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Economies of integration in the Spanish electricity industry using a multistage cost function

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Abstract

The Spanish electric sector is empirically analysed using a multistage–multiproduct quadratic cost function estimated with data on firms from 1985 to 1996. Economies of both vertical (EVI) and horizontal (EHI) integration are calculated through economies of scope. Estimated EVI indicate that joint generation and distribution saves 6.5% of costs, lower than what has been obtained in similar studies in the USA. This difference suggests that expenses in both system coordination and market transactions are a relevant source of economies, already accounted for in the Spanish electric sector where a central coordination agency exists. EHI between generation products are somewhat larger.

JEL classification: L94; L51

Keywords: Economies of vertical integration; Disintegration; Multiproduct–multistage cost functions

1. Introduction

An electricity supply system comprises four stages of production: generation, transmission, distribution and final delivery, with the last two usually regarded as one phase. These activities or productive stages are interdependent due to the particular characteristics of supply and demand, which is why an electric system requires coordination across

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stages. For an independent system to satisfy demand at a minimum variable cost, the marginal cost (adjusted for losses) should be equal for each generator. To achieve this, modern systems use a *central dispatch* method. The transmission phase normally includes this task of coordination and management.

On the other hand, different technologies can be used at the generation stage and, at the distribution stage, energy can be provided in both high and in low tension. Thus, electricity supply is an economic activity that can be described as both multistage and multiproduct, within the generation and distribution stages. Thus, multiproduct theory provides the adequate approach for the analysis of the electric sector.

Due to stage interdependency, the traditional organisation within the electric sector has considered the extension of the natural monopoly condition to all stages as a consequence of the existence of strong economies of vertical integration (EVI). These EVI have been looked at as a consequence of two type of savings regarding nonintegrated firms: the cost due to technological interdependency between stages, which includes stage coordination and the use of common inputs, and the market transaction costs.

Since the 1980s, an increasing number of articles in the economic literature are advocating vertical disintegration and the replacement of common property across stages, introducing competition where feasible. The idea is that the competitive system would replace, through market forces, the coordination of the whole system. Competition among the increasing number of firms would permit cost and price reductions and, therefore, efficiency gains that can compensate for the cost increases due to the loss of EVI. However, the greatest problems for deregulation processes arise in the processes of designing and operating the market because, as pointed out by Ramos-Real (in press) the problem of technical interdependencies can be solved with an independent system operator. For Newbery (2002), due to transactions costs, appropriate market regulation is required for the deregulation process to translate into improvements in the operation of the industry and into benefits for consumers. Hattori and Tsutsui (2004) finds that vertical disintegration has had an ambiguous effect over electricity prices because of the loss of the EVI, mainly transaction costs in the electric market.

In this paper, we present an empirical analysis of the Spanish electric sector in the period 1985–1996, which just precedes the liberalisation process due to the Electric Sector Law dictated in 1997 (ESL 97). The main objective is to analyse the EVI in Spain. To do this, we estimate a long run multistage–multioutput cost function, from which we also study the overall cost structure and the economies of horizontal integration (EHI). During the period studied, the electric sector in Spain presented a very particular structure where the characteristics of an integrated system co-existed along with those of a nonintegrated one (Ramos-Real et al., 2002). Thus, the values for the EVI are particularly interesting to analyse and compare with other studies, particularly in the USA, because of the different levels of integration observed and because the potential sources of efficiency gains differ across systems.

In Section 2, we describe the structure of the Spanish electric sector during the studied period and analysed briefly the liberalisation process after the ESL 97. In Section 3, we summarise the necessary concepts of multiproduct theory and we analyse the main empirical work using these tools reported for the electric industry. Section 4 contains the conceptual and analytical models, and data is described to some detail. General results, marginal costs and economies of scale are presented in the fifth section, while economies of vertical and horizontal integration are quantified and analysed in Section 6. The paper closes with the main conclusions.

2. The spanish electricity sector: 1985–1996

During the period 1985–1996, the Spanish electric sector was organised around the existence of an independent operator (Red Eléctrica de España, REE) in charge of the management of both the energy transmission and the existing generation capacity (dispatching). Distribution was mostly in the hands of large firms assigned exclusively to specific geographical regions and vertically integrated with generation. The main 14 companies were integrated into the sector's managerial group UNESA that in 1996 accounted for 88.9% of the gross production of energy and more than 90% of the distribution. Furthermore, there are some very small distribution companies that purchase power to REE and resell it to the consumer at the end of the chain. Likewise, there also exists a series of so-called "self-producers" who produce electricity for their own industrial processes and who sell the excess to the electricity companies who, in turn, are obliged to acquire this power at prices set by the legislation. Under the same terms, they have to buy the power mandatorily from independently produced renewable energy sources.

Under this scheme, REE took the role of coordination between stages, while a regulated system (including financial rewards to firms) implied that there were no market transaction costs. Within this context, the potential EVI between generation and distribution would represent only savings in some factor use. This scheme of vertical relations has not been altered after the liberalisation of the sector in 1997. However, a new operator has been created (Operador del Mercado de Electricidad: OMEL), managing the wholesale electric market where supply and final demand meet.

In the mid 1990s, a rapid process of concentration took place due to various mergers, which gave the ENDESA group (who controlled FECSA and SEVILLANA in 1996) 52% of the generation and 40% of the distribution market. The second group, IBERDROLA, holds a generation quota of 29% and 38% for distribution. The third and fourth producers, Union Fenosa and Hidrocantábrico, have 13% and 6% in generation and 15% and 5% in distribution, respectively.

