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**COST EFFICIENCY AND SCOPE ECONOMIES IN MULTI-OUTPUT UTILITIES IN SWITZERLAND**

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# Summary

This report explores the cost structure of the Swiss multi-output distribution utilities. Along with the recent waves of liberalization and deregulation in public utilities throughout Europe, the authorities are increasingly concerned about the efficiency of distribution sectors that due to their natural monopoly characteristics are not fully liberalized. Because of their considerable network economies, a direct introduction of competition is not optimal in sectors such as power, gas and water distribution. Instead, incentive regulation has been used to ensure (or maximize) the productive efficiency of the locally monopolistic companies. Everywhere in Europe, the traditional regulatory systems are being gradually replaced by incentive regulation schemes. Unlike the traditional contracting systems based on a reasonable Rate of Return, the incentive contracts are designed to induce incentives for reducing costs and increasing efficiency. Most incentive regulation schemes use benchmarking to evaluate the productive performance of the regulated companies in order to reward/punish them accordingly. Based on their efficiency performance, companies are allowed to keep some of their profits/savings through either differentiated price caps or adjustments in budget or network access fees.

The effectiveness of such regulation systems relies upon the accuracy of estimated efficiency levels of individual companies. However, due to a great variety of available methods of efficiency measurement and the observed discrepancy of results across different methods, benchmarking practice requires a methodology to adopt a single model among several legitimate approaches and specifications. This task is particularly complicated in network utilities in which unobserved firm-specific factors might be confounded with inefficiency. These difficulties are so serious that have led some experts to renounce the whole idea of benchmarking as an unfair and unrealistic approach. However, benchmarking methods are increasingly used in similar network industries especially in the electricity sector. This tendency can be explained by the necessity of implementing a practical and effective incentive mechanism, which inevitably requires a method of benchmarking.

Noting the dominance of multi-utilities operating in electricity, gas and water distribution in Switzerland, an important question is whether the benchmarking methods can be applied to multi-utilities as well as single-output distributors. Obviously the problem of unobserved heterogeneity is more important in multi-output distributors that

operate in several networks, each of which could have different types of cost drivers with specific characteristics. On the other hand, one might argue that given the actual tendencies for efficiency and competition, unbundling the multi-utilities into separate network operators for electricity, gas and water could be a solution, in which case regulation systems and benchmarking methods should be considered separately for electricity, gas and water. The horizontal unbundling of the multi-utilities have been subject to extensive policy debates both in the EU and Switzerland. However, according to the observed tendencies in the regulatory reforms, the multi-utilities especially those with moderate and small networks, will most probably remain dominant in the energy distribution industry in Switzerland. Moreover, the multi-utilities benefit from important synergies through combined provision of multiple outputs. There is suggestive empirical evidence that the provision of electricity, gas and water is a local natural monopoly, in which the multiple-output provision is more economical than separate operation.

Therefore, it is important to explore the natural monopoly question before studying the possibilities of benchmarking and incentive regulation in multi-utilities, which is relevant only if the integrated multi-utilities constitute an optimal solution as opposed to complete horizontal unbundling. Considering this issue, this study attempts to address the following policy questions. First, what is the optimal structure of the multi-utility sector regarding the degree of separation and independence of different services, and secondly, how can the productive efficiency of the companies be ensured through incentive regulation and benchmarking?

The present study has been conducted in three stages. In the first stage, the theoretical background and general methods of identifying natural monopoly characteristics as well as the estimation of productive efficiency particularly cost-efficiency have been discussed. After a brief review of the methodological difficulties in efficiency estimation, the recent panel data extensions to the conventional econometric methods have been reviewed. It is shown through several studies reviewed in this report, that these recent developments can be helpful to achieve more reliable estimates of inefficiency in presence of unobserved and omitted factors. The previous studies have used some of these methods in single-network distributors such as electricity and gas. However to our knowledge there is no reported empirical application in the multi-utility sector.

