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The measurement of scope, scale and diversification economies: How (in)efficient is electricity restructuring and unbundling?

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THE MEASUREMENT OF SCOPE, SCALE AND DIVERSIFICATION ECONOMIES: HOW (IN)EFFICIENT IS ELECTRICITY RESTRUCTURING AND UNBUNDLING?[a]

Pablo Arocena[b]

ABSTRACT: This paper estimates the degree of economies of scope, diversification and scale in the Spanish electricity industry by means of Data Envelopment Analysis. Our results show that there exist economies of integrating power generation and distribution, as well as economies of product diversification at the generation stage. Particularly, the hypothetical vertical unbundling and the generating product specialization of the existing diversified firms would raise the total operating costs of the Spanish electricity sector by 4.7 and 3.5 percent respectively. Additionally, size appears to be irrelevant provided that vertical scope and product-mix are preserved. Further, it is estimated that overall operating costs of the sector could be reduced by 2.7% by partitioning each of the diversified firms down the middle. In addition to improving firms' scale efficiency, such fragmentation would help to create a more competitive market structure.

Key words: Economies of scope, diversification, scale efficiency, electricity, DEA.
JEL Classification: D24, L94, L11.

RESUMEN: En este trabajo se estiman economías de alcance, diversificación y escala en el sector eléctrico español mediante Data Envelopment Análisis. Los resultados muestran que existen economías derivadas de la integración de las fases de generación y distribución de electricidad, así como economías asociadas a la diversificación entre productos de generación. En particular, una hipotética separación vertical de las empresas analizadas y una mayor especialización en la fase de generación elevarían los costes de operación en un 4,7% y en un 3,5% respectivamente. Asimismo, el tamaño de la empresa no es un factor importante siempre que se mantenga el grado de integración vertical y diversificación horizontal. En este sentido, se ha estimado que un fraccionamiento por la mitad de las empresas analizadas, además de contribuir a crear una estructura de mercado más competitiva, mejoraría la eficiencia de escala y originaría un ahorro del 2,7% de los costes de explotación.

Palabras clave: Economías de alcance, diversificación, eficiencia de escala, electricidad, DEA.
Clasificación JEL: D24, L94, L11.

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1. Introduction

The worldwide wave of liberalising reforms in the electricity industry have been aimed at introducing competition in a sector traditionally organised around monopoly, public ownership and intense regulation. However, the pro-competitive potential of these reforms is fundamentally determined by the market structure. Thus, as in any other industry, the existence of a sufficient number of competitors is an indispensable requisite for developing an effective competition. Further, in the electricity sector the effective separation between regulated and non-regulated business is essential to attain the benefits of competition[1].

In some countries these reforms failed to sufficiently restructure their electricity industries and the result has been the creation of power pools where major incumbents enjoy substantial market power. In others the industry at liberalisation was mostly comprised of a small number of vertically integrated private firms, so that the chances for restructuring through privatisation were more limited. Thus, in Spain the high level of horizontal concentration together with firms' vertical integration are considered the main obstacles for the competitive functioning of the electricity market eight years after market liberalisation (Arocena *et al* 1999, Kühn y Machado, 2004, Fernández-Ordóñez 2002, Ocaña 2003).

Some governments decided to intervene once liberalisation and privatisation had occurred with the aim of mitigating incumbents' market power, basically by promoting the partition of large firms in smaller units and thus increasing the number of competitors. Thus, the British electricity regulator required the two major generators successive plant divestments in order to improve the efficiency of the wholesale power market (OFFER 1994, 1998). [2] In the same vein, in California financial incentives were introduced (higher allowed rate of return) to induce divestiture of 50% of the fossil-fuel

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[1] Otherwise, a vertically integrated company would be able of (i) cross-subsidizing the competitive part of the business with profits from the regulated business; (ii) distorting competition by favouring their associated business over competitors, whether in quality of service or in the price charged for using the system. The threat of such anticompetitive behaviour is an effective entry deterrent. A third reason to introduce unbundling is to improve the effectiveness of regulation.

[2] Although the amount of divestiture was substantial, it was insufficient to ensure a competitive pool in England and Wales (Day and Bunn, 2001).

generation assets owned by the largest utilities. Likewise, the European Commission has followed the same strategy in its recent decisions on mergers. Thus, it authorised the acquisition of German electricity company EnBW by Electricité de France (EDF) subject to the divestment of 6,000 Megawatts of generation capacity located in France (EC, 2001).

Nevertheless, the (technically) efficient number of firms as well as their degree of vertical integration depends on the magnitude of the economies of scale and scope economies. Hence, if scale and horizontal diversification economies are limited or negligible, the break-up of large firms in smaller units will have a positive effect on reducing market power without damaging the costs of the resulting firms. On the contrary, if such economies are significant, the partition will lead to efficiency losses (and cost increases) that could counterweight the potential benefits derived from a more competitive functioning of the market.