The reform of the sector that got underway in 1997 had as its goal the complete deregulation of the areas of generation and merchandising. However, generation firms that operate in the wholesale market have exercised important market power in spite of the liberalisation, as indicated in various studies regarding the Spanish electric sector (e.g. Kühn and Machado, 2003). The main causes of this unpleasant facts that threw doubts regarding the success of deregulation are basically three: the low capacity for international connection, the excessive concentration in the sector and a high degree of vertical integration.

Following Fig. 1, within the period analysed empirically in this paper the typical Spanish firm uses production factors that are common to generation and distribution: labor, capital and intermediate inputs. Fuel is a factor that is used for generation only in

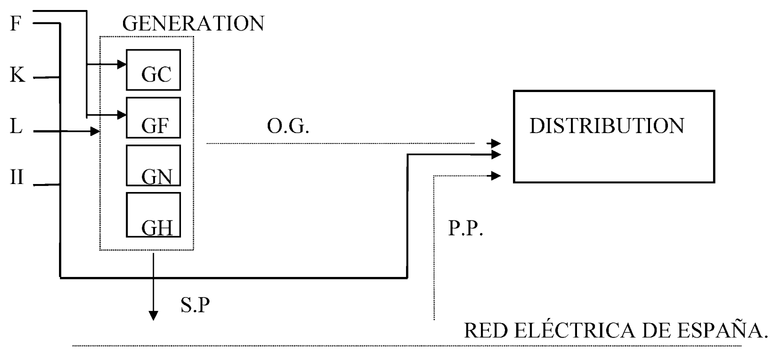

Fig. 1. Production process. F: fuel; K: capital; L: labor; II: intermediate input; PP: purchased power; SP: sold power; OG: own generation; CG: coal generation; GF: fuel-oil generation; GN: nuclear generation; GH: hydroelectric generation; Di: Distribution.

fossil-fueled plants. Generation is used either to feed the own market or to sell to other electric firms through the network managed by the REE; purchased power is a factor that is specific to the distribution phase when self-produced generation is not enough.

3. Multiproduct theory and the economies of vertical integration

In this section, we present first the theoretical elements of multiproduct theory that will be used in the empirical analysis, and then we review the methods applied by different authors in the literature to measure the EVI in the electric sector.

Omitting factor prices for simplicity, a cost function $C(Q)$ represents the minimum necessary expenditure to produce a product vector Q (at given factor prices). Following Baumol et al. (1982), BPW, the (multioutput) degree of scale economies S represents the maximum proportional expansion of outputs after a proportional expansion of inputs, and it can be calculated from the cost function because of its dual properties regarding technology as

$$S = \frac{C(Q)}{\sum_j Q_j C_j(Q)} = \frac{1}{\sum_j \varepsilon_{C,Q_j}} \tag{1}$$

where Q_j is amount of product j, C_j is its marginal cost and ε is its cost elasticity.

The key concept to analyse the convenience of joint production is *economies of scope*[1]. They exist if production of the whole set M at a given level is less costly with one firm

[1] The condition of natural monopoly requires subadditivity of the cost function within the required range of products, which means that the division of total production in more than one firm is more expensive than concentration in a single one. Economies of scope are necessary but not sufficient for subadditivity. Stronger conditions are required, involving scale properties as well. Nevertheless, economies of scope play an important role in the study of optimal industry structure in general and of vertical and horizontal integration in particular.

than with various firms, each producing a subset of products that constitute an orthogonal partition R_i of M, this is if

$$C(Q) < \sum_{i=1}^{k} C(Q_{R_i}) \tag{2}$$

Originally, BPW defined the degree of economies of scope for a simple orthogonal partition as

$$\mathrm{SC}_R \equiv \frac{1}{C(Q)}[C(Q_R) + C(Q_{M-R} - C(Q_M)] \tag{3}$$

such that a positive value for SC means the convenience of one firm over two specialized ones.

The cost function exhibits costs complementarity between products i and j if the marginal cost of i does not increase when the volume of j increases, this is

$$\frac{\partial^2 C}{\partial Q_i \partial Q_j} \leq 0 \tag{4}$$

The existence of cost complementarity between two products reflects advantages in their joint production. If they exist for all product combinations up to the level of production, economies of scope will be present, but these latter can exist even if cost complementarity is not present. This could happen, for example, if relevant product specific fixed costs exist.

There are two alternative methodologies used in the electric sector to examine EVI. One attempts to identify the existence of EVI through the analysis of separability of the cost function between phases, including stage-specific factor prices and examining the significance of the cross terms among these and the products. Following this methodology, Hayashi et al. (1998) using a single output approach, and Roberts (1986) and Thompson (1997), which differentiate between products according to the level of tension, reject separability between stages, which is interpreted as a sign of the existence of EVI. As evident, the advantages or disadvantages of vertical and/or horizontal integration cannot be properly quantified from this approach.

The second methodology, which is the approach we will take in our work, makes it possible to detect and quantify the EVI for different entrepreneurial set ups by using scope economies. If the product vector includes outputs at different stages, the existence of economies of scope between stage-associated subsets is equivalent to EVI, provided double counting of products (costs) at the superior level is avoided (Kaserman and Mayo, 1991; Gilsdorf, 1994; Kwoka, 2002). Note that economies of scope between subsets of products at the same stage provide a direct measure of EHI.

Calculation of economies of scope requires an orthogonal partition of the product vector, which means that all components should be valued at zero for one of the firms in the partition. In this case, the rather popular translogarithmic functional form is not well defined, which is why it is not particularly appropriate for scope analysis unlike the quadratic functional form. The articles by Gilsdorf (1994, 1995) try to resolve this question by studying the complementarity relations, in the former, and by using Evans and

Heckman's (1984) subadditivity test, in the latter. This test limits the area of study of the subadditivity depending on the sample data used. As mentioned earlier, complementarity and scope are related but different concepts.