In the second stage, the empirical evidence reported in previous studies both at national and international levels has been reviewed and the specific characteristics of Switzerland in energy and water distribution sectors have been discussed. The literature review includes both the studies of separate sectors and those dealing with combined provision of two or three energy products. It has been shown that the empirical evidence in general favors the presence of the economies of scope at least for a considerable fraction of companies and output levels. Moreover, most studies provide evidence of scale economies both in multi-utilities and in the single-output case for electricity, water and gas.

Finally, in the third stage the study provides an extensive empirical study to explore the two questions mentioned above. This part consists of an econometric analysis of the cost structure of 34 Swiss multi-utilities operating from 1997 to 2005. A translog cost function and several econometric specifications have been used. The question of natural monopoly has been investigated by testing the subadditivity of the estimated cost function and exploring the economies of scale and cost-complementarities that could be present between different outputs. In addition, the cost-efficiency of the studied multi-utilities has been analyzed using stochastic frontier methods. Several stochastic cost frontier models including one of the recently developed panel data models namely, the True Random Effects model proposed by Greene (2005), have been applied to the data in order to estimate the cost efficiency across individual companies. The results have been compared across different econometric specifications.

The estimation results indicate significant cost complementarities across different networks. The results also confirm the findings reported in previous literature, indicating the presence of global economies of scale at most output levels as well as scope economies. These results, together with the evidence of the convexity of the cost function at least along some directions, provide suggestive evidence that the Switzerland’s multi-utilities are a local natural monopoly. Therefore, the horizontally integrated companies benefit from considerable synergies that would be lost if they are unbundled. These synergies are especially important for small and moderate-size companies. Regarding the estimation of cost efficiency the results indicate the importance of an adequate accounting for the firm-specific unobserved factors that are not necessarily associated with the firms’ productive performance. While highlighting

the potential problems in benchmarking multi-utilities, this study shows that adequate panel data models can be used to identify the inefficient companies and quantify to certain extent, which part of their excess costs has been persistent and which part has varied over time. Moreover, if appropriately used, these models can provide reasonably well defined measures of inefficiency that can be useful for incentive regulation purposes.

The policy implications of this study can be summarized as follows: First, regarding the issue of unbundling, the results of this study do not favor the horizontal unbundling of the distribution utilities for electricity, gas and water. In fact separate single-output companies could not fully exploit the economies of scope across the sectors. It should be noted however, that keeping separate accounts for different services i.e. accounting unbundling does not retain companies from using the synergies and can be helpful for enhancing the transparency of companies' operation and improving the effectiveness of the regulator's activities. Secondly, given the provided suggestive evidence of natural monopoly in multi-utilities and the evidence of economies of scale in all three sectors, this study does not favor the side-by-side competition model in Switzerland's multi-utility sector. Third, large and integrated multi-utilities can benefit from the economies of scale. Therefore, provided a strong and independent regulatory system that can monitor prices and ensure productive efficiency, the results of this study provide suggestive evidence in favor of mergers and acquisitions in multi-utilities. Finally, the results indicate that the Swiss multi-utilities might have slight to moderate cost-inefficiencies. Therefore, it is crucial to ensure the cost efficiency of local monopolists by implementing incentive regulation systems and appropriate benchmarking methods.

# Cost Efficiency and Scope Economies
# in Multi-Output Utilities in Switzerland

## 1 Introduction

In several countries, the distribution of electricity, gas and water is provided by single utilities and multi-utility companies that operate at the local level. In some municipalities the organization of the distribution of these three goods is organized through integrated multiple output companies whereas in others by three separate utilities. In the electricity sector some of these utilities also own small power generation plants.

During the past two decades, many industrial countries have stepped up measures to liberalize and reform their energy and water markets. These reforms are also increasingly common in developing countries (Estache et al., 2006). The adopted regulatory reforms are mainly aimed at introducing competition in the sectors that do not have a monopolistic nature and introducing new regulatory instruments in the sectors that have a monopolistic nature. For example, the operation of power and water distribution networks is often considered as a natural monopoly, namely, an industry in which the optimal market structure consists of a single consolidated company rather than several competitive firms. The reform introduced in the regulation of the energy and water distribution networks are mainly aimed at improving the productive efficiency of the companies. For instance, in many cases the states have set up a monitoring system generally in the form of a regulator to ensure productive efficiency, quality of service and optimal investment in these sectors.

