COST FUNCTIONS AND THE ELECTRIC UTILITY INDUSTRY.

A CONTRIBUTION TO THE DEBATE ON DEREGULATION

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Abstract:

This study analyses the main articles that estimate cost functions in the electricity utility industry with a view to studying of the initial arguments for proposing competition and vertical disintegration. The works reviewed here, in general terms, confirm the initial arguments in favour of the deregulation process, mainly, the exhaustion of scale economies for moderate size firms in generation and the condition of natural monopoly for transmission and distribution. However, the savings obtained from undertaking different activities together should be kept in mind when restructuring the sector. On the other hand, the improvements in productivity deriving from the reforms have not translated into reductions in the price of electricity in many countries. These last two results suggest the need for appropriate market regulation for the deregulation process to translate into an improvement in how the sector works and into benefits for consumers. There is still insufficient empirical literature on these issues due to the fact that the process is still on-going in many countries and more time will have to transpire before sufficient data is available.

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1. - INTRODUCTION

The traditional organisational model for electricity systems assumes that there are major economies of vertical integration between the different stages of supply, giving the operation as a whole, the characteristics of a natural monopoly. The fact that it was a natural monopoly, was the justification for a single company operating all the different stages of supply and, therefore, for its economic regulation through a pricing policy. In this traditional framework, the best known kinds of regulation are cost plus regulation, which is based on the use of rate of return regulation (ROR), marginal cost pricing and price cap regulation.

This traditional model of integration and regulation first began to be questioned in the eighties in the industrialised countries. The first criticism was focussed on the lack of incentives for reducing costs, due to the distortions introduced by regulation, and the lack of competition in the market. The second criticism cast doubt on the assumption that the set of activities as a whole were a natural monopoly, although some of the stages do meet all the requirements.

Based on these arguments, there are many vertical disintegration experiences being carried out in countries like UK, New Zealand, Norway, the United States, Chile, Argentina and Spain. The aim of this disintegration is to foster competition in the sector, in the stages of the business where this is feasible. This way, pressure would be brought to bear on prices and costs to reduce them and the regulation failures that are characteristic of an integrated system would be avoided. On the other hand, new incentive-based regulation systems are proposed, in those stages of the business that remain subject to regulation. In this sense, in England, yardstick competition has been used for the regional distribution companies.

These changes of the organisational structure and market mechanism in the electric utilities, however, have had to face a series of difficult problems that have shown that the electricity markets present a set of characteristics that complicate the process of deregulating the sector. These proposals for deregulating[1] the electric utility industry make a series of assumptions concerning the technology and the underlying cost structure in the different stages of the sector. Knowing the industry cost function is fundamental for evaluating and discussing the pros and cons of these proposed reforms.

The objective of this study is to analyse the results of the main studies that have estimated cost functions in the electricity industry for the purpose of studying the validity of the initial arguments for proposing competition and vertical disintegration. We will also see whether the process of reforms has translated into reductions in costs and/or final consumer prices. Fundamentally, we analyse those works that have used the company as the unit of study and which use parametric methods. Parametric methods make it possible to estimate cost functions econometrically and, moreover, they give us an adequate approximations of the underlying production function through the specification of an adequate functional form. Most of these have been carried out in the context of the electricity industry in the United States of America.

This work is structured as follows. In section two, we briefly discuss the prior assumptions on which this proposed deregulation is based. We pay special attention to the sources of economies of vertical integration (EVI) in the sector, which is a fundamental element in the debate on deregulating the industry. In the next three sections, we analyse the results of the articles we have reviewed. In section three, we consider economies of scale (SE) in the different stages of the industry and the economies of density in network activities. In section four, we take an in-depth look at the EVIs between the different stages of the industry. To do this, a detailed study of the work done in the area of multi-output must be done, as the most appropriate framework for studying the economies of joint production. In section five, we study the effects of the reforms carried out in some countries on the industry. Finally, we will summarise the most important conclusions. Appendix I presents a detailed summary of the characteristics and the most interesting aspects and results of the main studies done in the single output area (table 1 and table 2) and the multi-output area (table 3).

2.- THE COMPETITIVE MODEL AND THE ECONOMIES OF VERTICAL INTEGRATION

2.1.- The competitive model

Electrical systems encompass a whole set of differentiated activities, all of which are necessary for providing or supplying the final service. These activities are: generation, transmission[2], distribution and supply (marketing) of electricity services to the end-users[3]. As against the traditional integrated model, the competitive model make a series of assumptions concerning the technology and the underlying cost structure in the different stages of the sector and how it works as a whole. In line with Landon (1983) and Joskow (1996), we can summarise these elements as follows:

1.- In the generation stage, there is an exhaustion of SE related to market size, making competition among generators possible.

2.- There are no major EVI between stages, that is, integration does not lead to significant cost savings, so these would be off-set by improvements in efficiency arising from market competition.

3.- Their network characteristics of transmission and distribution make these activities a natural monopoly and should continue to be regulated. These activities are the key component for competition as they must guarantee access to network services without any form of discrimination. Furthermore, transmission must physically ensure the balance of the system and ensure a reliable supply.

4.- Metering and billing can be separated from distribution. These activities do not have the characteristics of a natural monopoly and its possible deregulation could be one way of passing on the efficiency gains in generation arising from competition, to the final consumer.

The essential component for there to be competition in the electricity industry is to create a wholesale electricity market for generators and final energy users. Depending on the scope of the market reform, these end users are the following: the distributors that still have captive clients subject to a regulated tariff, the clients that are authorised to go directly to the wholesale market and the marketing agents (which can be the local distributor himself) that intervene as intermediaries between consumers that demand their services and the suppliers of energy.

2.2.- The economies of vertical integration

In the following sections, we present empirical results on the assumptions on which this proposed deregulation is based. Here, we briefly discuss the sources of EVI in the sector. The debate on whether there are EVI in the industry is an important one, because, if these exist, they would represent a cost for the processes of reform. This discussion gives us an understanding of the existence of some of the problems that these proposals have faced concerning the design and operation of a competitive market.

The main sources for EVI in this sector arise fundamentally because of the major technical interdependencies between stages and the fact that there are transaction costs that could occur in a decentralised market. Technically, an electric system should function as a whole, making coordination of the generating capacity needed to meet demand at any one time fundamental. If the owners of the different stages of an electricity system do not take into account the effects of their actions on the rest, the classical problem of externality will arise. This problem is resolved if a single company integrates all the activities involved. The competitive model implies that necessary coordination among generators, and transmision of electric power between the generators and distributors, can be efficiently performed by a independent system operator[4].