Using this latter approach and a quadratic cost function, Kaserman and Mayo (1991) and Kwoka (2002) have measured EVI for the electric industry in the USA. They found values of 12% and 42%, respectively for EVI, both measured at the mean of their samples. If measured at the same production level, these estimates are in fact very close; for example, considering 10,000 GWh generation and 8000 GWh distribution yields EVI of 20% for Kaserman and Mayo and 22.5% for Kwoka.

It is worth noting that the interpretation and comparison of results should be made cautiously. First, the EVI depend on the characteristics of the sample, particularly on the degree of vertical integration prevailing in the different countries. For instance, both Kaserman and Mayo and Kwoka study the advantages of joint production including three types of firms in their samples: some are totally integrated, others only generate, and a third group includes transmission and generation only. Because of this, their calculated EVI do account for transaction costs and both components of the costs associated with technological interdependency. In the Spanish case, only generation and distribution costs should be considered when using firm data, as an independent operator manages the transmission stage; as explained below, the interpretation of the estimated EVI is somewhat different. Finally, the value of the EVI will depend also on whether purchased power or intermediates inputs are included or not as a cost, as double counting should be avoided as discussed below (Section 4.2).

4. The model

4.1. A cost function for spanish electricity supply

From our perspective, the most adequate form of analysis of both vertical and horizontal integration in the electricity supply industry, requires the specification of a multiproduct, multistage cost function that permits the calculation of economies of scope. For this purpose, the quadratic functional form is particularly appropriate as it is flexible, in the sense that no a priori signs are assigned to either first or second derivatives, which implies that marginal costs, cost complementarity between products and price elasticities of factor demands flow freely from the data. Most important, it can be evaluated at zero values for one or more outputs, which allows for the calculation of economies of scope. On the other hand, note that the quadratic has limitations, as linear homogeneity and input price concavity can be verified only a posteriori.

This functional form has been used by Kaserman and Mayo (1991) and Kwoka (2002). The former work, however, sacrifices some flexibility of the cost function as it does not include cross products and factor prices are included linearly only. On the other hand, Kwoka does not completely specify the cost function either, such that the input demands cannot be estimated together with the cost equation. We specify and estimate the complete quadratic cost function proposed by Lau (1974) together with the input expenditure equations.

In addition to outputs and factor prices, we have included a time trend that interacts with all other variables, a firm specific dummy and a variable representing capacity utilization (generation) that also interact with other variables. To facilitate analysis at the mean of the observations, all variables were deviated with respect to the sample mean. The resulting model is:

$$\begin{aligned} C = {} & \alpha_0 + \sum_i^m \alpha_i (Q_i - \bar{Q}_i) + \sum_i^n \beta_i (W_i - \bar{W}_i) + \varphi_T (T - \bar{T}) + \varphi_{\mathrm{CU}} (\mathrm{CU} - \overline{\mathrm{CU}}) \\ & + \frac{1}{2} \sum_i^m \sum_j^m \delta_{ij} (Q_i - \bar{Q}_i)(Q_j - \bar{Q}_j) + \frac{1}{2} \sum_i^n \sum_j^n \gamma_{ij} (W_i - \bar{W}_i)(W_j - \bar{W}_j) + \sum_i^m \sum_j^n \rho_{ij} (Q_i - \bar{Q}_i)(W_j - \bar{W}_j) \\ & + \sum_i^m \lambda_{iT} (Q_i - \bar{Q}_i)(T - \bar{T}) + \sum_i^m \lambda_{i\mathrm{CU}} (Q_i - \bar{Q}_i)(\mathrm{CU} - \overline{\mathrm{CU}}) + \sum_i^n \mu_{iT} (W_i - \bar{W}_i)(T - \bar{T}) \\ & + \sum_i^n \mu_{i\mathrm{CU}} (W_i - \bar{W}_i)(\mathrm{CU} - \overline{\mathrm{CU}}) + \pi_{TT} (T - \bar{T})(T - \bar{T}) + \pi_{\mathrm{CUCU}} (\mathrm{CU} - \overline{\mathrm{CU}})(\mathrm{CU} - \overline{\mathrm{CU}}) + \sum_i^{N-1} \omega_i D_i \end{aligned} \tag{5}$$

where the bar represents sample mean, m is the number of products, n is the number of factors, W_i is a factor price, Q_i is a product quantity, T is trend (time), CU is capacity utilization, D_i is the firm specific dummy variable and N is the number of firms. The remaining symbols are the parameters to be estimated.

The time trend reflects the change over time of the cost function itself. The CU variable represents the (short run) effect of the rate of use of the installed generation capacity on production costs. The binary dummy variables capture firm specific effects that are fixed across observations in time. They account for differences between firms that are not explained by the rest of the variables and are independent of time. These dummies reflect firm heterogeneity in general, including not only relative inefficiency but also other structural differences. Some studies include the size of the geographical area served as a variable that influences distribution costs, concluding that this effect cannot be detected if production and the number of customers vary proportionally (Roberts, 1986; Thompson, 1997). In our case, there is a 0.93 correlation between this two variables, which made us discard the inclusion of the area served in the model.