The role of regulatory agencies is basically to design price or reimbursement mechanisms that ensure low prices while providing the regulated companies with a “fair” amount of revenues for a sustainable performance and optimal investment. It is generally argued that in the traditional cost-of-service regulation systems companies recover their costs with a risk-free fixed rate of return and therefore have little incentive to minimize costs. As market liberalization takes the upper hand in public utilities, the traditional regulation systems are increasingly replaced by high-powered incentive regulation.

The incentive-based schemes are designed to provide incentive for cost-efficiency by compensating or punishing the companies with parts of their savings or losses. A variety of methods are proposed in the literature. Main categories of incentive-based schemes used for utilities are: price or revenue cap regulation schemes, sliding-scale rate of return, partial cost adjustment, menu of contracts, and yardstick regulation.[1] Virtually all the models used in practice, are based on 'benchmarking' that is, measuring a company's efficiency against a reference performance. As pointed out by Weyman-Jones et al. (2006), when the network service is provided by several companies that are not in direct competition, benchmarking can be used to induce productive efficiency. Through comparison with the best practice observed or any other benchmark, regulators can create 'yardstick' competition in the spirit of Schleifer (1985). Schleifer showed that theoretically, regardless of the position of the benchmark, the efficiency will be induced.

In addition to their use in incentive regulation, reliable methods of efficiency measurement can be used to assess the effectiveness of regulatory reforms and policy measures that have been used to improve productive efficiency. Literature provides many cases of studies that have used efficiency analysis for policy assessment purposes.[2]

Several OECD countries have already integrated a benchmarking practice in their regulation systems for electricity distribution networks (Farsi, Fetz and Filippini, 2007a; Crouch, 2007). A few countries have also introduced such incentive schemes based on performance in their water industry (Saal et al., 2007; Antonioli and Filippini, 2001). The application of benchmarking methods in the gas sector is not as advanced as that observed in the electricity industry. However, the use of incentive schemes based on performance has been proposed in several studies (*cf.* Casarin, 2007). In Switzerland the distribution utilities are monitored and regulated by cantonal and federal governments. Although Switzerland has not yet implemented any incentive regulation

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[1] See Joskow (2007) and Joskow and Schmalensee (1986) for a review of regulation models. See also Jamasb and Pollitt (2001) for a survey of different regulation practices in electricity markets.

[2] An interesting example is Knittel (2002) that has used a stochastic frontier model to explore the efficiency impact of several policy programs in the US electricity generation sector.

system, the actual debates suggest that the regulators will probably follow similar reforms in the near future. However, the energy sector in Switzerland has particular characteristics that might delay the implementation of an effective regulation system.

There are two important aspects that distinguish Switzerland distribution utilities from those in its neighboring countries. First, there exist a relatively large number of distribution utilities.[3] This implies that many companies operate in relatively small areas that differ considerably in their environmental factors and network characteristics. As we will see later, the effectiveness of most benchmarking models relies on the assumption that the companies of interest have a more or less similar operation. Secondly, multi-utilities play an important role in all three sectors: The share of multiple-output utilities in the electricity and gas sectors is respectively about 35 and 75 percent of the total national consumption. With a roughly estimated share of 80 percent of the total national consumption, multi-utilities are also dominant in the water sector.[4] In general multi-utilities tend to be active in all three sectors. The share of double-output utilities is quite low (limited to a few percentage points), especially in the gas sector. Although, most of these companies have separate accounting reports for their three services, the accuracy of such accounts by output is not sufficient for a reliable comparison with single-output companies. Therefore, the multi-utilities would require a benchmarking analysis independent from the single-output companies.