A similar argument applies to the vertical scope of the firm. If power could be efficiently supplied by means of specialized firms competing in their respective stages of the business, vertical separation could help to increase the competitive pressure in the market without cost penalties. Conversely, if vertical or scope economies across stages are important, potential benefits of unbundling could be counterbalanced by the loss of productive efficiency.

Defenders of large firms and vertical integration remark the existence of economies of scope and scale economies, while advocates of unbundling cite the benefits of competition and deregulation. Therefore, the estimation of such economies has important policy implications on further restructuring (or not) (Pittman, 2003). However, while a great deal of attention has been paid to the competitive effects of restructuring policies, the analysis of the potential costs in terms of productive efficiency losses has devoted considerable less attention. Nevertheless, the available empirical work suggests that vertical economies across generation and transmission/distribution stages, as well as scale and horizontal diversification economies at generation and distribution stages might be significant (Kaserman and Mayo 1991, Gilsdorf 1995, Lee 1995, Thompson 1997, Hayashi *et al* 1997, Kwoka 2002, Nemoto and Goto 2004, Jara-Díaz *et al* 2004).

The objective of this paper is the estimation of these economies in the Spanish electricity sector by means of an alternative approach. Particularly, we use non-parametric methods based on linear programming models (Data Envelopment Analysis). This approach presents some attractive features over the traditional cost function estimation. First, it implies the estimation of a frontier rather than the non-frontier cost function, which implies to implicitly assume that firms are efficient. Second, we do not impose a priori any functional form relative to the underlying technology (i.e. quadratic, translog, etc.). Finally, specific benchmark frontiers are constructed for diversified and specialized utilities. This avoids a general assumption of parametric approaches: the definition and estimation of identical forms of cost functions regardless of whether outputs are jointly produced or separately produced.

The paper is organised as follows. Section 2 reviews the theoretical background of scope and scale economies. Section 3 describes the non-parametric frontier methodology we use to estimate the economies of integration. Section 4 presents data and variables while results are displayed in Section 5. Final section summarizes the empirical results and makes conclusions.

2. Economies of scope, diversification and scale: Theoretical background.

Firm boundaries and, consequently, the configuration of the industry, is largely determined by the properties of the firms' cost function. In this respect, the notion of cost subadditivity is particularly relevant. A cost function $C(y)$ is said to be subadditive at the output level y if for any and all quantities of outputs $y_1,\ldots y_n$, $y_j \neq y$, $j = 1,\ldots,n$, such that $\sum_i y_i = y$, we have $\sum C(y_i) > C(y)$. That is, if the cost function is subadditive, it is more cost efficient to combine the output bundles produced by several firms into a single bundle to be produced by one larger firm. Further, if the firms' cost function is subadditive over the entire relevant range of outputs, then the industry is said to be a natural monopoly since a single firm can produce all relevant output vectors more cheaply than two or more firms. Alternatively, if the cost function were superadditive it would be cost efficient to break up the output of a large firm into several bundles to be produced by a number of smaller firms.

Cost subadditivity shapes both the horizontal and vertical boundaries of the firm. Thus, it is related to the degree of (i) economies of scale; (ii) vertical (or multistage) economies of scope across stages; and (iii) horizontal (or product-mix) economies at one stage.

2.1   Multistage scope economies: Vertical integration.

Economies of scope arise from cost savings obtained from joint production. That is, it is more efficient to produce an output bundle by a single diversified firm than splitting up the production of each output, or subset of outputs, between separate specialised firms. Following Baumol *et al* (1982 p.71-72), let *N* be the set of outputs produced by a firm. Consider a subset of the firm's outputs $S \subseteq N$. Let $P = \{T_1, T_2, ..., T_k\}$ be a non-trivial partition of *S*. That is, $\cup_i T_i = S$, $T_i \cap T_j = 0$ *para* $i \neq j$. $T_i \neq 0$, $k > 1$. There are economies of scope at y_s with respect to the partition *P* if $\sum_{i=1}^{k} c(y_{Ti}) > c(y_s)$.

Diseconomies of scope occur if the inequality is reversed. Economies of scope is a necessary –though no sufficient- condition for subadditivity.
Thus, for the two-output case (y_1, y_2) there are economies of scope if

$$C(y_1, y_2) < C(y_1, 0) + C(0, y_2) \qquad [1]$$

When y_1 and y_2 are outputs corresponding to adjacent stages in the vertical chain (i.e. generation and distribution of electricity), [1] reveals the existence of vertical (or multistage) scope economies (Kaserman and Mayo, 1991).
Note that economies of scope is a restricted form of subadditivity, where the output vectors of specialized firms are restricted to be orthogonal to one another, that is, such that $y_i \cdot y_j = 0$, i≠j. Thus, for the three-output case $y = (y_1, y_2, y_3)$, economies of scope are said to exist with respect to partition $P = \{T_1, T_2\}$, $T_1 = (y_1, 0, 0)$, $T_2 = (0, y_2, y_3)$ if [3]

$$c(y_1, 0, 0) + c(0, y_2, y_3) > c(y_1, y_2, y_3)$$

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[3] This is only one possible partition of the output vector. Scope economies could be calculated relative to any non-trivial partition. For example, P' = (T₁, T₂, T₃) where T₁ = (y₁, 0, 0), T₂ = (0, y₂, 0), T₃ = (0, 0, y₃), which would imply full specialization.

