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Vertical and Horizontal Economies in the Electric Utility Industry:
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Abstract

The empirical literature on the cost structure of the electric utility industry traditionally focused on the measurement of specific technological properties: *i*) scale economies in generation or distribution; *ii*) multi-product (or *horizontal*) economies of scope at the downstream stage; *iii*) multi-stage (or *vertical*) economies of scope between generation, transmission and distribution. This paper extends the results of previous studies by adopting an integrated approach, which simultaneously considers both horizontal and vertical aspects of the technology. The methodology is based on the estimation of a *Composite* cost function model (Pulley and Braunstein, 1992), which has been proven to be particularly apt for the analysis of cost properties of multi-output firms. The econometric evidence for a sample of 25 Italian electric utilities, operating in generation and distribution and serving different categories of users, highlights the presence of both vertical integration gains and scope economies at the downstream stage. In the light of recent regulatory changes in Europe, our findings have important policy implications for the optimal reorganization of the electric markets. Finally, our methodology can be usefully applied to the study of other network utilities involved in vertical and horizontal expansion processes, such as gas, water and telecommunications.

Key words: Electric utilities; Vertical and horizontal scope economies; Composite cost function

JEL: C52; D20; L50; L94

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1. Introduction

A typical network utility is involved in a vertical process in which intermediate outputs are produced at upstream stages and transferred to downstream stages. They are then used, together with other inputs, to obtain the final output, that generally consists in the provision of one or more services to end users. For example, in the electricity industry the power generated is conveyed into the grid and distributed to different categories of customers.

Empirical studies of the cost function of electric utilities (figure 1) traditionally focused on a *particular stage* of the vertical chain and were mainly aimed at measuring the extent of scale economies (e.g., Christensen and Greene, 1976, for generation and Filippini, 1996, and Yatchew, 2000, for distribution). By letting the cost function to accommodate for more than one output, one can investigate the presence and the extent of multi-product (or *horizontal*) scope economies too (e.g., Salvanes and Tjotta, 1998, Greer, 2003). Kaserman and Mayo (1991) were the first to apply the latter concept to derive a measure of multi-stage (or *vertical*) scope economies for a sample of US electric utilities. The methodology developed in such a seminal contribution was subsequently refined (Gilsdorf, 1994; Kwoka, 2002; Nemoto and Goto, 2004) and applied to other network industries, such as gas (Casarin, 2002) and water (Garcia et al., 2004).

The above cited studies addressed some important policy issues, such as the optimal organization of network industries (for example, they suggested the breakdown of State-owned monopolies in order to promote more competition, or the deverticalization of the industry as an effective way to contrast the dominant position of incumbent firms). In this paper we contribute to this branch of literature by adopting an integrated approach that allows to *jointly consider* vertical and horizontal technological aspects. Using a sample of 25 Italian municipal electric utilities observed for the period 1994-2000, we estimate a cost function which includes two outputs at the downstream stage (number of industrial users and number of residential users) and one output (generation) at the upstream stage. To the better of our knowledge, only Ivaldi and McCullough (2001), in the context of the railways industry, have estimated a variable cost function allowing to infer simultaneously on the presence of both economies of scope and economies of vertical integration.

From a methodological point of view, we estimate the general specification of the Composite Cost Function model firstly introduced by Pulley and Braunstein (1992). The latter has been widely cited (but, perhaps surprisingly, rarely used in the empirical literature as yet) and recommended as a model which is particularly suitable for the analysis of cost properties of multi-output firms (Piacenza and Vannoni, 2004).

2. Methodology

Pulley and Braunstein (1992) estimated the following *General* cost function specification (PB_G):

$$c^{(\phi)} = c(y;w)^{(\phi)} = \left\{ \exp\left[\left(\alpha_0 + \sum_i \alpha_i y_i^{(\pi)} + \frac{1}{2} \sum_i \sum_j \alpha_{ij} y_i^{(\pi)} y_j^{(\pi)} + \sum_i \sum_r \delta_{ir} y_i^{(\pi)} \ln w_r \right)^{(\tau)} \right] \right.$$

$$\left. \cdot \exp\left[\beta_0 + \sum_r \beta_r \ln w_r + \frac{1}{2} \sum_r \sum_l \beta_{rl} \ln w_r \ln w_l + \sum_r \sum_i \mu_{ri} \ln w_r y_i^{(\pi)} \right] \right\}^{(\phi)}$$

[1]

where $c(y;w)$ is the long-run cost of production, y_i and w_r refer to outputs and factor prices, respectively, and the superscripts in parentheses ϕ, π and τ represent Box-Cox transformations (for example $y_i^{(\pi)} = (y_i^\pi - 1)/\pi$ for $\pi \neq 0$ and $y_i^{(\pi)} \rightarrow \ln y_i$ for $\pi \rightarrow 0$).