With regard to transaction costs, there is a wide range of different opinions; for Landon (1983), there is a set of characteristics of the intermediate products markets for bulk electricity that might emerge if widespread vertical divestiture is imposed on the industry. These peculiarities arise from the uncertainty and the complexity of decentralised transactions in an electric system, due to the specificity of the assets and the fact that there are major sunk costs[5]. According to Landon (1983), these factors make it difficult to establish prices between the different stages, which is why the long term operating costs of a pricing and contracting system are exceedingly high.

The proponents of disintegration consider that market mechanisms in the short and long term can appropriately remunerate different players, and in this way create sufficient incentives for the continuation of the activity in the long term. Weiss (1975) points out that there do not seem to be any major economies of integration, although he does say that this should be confirmed by in depth and developed analyzes. Kaserman and Mayo (1991) come to the conclusion that the importance of this kind of economies is an issue that should be resolved by empirical validation. Hayashi et al. (1998) suggest that the crucial question is whether the cost reduction by creating competition exceeds the cost reduction due to vertical integration. In section four, we address this debate and present the works that have quantified this kind of economies.

3. – ECONOMIES OF SCALE AND DENSITY

3.1- Scale Economies in generation

Many articles provide empirical evidence on this issue for the different stages of the industry. Concerning the generating stage, we have to make the distinction between the studies that use the plant as the sample unit, and those that use the company.

Table 1 shows the results of the studies done for generating plants. Joskow and Schmalensee (1983) present a summary of different studies carried out in the USA based on econometric estimations and engineering methods. The minimum efficient scale (MES) for conventional electricity generation is around 800 MW, and around 2000 MW for nuclear energy. Maloney (2001) estimates MES at 321 MW and 260 MW for coal and gas-fired plants respectively, but the average cost curve is flat at this level. Kleit and Terrell (2001) and Hiebert (2002), also for USA, find increasing SE for most observations. Hiebert finds that the degree of SE is 20% in coal-fired plants and 12% for natural gas-fired plants for average sample values (780 MW and 284 MW respectively). This work also finds that major economies can be attained by producing with more than one plant for each kind of generation.

This latter aspect highlights the importance of distinguishing between plant and company in generation. As Huettner and Landon (1977) point out, the relationships observed at plant level, particularly SE, are often modified by interrelationships at higher levels of decision making, such as the firm level. For this reason, we focussed our attention on the works that use the company as the sample unit. Most of these consider cost functions where the product is the kWh of conventional fossil fuel generation like Christensen and Greene (1976), Huettner and Landon (1977) and Atkinson and Halvorsen (1984) among others. The works of Kamerschen and

Thompson (1993) and Thompson and Wolf (1993), study possible cost differences between conventional electricity generating technology (fossil fuel generation) and nuclear electricity generation. Table 2 details the characteristics and the results of these and other works undertaken in the single output area.

We highlight the article by Christensen and Greene (1976) because it was one of the first of this kind of studies and sets a methodology that has inspired most later works in one way or another. These authors consider there is a single output cost function for conventional fossil fuel generation from a cross section sample taken in the United States for the years 1955 and 1970, using a translogarithmic cost function. It is assumed that factor prices (capital, labor and fuel) and production (kwh of fossil fuel generation) are exogenous variables. The cost function is estimated jointly with the factor cost share equations, following Zellner's method (1962). The most important conclusions of this work suggest that in 1955, the average representative company operated in a range in which SE had not been exhausted, whereas in 1970, they operated with constant SE. In 1995, MES occurs at 5 GWh and, in 1970, at 20 GWh (equivalent to 4000 MW capacity). The average cost curve is L shaped and, at half MES, SE is about 6% in 1970. Huettner and Landon (1977) also find diseconomies of scale beyond moderate firm sizes in fossil-fuel generation in USA. These authors find that the MES is between 1600-3100 MW and that generation has a very flat U shaped cost curve as, for 9000 MW, the average cost only increase by 1% and 2.4% for 100MW. The work of Atkinson and Halvorsen (1984) establishes the MES at 23.2 GWh. The average enterprise is situated at 8.78 GWh, with 5.6% SE at this level of production and 4.1% for half MES. These works use data from 1971 and 1970 respectively. Pollit (1995) uses a sample of companies from different OECD countries for fossil fuel generation with

1986 data. The MES is over 20 GWh, but SEs, however, are 20% at the average values of the public companies included in the sample, and 4% in private companies.

The works of Kamerschen and Thompson (1993) and Thompson and Wolf (1993), which use 1985 data for USA, differentiate by types of generation. The first of these works finds that the MES is 10 and 14 GWh for nuclear and conventional fossil fuel generation respectively. There are significant cost penalties arising from producing at half MES, SEs are 20% for nuclear fired generation and 15% for conventional fossil fuel generation. The average sample company finds itself in an area of increasing SE for nuclear generation (7.73 GWh) and constant SE for conventional generation (14.89 GWh). The latter of these works presents similar results for nuclear fired generation, but it differentiates fossil fuel generation by type of technology. For oil fired generation, MES is less than 10 GWh and for gas fired generation, MES is less than 5 GWh.

In summary, although MES varies substantially depending on the generation technology used and the period studied, the first theoretical argument on which the deregulation process is founded, that is, the exhaustion of SE for generation stage at moderate levels of production, seems to be confirmed. However, there are many electricity systems with a dimension that is far below MES and, therefore, which do not exhaust SEs. In the same way, the results suggest that the cost penalties arising from not reaching an efficient scale are not insignificant. The combination of these two elements represents a serious obstacle to deregulating the electricity utility industry in some countries.

3.2.- Economies of scale and density in transmission and distribution

Some works estimate the economies of scale for the transmission and distribution phases, like Huettner and Landon (1977) who found the MES around 2600 MW capacity. Kaserman and Mayo (1991) also find specific economies of scale for these phases, and they situate the MES around 5 GWh. But the network phases and the costs involved in these activities can be studied in greater depth by studying economies of density. This concept explains the evolution of average costs when production is increased and some of the characteristics that define the product are maintained constant, for example, the size of the service area or the number of consumers.