The prevalence of multi-output distribution is often explained by the scope economies in the operation of distribution networks as well as the possibility of a relatively high quality of service through integrated services (Farsi, Fetz and Filippini, 2007b). The economies of scope can result from sharing or joint utilization of labor and capital inputs as well as common activities like billing and advertisement (Baumol, Panzar et al. (1982)). The distribution of water, gas and electricity requires similar equipment such as wires, overhead line and similar skills in the operation and

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[3] The Swiss energy sector is a fragmented market characterized by a strong heterogeneity across the 3,023 communities. With a total of 940 electricity utilities, 124 gas companies and 2,995 water distributors Switzerland's energy sector is characterized by its staggeringly large number of distributors with a prevalence of small and medium size companies throughout the 3,023 Swiss communities (*cf.* Dymek and Glaubitz (2003), VSG (2007) and Föllmi and Meister (2005)).

[4] The numbers for electricity and gas are based on the data from 127 electricity distributors and 80 gas companies that respectively provide about 90% of electricity and gas consumption in Switzerland. The share in water distribution is estimated based on the available data from 72 companies that provide about 37 percent of the national water consumption. See Farsi, Fetz and Filippini (2007b) for more details.

maintenance of networks. Multi-utilities can also share a same reserve capacity during emergencies and maintenance periods (Waldman and Jensen (2001)).

Along with the implementation of the recent reform measures in several EU countries, there is a tendency to separate electricity, gas and water distribution into independent operations. This practice is also known as ‘horizontal unbundling’. Unbundling the services into separate functions allows a greater efficiency through stronger and more transparent competition that can be separately introduced in electricity, gas and water sectors. However, the implementation of the unbundling requirements will reduce the possibility of exploiting the economies of scope.

The unbinding guidelines released by the EU Directorate-General of Energy and Transport (DG Energy & Transport (2004)) state, that the extent of management separation between activities related to different sectors “can only be decided on a case by case basis”. Further it is highlighted that a clear answer to this unbundling question requires a “balanced assessment of, on the one hand, the need for independence and, on the other hand, the interest of multi-utility operators to look for possible synergies.” While allowing certain flexibility in unbundling multi-utilities, this note requires the policy makers to assess the extent of the economies of scope before taking policy decisions. According the EU policy directive all the utilities with fewer than 100,000 customers can be exempt from any functional unbundling requirement. The distinction of small and large companies is based on the relative insignificance of scope economies in large companies that exploit scale economies. Such discriminative policies allow small companies to benefit from other synergies than scale economies. Since Switzerland is among the European countries with a large number of small companies in its energy sector, it provides a policy-relevant context for exploring the economies of scope. Moreover, although Switzerland does not belong to the European Union, the Swiss unbundling requirements upcoming in the near future, will probably reflect those discussed in the European directives.

The crucial question in designing an optimal structure for the distribution sector is related to the extent of natural monopoly in the industry, which depends on the existing economies of scope and scale. In a multiple output industry with a sub-additive cost function, an integrated firm has lower costs than independent companies. While the monopolistic nature of energy distribution has been widely recognized in water, gas and electricity sectors separately, the issue across the entire sector is subject to debate.

Therefore, an important policy question in the regulation of energy and water distribution revolves around the economies of scale and scope across the three sectors. The extent of these cost complementarities is a determining factor in the effective regulation of distribution networks. This is especially important as in the actual situation the horizontally-integrated companies constitute an essential part of the energy networks.

Given the above discussion, the design of an effective regulatory system in Switzerland's energy and water distribution sector requires an insight to the two following policy issues: First, it is important to identify the extent of the economies of scale and also cost complementarities across electricity, gas and water distribution. Namely, it is important from a policy point of view to verify the hypothesis of a natural monopoly in the distribution of gas, water and electricity. Secondly, if the presence of integrated multi-utilities is justified from an economic point of view, adequate benchmarking methods on the productive efficiency of the companies should be developed. These benchmarking methods are very important for the implementation of the new regulatory instruments such as price cap regulation and yardstick competition. Of course, due to the observed and unobserved heterogeneity of these multi-utilities companies, obtaining reliable indicators of the productive efficiency of these companies is not an easy task.