By applying the *Shephard's Lemma*, one can easily obtain the associated input cost-share equations:

$$S_r = \left(\sum_i \delta_{ir} y_i^{(\pi)} \right) \cdot \left[\alpha_0 + \sum_i \alpha_i y_i^{(\pi)} + \frac{1}{2} \sum_i \sum_j \alpha_{ij} y_i^{(\pi)} y_j^{(\pi)} + \sum_i \sum_r \delta_{ir} y_i^{(\pi)} \ln w_r \right]^{\tau-1}$$

$$+ \beta_r + \sum_l \beta_{rl} \ln w_l + \sum_i \mu_{ri} y_i^{(\pi)}$$

[2]

Equation [1] embraces several of the most commonly used cost functions. The *Generalized Translog* (GT) and the *Standard Translog* (ST) models can be easily obtained by imposing the restrictions $\phi = 0$ and $\tau = 1$ (and $\pi = 0$ for the ST model). The *Composite Specification* (PB_C) is a nested model in which $\pi = 1$ and $\tau = 0$, while the *Separable Quadratic* (SQ) functional form requires the further restrictions $\delta_{ir} = 0$ and $\mu_{ri} = 0$ for all i and r. The PB_G and PB_C specifications originate from the combination of the log-quadratic input price structure of the ST and GT models with a quadratic structure for outputs. The latter is appropriate to model cost behaviour in the range of zero output levels and gives an advantage over the ST and GT forms as far as the measurement of both economies of scope and product-specific economies of scale are concerned. In addition, the log-quadratic input price structure can be easily constrained to be linearly homogeneous.[1]

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[1] To be consistent with cost minimization, [1] must satisfy symmetry ($\alpha_{ij} = \alpha_{ji}$ and $\beta_{rl} = \beta_{lr}$ for all couples i, j and r, l) as well as the following properties: *a*) non-negative fitted costs; *b*) non-negative fitted marginal costs with respect to outputs; *c*) homogeneity of degree one of the cost function in input prices ($\Sigma_r \beta_r = 1$ and $\Sigma_l \beta_{rl} = 0$ for all r, $\Sigma_r \delta_{ir} = 0$ and $\Sigma_r \mu_{ri} = 0$ for all i); *d*) non-decreasing fitted costs in input prices; *e*) concavity of the cost function in input prices.

In this paper we estimate the system [1]-[2] and carry out LR tests - in the case of nested models - and Vuong's tests - in the case of non-nested models, in order to select the specification best fitting observed data (Vuong, 1989). We then obtain estimates of aggregate scale and scope economies for our sample of Italian electric utilities. Finally, by fully exploiting the informational content of our specification, we investigate the presence of scope economies at the downstream stage (i.e. horizontal economies) and across stages (i.e. vertical economies).

3. Data and estimation

Our database refers to a balanced panel of 25 Italian municipal electric utilities observed over the period 1994-2000, for a total of 175 *pooled* observations. 11 firms are pure distributors while 14 firms are integrated electric utilities.

Data on costs, output quantities and input prices are obtained by integrating the information available in the annual reports with additional information drawn from questionnaires sent to managers. Total costs (c) are the sum of labor cost and of the cost of other inputs, a residual category that includes depreciation, maintenance, materials and services, but excludes the costs of purchased power.[2] All monetary variables are expressed at constant prices at year 2000. Outputs are kilowatt hours of generation (y_G) and the number of residential (y_{DR}) and industrial (y_{DI}) users. Productive factors are labor (L) and other inputs (O). The price of labor (w_L) is given by the ratio of total salary expenses to the number of employees. The price of other inputs (w_O) is obtained by dividing residual expenses by the sum of generated and distributed electricity.[3] Summary statistics are shown in table 1.

All the specifications of the multi-output cost function are estimated jointly with their associated input cost-share equations via a non-linear GLS estimation (NLSUR). In our two-inputs case, to avoid singularity of the covariance matrix of residuals only the labor equation (S_L) was retained and included in the system.