The degree of scope economies at *y* relative to the partition *P* is defined as

$$SC_P(y) = \frac{C(y_T) + C(y_{N-T}) - C(y)}{C(y)}$$

[2]

That is, it measures the relative increase in cost that would result from dividing the production of *y* into product lines *T* and *N-T*. Such a fragmentation of the firm increases, decreases, or leaves unchanged the total cost, as *SC(y)* is greater than, less than, or equal to zero, respectively.

2.2 *Economies of horizontal diversification or product-mix economies.*

Grosskopf *et al* (1992) define economies of diversification as the cost savings that may result from a firm's increasing the number of simultaneously produced (different) outputs. Consider the three-output case and two firms (A,B). Additionally, let us assume that outputs 1 and 2 are produced in the upstream stage (i.e. hydroelectric and thermal power generation) while output 3 is the downstream product (i.e. power distribution). Firm A specializes in the production of output 1, firm B specializes in the production 2, while both firms produce some of output 3. That is, both firms are vertically integrated but are specialized in the upstream stage. Economies of horizontal diversification are said to exist if

$$c\left(y_1^A, 0, y_3^A\right) + c\left(0, y_2^B, y_3^B\right) > c\left(y_1^A, y_2^B, y_3^A + y_3^B\right)$$

Diseconomies of diversification occur if the inequality is reversed. For the three-output case, the degree of economies of diversification can be measured as

$$DIV(y) = \frac{c\left(y_1^A, 0, y_3^A\right) + c\left(0, y_2^B, y_3^B\right) - c\left(y_1^A, y_2^B, y_3^A + y_3^B\right)}{c\left(y_1^A, y_2^B, y_3^A + y_3^B\right)}$$

[3]

If *DIV(y)* is positive (negative) then economies (diseconomies) of diversification exist at *y*. If *DIV* is zero, costs are additive at *y*. *DIV(y)* compares the costs of two vertically integrated firms each producing some unique output to the cost of a single multiproduct firm which produces all of the products at the same levels of total output.

It is therefore, an appropriate measure to evaluate decisions on expansion of product line, as well as to assess the cost consequences of merging (breaking up) power firms with diverse generation mix.

2.3 Multiproduct Scale Economies

Multiproduct scale economies are said to exist when total costs go up less than proportionally when the output of all products is increased by the same proportion. This is equivalent to decreasing ray average cost. Ray average cost is the multiproduct equivalent of average cost as defined for the single-product firm, and is defined as the average cost of producing the fixed bundle for a given scale of production. That is, the measure of total output when there are *N* products is done by fixing a bundle of the *N* products and the measure of output is then the number of bundles produced. This is equivalent to assuming that output is produced in fixed proportions and the measure of output is then the scale of production. The degree of multiproduct scale economies is given by

$$MSE(y) = \frac{C(v_i y^A) + C(v_i y^B) - C(y)}{C(y)} \qquad [4]$$

where v_i denotes output proportions, with $1 > v_i > 0$ and $\sum_i v_i = 1$. *MSE(y)* >1 (<1) implies multiproduct economies (diseconomies) of scale. When *RAC* is decreasing at *y*, it is not possible splitting up the output bundle *y*, holding the mix of products constant, without increasing total cost[4].

Figure 1 depicts total cost and average cost along the ray *OR*, which keeps constant the proportion in which product 1 and product 2 are produced (y_2/y_1). *RAC* reaches its minimum at the output $y = y^o$ at which the ray *OT* is tangent to the total cost surface in the hyperplane erected on *OR*. Any output vector to the left or right of y^o presents higher average costs along *OR*. Putting in other words, only y^o is scale efficient in *OR*, it is the optimal scale of production for such output proportion (y_2/y_1). For example, the partition

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[4] Decreasing ray average costs up to *y* imply *ray subadditivity* at *y* (Baumol et al, 1982 p.175).

of a single firm producing y^0 in two identical firms by dividing y^o down the middle (i.e. $v = 0.5$ resulting in two firms producing $y^o/2$) along *OR*, will increase *RAC* due to the scale inefficiency.