Applying Shephard's lemma to Eq. (5) and multiplying times the factor prices, we obtain the factor expenditure equations given by

$$\begin{aligned} G_i = W_i \times \Bigg[& \beta_i + \gamma_{ii} (W_i - \bar{W}_i) + \mu_{iT} (T - \bar{T}) + \mu_{i\mathrm{CU}} (\mathrm{CU} - \overline{\mathrm{CU}}) + \sum_{j \neq i}^m \gamma_{ij} (W_j - \bar{W}_j) \\ & + \sum_{j \neq 1}^n \rho_{ij} (Q_j - \bar{Q}_j) \Bigg] \end{aligned} \tag{6}$$

where i stands for factor type and X_i are the factor derived demands. Joint estimation of Eqs. (5) and (6) increases the efficiency of the estimated parameters.

4.2. The variables

The dependent variable is the long-run economic cost of production and the explanatory variables are essentially production and factor prices. All expenditure variables are expressed in constant pesetas (1996). Costs are actual expenses gathered from the firms annual reports. The term economic reflects the fact that capital costs include both amortisation and the opportunity cost.

Following Gilsdorf (1994, 1995) and Kwoka (2002), purchased power was not included as a factor of production in our model; accordingly, its price was not included in the cost function and these expenses were not included in C. Thus, the dependent variable includes generation costs plus operating distribution costs only. We want to emphasise that these latter include those costs that arise because of transport of energy and maintenance of the network as well as delivery to final consumers either in low or high voltage, besides capital costs. As evident, distribution expenses are independent of the origin of energy (self-generated or purchased), which is the reason why all distributed energy is included in the corresponding output measure. In this manner, double counting of generation costs is avoided when calculating EVI from the definition of economies of scope. Kaserman and Mayo (1991), who do consider this input, calculate the degree EVI from the degree of economies of scope, but taking into consideration that generation is a derived demand when calculating the cost of distribution individually.

For the purpose of the main analysis in this paper, the specification of product is most important. We will be dealing with firms that generate and distribute. In fact, the whole idea behind the vertical analysis is to examine whether these two stages could be better produced separately. Thus, both stages were considered, and each contains more than one output. As shown below, 9 out of 12 firms in our sample use more than one energy source for generation. Accordingly, we identified four types of generation products: coal (gc), oil-gas (gf), hydroelectric (gh), and nuclear (gn). Regarding distribution, although two outputs were identified according to final delivery voltage (high and low tension), they were highly correlated, which convinced us that only a single distribution product should be specified (di). Production was measured in million kWh units. Thus, the product vector is Q=(gc, gf, gh, gn, di).

As factors are in fact aggregates (capital, labor, fuel and intermediate input), we have to construct indices for factor prices, which requires the corresponding expenditures and a proxy measure for each factor. Thus, the calculation of a single labor price (pl) index is straightforward and units are million annual pesetas per worker. We use a fuel price (pc) variable obtained from the cost of an equivalent ton of coal that represents the cost of fossil fuels[2], obtaining pts/kWh (only gc and gf).

An index for the price of capital for each firm was obtained as $p_{kt} = \frac{A_t + r_t * \mathrm{FP}_t}{\mathrm{IMNE}_t}$, where p_{kt} is the price of capital in year t, A_t is the amortisation in year t, r_t is the average rate of return in the electric sector in year t, FP_t is stockholders' equity in year t and IMNE_t are the net tangible fixed assets used during year t.

The price of capital thus defined is a relative rate that takes into account the depreciation charges of each year and the return on own funds as a proxy of capital expenditures. We use as the measure of capital the net tangible fixed assets currently used. We use as the return on own funds (r_t) the average financial returns (net profit before taxes/

[2] We do not consider the fuel factor in the case of nuclear energy. The annual consumption of uranium is included as depreciation for the same year (i.e. part of the cost of capital).

own funds before taxes) of the firms which are members of the confederation Unidad Eléctrica Española (UNESA).

Expenditures in intermediate inputs are related with operating expenses, excluding labor costs and procurements (purchased power and fuel). It is a quite heterogeneous aggregate that is very much short run oriented. Therefore, to obtain a price index (pi), the corresponding expenses were divided into net revenues, subtracting those from purchased power.

Finally, some considerations regarding the derived demand for fuel and capacity utilization have an effect on the specification of the cost function. First, fuel demand depends on coal and fuel-oil generation only; the rest of the generation and distribution outputs do not use it. Therefore, and according to Shephard's lemma viewed in reverse, fuel price should not be cross-multiplied with these latter outputs. Second, fuel has no technical substitute in the production process of the two types of thermal generation, but we do admit potential substitution with capital in the long run; this indicates that fuel price should not interact with other factor prices either.

Therefore, fuel demand X_f is given by $X_f = X_f(\text{pc, pk, gc, gf}, T, \text{CU})$, which makes fuel price interact only with these variables in the cost function. The rest of the factor prices receive the usual general treatment.

Capacity utilization (CU) is measured as the ratio between energy generated and installed power, multiplied times annual hours, such that CU moves between 0 and 1. It enters the specification in three forms: linear, squared and crossed with generation products and the prices of capital and fuel. This makes marginal costs of generation and the derived demands for capital and fuel (potentially) dependent on CU.