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[2] Such latter costs represent a simple transfer from the producer to the consumer, and they do not reflect "any productive activity by the purchasing utility in and of itself" (Gilsdorf, 1994, p.279).
[3] Our sample includes integrated operators and pure distributors, but detailed information on the value of fixed assets at the different stages, which is crucial in order to obtain acceptable proxies for the price of capital, is lacking. By including capital as a separate input and by dividing the user cost of capital by the length of the network, one would have ended up with an unjustified overestimation of the price of capital for vertically integrated firms as compared to pure distributors. The use of a residual category for all inputs different from labor, whose price (w_O) is obtained dividing the relative cost by the sum of generated and distributed electricity, is the best we can do, given the existing information, to take into account the fact that outputs at the generation stage can be zero or positive.

Before the estimation, all variables were standardized on their respective sample median values, except for y_G, which has been divided by the kwhs of generation required to serve a number of industrial and residential customers equal to the sample medians[4]. Differently from Pulley and Braunstein (1992), we have been able to obtain estimates of the coefficients μ_{ri}, while we had to drop the second constant term β_0 in order to ensure convergence.

Table 2 presents in the second column our main results for the general specification. Two control variables have been added to [1] in order to test for the presence of technological progress (time trend t) and density effects (DEN = total number of users/network length). The summary statistics show that the estimated model performs quite well. The R^2 for the cost function and for the labor share equation are 0.999 and 0.708, respectively, and the model exhibits a good degree of satisfaction of both output and input price regularity conditions (98% and 99% of sample points, respectively). The estimated ϕ, τ and π are 0.33, -0.03 (not significantly different from zero) and 1.03, respectively, and suggest that the PB$_C$ specification (table 2, third column) performs better than the GT and ST alternatives[5].

For the 'median' firm[6], the estimates of cost elasticities with respect to outputs ($\varepsilon_{cy_i} = \partial \ln c(y;w) / \partial \ln y_i$, $i = G, DR, DI$) are 0.61 (s.e. = 0.03), 0.09 (s.e. = 0.09) and 0.34 (s.e. = 0.09), respectively, while the cost elasticity with respect to labor price ($\varepsilon_{cw_L} = S_L$) is 0.34 (s.e. = 0.02). The measure of global scale economies is computed as follows:

$$SE(y;w) = \frac{c(y;w)}{\sum_i y_i MC_i} = \frac{1}{\sum_i \varepsilon_{cy_i}} \qquad [3]$$

where $MC_i = \partial c(y;w) / \partial y_i$ is the marginal cost, while the measure of global scope economies reads as follows:

$$SC(y;w) = \frac{[c(y_G,0,0;w) + c(0,y_{DR},0;w) + c(0,0,y_{DI};w) - c(y_G,y_{DR},y_{DI};w)]}{c(y_G,y_{DR},y_{DI};w)} \qquad [4]$$

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[4] Thus, our point of approximation is a median-sized fully integrated utility, i.e. a firm generating 100% of its distribution needs.

[5] The LR statistics lead to the rejection of the (nested) GT, ST and SQ specifications, while the PB$_C$ model cannot be rejected. Moreover, the Vuong's statistics (Vuong, 1989) suggests that the PB$_C$ model has to be preferred to the GT and ST ones. Results are available upon request. For more details on model selection procedures, see Piacenza and Vannoni (2004) and Fraquelli et al. (2004).

[6] The 'median' firm is an hypothetical unit observed in year 1997 that generates about 178 million kwhs (recall our hypothesis of 100% own-generation ratio), distributes electricity to 20.175 residential customers and to 7.247 industrial users, and faces median values of input prices and customer density.

For the median firm, *SE* is equal to 0.96 (s.e. = 0.02), suggesting that costs increase more than proportionally with the increase of all outputs, while *SC* is equal to 0.24 (s.e. = 0.13), highlighting that costs of (horizontally and vertically) integrated firms are significantly lower than the sum of costs of three utilities specialised in the production of y_G, y_{DR} and y_{DI}.

Given our three-output specification, several measures of stage-specific and product-specific scale and scope economies can be computed. However, we are particularly interested in detecting the presence of vertical economies between generation and distribution and of economies of scope at the downstream stage. The measure of *vertical economies* can be computed via[7]

$$VE(y;w) = \frac{\left[c(y_G,0,0;w) + c(0,y_{DR},y_{DI};w) - c(y_G,y_{DR},y_{DI};w) \right]}{c(y_G,y_{DR},y_{DI};w)} \qquad [5]$$

while a measure of scope economies in the distribution phase only (under the assumption that output generated is zero) is:

$$SC_D(y;w) = \frac{\left[c(0,y_{DR},0;w) + c(0,0,y_{DI};w) - c(0,y_{DR},y_{DI};w) \right]}{c(0,y_{DR},y_{DI};w)} \qquad [6]$$