Figure 1. Ray average cost and scale efficiency.
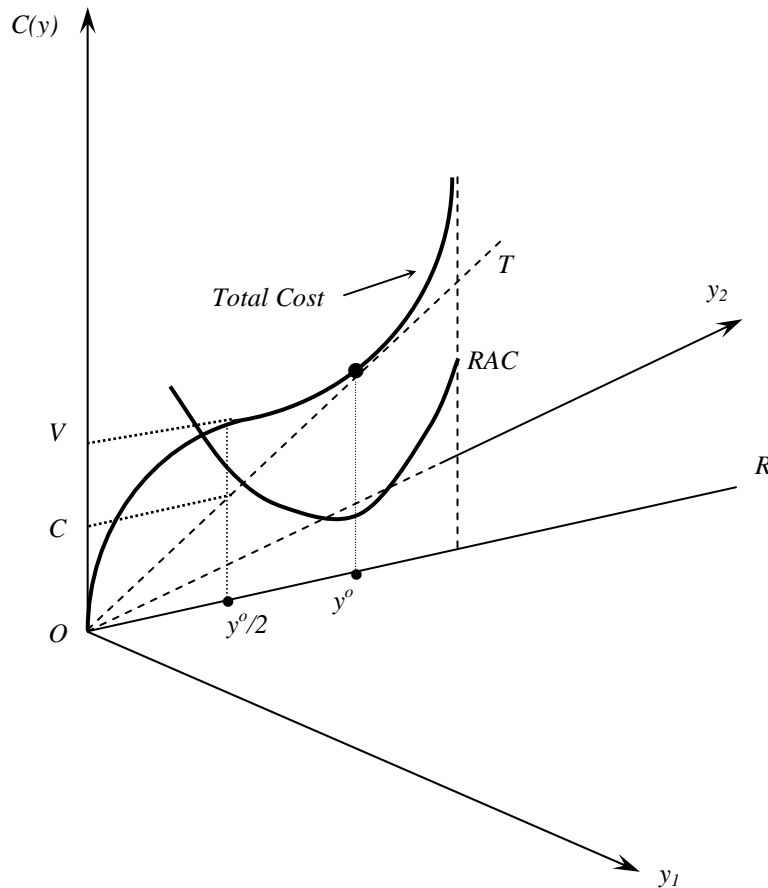
3. Methodology

Most empirical analysis on scope, scale and product-mix economies typically relies on the estimation of multiproduct cost functions. Ramos-Real (2005) provides a recent and comprehensive review of this approach in the electricity industry. Nevertheless, there have been various adaptations of the DEA methodology to estimate the efficiency of joint production and diversification versus especialization (Färe, 1986; Färe *et al*, 1994). Particularly, this approach has been applied to the estimation of scope and

diversification economies in different contexts, such as municipalities (Grosskopf and Yaisawarng 1990), banks (Ferrier *et al*, 1993), hospitals (Prior, 1996; Fried *et al*, 1998, Prior and Solá 2000, Kittelsen and Magnussen, 2003) and cogeneration systems (Kwon and Yun, 2003).

Let $y = (y_1,...., y_M) \in R_+^M$ be the output vector produced by means of the input vector $x = (x_1,....., x_N) \in R_+^N$. Production technology can be represented by the input requirement set, which includes all input vectors yielding output y. $L(y) = \{x : x \text{ produce } y\}$. Technology can also be completely described by the cost function

$$C(y,w) = \min_{x} \{wx : x \in L(y)\}, \qquad [5]$$

where $w = (w_1,...., w_N) \in R_+^N$ is the vector of input prices. The cost function describes the minimal costs to produce the corresponding combination of outputs with given input prices.

Assume that there are two output bundles, named y^A and y^B, which can be either jointly or individually produced from the same inputs (x_1, x_2), by diversified or specialized firms respectively. Let $L(y^A, y^B)$ denote the input combinations necessary to jointly produce y^A and y^B. In Figure 2 this input set is the area bounded from below by the isoquant Isoq-$L(y^A, y^B)$. Therefore, Isoq-$L(y^A, y^B)$ represents the frontier of technology of the diversified firms. Additionally, in Figure 2 two isocost lines are indicated given the input prices $w = (w_1, w_2)$. The lower one represents minimal cost relative to $L(y^A, y^B)$.

Let us consider a diversified firm like *F*. This firm is inefficient because it could produce (y^A, y^B) with less consumption of both inputs (technical inefficiency), and consequently, with lower total costs. The overall economic inefficiency of firm *F* can be represented by the distance to the isocost line $C_d C_d'$. Thus, the ratio OF_d^* / OF measures the reduction in costs attainable by firm *F* once both technical and allocative inefficiency are eliminated.