In this field, we highlight the works of Nelson and Primeaux (1988), Roberts (1986) and Thompson (1997), all carried out in the USA.These works study costs per Kwh of electricity distributed. Roberts (1986) and Thompson (1997) differentiate product according to tension level. The results suggest that there are economies of density-product specific economies in that, for a given network size and a fixed number of clients, average costs fall when the quantity of power supplied increases (Thompson's results indicate a 0.3% fall in average cost for every 1% increase in supply). But, as Joskow and Schmalensee (1983) pointed out, one gets to the point when a proportional increase in product, the service area and consumers no longer leads to a reduction in average production costs. Thompson observed this phenomenon above 26 GWh (at sample mean).

These findings indicate that there would be efficiency losses if individual customer were served by more than one utility. This imply that transmission and distribution grids are natural monopolies, as it would not make sense to duplicate them and, moreover, costs are reduced at higher levels of supply. However, for large firms, an increase in the service area, does not generate any significant decrease in average cost. Thus, prevent competition among companies at the borders of their service area, would not appear to result in efficiency gains.

4.– THE ECONOMIES OF VERTICAL INTEGRATION

In this section, we will study the presence of EVIs in the electricity sector. There are two alternative methodologies; the first enables us to identify the existence of EVIs by comparing the separability of total supply cost function. The second methodology makes it possible to detect and quantify EVIs for different entrepreneurial set ups by using multioutput theory.

4.1.- Supply cost function separability

We highlight the work of Hayashi et al. (1998) in the area of single output, and those of Roberts (1986) and Thompson (1997), which differentiate between supplies according to the level of tension. To use this methodology, a sample of companies that are vertically integrated in all the different phases must be used. This way, a company's output is the number of kwh for final delivery, whereas the costs to be explained are the global costs of supply. In these works, generation and the purchased power are factors of production of the supply production function, along with capital and labour.

This characterisation must then be used to check how separable costs are in the different phases of activity. The three works reject separating between generation costs and transmission-distribution system costs and, therefore, the separability of the supply cost function. Rejecting separability implies the beneficial use of common inputs and that there are economies of joint production between stages, or, in other words, EVI.

4.2.- Economies of vertical integration and multiproduct theory

Electrical systems encompass a whole set of differentiated stages. Moreover, more than one product may be produced in each stage, so the most complete way to treat the activity is to characterise it as multistage and multioutput. In this context, we can analyse whether there are joint economies of production correctly. To this end, we have to estimate the function of costs of an industry in the multioutput area and see if there is a natural monopoly by using the different concepts provided by the multiproduct theory[6].

The subadditivity of the function of costs is synonymous with there being a natural monopoly and means that any partition of production is more costly than joint production, that is:

$$C(Q) \leq \sum_{j=1}^{k} C(q_j) \quad \text{subject to:} \quad Q = \sum_{j=1}^{k} q_j \qquad [1]$$

where:

q_j is production of firm j

k is the number of firms

But this is a very difficult concept to verify empirically, because of the need for data that, in most cases, do not exist. The concept of economies of scope represents the same idea, but restricted to orthogonal partitions of production, i.e., the cost of joint production is compared with that of the specialist production of each product by a company:

$$C(Q) < \sum_{i=1}^{k} C(Q_{Ri}) \qquad [2]$$

$$\{Ri\} \text{ is a orthogonal partition of production}$$

Economies of scope are the equivalent of EVI if we identify each stage as a product and to economies of horizontal integration for products of the same stage. Although it is the subadditivity that determines the condition of natural monopoly, economies of scope play an important role in studying the optimum structure of an industry, as, if there are economies of scope to be gained, it makes no sense to have different companies, each with their own specialist production.

Another concept associated with the advisability of joint production is complementarity of costs that tells us that the marginal costs of a product decline as the production of other products increases, this is:

$$\frac{\partial^2 C}{\partial Q_i \partial Q_j} \leq 0 \qquad [3]$$

4.3.- Multistage and multioutput works.

In this section, we examine the works that estimate multistage cost functions, in order to study EVI. Table 3 shows a summary of the main points and results of these woks in chronological order. These works are: Kaserman and Mayo (1991), Gilsdorf (1994, 1995), Ramos-Real (2000) and Kwoka (2002). All the works considered have been carried out in the context of the United States electric utility industry, with the exception of the work of Ramos-Real (2000), which studies this industry in Spain. For our comparative study, we will deal with the following aspects that characterise the cost functions: definition of products, input prices and functional form. We then present the results.

Definition of products and input prices

As we have already mentioned, these works consider the stages as products, that is, generation, transmission and distribution. All of them, however, integrate the phases of transmission and distribution except Gilsdorf (1995) and Ramos-Real (2000). In this latter work, the transmission stage is not taken into account, as this task is carried out by an independent operator in Spain, while companies integrate generation and distribution. This is important for interpreting the results of this work because, as Ramos-Real et al. (2002) point out, this operating structure remains the same before and after competition was introduced into the industry.

To study economies of horizontal integration, one must take into account that more than one product is considered in each stage. In distribution, the distinction is made by type of supply. The work of Ramos-Real (2000) is the only one to differentiate between the products of the generation stage, which is done by distinguishing between different techniques: coal, hydro, nuclear and oil.

Normally, labour, capital and fuel are considered with regard to the price of the factors of production. But, by specifying the phases as products, whether the energy acquired is considered an input or not is important. Gilsdorf (1994, 1995) excludes purchased power and Ramos-Real (2000) and Kwoka (2002) applies the same criterion. Ramos-Real points out that this way, the costs of the distribution stage are only the costs of maintaining and operating the grid, i.e. the operating distribution costs, together with marketing costs. This formula avoids counting the generation product twice in calculating the economies of vertical integration. Kaserman and Mayo (1991), who do consider this input, calculate the degree EVI from the degree of economies of scope, taking into consideration that generation is a derived demand for calculating the cost of distribution individually.

Finally, Ramos-Real (2000) also incorporates intermediate input as a factor of production. This factor represents a series of very different expenditures (out-sourced services, miscellaneous inputs, certain taxes, etc.) that represent a large item that can maintain economic interrelations with the other factors.

Functional form

Most authors have used the translogarithmic flexible functional form[7] estimating the factor share equations as a whole, using the Zellner method. The main problem arising is that it is impossible to calculate economies of scope between stages[8]. The articles by Gilsdorf (1994, 1995) try to resolve this question by studying the complementarity relations, in the former case, 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.