4.3. Data

We have gathered annual information on the most important 12 firms that generate and distribute electricity in Spain, from 1985 to 1996. Data was obtained directly from the annual reports released by the firms. Because information was not available for some firms during some years, a total of 106 observations were finally obtained. All firms are organised within UNESA; it is worth noting that ENDESA-Generación was excluded because their expenditure data include mining activities as well, and there is no form to separate expenses a priori. We have also excluded self-generators, local distributors and autonomous systems that operate beyond mainland Spain. By 1992, ENDESA-Generación represented 25% of total (national) generation, and it was not directly involved in distribution, which was done through firms that were part of the ENDESA group.[3]

The firms finally considered are the following: Unión Eléctrica Fenosa (FENOSA), Compañía Sevillana de Electricidad (SEVILLANA), Fuerzas Eléctricas de Cataluña (FECSA), Empresa Nacional Hidroeléctrica del Ribagorzana (ENHER), Hidroeléctrica del Cantábrico (HC), Electra de Viesgo (VIESGO), Hidroeléctrica de Cataluña (HEC),

[3] By the end of the period, the ENDESA group included ENDESA Generación, ENHER, VIESGO, HEC, ERZ and ENECO. Each firm operated autonomously until 1996, keeping separated accountability independently of ENDESA Generación (the parent company). Only this latter has been eliminated as explained in the text.

Hidroléctrica Española (HE), Iberduero, Eléctricas Reunidas de Zaragoza (ERZ) and Empresa Nacional de Córdoba (ENECO), which only generates. During the period, Hidroeléctrica Española and Iberduero merged, giving birth to Iberdrola, which was regarded as yet another firm from 1992 onwards.

By 1996, the firms listed above represented 84% of UNESA customers, 81% of the net consumption of electric energy in Spain, and approximately 50% of the gross production of electricity. Tables A1 and A2 in Appendix A contain the mean values of the variables included in the estimation, as well as other variables and ratios that are of interest. Note that the existence of some firms that do not produce some of the outputs improves the reliability of the analysis of scope, which is essential for our study of horizontal and vertical integration from a multiproduct, multistage cost function. Tables A3 and A4 in Appendix A contains product and factor participation for all firms for 1989, 1996 and for the whole period. Regarding production, thermal, hydraulic and nuclear generation mean roughly one third each. The overall G/D ratio less than one shows that firms in the sample have to purchase power as a whole.

5. General results, marginal costs and economies of scale

We estimated a system of equations formed by the cost function (5) and the expenditure equations (6) for labor, fuel, capital and intermediate input. Zellner's (1962) iterative procedure was used, and the outcome is shown in Appendix B. Hausmann's test has verified the existence of correlation between the independent variables and the error term, thus allowing for the use of the fixed effects model.

Before analysing results in depth, it should be noticed that the estimated coefficients fulfill various nice properties in terms of signs and values. First, the cost function evaluated at the mean of the variables is the constant (C1) plus the mean of the dummies (C68 to C78), which correctly yields a value that is fairly close to the observed mean cost. On the other hand, the marginal costs by product at the mean are represented by parameters C2 to C6, which are all positive and significant. In addition, this is a property (product monotonicity) that extends to all observations in the sample.

Due to Shephard's lemma, parameters C8 to C11 represent factor demand at the mean and they are all positive as expected, and significant. Monotonicity in factor prices extend to all observations as well. If factor demand are multiplied times each average factor price, they replicate average expenditure on each factor. This implies that homogeneity of the cost function regarding factor prices is fulfilled at the mean. The pure time related parameter (C12) is negative and significant while the parameter of T squared (C66) is positive but insignificant, which indicates that ceteris paribus cost diminishes with time at a constant rate.

Regarding the effect of capacity utilization, CU, the interpretation of the results at the mean are also quite interesting. The first order term (C7) is negative and significant and the squared term (C67) is not significant. This indicates that better utilization diminishes total costs, as expected. The crossed terms of CU with pc (C60) and pk (C65) are both negative and significant, which means that the derived demands for both fuel and capital diminish with a better utilization of installed capacity, making a more efficient use of both factors.

Table 1
Marginal costs estimates

Product	Marginal cost (PTAs/kWh)	T-stat.
gc	9.52	71.22
gf	17.02	16.17
gh	7.15	4.09
gn	7.94	10.05
di	2.95	16.13

From the estimated parameters, many relevant quantities can be directly calculated. To begin with, Table 1 contains marginal costs of all products, evaluated at the mean of the right-hand side variables. This shows that generating one additional unit of electricity is more expensive than its distribution; the largest values correspond to thermal generation.

Marginal costs can be calculated for each firm as well, taking the derivative of Eq. (4) with respect to any output and evaluating the variables at the mean of the corresponding firm. These are shown in Table 2, where we can observe that they are all positive and present no large variation across firms. The values for each firm present the same relative ordering as for the overall mean.

For a reference on the order of magnitude of the results obtained on marginal costs, we can consider the average price of purchased power, which by 1995 was 6.75 PTAs/kWh. This can be compared against the weighted sum (by relative production) of the long run marginal costs of generation, which yield 8.47 PTAs/kWh using our results.

Derived factor demands are related with those parameters that involve the corresponding factor price. When these prices interact with products, the parameters are all positive, which means that factor demands increase with production. On the other hand, the significant parameters involving prices and time are all negative, which indicates that, ceteris paribus, factor demands decrease in time.

The second order terms involving two different factor prices indicate the variation of factor demand after the variation of other factor price. The results in Appendix B indicate substitution between capital and labor (C55) and between capital and intermediate inputs

Table 2
Marginal costs by firm

Firm	gc	gf	gh	gn	di
Average	9.52	17.02	7.15	7.94	2.95
ENECO	12.81	–	–	–	–
ENHER	–	–	6.77	–	3.42
ERZ	–	–	6.95	–	3.28
FECSA	8.63	15.88	5.65	6.77	2.95
FENOSA	8.69	14.56	5.63	6.18	2.87
H.C.	8.88	–	5.91	6.33	3.22
H.E.	–	17.08	6.06	7.86	2.82
H.E.C.	–	–	6.07	6.69	3.14
IBERDUERO.	9.70	15.89	5.99	6.75	2.97
IBERDROLA	9.60	18.28	7.33	9.77	2.46
SEVILLANA	9.89	17.75	8.49	9.41	2.36
VIESGO	9.15	–	6.89	–	3.01

Table 3
Product elasticities and economies of scale

Product	$\varepsilon_{C,q}$	T-student
Coal	0.23	13.22
Fuel	0.03	3.20
Hydraulic	0.14	6.40
Nuclear	0.23	9.32
Distribution	0.30	9.90
S	1.074	52.47

(C61), and complementarity between labor and intermediate input (C54). As found in other studies, there is also substitution between capital and fuel reflected in a positive parameter (C58), suggesting that increases in fuel price induce fuel saving capital investments.