Figure 2. Efficiency gains from joint versus separate production.
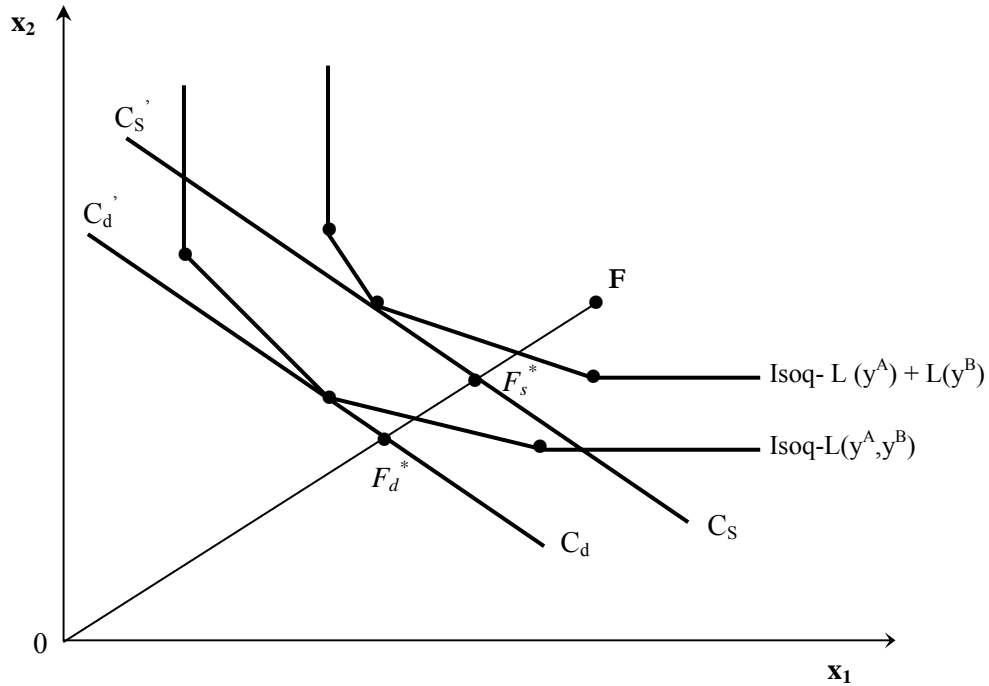
On the other hand, the isoquant labelled by Isoq-L(y^A)+L(y^B) and the isocost line C_SC_S' represents the efficient frontier for separate production of y^A and y^B. It is an additive frontier constructed by summing the inputs quantities employed by the specialized firms in the production of output vectors y^A and y^B. In Figure 2 it is easy to see that the inefficiency of our diversified firm F is smaller relative to this additive frontier. This is measured by the distance OF_S^*/OF, which is smaller than OF_d^*/OF. Therefore, given input prices w, the minimum cost attainable from producing (y^A, y^B) in separate firms is higher than their joint production. In other words, the cost of splitting up the production of (y^A, y^B) into specialized firms equals to the ratio $OF_d^*/OF_S^* = C_d^*/C_S^*$

The source of the (dis)economies behind this distance is given by the characteristics of the specialized vectors used in the construction of the additive frontier L(y^A)+L(y^B). For example, if output vectors y^A and y^B are orthogonal, the ratio OF_d^*/OF_S^* accounts for (dis)economies of scope. Otherwise, it may account for (dis)economies of diversification as defined above.

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In summary, we can estimate the efficiency gains due to integration by comparing the cost frontier of joint production $C(y^A, y^B)$ with that corresponding to separate production $C(y^A) + C(y^B)$.

Let $\mathbf{Y}$ be the matrix MxK of observed outputs and $\mathbf{X}$ the (NxK) matrix of observed inputs. That is, there are M different outputs and N different inputs for each of K firms. We construct a piecewise linear reference technology based on these observed outputs and inputs by taking convex combinations of the observed data points and their extensions

$$L(y) = \left\{ x : \mathbf{Y} \cdot z \geq y, \mathbf{X} \cdot z \leq x, z \in \Re_+^K, \sum_{k=1}^{K} z_k = 1 \right\} \qquad [6]$$

where L(y) is the input requirement set for output vector y and z is a $Kx1$ vector of intensity variables from activity analysis. The restriction on the z variables implies that the technology represented by (6) allows for variable returns to scale.[5]

The minimal costs for each diversified firm relative to their own technology may be calculated as the solution to the following linear programming problem for each observation k

$$E^d \left(y_k^d, c_k^d \right) = \min_z \lambda$$

$$s.t$$

$$Yz \geq y_k^d$$

$$C^d z \leq \lambda c_k^d \qquad\qquad [7]$$

$$z \in R_+^K$$

$$\sum_{k=1}^{K} z_k = 1$$

where superscript d stands for the sample of diversified firms. Hence, C^d is the $1xK$ vector of observed costs of the diversified firms and c_k^d is the scalar-valued cost for firm k. The value of E^d obtained is the efficiency score for the k-th diversified firm. It satisfies that $E^d \leq 1$ with a value of 1 indicating an economically efficient firm. A value

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[5] See Färe *et al*. (1994) for a detailed analysis of the properties of this technology.

of E^d is then obtained for each firm, i.e. the problem [7] mast be solved K times, once for each firm in the sample. Similarly, we calculate the efficiency of the diversified firm relative to the additive frontier by solving

$$
\begin{aligned}
& E^S\left(y_k^d, c_k^d\right)=\min_z \lambda \\
& s.t \\
& Y^S z \geq y_k^d \\
& C^S z \leq \lambda c_k^d \\
& z \in R_+^K \\
& \sum_{k=1}^K z_k = 1
\end{aligned}
\tag{8}
$$

where superscript s denotes the set of the additive combination of specialized firms. Thus, Y^S is the (MxK) output matrix and C^S is the ($1xK$) vector of total cost, both referred to the additive data set. E^S therefore measures the economic (in)efficiency of the diversified k-th firm in producing output vector y^d relative to the minimum cost attainable by separate specialized firms.