The quadratic flexible functional form, that enables authors to study economies of scope, has been used by Kaserman and Mayo (1991), Ramos (2000) and Kwoka (2002). The specification of the first of these sacrifices the flexibility of cost function because it does not cross products and it includes factor prices linearly[9]. Kwoka does not completely specify the cost function either, so the input demands cannot be estimated together with the cost equation. Ramos-Real estimates the complete square cost function proposed by Lau (1974) together with the input demands using the Zellner's method.

Results

There is no unanimous opinion on whether or not there is subadditivity in the cost function. But, works studying EVI between stages, in general, are inclined to believe that there is.

Gilsdorf (1994) finds no evidence of EVI as he did not find any complementarity of costs between stages. Gilsdorf (1995) does, however find evidence of EVI using the Evans and Heckman subadditivity test (1984). In this latter work, he also observed economies of horizontal integration in distribution, depending upon supplies by type of final consumer.

Kaserman y Mayo (1991) see that SE of each stage in isolation are exhausted well within the range of representative outputs (4 GWh for distribution and 9 GWh for generation). However, the presence of cost complementarities across vertical stages extend the region of the multistage SE. They estimate that the EVI between the stages of generation and transmission-distribution signify a cost saving of 12% evaluated at the sample mean (16 GWh of mix output). For these authors, the origin of these economies lies both in the technical interdependencies between stages and in the complexity of organising a market in the intermediate stage of transmission. Kwoka (2002) draws similar conclusions, finding that the cost penalties of stand-alone operation rise from a modest 3% for small firm outputs (5 GWh of mix output) to 57% for larger firms (25 GWh of mix output) and are 43% at sample mean.

Ramos-Real (2000) finds that there are economies of horizontal integration in the generation and distribution stages and slight EVI between distribution and generation (approximately 5% evaluated at the sample mean). This result may be a fair estimate of the EVIs that exist in the new desintegrated model, given that there has been no significant change in the structure in Spain with the introduction of competition. Furthermore, the existence of an independent operator responsible for the technical coordination of the system could also justify the lower EVIs.

5.- EVALUATING THE DEREGULATIONPROCESS

In this section, we present the results of the works that, in the scope of our analysis, provide empirical evidence on the reductions in costs arising from the process of deregulating the electricity industry. It must be pointed out that there are not many of these yet because this process has only been recently started in most countries. However, there are important signs of productive improvements that have translated into cost savings. We conclude this section with a study of whether these savings have translated into price reductions for consumers.

Some works have studied inefficiencies in the framework of the traditional operating system and regulation in the industry. The size of these gives us information on the potential for improvement of the de-regulation process. We can differentiate between allocative and technical inefficiencies. The works of Pescatrice and Trapani (1980), Koh et al. (1996) and Hayashi et al. (1985) demonstrated the existence of allocative inefficiencies that led to a certain degree of over-capitalisation in USA in the context of ROR. Nemoto et al. (1993) found the same phenomenon for Japan. Atkinson and Halvorsen (1986) find that this inefficiency generates 2.4% greater costs for the average company in USA.

Studies on technical inefficiencies have focussed more on generating plants. The works of Maloney (2001), Kleit and Terrell (2001) and Hiebert (2002), all carried out in USA, find productive inefficiencies of over 10%, due mainly to infra-use of capacity. They also suggest that this situation could be corrected in the new competitive context. Hiebert (2002) finds evidence that the average operating efficiency of coal-fired plants increased in the states where the transition to retail competition had begun in 1996.

The study of total factor productivity (TFP) in the industry is particularly interesting. This method makes it possible to break down the different components that explain cost reductions. The works of Gollop and Roberts (1981) and Nelson and Wohar (1983) were carried out for periods prior to the process of reforms, and they found annual improvements in productivity between 1950-1975 of 2.5% in USA. These works find that technical change and, to a lesser extent, benefiting from SEs are the main factors explaining improvements in productivity. Martínez-Budría et al. (2003), for the case of Spain, find annual improvements in productivity of 5.3% between 1983 and 1996, explained to a great extent, by the system of incentive regulation designed in Spain between 1987 and 1996, before the process of reforms was implemented.

The work of Scully (1998) studies the effect of the reforms in New Zealand. There, they created a wholesale generating market and retail competition was introduced. Between 1988 and 1994, there were annual importants improvements in productivity explained, fundamentally, by labour productivity as a result of a change in labour legislation in the industry. The results indicate cost savings that are directly attributable to the process of reforms. First of all, there was a 0.9% saving arising from the merger process between distribution companies to benefit from economies of horizontal integration. Second, privatization and profit orientation of firms generated savings of 1.8%. These savings benefited consumers, although the effect was not evenly felt as the real price of electricity fell 16.4% over the period, but for households, it remained about the same.

At the end of this section, we mention some works that, while they do not fall strictly within the scope of this work, they do provide food for thought concerning the repercussions of the process of reforms on prices. Newbery and Pollitt (1997) study the pioneering case of the UK using a social cost-benefit analysis. These authors find a permanent annual cost reduction of 6% in comparison with the non-reform counterfactual for the period 1988-1996. They found that the main gains came from the efficiency in operating the generating companies. These improvements, however, have not translated into a fall in consumer prices, in fact, they conclude that consumers and government lose and producers gain more than the cost reduction.

The impact of regulatory reforms on price in the electricity supply industry has been studied in depth by Steiner (2000) using panel data for 19 OECD countries for the period 1987-1996. Hattori and Tsutsui (2003) make a comparative analysis using the same methodology and the same sample, but they extend the period to 1999.

We can draw a series of conclusions from the results of these two works. First of all, expanding retail access is likely to lower the industrial price, while at the same time increasing the price differential between industrial customers and household customers. This result can be unambiguously seen after the expansion of retail access after 1996. Secondly, unbundling of generation did not necessarily lower the price and may have possibly resulted in a higher price. Unbundling has led to lower prices in some countries but not in others. It is possible that EVI might be lost as a result of unbundling and, making the net impact ambiguous. Finally, with regard to the effect of introducing a wholesale power market, the results of the two works are contradictory. But, as Hattori and Tsutsui point out, in the light of the experiences in some countries, the exercise of market power by generators has not generally led to price reductions for consumers.