Regarding the dummy variables, those of FECSA and HE (C70 and C73) are negative and significant, which indicates that ceteris paribus the costs of these firms are below those of ENECO, which was used as the reference. The rest of the dummies are insignificant, suggesting no particular cost advantages of the other firms regarding ENECO.

Table 3 shows the values of the product elasticities of cost plus the global degree of economies of scale calculated as in Eq. (1), evaluated at the mean, all statistically significant. The overall value of 1.074 for *S* indicate slightly increasing returns to scale at the mean, i.e. a proportional expansion of all products by 1% would provoke an increase of costs by 0.93%. We have estimated that returns to scale get exhausted after a proportional increase of 7% in production at the mean. Product specific returns to scale are all constant (not shown).

Finally, global economies of scale by firm at each mean are shown in Table 4. In general, the values of *S* are inversely related with a size index represented by aggregated production ($G+D$). Nevertheless, exceptions to this rule are also present, which are likely to arise because of the different product combinations.

Table 4
Product elasticities and economies of scale by firm

Firms	gc	gf	gh	gn	di	$G+D$ (GWh)	*S*
Average	0.23	0.03	0.14	0.23	0.30	19,589	1.074
ENECO	1.33	–	–	–	–	2042	0.751
ENHER	–	–	0.30	–	0.56	10,868	1.161
ERZ	–	–	0.18	–	0.62	4248	1.260
FECSA	0.05	0.04	0.05	0.38	0.29	20,334	1.223
FENOSA	0.37	0.02	0.09	0.13	0.25	36,480	1.144
H.C.	0.70	–	0.06	0.05	0.27	11,839	0.934
H.E.	–	0.04	0.11	0.46	0.27	40,022	1.136
H.E.C.	–	–	0.12	0.17	0.41	4785	1.430
IBERD.	0.12	0.01	0.28	0.14	0.32	39,264	1.157
IBERDROLA	0.11	0.04	0.16	0.44	0.26	94,248	0.983
SEVILLANA	0.31	0.10	0.02	0.30	0.29	29,419	0.971
VIESGO	0.32	–	0.16	–	0.34	4690	1.210

6. Analysis of the economies of horizontal and vertical integration

Let us now move to the integration analysis. Before going into the calculation of SC to examine EVI and EHI, it should be mentioned here that, regardless of significance, product related second order term parameters are small in absolute terms, which means that technical relations among products are not particularly relevant, as suggested by Kühn and Regibeau (1998).

Regarding economies of horizontal integration at the generation level, the idea is to compare the cost of producing all generation products with a single firm as opposed to splitting production among two or more firms. The cost of producing with a single firm was represented by the cost function evaluated with the distribution product put to zero, in order to avoid the effects of vertical integration. Many type of economies of scope can be calculated at the generation level; in Table 5, the values involving one specialized firm are shown. Results are all within the theoretical correct range, varying from 0.1 to 0.092 depending on the type of generation specialization examined, suggesting between 9.2% and 10% savings due to joint generation. We have also calculated the savings from joint production in generation as compared with four specialized firms, obtaining a 28.1% savings. It should be noted that, as output is exogenous in this type of analysis, the correct conclusion here is that generation of all four types is advantageous with one firm if in fact all four types are deemed necessary.

As explained above, economies of vertical integration can be examined by comparing the cost of generating and distributing with a single firm, C(gc,gf,gh,gn,di), against the sum of the cost of one generation firm, C(gc,gf,gh,gn,0) and those of a distribution firm, C(0,0,0,0,di). This is, of course, the degree of economies of scope for such a partition using the estimated cost function. This yields a value of 0.065, which indicates the existence of slight economies of vertical integration or, analogously, that there is a 6.5% savings due to joint production.

As pointed out earlier, second order terms happened to be relatively small in general. It can be easily shown that, if the cost function is close to linear in outputs, the degree of economies of scope is given by the fixed term (i.e. the cost function evaluated at zero products) divided into the total cost (see Jara-Díaz et al., 2002). In our case, although the function is not linear, the cost of joint production means roughly a 7000 million pesetas (1996) savings for most alternative partitions. This suggests that the economies of integration come basically from some potential duplication of expenditures. As technical

Table 5
Economies of scope for vertical and horizontal integration analysis

Production involved	Costs savings millions pts 1996	T-student	Scope econ.
Distribution – generation	7263	3.41	0.065
Coal – fuel, hyd, nuclear	7112	3.68	0.092
Fuel – coal, hyd, nuclear	7109	3.66	0.091
Hyd – coal, fuel, nuclear	7115	3.69	0.092
Nuclear – coal, fuel, hyd	7733	4.17	0.100
Four specialized firms	21,521	3.78	0.281

relations are not relevant, we believe that savings due to joint generation come from avoiding the duplication of some structural costs in administration as central management, accounting, personnel departments, marketing, and so on.