Finally, note that in our DEA model specification we assume that all firms face identical input prices. We consider this to be realistic assumption since all firms included in the analysis operate in a similar economic environment, i.e. the same country and a common regulatory regime[6].

4. Data and variables

Our data set consists of production levels and costs of twelve Spanish electrical utilities throughout the period 1991-1997. These firms accounted for the totality of power generation and distribution in Spain over the period.

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[6] When it is believed that firms under consideration face different prices (e.g. as in international comparisons), problem [7] can be easily formulated as
min $w_k' x_k$
s.t.
$Yz \geq y_k$; $Xz \leq x_k$; $z \in R_+$ where w_k is a vector of input prices for the k-th firm

For the generation outputs, we consider the megawatts/hour of hydroelectric (HYDRO) and thermal power (THERMAL)[7]. Regarding distribution/supply, we include low voltage (LV) and high voltage (HV) power distribution, both measured in megawatts hour, as well as the total number of customers (CUSTO).[8] Finally, net operating costs (that is, exclusive of purchased power) were measured at constant 1990 prices and calculated as the sum of fuel costs, personnel costs, depreciation and other external operating costs. Data were drawn from the National Energy Commission (CNE, 1997) and the annual reports of companies. Table 1 shows the output bundles and costs for each company over the period 1991-1997.

[Table 1]

As a first step, firms were classified in four groups, according to their degree of business specialization.

Group 1. Generating firms only, that is, firms that do not distribute the power they produce, but resale to other firms. This group is formed by only one firm, ENDESA.

Group 2. Firms specialized in power distribution, with some percentage of power generation, being that produced mostly by hydro facilities. This group is comprised of three companies: ERZ, ENHER and HEC.

Group 3. Power generating and distributing companies with a clear thermal specialization: GESA, UNELCO and SEVILLANA.

Group 4. Diversified firms with a vertical integration ratio (generated MWh/ Distributed MWh) above 75%. This group is comprised of five firms: IBERDROLA, UNIÓN FENOSA, HIDROCANTABRICO, VIESGO and FECSA.

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[7] HYDRO figures also includes power generated from wind turbines, while THERMAL covers power produced from fossil-fuelled stations –mostly coal based- and nuclear plants.

[8] In Spain, transmission -or high voltage transport- is carried out by a single firm, *Red Eléctrica de España*, which at the time considered in this study was a public monopoly. Nevertheless, various utilities retained some transmission lines which were accounted into their distribution business.

Next, we construct combinations of specialized firms included in 1-3 groups. Our purpose consists of creating hypothetical companies with which we can construct the additive technology $C^S(y,c)$, which serves as a benchmark for costs where production is organized in separate specialized firms. To this end, following Grosskopf and Yaisawarng (1990) and Ferrier *et al*. (1993), we construct all possible permutations of specialized firms in one group with each other, which are then added pairwise with the permutations of the other group. We form two types of composites according to the firms' group of origin.

(i) Type A composites. They are the result of adding firms of groups 1 and 2. By means of the method referred to above, we obtain seven hypothetical companies for each year over the period 1991-1997. These composite observations have costs that are strictly additive and are used to construct an additive frontier.

The distinctive feature of these composites is that they are formed from the sum of output vectors of specialized firms that are orthogonal to one another[9]. Further, this makes them suitable to measure the potential economies of scope between generation and distribution, i.e. vertical economies.

(ii) Type B composites. They are formed from additive combinations of specialized firms included in groups 2 and 3. We obtain 49 hypothetical firms for each year, which gives a total of 343 composites. The characteristic of these composites is that the aggregation of specialized firms would result in higher horizontal diversification. Unlike type A composites, output vectors of specialized firms are not orthogonal, since all these firms distribute power. The resulting additive frontier is a suitable benchmark to measure the potential economies of diversification as defined above.

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[9] To be precise, *almost* orthogonal, since Endesa's production of hydroelectric power is not zero, but represents about 3.5% of total utility's generation.

5. Results

5.1 Economies of vertical integration

First, we measure the cost efficiency of diversified firms included in group 4 relative to their own technology i.e. we calculate the distance $E^d(y^d,c^d)$ by solving problem [7]. We construct the frontier using the whole sample of diversified firms as the reference production set. That is, we merge the data for all the years 1991-1997 into one set to construct an intertemporal frontier (Tulkens and Vanden Eeckaut, 1995).

Next, we do the same thing with type A composites (49 units) and measure the cost efficiency of diversified firms relative to this additive frontier. That is, we compute the distance $E_A^S(y^d,c^d)$ by solving problem [8]. The degree of scope economies for each diversified firm is given by

$$SC\left(y_k^d\right)=\frac{E_A^s\left(y_k^d,c_k^d\right)\cdot c_k^d - E^d\left(y_k^d,c_k^d\right)\cdot c_k^d}{E^d\left(y_k^d,c_k^d\right)\cdot c_k^d}=\frac{E_A^s\left(y_k^d,c_k^d\right)}{E^d\left(y_k^d,c_k^d\right)}-1$$

which is equivalent to [2].