6.- CONCLUSIONS

The purpose of this study is to analyse the results of the main studies that have estimated cost functions in the electricity industry with a view to studying the validity of the initial arguments for proposing competition and vertical disintegration. We have mainly analysed those works that have used the company as the unit of study and which use parametric methods. Based on the results obtained in the works studied here, we can highlight the following results in comparison with the arguments that underpin the de-regulation process:

1.- Competition is possible in generation because economies of scale are exhausted for moderate size firms. The size of many electricity systems, however, represents a serious obstacle for deregulating the electricity utility industry in many countries.

2.- There would be efficiency losses if individual customer were served by more than one utility. This imply that transmission and distribution grids are natural monopolies, as it would not make sense to duplicate them.

3.- The multiproduct framework provides the opportunity for a fuller analysis of EVI in the electric utility. The works that have been done in the context of the traditional integrated model mainly suggest the existence of EVI. Nevertheless, empirical studies are required to check whether the complementarities between phases have been affected in the industry’s new operational model.

4.- There are not many works that have evaluated savings arising from the deregulation process. But, allocative inefficiencies are observed in the framework of traditional regulation, along with technical inefficiencies that could be corrected on introducing competition. On the other hand, improvements in productivity have been observed after reforms have been implemented.

5.- Certain problems in the way electricity markets work have made it impossible to pass on productivity gains to prices for final consumers.

From our point of view, these results, in general terms, confirm the initial arguments in favour of deregulation. However, the savings obtained from undertaking different activities together should be kept in mind when restructuring the sector, but it is not incompatible with vertical disintegration of the sector as long as the market allows for effective competition. The costs of disintegration mainly arise from powerful technical interdependencies between the different stages of supply and from market transaction costs. In the competitive model, the problem of technical interdependencies can be resolved with a independent system operator in the transmission stage who has certain authority over individual producers.

The greatest problems for deregulation processes arise, however, in the processes of designing and operating the market. For Newbery (2002), appropriate market regulation is required for the deregulation process to translate into improvements in the operation of the industry and into benefits for consumers. According to Borenstein (2002), these problems include: generators exercising market power, as appears to have occurred in England, California or Spain; the volatility in the spot market price; the creation of suitable incentives to generate investments in generation that ensure supply to final consumers in the long term (highlighting the problems that have arisen in California and Chile); the establishment of transmission charges for using grids and, in general, remuneration of the stages subject to regulation; and the creation of a workable structure for retail competition. The same author proposes some solutions, such as creating long term contracts to make more difficult the exercise of market power, and/or setting real-time retail prices to reduce consumption at peak demand, and/or imposing price caps to mitigate the price volatility.

In summary, it is still too early to accurately evaluate the effects of the reforms and to suggest definitive solutions for the problems identified in implementing these reforms. There is still insufficient empirical literature on this issue due to the fact that the process is still on-going in many countries and more time will have to transpire before sufficient data is available.

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Table 1. SINGLE OUTPUT COST FUNCTIONS IN THE ELECTRIC INDUSTRY. ELECTRIC GENERATING PLANTS

Authors	Title	Product	Objective	Sample	Factors	Func. form and estimation	Results
Krautman, A.C.& Solow, J.L. (1988).	Economies of Scale in Nuclear Power Generation	Nuclear gener. plants Expected output	Scale economies at plant level of one and two reactors	Cross seccional sample of 43 observations, 11 birreactors. Years 1976-77-78. US.	Labor, fuel and fixed capital	Short run Translog. with share equation Iterative estimation proced. (IEP) Zellner (1962)	One reactor plants operate with long run SE. Two reactors plants are more efficient for bigger output levels
Pollit, M.G (1995) Chapter 6	Ownership and performance in Electric Utilities	Kwh of thermal power plants	Technical efficiency in electric power plants	768 power plants in 1989. US (606), UK (48), Japan (24), Australia (20), Canada (20), South Africa (13) and other countries.	Labor, fuel and capital	Long run Translog shadow cost function (parametric aproximation) and factor share equations IEP. Zellner	Very little average of technical inefficiency. Load factor is the major explanatory factor of inefficiency. No significant difference by ownership type
Pollit, M.G (1995) Chapter 7	Ownership and performance in Electric Utilities	Kwh of thermal power plants	Allocative efficiency in electric power plants	164 base load power plants in 1989 from different countries	Labor, fuel and capital	Long run Translog shadow cost function (parametric aproximation) and factor share equations IEP. Zellner	Implausibly high level of allocative efficiency for private firms
Maloney, M.T (2001)	Economies and Diseconomies: Estimating Electricity Cost Functions	Level of capacity utilization from coal and gas generation plant	Cost and capacity utilization	Cross secctional sample of 514 coal and 261 natural gas and oil plants for 1995 and 1996. US	Labor, fuel and operating expenses	Translog. variable cost function with share equations. IEP Zellner	Average costs reach MES about average plant size (coal: 321MW and gas: 260 MW) and is flat at this level for larger firms Capacity utilization is the most important determinant of cost specially in coal plants (average cost diminish 0.5% for an increase of 1%). Under utilization could diminish with competitive pricing
Kleit, A.N. & Terrell, D. (2001)	Measuring potential efficiency gains from Deregulation of Electricity Generation: a Bayesian Approach	Kwh of natural gas generation plants and peak output	Efficiency of Electric Power Generation	78 plants for the year 1996. US	Labor, fuel and capital	Long run translog. cost frontier. Share equations. Bayesian approach	Plants on average could reduce by up to 13% by eliminating production inefficiency. Only one firm operate at decreasing returns to scale (average SE is 12% for the entire sample). Aver. outp. 1.54 GWh.
Hiebert, L.D (2002)	The determinants of the cost efficiency of Electric Generating Plants: a Stochastic Frontier Approach	Kwh of coal and gas generation plant	Plant operating cost efficiency	Unbalanced panel of 432 coal and 201 natural gas and oil plants over the period 1988-1997. US	Fuel, and fixed capital (capacity)	Stochastic frontier cost function. Normalized Short Run Translog.	SE at sample mean for coal (3.9 GWh) is 20% and for gas (1.42 GWh) is 12%. Inneficiencies of 12% for coal plants and 20% for gas over the period. Inneff. decreases as plant capacity utilization rises. Large number of plants achieve bettter performance. Average eficiency of coal plants increase where retail competition had begun