As argued earlier, comparisons with other studies should be made taking into account differences in the regulatory context and in the samples used. We will see that this exercise in fact contributes to a richer discussion of results. As measures of SC are local (i.e. they depend on the point of evaluation), we have approximated (by interpolation) the values obtained by Kaserman and Mayo (1991) and by Kwoka (2002) to the mean level of production in our sample for the comparison to be relevant and easier. For 8.2 thousand GWh generation and 11.35 thousand GWh distribution, these values are 22.5% and 26% savings for Kaserman and Mayo (1991) and Kwoka (2002), respectively, larger than the 6.5% obtained here as expected. As explained earlier, both papers include not only the technological interdependencies but also transaction costs. In our case, the modest 6.5% represents technological savings because of common factors only, because coordination costs are absorbed by the REE as described earlier. Thus, in our view, the difference should be interpreted as savings that correspond to transaction and coordination costs, which in the Spanish case are already accounted for exogenously to the firms; the costs attributable to common factors that are shared because of technical needs seem to account for a relatively low proportion of EVI.

7. Synthesis and conclusions

We have presented an empirical analysis of the Spanish electric sector, based upon the estimation of a multistage, multiproduct cost function that includes generation and distribution. The special circumstances of the Spanish case make the inclusion of the transmission phase unnecessary.

Products are identified at two levels or stages, with four components within the generation phase. This permits an exhaustive analysis of economies of both vertical and horizontal integration through economies of scope. A complete quadratic form is used, including all parameters except those that can be suppressed a priori on economic grounds (fuel factor demand). The most relevant results can be synthesised as follows. As presently organised, the Spanish electric sector exhibits slightly increasing scale economies at the mean of the observed production levels; decreasing returns are observed thereafter (from about 7% of ray growth from the sample mean). By the end of the analysed period returns to scale are completely exhausted.

EVI indicate that joint generation and distribution saves 6.5% of costs, lower than savings estimated in other studies that include both system coordination costs and market transaction costs; our figure includes only technological interdependencies savings. This suggests that the present scheme within the Spanish electric sector is already accounting for most of these savings. On the other hand, economies of horizontal integration between generation products are somewhat larger. Orthogonal partitions into two firms show that savings are in the neighbourhood of 6.5% (in the extreme case of total specialization with four different firms, this would mean a 28.1% increase in cost). These results suggest that the economies of vertical and horizontal integration arise mostly because specialization implies some duplication of expenditures, which might be mostly related with administration. This indicates the existence of some start-up costs, which could be an entry barrier.

The results obtained show that network coordination and market transaction costs are far from negligible and should be taken into account in the analysis of vertical disintegration. We have detected cost advantages between various forms of generation (EHI) and between generation and distribution. This means that the creation of a market is not incompatible with participation in more than one stage, provided that strategic behaviour is properly controlled. This fact, plus the presence of decreasing returns for large levels of production, can be translated into policies within the Spanish electric sector. This is of interest because of the process of concentration that is currently taking place along with deregulation and restructuring within the Spanish electric sector. Our results suggest that, in spite of the advantages of joint production, a larger number of firms combining optimal size and optimal product mix would be desirable, avoiding concentration in the hands of a few firms acquiring relevant market power.

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Appendix A. Description of firms

Table A1
Mean production by firm in the period 1985–1996 (million kWh)

	gc	gf	gh	gn	Total gener.	di	*G*+*D*	*G*/*D*	CU
Average	2706	197	2176	3160	8239	11,350	19,589	0.72	0.32
Variation coef.	1.16	2.35	1.48	1.69	1.16	1.05	–	–	0.38
ENECO	2042	0	0	0	2042	0	2042	–	0.59
ENHER	0	0	2296	0	2296	8572	10,868	0.27	0.21
ERZ	0	0	503	0	503	3745	4248	0.13	0.25
FECSA	710	328	1033	6633	8704	11,630	20,334	0.75	0.27
FENOSA	9178	273	3540	4621	17,613	18,867	36,480	0.93	0.38
H.C.	5188	0	641	529	6358	5481	11,839	1.16	0.46
H.E.	0	585	4111	13,439	18,135	21,887	40,022	0.83	0.27
H.E.C.	0	0	535	702	1237	3548	4785	0.35	0.25
IBERDUERO	2625	133	9636	4264	16,658	22,607	39,264	0.74	0.28
IBERDROLA	5483	1163	11,035	22,813	40,494	53,753	94,248	0.75	0.28
SEVILLANA	4777	865	429	4876	10,948	18,472	29,419	0.59	0.30
VIESGO	957	0	624	0	1581	3109	4690	0.51	0.21

Source: firm released data.

Table A2
Mean expenditure and input prices by firm in the period 1985–1996

	Million pesetas 1996					MPt/worker	pk	10^3 PTAs/eot	pi
	Total	Labor	Fuel	Int. inp.	*K*	pl		Pc	
Average	10,7717	24,963	17,099	18,588	47067	7.28	0.12	8.28	0.148
Variat. coef.	1.07	1.09	1.15	1.22	1.17	0.12	0.47	1.04	0.29
ENECO	19,625	1469	11,988	1200	4967	6.46	0.254	8.06	0.054
ENHER	52,097	16,005	0	12,930	23,162	7.68	0.107	–	0.193
ERZ	19,863	7050	0	4905	7908	6.70	0.11	–	0.201
FECSA	117,829	27,779	7219	18,947	63,883	7.61	0.093	8.10	0.141
FENOSA	213,259	43,689	57,790	29,970	81,810	7.68	0.087	8.57	0.134
H.C.	66,199	8393	30,569	7943	19,294	7.57	0.092	8.57	0.159
H.E.	229,728	51,072	5871	43975	128,810	7.70	0.101	7.79	0.146
H.E.C	27,299	8479	0	4619	14,202	7.79	0.101	–	0.139
IBERD	209,836	56,958	18,983	38,318	95,577	7.95	0.094	9.15	0.146
IBERDROLA	501,024	119,234	37,369	103,601	240,820	7.94	0.119	7.94	0.155
SEVILLANA	151,195	37,176	27,204	23,976	62,839	6.25	0.146	7.97	0.125
VIESGO	27,102	6683	5722	4281	10,417	6.51	0.113	7.97	0.167

eot: equivalent oil ton.
Source: firm released data.

