20.

*Estimates of economies of scale (measured by RTS) are for integrated firms.

Table A2
Parametric estimates.

	Integrated firms	Specialized firms, distribution	Specialized firms, generation
L	29.28 (24.72)	22.29 (8.77)	
L*L	−0.04 (0.07)	−0.01 (0.01)	
Q	1.16 (1.07)	1.52 (0.20)	
Q*Q	0.000 (0.00)	−0.000 (0.00)	
E	0.11 (0.05)		0.04 (0.01)
E*E	0.000 (0.00)		−0.000 (0.00)
N	367.60 (1727.86)		782.46 (222.34)
N*N	−266.76 (245.35)		−26.63 (6.44)
L*Q	−0.001 (0.01)	0.001 (0.00)	
L*E	−0.001 (0.00)		
L*N	19.03 (9.45)		
Q*E	0.000 (0.00)		
Q*N	−0.55 (0.45)		
E*N	−0.03 (0.02)		0.004 (0.00)
t	−495.12 (676.33)	−1049.50 (470.86)	−549.24 (557.39)
	−65.04 (109.90)	225.46 (81.90)	34.34 (94.84)
t*L	−0.72 (2.08)	2.24 (0.86)	
t*Q	0.12 (0.11)	−0.13 (0.02)	
t*E	0.01 (0.11)		0.01 (0.00)
t*N	35.07 (203.19)		−25.05 (32.90)
Const.	4088.680 (3714.10)	3575.15 (1974.99)	4317.90 (2095.94)
Observations	316	671	507
Log- likelihood	−15654.7		
	0.89		

Notes: Standard error in parentheses.
R^2 is calculated as squared correlation between estimated and observed costs, which is equivalent to R^2 from OLS.

In Table A2, we present the parameter estimates. Note that even though the parameter estimates for each firm type are presented in different columns, the cost function for integrated, distribution, and generation firms is estimated jointly. The constant term refers to *Idum*, *Ddum*, and *Gdum* from eq (3). The estimation results are in levels.

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