Table 2. SINGLE-OUTPUT COST FUNCTIONS IN THE ELECTRIC INDUSTRY. FIRMS

Authors	Title	Product	Objective	Sample	Factors	Functional form and estimation	Results
Nerlove, M. (1963)	Returns to scale in Electricity Supply	Kwh of fossil-fuel generation	Scale economies at plant level	Cross seccional sample of 145 privately-owned firms in 1955. US	Capital, labor, fuel	Cobb-Douglass Ordinary least squared (OLS)	Exhaustion of SE as firm size increases
Petersen , H.C.(1975)	An empirical test of regulatory effects	Kwh of fossil-fuel generation	Effects of rate of return regulation (ROR) and scale economies	Cross seccional sample of 56 plants of generation between 1966 and 1968. US	Capital, labor, fuel	Translog. (OLS)	Existence of Averch-Jonhson (A-J), effect, SE in low output levels, neutral technical change and factors sustituibility
Christensen, L.R & Greene, W.H. (1976).	Economies of Scale in U.S. Electric Power Generation	Kwh of fossil-fuel generation	Scale economies, technical change and elasticity of substitution	Cross seccional sample of 124 privately-owned firms in 1955 and 114 in 1970. US	Capital, labor, fuel	Long run Translog. and factor share equations. IEP Zellner	Exhaustion of SE in 1970 for the bulk of electric gener. Tech. Change 1955-1970. MES was about 5 GWh in1955 and 20 GWh in 1970 (4000 MW). ES at half MES in 1970 is 6%. Average cost curve is L shaped
Huettner, D.A. & Landon, J.H. (1977)	Electric Utilities: Scale Economies and Diseconomies	Peak capacity and rate of utilization	Scale economies at firm level for generation, transmission, distribution administration and customer sales	74 vertically integrated electric utilities in 1971 At least 80% fossil-fueled generation and generate at least 80% of their own power. US	Capital, labor, fuel	Average variable cost from Single equation models separating fixed cost and operating costs	Diseconomies of scale beyond moderate firm sizes except for sale expenses. Generation MES is between 1600-3100 MW with a very flat U shaped cost curve (only a 1% increase in average costs at 9000 MW and 2.4% at 100 MW) Distribution and administration MES is about 2600 MW No significant cost savings from participation in a holding companies
Christensen, L.R & Greene, W.H. (1978).	An econometric assessment of cost savings from coordination in U.S Electric Power Generation	Kwh of fossil-fuel generation	Estimation of cost savings attributable to power pooling arrangements	114 privately-owned firms in 1970. US	Capital, labor, fuel	Long run Translog. and factor share equations. IEP Zellner . Dummies for power pool fims	They don´t find cost advantages of pooling contracts over informal relationships, arms-length, transactions or participation in a holding companies.
Pescatrice, D.R. & Trapani ,J.M (1980)	The performance and objectives of public and private utilities operating in U.S	Kwh of fossil-fuel generation	A-J effect when rate of return regulation (ROR) by type of ownership	Cross seccional sample of 23 publicly owned firms and 33 privately owned firms in 1965 and 1970. US	Capital, labor, fuel	Long run Translog. and factor share equations including regulated capital price. IEP. Zellner	Publicly ownership is more efficient than production by private firms when regulated by ROR
Gollop, F.M & Roberts, M.J. (1981).	The Sources of Economic Growth in the U.S. Electric Power Industry.	Distributed Kwh from fossil-fuel generation	Scale economies and technical change	Cross seccional sample of 11 privately-owned firms vertical integrated 1958-1975. US.	Capital, labor, fuel	Long run Translog. and factor share equations IEP. Zellner	Technical change is the most important component of Total Factor Productivity (TFP)

Table 2. SINGLE-OUTPUT COST FUNCTIONS IN THE ELECTRIC INDUSTRY. FIRMS

Authors	Title	Product	Objective	Sample	Factors	Func. form and estimation	Results
Nelson,R.A. & Wohar,E. (1983)	Regulation, Scale Economies and productivity in Steam-Electric Generation	Kwh of fossil-fuel generation	Decomposition of TFP in scale-economies, technical change and regulation bias	Cross seccional sample of 50 privately-owned firms in the period 1950-70. US	Capital, labor, fuel	Long run Translog. and factor share equations including regulated capital price. IEP. Zellner	Average TFP growth is 2.5% on average for the period. Positive contribution of tech. change and SE in TFP, negative for regulation bias. Existence of A-J and factors sustituib.except for capital-fuel. ES are 5.35% on average over the period 1950-78 for sample mean.
Atkinson, S.E. & Halvorsen R. (1984)	Parametric efficiency test, Economies of Scale, and input demand in U.S. Electric Power Generation	Kwh of fossil-fuel generation	Parametric test of efficiency and Scale Economies	123 privately-owned firms in 1970. US	Capital, labor, fuel	Long run Translog shadow cost function (parametric aproximation) and factor share equations IEP. Zellner	12 firms have negative SE. MES is about 23.2 GWh For sample mean (8.78 GWh) ES is 5.6% ; SE at half MES is 4.1% There is price inefficiency on total cost and input demands. Average effect on cost 3.8% at sample mean
Atkinson, S.E. & Halvorsen R. (1986)	The relative efficiency of Public and Private firms in a regulated Environement: the case of U.S. Elect. Utilities	Kwh of fossil-fuel generation	Relative efficiency when ROR by type of ownership	123 privately-owned and 30 publicly-owned firms in 1970. US.	Capital, labor, fuel	Long run Translog shadow cost function (parametric aproximation) and factor share equations IEP. Zellner	Not significative difference in allocative efficiency between publicly and privately owned firms Average effect on cost 2.4% at sample mean
Baltagi, B.H. & Griffin J.M. (1988)	A general Index of Technical Change	Kwh of fossil-fuel generation	Decomposition of technical change	Cross seccional sample of 30 utilities 1951-1978. US.	Capital, labor, fuel	Long run Translog. and factor share equations IEP. Zellner	ES are 5.5% on average over the period 1951-78 for sample mean. Scale economies account for only 13,6% of the growth in productivity (2% on average for the period)
Nelson R.A &Primeaux, W.J (1988)	The effects of competition on transmission and distribution costs in the Municipal Electric Industry	Kwh sales Hedonic vbles: service area, number of customers	Desirability of competition in the transmision and distribution of electric power	Cross seccional sample of 23 municipally owned electric utilities 1961-76. US	Labor and Purchased Power**.and fixed capital	Translog short run cost function	SE appear to have been exhausted for larger firms in the sample (increases in output and customer, holding output per costumer constant,). Competition may be feasible in large municipal markets but only from two or more firms serving a given consumer.
Nemoto, J., Nakanishi, Y. & Madono, S (1993).	Scale Economies and over – capital in Japanese Electric Utilities	Distributed Kwh	Short and long run scale economies, Cost Subadditivity and A-J efect	Cross seccional sample of 9 vertical integrated firms in the period 1981-85. Japan	Labor, fuel and fixed capital	Short run Translog. with share equation Maximun likelihood	Short run economies of scale and long run diseconomies. Existence of A-J effect. Not evidence of cost subadditivity