Table A3
Product participation (generation, all firms)

Product	1989	1996	Period
Gen. coal	32%	25%	33%
Gen. fuel	2%	1%	2%
Gen. hyd.	19%	35%	26%
Gen. nuclear	47%	39%	38%
Ratio *G*/*D*	0,72	0,69	0,72

Source: firm released data.

Table A4
Factor participation in total cost

Factor	1989	1996	Period
Fuel	15%	10%	16%
Labor	23%	23%	23%
Int. input	15%	19%	17%
Capital	46%	49%	44%

Source: firm released data.

Appendix B. Estimated coefficients of the cost function

Estimated coefficients of the cost function

Parameter	Value	T-student
α (C1)	111,874	71.22
α gc (C2)	9.52	16.17
α gf (C3)	17.02	4.09
α gh (C4)	7.15	10.05
α gn (C5)	7.94	16.13
α di (C6)	2.95	15.62
φ CU (C7)	− 36,390	− 4.61
β pl (C8)	3278	67.45
β pc (C9)	2089	51.83
β pi (C10)	124,761	106.21
β pk (C11)	435,818	43.40
φ *T* (C12)	− 2997.54	− 6.86
δ gc − gc (C13)	− 0.12e − 4	− 2.03
δ gc − gf (C14)	− 0.389e − 4	− 0.34
δ gc − gh (C15)	0.30e − 4	2.48
δ gc − gn (C16)	− 0.58e − 5	− 0.52
δ gc − di (C17)	0.516e − 5	0.79
λ gc − CU (C18)	0.176	0.78
ρ gc − pl (C19)	0.019	1.02
ρ gc − pc (C20)	0.674	53.16
ρ gc − pi (C21)	2.91	6.09
ρ gc − pk (C22)	28.16	6.86
λ gc − T (C23)	0.012	3.10
δ gf − gf (C24)	0.302e − 3	1.94
δ gf − gh (C25)	0.657e − 4	0.67
δ gf − gn (C26)	0.165e − 3	3.10
δ gf − di (C27)	− 0.773e − 4	− 1.37
λ gf − CU (C28)	6.04	0.90
ρ gf − pl (C29)	0.373	2.22
ρ gf − pc (C30)	0.509	6.34
ρ gf − pi (C31)	17.91	4.20
ρ gf − pk (C32)	63.53	2.32
λ gf − T (C33)	0.107	1.88
δ gh − gh (C34)	0.124e − 4	1.43
δ gh − gn (C35)	− 0.147e − 4	− 1.24
δ gh − di (C36)	0.3e − 5	0.30
λ gh − CU (C37)	− 0.111	− 0.34
ρ gh − pl (C38)	0.017	0.49
ρ gh − pi (C39)	6.37	6.65
ρ gh − pk (C40)	51.53	11.15
λ gh − T (C41)	− 0.83e − 3	− 0.10
δ gn − gn (C42)	0.406e − 4	4.16
δ gn − di (C43)	− 0.29e − 5	− 0.27
λ gn − cu (C44)	− 0.297	− 0.84
ρ gn − pl (C45)	0.021	0.83
ρ gn − pi (C46)	8.52	12.58
ρ gn − pk (C47)	54.12	17.02
λ gn − T (C48)	− 0.75e − 2	− 1.26

(continued on next page)

Appendix B (*continued*)

Parameter	Value	T-student
δ di – di (C49)	– 0.735e – 5	– 1.96
ρ di – pl (C50)	0.268	14.23
ρ di – pi (C51)	6.94	13.46
λ di – T (C52)	0.494e – 3	0.14
γ pl – pl (C53)	– 1.63	– 0.45
γ pl – pi (C54)	– 240.9	– 1.39
γ pl – pk (C55)	272.84	1.10
μ pl – T (C56)	– 156.41	– 9.80
γ pc – pc (C57)	– 3.70	– 3.27
γ pc – pk (C58)	331.72	2.29
μ pc – T (C59)	– 7.68	– 0.69
μ pc – CU (C60)	– 511.32	– 1.57
γ pi – pk (C61)	13,277	1.30
μ pi – T (C62)	– 1760.49	– 5.05
μ pk2 (C63)	– 10,688	– 3.33
μ pk – T (C64)	– 13,191	– 4.49
μ pk – CU (C65)	– 277,199	– 5.09
π T – T (C66)	0.38	0.027
ð CU – CU (C67)	– 559	– 0.44
ω enh (C68)	– 551	– 1.36
ω erz (C69)	– 491.6	– 1.82
ω fec (C70)	– 1549.8	– 2.57
ω fen (C71)	– 108.23	– 0.14
ω hc (C72)	– 558.27	– 1.71
ω he (C73)	– 4518.07	– 3.31
ω hec (C74)	– 443.22	– 1.70
ω ibo (C75)	– 150.13	– 0.10
ω iba (C76)	– 1809.9	– 0.69
ω sev (C77)	63.81	0.1
ω vi (C78)	– 313.85	– 1.48

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