Results are shown in Table 2. $SC(y_k) > 0$ for every diversified firm, that is, the partition of the output vector (y^H, y^T, y^D) into $(0, y^T, 0)$ and $(y^H, 0, y^D)$ would result in efficiency losses due to the loss of scope economies, where y^H, y^T and y^D stand form hydro generation, thermal generation and power distribution respectively. Table 2 also reveals wide differences between firms. Thus, the output bundle of Unión Fenosa presents the highest degree of scope economies (21.1%), while figures for the other firms range from 2.1%-8%.

Additionally, we have calculated the impact that such a fragmentation of the five diversified firms would have on the total operation costs of the Spanish electricity sector. Column 1 in Table 3 shows that this alternative would be, on average, 4.7% more expensive than keeping the diversified firms with their actual output bundles.

[Tables 2 and 3]

5.2 Economies of horizontal diversification

To estimate the diversification economies in the generation stage we compare $E^d(y^d,c^d)$ with $E_B{}^S(y^d,c^d)$. Subscript B indicates that the additive frontier is constructed with type B composites. We compute the degree of economies of diversification for each of our diversified firms according to [3] as

$$DIV\left(y_k^d\right)=\frac{E_B^S\left(y_k^d,c_k^d\right)\cdot c_k^d-E^d\left(y_k^d,c_k^d\right)\cdot c_k^d}{E^d\left(y_k^d,c_k^d\right)\cdot c_k^d}=\frac{E_B^S\left(y_k^d,c_k^d\right)\cdot c_k^d}{E^d\left(y_k^d,c_k^d\right)\cdot c_k^d}-1$$

As shown in Table 2, with the exception of HidroCantábrico, economies of horizontal diversification are less significant for utilities than scope economies. Further, one utility (Viesgo) does not enjoy economies of diversification while Fecsa's are very modest (0.5%). As Table 3 shows, such a partition for each of the five diversified utilities would increase 3.5% total operating costs of the electricity sector.

5.3 Scale economies

As shown before, any partition of diversified firms that implies the reduction of their vertical and/or horizontal integration would inevitably lead to a cost increase. Hence, one may ask whether it is efficient to divide the existing firms in smaller companies while keeping constant their current degree of vertical integration and horizontal diversification. This requires checking if the increase of the number of competitors is not counterweighted by the efficiency losses due to the reduction of the firms' scale of operations. To that purpose, we divide down the middle the output bundles of the five diversified firms. Such a partition keeps constant their output proportions, and consequently, their degree of horizontal and vertical integration.

A firm operating at optimal scale is scale efficient and any deviation from the point of scale efficiency raises average costs above the minimum. Scale efficiency is computed as the distance to the optimal scale size. In Figure 1, the tangent to the total cost curve is the ray OT, which measures the optimal production scale at output y^o. Only y^o is scale efficient while the vertical distance OC/OV measures the scale inefficiency for $y^o/2$, which is the ratio of total costs and costs on the OT ray at the output level $y^o/2$. Points

on the *OT* ray are feasible when constant returns to scale prevail. Hence, scale efficiency is computed as the ratio between the distance to the cost frontier under constant returns to scale (CRS) and the distance to the cost frontier under variable returns to scale (VRS).

Let ε_d denote the scale efficiency corresponding to the original output of diversified firms while $\varepsilon_{d/2}$ that corresponding to the halved firms, then

$$\varepsilon_d = \frac{E_{crs}^d\left(y^d, c^d\right)}{E_{vrs}^d\left(y^d, c^d\right)} \qquad\qquad \varepsilon_{d/2} = \frac{E_{crs}^d\left(y_d/2, c_d/2\right)}{E_{vrs}^d\left(y_d/2, c_d/2\right)}$$

Ray average cost is decreasing, increasing or constant if $\varepsilon_d/\varepsilon_{d/2}$ is lower than, greater than of equal to unity respectively.[10] The degree of multiproduct scale economies for each firm is computed as

$$RSE(y^d)\frac{C\left(y^d\right)\cdot\varepsilon_d - 2\left(\varepsilon_{d/2}\cdot C\left(y^d/2\right)\right)}{C\left(y^d\right)\cdot\varepsilon_d} = 1 - \left(\frac{E_{crs}^d\left(y^d/2, c^d/2\right)}{E_{vrs}^d\left(y^d, c^d\right)}\right)$$

Results for *RSE* (*y*) are shown in last three columns of Table 2. It is clear that fragmentation of firms would produce cost savings due to the improvement of scale efficiency. Thus, the break-up of each diversified firm into two identical units (holding constant its original output proportions) would improve scale efficiency of three out of five firms, while for the other two the impact would be negligible (0.1%) The overall annual cost savings for the electricity sector would represent 2.7% on average, as shown in Table 3. These result is consistent with earlier studies showing that economies of scale are exhausted for relatively small sizes, both at plant and firm level (see Ramos-Real, 2005 for a comprehensive review).