** Price of PP is a weighted average between cost of own generation and Purchased Power expenditures.

Table 2. SINGLE-OUTPUT COST FUNCTIONS IN THE ELECTRIC INDUSTRY. FIRMS

Authors	Title	Product	Objective	Sample	Factors	Fun. form and estimation	Results
Kamerschen, D.R. & Thompson, J.R. (1993)	Nuclear and Fossil Fuel Steam Generation of Electricity: differences and similarities	Kwh of nuclear and fossil fuel generation	Cost differences between generation technologies and consumers price structure efficiency	40 privately owned firms in 1985. 36% aprox. of nuclear generation. US.	Labor, fuel and capital	Long run Translog. and factor share equations IEP Zellner	Nuclear and fossil fuel gener. should be treated as separate samples. SE diminish as firm size increases. Nuclear MES is about 10 GWh ES of 20% at half nuclear MES Fossil-fuel MES is about 14GWh ES of 15% at half fossil MES Typical fitms are 7.8 and 14.9 GWh
Thompson, J.R. & Wolf, L. (1993)	General differences in Nuclear and Fossil-Fuel Gener. of Electricity	Kwh of nuclear and fossil fuel generation	Regional and tecnological differences in costs, elasticities of substitution and scale economies	90 privately owned firms of fossil-fuel generation in 1985 and 40 of nuclear generation. US.	Labor, fuel and capital	Long run Translog. and factor share equations IEP Zellner	Differences in gener. technologies SE diminish as firm size increases Nuclear MES is about 2250 MW (>10 GWh.) ES of 20% at half nuc. MES. Combined fossil-fuel MES is about 2500 MW (> 20 GWh) ES of 9% at half of comb. MES Oil MES is less than 10 GWh and gas MES is less than 5 GWh
Pollit, M.G (1995) Chapter 5	Ownership and performance in Electric Utilities	Kwh of fossil fuel generation	Productive efficiency of the public and private firms and Scale Economies	95 firms from US (73), Australia (5), Japan (9), UK (3), France (1), Italy (1), Denmark (1), Canada (1) & Ireland (1). 1986.	Labor, fuel and capital	Long run Translog shadow cost function (parametric aproximation) and factor share equations IEP. Zellner	MES between 20 and 30 GWh Strong evidence of SE for small firms. L shaped average cost curve. SE of 4% for private firms and 20% for public firms at sample mean Price efficiency can not be rejected. Not sup. Performance of private firms
Koh, D-S., Berg, S. & Kenny, L. (1996)	A comparison of Costs in Privately Owned and Publicly Owned Electric Utilities: the role of Scale	Kwh of fossil fuel generation	Differences in efficiency between Privately Owned and Publicly Owned Electric Utilities in the ROR framewok	121 privately owned firms and 61 publicly owned firms in 1986. US.	Labor, fuel and capital	Long run Translog shadow cost function (parametric aproximation) and factor share equations IEP. Zellner	Not economies of joint production between electricity and gas. Publicly owned firms are more efficient than privately at low output levels and are less efficient at high output levels
Hayashi, P., Yeoung, J & Chamberlain, W. M (1998)	Vertical Economies: the case of U.S. Electric Utility Industry, 1983-1987.	Distributed Kwh from fossil-fuel generation	Stage separabilty of cost function . Vertical integration economies	Cross seccional sample of 50 privately owned vertical integrated firms Period 1983-1987. US.	Capital, labor and generated energy	Long run Translog. and factor share equations . IEP Zellner	Rejection of the separability of cost function.Existence of EVI.. SE are not exhausted in generation stage
Scully, G.W (1998)	Reform and efficiency gains in the New Zealand Electrical Supply Industry	Kilowatt hour sales	Testing if deregulation is efficiency- improving and scale economies	704 obsevations of ESAs (firms that deliver electricity directly to customers) over the period 1982-94. New Zealand	Capital, labor and Purchased Power**	Long run Translog. and factor share equations IEP Zellner	SE over observed range of output and diminish as output expands. SE of 4.8% at 21.6 MWh, 4% at 200 Merger process reduce cost (0.9%), privat. and profit-orientation a 1.8% Real price of electricicty fell 16.4% (82-94) but is the same for households

Table 3. MULTIPRODUCT COST FUNCTIONS IN THE ELECTRIC INDUSTRY

Authors	Title	Products	Objective	Sample	Factors	Funtional form	Results
Hayashi, P.M., Sevier, M. & Trapani (1985).	Pricing Efficiency under (ROR): Some Empirical Evidence for the Electric Utility Ind.	Residential, commercial and industrial kilowatt hour sales	Specify a regulated cost function under Rate of return regulation	Cross sectional sample of 32 privately-owned firms vertical integrated in 1965 and 1970. Only conventional fossil fuels of generation and no purchased power. US	Labor, fuel and capital	Translog and factor share equations. IEP Zellner	Averch-Johnson effect and overcapitalization. Regulated cost greater than measured cost.
Roberts, Mark J. (1986).	Economies of Density and Size in the Production and Delivery of Electric Power	Kwh sales D_H and D_L. Hedonic vbles: service area, number of customers	Economies of density and size for the delivery of electricity	Cross sectional sample of 65 privately-owned firms vertical integrated in 1978. US	Capital of T, capital of D, labor and purchased power	Long-run Translog and factor share equations. Iterative IEP Zellner	Firms that expand output, customer and service territory proportionately will not decrease the averge cost for large firms The source of declining ray average cost is the quantity of output consumed per costumer Competitive bidding for the right to provide new service could produce efficiency gains. Rejection of the separability of cost function between stages
Kaserman, D.L. & Mayo, J.W. (1991).	The Measurement of Vertical Economies and the Efficient Structure of the Electric Utility Business	Kwh of G and T+D. Hedonic vbles: share of generation technologies, share of D_L and D_H...etc.	Economies of vertical integration (EVI) between generation-transmission and cost subadditivity (CS)	Cross sectional sample of 74 privately-owned firms vertical integrated in 1981. 50 firms in G and(T+D), 10 only in G and 14 only in T+D. US	Capital , labor, fuel and purchased power.	Quadratic in products and lineal in factor prices. OLS	Stage-specific economies of scale exhausted in each stage (about 5 GWh in T-D and 9 in G). Vertical cost complementarities. 59 firms are natural monopolies and there is a 12% of savings for vertical integration at the sample mean (7 GWh in T-D and 7 in G) . No EVI for very small firms
Gilsdorf, Keith (1994):	Vertical Integration Efficiencies and Electric Utilities: A cost Complementarity Perspective	Kwh of G, especific measure of T, served customers in D and especific density customers measure	EVI between generation and transmission-distribution through complementarity	Cross sectional sample of 72 privately-owned firms vertical integrated in 1985. At least 65% of non nuclear electric generation. US	Labor, fuel and capital	Long-run Translog and factor share equations. Iterative IEP Zellner	Complementarity is not found. Existence of stage-specific economies of scale in all three stages.