VE is equal to 0.08 (s.e. = 0.04), while SC_D is equal to 0.39 (s.e. = 0.30), suggesting that a median size utility can enjoy cost savings by joining generation and distribution activities and that the choice to serve different categories of users is to be preferred to the alternative specialization strategy. It might be useful to report a relationship that nicely highlights the links between aggregate scope economies, vertical economies and scope economies at the distribution stage:

$$SC(y;w) = SC_D(y;w) * \frac{c(0,y_{DR},y_{DI};w)}{c(y_G,y_{DR},y_{DI};w)} + VE(y;w) \qquad [7]$$

Summarizing, our results suggest that both vertical economies (in the order of 8%) and scope economies at the final stage (in the order of 16%, if compared to the costs of a fully integrated and diversified firm) contribute to explain the emergence of aggregate scope economies in the order of 24%.

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[7] Equation [5] is a correct measure of vertical economies provided that purchased power expenses are netted out from distribution costs (see also note 2).

4. Conclusions

This paper analyses the cost structure of a sample of electric utilities operating at upstream and downstream stages and serving different categories of users. The empirical strategy focuses on the Composite cost function model (PB$_C$) introduced by Pulley and Braunstein (1992). After having set several alternative functional forms (including the Translog and the Quadratic models) within a general specification (PB$_G$), we carried out LR-type tests in order to select among nested and non-nested models. The results confirm the merits of the PB-type cost functions and show for the median firm the existence of global economies of scope. More interesting, we found evidence of moderate vertical integration gains and of more substantial scope economies at the distribution stage.

From a policy standpoint, our findings suggest that specialized firms could reduce their costs becoming active at different vertical stages and serving different categories of users. In the light of recent regulatory changes in the European electricity industry, which are in favour of a gradual liberalization of the sector, our results suggest caution in separating generation from distribution in order to promote competition among generators. In fact, an undiscriminating and systematic breakdown of a structure that was traditionally dominated by large vertically integrated utilities cannot be an optimal policy if substantial vertical economies are at place.

From a methodological standpoint, our approach, that simultaneously considers both horizontal and vertical aspects of technology and uses a functional form which is particularly apt to undertake such an endeavour, can be easily extended to the study of other network industries, such as gas, water, telecommunications, public transit systems.

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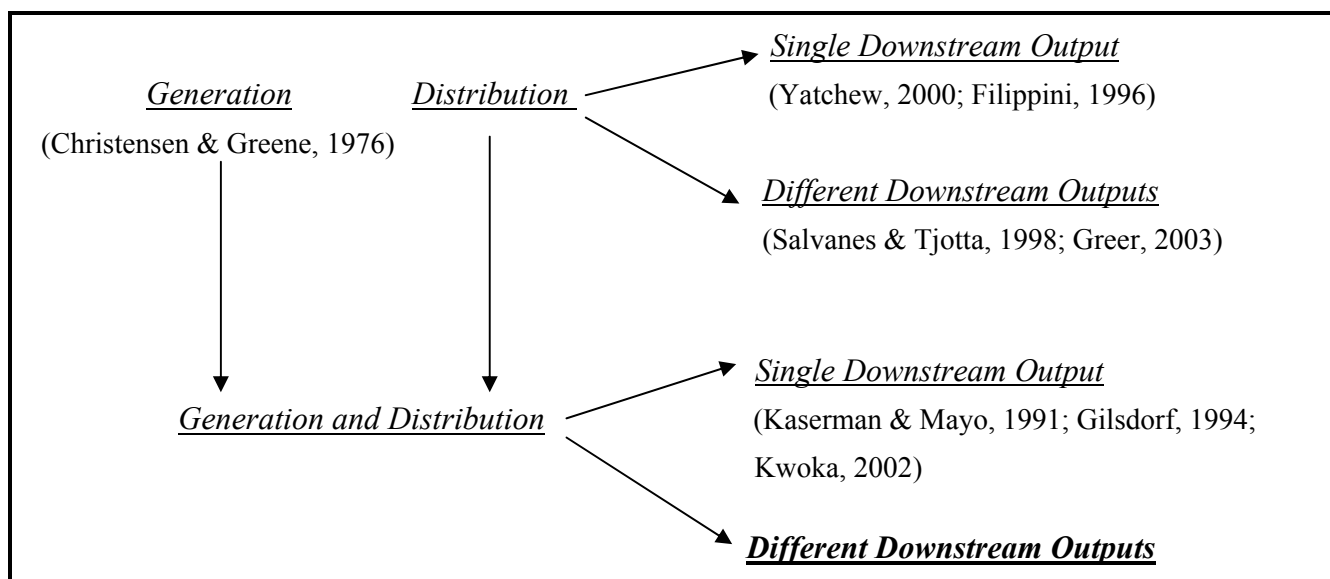**Figure 1. Classification of empirical studies on electric utilities**