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[10] Efficiency under constant returns to scale is computed by deleting the restriction $\sum_{k=1}^{K} z_k = 1$ to the linear problem [8]. See Cooper *et al* (2000) for further details.

6. Conclusions and policy implications

This paper has estimated the degree of economies of scope, horizontal diversification and scale in the Spanish electricity sector by means of Data Envelopment Analysis. Our results may be summarized as follows: (i) We find scope economies between generation and distribution for every diversified utility in a range of 2.1% to 21.1%. Complete vertical unbundling would have raised operating costs of the sector about 4.7 percent over the period 1991-1997; (ii) Cost savings due to the diversification of power generation accounted up to 17.5% for the average firm over 1991-1997. Thus, the eventual horizontal specialization at the generation stage would have risen the operating costs of the period by 3.5%; (iii) Economies of scale are not important provided that vertical scope and product-mix are preserved. On average, overall operating costs of the sector could be reduced by 2.7% by dividing each of the diversified firms down the middle.

These results have important policy implications for the restructuring of the electric power sector. Thus, any break-up of firms implying complete vertical disintegration and/or firm's specialization on the generation stage is expensive options in terms of efficiency losses. Therefore, the expected competitive gains of such partition should be compared with the sacrifice of vertical and horizontal economies.

By contrast, a partition of large diversified firms would be rational on the grounds of economic efficiency provided that vertical and horizontal output proportions are preserved. In addition to the likely benefits from higher competition, the combined cost of the constituent smaller firms would be lower than the cost of the larger firms because of the improvement in their scale efficiency.

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Table 1. Descriptive statistics of outputs and cost by electric utility

	COST (thousand €)	HYDRO (GWh)	%	THERM (GWh)	%	LV (GWh)	%	HV (GWh)	%	CUSTOM	*VI* ratio * (%)
Hidro. Cantábrico	288263	720	9	7002	91	1288	21	4748	79	444809	128
Unión Fenosa	921183	3559	18	16300	82	8584	41	12351	59	2340727	95
Iberdrola	1750724	13188	30	30982	70	27790	63	2647	49	7991148	81
Endesa	1289465	1486	4	37626	96	0	0	0	0	0	0
Sevillana	585596	1039	8	11149	92	9242	48	10195	52	3368529	63
Fecsa	414163	2036	18	9322	82	7825	53	6908	47	1828987	77
ERZ	88223	697	100	0	0	2046	47	2321	53	634754	16
ENHER	330989	2618	87	400	13	4501	46	5236	54	924965	31
GESA	132595	0	0	3090	100	2145	81	489	19	496757	117
UNELCO	288919	0	0	4250	100	2663	68	1260	32	727823	108
VIESGO	101253	831	32	1730	68	1229	38	2003	62	447002	79
HEC	96246	613	100	0	0	2311	61	1487	39	538498	16
Average diversified firm	695119	4067	24	13067	76	9343	47	10495	53	2610535	86

Note: Average values 1991-1997

* Vertical Integration ratio = (HYDRO + THERM) / (HV + LV)

Table 2. Degree of economies of scope, diversification and scale by electric utility (mean values 1991-1997).

	Vertical economies			Diversification economies			Scale economies		
	$E^d(y_k^d, c_k^d)$	$E_A^S(y_k^d, c_k^d)$	$SC(y_k^d)$	$E^d(y_k^d, c_k^d)$	$E_B^S(y_k^d, c_k^d)$	$DIV(y_k^d)$	ε_d	$\varepsilon_{d/2}$	$RSE(y_k^d)$
FECSA	0.957	1.003	0.049	0.957	0.962	0.005	0.999	1.000	-0.001
HIDRO. CANTÁBRICO	0.883	0.935	0.059	0.883	0.940	0.065	0.947	0.985	-0.039
IBERDROLA	0.912	0.990	0.080	0.912	0.955	0.045	0.941	1.000	-0.059
UNIÓN FENOSA	0.816	0.986	0.211	0.816	0.983	0.207	0.857	0.943	-0.092
VIESGO	0.946	0.966	0.021	0.946	0.947	0.000	0.991	0.992	-0.001
Average diversified firm	0.826	1.026	0.240	0.826	0.971	0.175	0.969	0.993	-0.024

Table 3. The impact of alternative partitions on the operating costs of the Spanish electricity sector (percentage on total costs).

	$SC(y_k^d)$	$DIV(y_k^d)$	$RSE(y_k^d)$
1991	7.3	6.6	-1.3
1992	3.4	3.6	-5.9
1993	3.4	2.6	-4.5
1994	3.5	3.1	-0.7
1995	4.7	3.9	-4.5
1996	7.6	4.1	-0.4
1997	2.8	1.2	-2.3
Mean	4.7	3.5	-2.7

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