Table 3. MULTIPRODUCT COST FUNCTIONS IN THE ELECTRIC INDUSTRY

Authors	Title	Products	Objective	Sample	Factors	Funtional form	Results
Gilsdorf, Keith (1995):	Testing for Subaditivity of Vertically Integrated Electric Utilities	Kwh of G and T+D. Hedonic variables: consumption density, capacity utilization..etc	EVI between generation and transmission-distribution and CS through the test of Evans & Heckman.	Cross sectional sample of 72 privately-owned firms vertical integrated in 1985. At least 65% of non nuclear electric generation. US	Labor, fuel and capital	Long-run Translog and factor share equations. Iterative IEP Zellner	No evidence of cost subaditivity over the admissible region. Some evidence of EVI. Economies of scope between sales for resale and ultimate sales. Cost reducing effect for higher load factor
Thompson, H.G. (1997)	Cost Efficiency in Power Procurement and Delivery in the Electric Utility Industry	Kwh sales D_H and D_L. Hedonic vbles: service area, number of custormers	Economies of density and size for the delivery of electricity	Cross sectional sample of 83 privately-owned firms vertical integrated in 1977 and 1982 and 85 in 1987 and 1992. US	Capital of T, capital of D, labor of T, labor of and D and purchased power**	Long-run Translog and factor share equations with time trend. IEP Zellner	Confirmation of Roberts's results. Firms that expand output, customer and service territory proportionately will not decrease the averge cost for large firms (this occurs at sample mean 26 GWh). Strongly rejection of the separability of cost function between stages. Existence of EVI
Ramos Real, F.J. (2000)	Economías de integración y productividad en el sector eléctrico español 1983-1996. Un enfoque multiproductivo	Kwh of four types of generation and Kwh sales D_H and D_L Firms dummies	Economies of scale, economies of integration and TFP	Asimmetric pool of 12 firms operating in generation and distribution in the period 1983-1996. Spain	Labor, fuel, capital and purchased power	Long run quadratic and input equations with time trend. IEP Zellner	Exhaustion of stage-specific scale economies, 5% of EVI and existence of economies of horizontal integration in each stage (about 7.5% in G) at the sample mean (8 GWh in G and 11 in D)
Kwoka, J.E. (2002)	Vertical economies in electric power: evidence on integration and its alternatives	Kwh of generation & kwh of distribution. Hedonic vbles: share of generation, utilization capacity...etc	Measuring economies of vertical integration	147 investor-owned utilities in 1989. US	Labor, fuel and capital	Quadratic in products but not complete in factor prices. OLS	EVI of 3% for small mix outputs, 42 % at sample mean levels for both distribution and generation (9.6 and 8.2 mill kwh). Largest EVI for big firms and when both outputs are similar. No EVI for very small firms
Martínez- Budría, E., Jara-Díaz, S & Ramos-Real, F.J. (2003)	Adapting productivity theory to the quadratic cost function. Application to the Spanish electric sector	Kwh of four types of generation and Kwh of distribution. Firms dummies	Economies of scale, decomposition of technical change and TFP	Asimmetric pool of 12 firms operating in generation and distribution in the period 1983-1996. Spain	Capital, labor, fuel and intermediate input Labor is the normalizing price factor	Normalized long run quadratic and input equations with time trend. IEP Zellner	No exhaustion of multistage SE at sample mean. Average annual productivity improvement of 5.3% where 45% corresponds to technical change. Pure Tech. Change is the most relevant effect.

Products = G:generación , T: transmision , D: distribution; D_H: high tension; D_L: low tension.
** Price of PP is a weighted average between cost of own generation and Purchased Power expenditures.

[1] We use the term deregulation for the reforms related to changes in the organisational structure (disintegration) of electric utility industry and that allow a greater role to market mechanisms.

[2] Transmission encompasses the management of the high tension transport network and also the coordination and management of generating capacity, or energy dispatch.

[3] Although traditionally considered as part of distribution, activities related with direct contact with clients like charging and billing can be considered as an independent activity.

[4] For example, in Spain, the market will be overseen by two operating companies: the system operator who physically manages both the network and the delivery of power and the market operator who directs the energy transfer to determine the market price.

[5] The sunk costs are derived from the fact that the electricity industry is exceptionally capital intensive, long periods are required for construction and the useful life of the facilities is greater than the average of other industries. Thie specific character is due to the fact that practically every single piece making up the system has no alternative use. For example, the only use for the distribution grids is to distribute the energy on the final step, when the consumer makes a connection with the transmission grid. Depending on this characteristic, the possibility of appropriating quasi-rents is very high in the absence of regulation.

[6] The main concepts of the theory of multioutput that we will use are defined in Baumol, Panzar and Willig (1982).

[7] Flexibility arises from the fact that the signs of the first and second derivatives are not imposed a priori.

[8] As Röller (1990) points out, the translogarithmic model is not appropriate for detecting economies of scope, despite its qualities in other aspects, as this model cannot accept any zeros in productions.

[9] As Gilsdorf (1995) indicates, this specification assumes that marginal costs are independent of factor prices, thus sacrificing the flexibility of cost function and it can induce significant bias in the estimation.