Generation
(Christensen & Greene, 1976)

Distribution

Single Downstream Output
(Yatchew, 2000; Filippini, 1996)

Different Downstream Outputs
(Salvanes & Tjotta, 1998; Greer, 2003)

Generation and Distribution

Single Downstream Output
(Kaserman & Mayo, 1991; Gilsdorf, 1994; Kwoka, 2002)

Different Downstream Outputs

Table 1. Summary statistics

		min	1st quartile	median	3rd quartile	max
VARIABLES						
c	Total costs (10^6 Italian lire)	1,007	6,373	13,697	41,799	496,645
y_G	Generated power (10^6 Kwh)	4	48	152	642	3,412
y_{DR}	Served residential users	1,683	8,942	20,175	49,108	677,567
y_{DI}	Served industrial users	773	3,149	7,247	17,611	98,658
w_L	Price of labor (10^6 Italian lire)	66.78	76.39	82.41	89.59	118.04
w_O	Price of other inputs (10^6 Italian lire)	11.07	32.91	38.88	47.70	84.53
S_L	Labor cost-share	0.15	0.31	0.42	0.52	0.82
S_O	Other inputs cost-share	0.18	0.48	0.58	0.69	0.85
DEN	User density	13	34	49	75	202

Table 2. NLSUR parameter estimates for the *General* (PB_G) and *Composite* (PB_C) cost functions

REGRESSORS [a]	PARAMETERS	PB_G MODEL estimates	s.e.	PB_C MODEL estimates	s.e.
Box-Cox	ϕ	0.328***	(0.067)	0.324***	(0.063)
Box-Cox	τ	-0.027	(0.146)	0	-
Box-Cox	π	1.028***	(0.126)	1	-
Constant	α_0	0.635***	(0.022)	0.634***	(0.020)
y_G	α_G	0.372***	(0.032)	0.372***	(0.018)
y_{DR}	α_{DR}	0.052	(0.070)	0.052	(0.052)
y_{DI}	α_{DI}	0.212***	(0.080)	0.209***	(0.055)
y_G^2	α_{GG}	0.021	(0.040)	0.022	(0.022)
y_{DR}^2	α_{DRDR}	0.045	(0.038)	0.049	(0.039)
y_{DI}^2	α_{DIDI}	0.171	(0.132)	0.189	(0.119)
y_{GDR}	α_{GDR}	-0.014	(0.038)	-0.015	(0.021)
y_{GDI}	α_{GDI}	0.009	(0.061)	0.006	(0.030)
y_{DRDI}	α_{DRDI}	-0.080	(0.073)	-0.087	(0.074)
$y_G \ln w_L$	δ_{GL}	-0.038***	(0.009)	-0.037***	(0.007)
$y_{DR} \ln w_L$	δ_{DRL}	0.004	(0.021)	0.005	(0.021)
$y_{DI} \ln w_L$	δ_{DIL}	0.029	(0.025)	0.029	(0.024)
$\ln w_L$	β_L	0.336***	(0.017)	0.337***	(0.017)
$\ln w_L^2$	β_{LL}	0.252***	(0.022)	0.254***	(0.022)
$\ln w_L y_G$	μ_{LG}	-0.002	(0.009)	-0.002	(0.007)
$\ln w_L y_{DR}$	μ_{LDR}	-0.010	(0.008)	-0.011	(0.007)
$\ln w_L y_{DI}$	μ_{LDI}	0.033*	(0.020)	0.033**	(0.016)
DEN	γ_{DEN}	-0.031*	(0.017)	-0.027*	(0.014)
t	γ_t	0.001	(0.007)	0.002	(0.007)
System log-likelihood		388.190		387.920	
Cost function R^2		0.999		0.999	
Labor-share equation R^2		0.708		0.707	
Regularity conditions:					
- output regularity satisfaction		98%		94%	
- price regularity satisfaction		99%		96%	

[a] The coefficient subscripts are G = generated power, DR = residential users, DI = industrial users, L = labor input, t = time trend, DEN = user density.

*** Significant at 1 percent level in a two-tailed test.
** Significant at 5 percent level in a two-tailed test.
* Significant at 10 percent level in a two-tailed test.