The problem of unobserved heterogeneity in network industries with a single network has been explored in several studies.[5] The importance of the unobserved network and environment characteristics is obviously much more important in companies that operate multiple networks. This study argues that given the special importance of unobserved heterogeneity in multi-utilities, the conventional benchmarking methods could provide misleading results, thus cannot be applied to these companies in a sustainable manner. Therefore, it is important to explore and develop methods that can deal with unobserved differences among companies. Such methods can also be used in other cases in which the regulated companies are active in

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[5] See Farsi, Filippini and Greene (2005, 2006) and Farsi, Filippini and Kuenzle (2006) for examples, respectively in electricity distribution, railroads and bus transport companies.

several network services, which is increasingly common in public services such as transport, telecommunication and energy sectors.[6]

In order to address these questions, this study explores the cost structure of the multiple-output distribution utilities. First, the existing scope economies across separate sectors have been studied. The extent of scope economies estimated in this study and several previous papers have been used to justify the prevalence of horizontal integration in Switzerland. Secondly, the issue of measuring productive efficiency of multi-utilities in relation with the regulation systems has been studied. The basic idea is to identify an adequate benchmarking method that can be used to assess the relative performance of these companies. Different methods have been reviewed and their reliability has been compared. The methods have been applied to a data set from a sample of Swiss multi-utilities operating from 1997 to 2005.

The rest of the report is organized as follows. Chapter 2 provides a general description of the methods and the theoretical background. The concept of efficiency and the methods used for its measurement are discussed in detail. Chapter 4 presents the empirical results including the data, the model specification and the adopted econometric method. Chapter 6 concludes the report with a summary of the main results and the policy implications.

## 2 Methods and Theoretical Background

Productive efficiency is a broad concept that can be classified in several ways. In the context of multi-output production the concept of productive efficiency can be broadly classified into two categories: The first group deals with the optimal structure of the suppliers in the market, namely, scale and scope efficiency. The question here is to identify the level of outputs (scale) and their combination (scope) that would result in minimum costs. Here, the efficiency of a production unit or an industry depends on the extent to which it exploits the economies of scale as well as cost complementarities across different outputs. The concept of scale efficiency is based on an optimal operation scale, namely the output level that minimizes the average costs, whereas

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[6] The extension and diversification of companies in related services might be related to regulatory reforms pressing regulated companies to find new scopes for potential synergies rather than scale economies through simple extension.

scope efficiency is associated with the optimal mix of several outputs. The extents of scale and scope economies can be used to identify whether an industry is a natural monopoly. If the industry is classified as a natural monopoly, it is optimal to assign the provision of energy, gas and water to regional, fully-integrated companies.

Following Farrel (1957) the second group of measures consists of three concepts defined as technical, allocative and overall or cost efficiency. In this framework, inefficiency is defined as the distance of a firm or a production plan from a production or cost frontier accepted as the benchmark. For instance, if a firm's actual cost-ouput point lies on the cost frontier it is perfectly cost efficient. If it lies above the cost frontier then it is inefficient, with the ratio of minimum to observed cost defining the level of efficiency of the given firm. As we will see later, while the concepts of scope and scale economies are used to design an optimal organization of the industry, the measures of cost or technical efficiency are usually used to induce productive efficiency by rewarding (penalizing) the companies with relatively efficient (poor) performance.

The inefficiency of a production unit is therefore measured as its distance form a frontier (envelope) that is the locus of the optimal production plans. Such distances are measured by 'distance' functions defined in the space of output(s) or input(s), resulting respectively in output-oriented and input-oriented measures of efficiency.[7] Both cost and production frontiers belong to the general family of 'distance' functions.

Production functions have often been used to estimate efficiency, however, for the following reasons are excluded from this discussion. First, compared to output-input measures (commonly referred to as productivity measures) the measures of efficiency based on costs are more interesting from an economic point of view. In addition to technical inefficiencies resulting from inadequate technologies or the use of less productive input factors (technical efficiency), these measures account for inefficiencies due to a suboptimal allocation of input factors (allocative efficiency). Secondly, the regulated companies do not have much control if any, on the output level, which is usually determined by the demand side and the structure of the market that are designed by the states and regulators. This is exactly the basic condition of a cost function that is, minimizing costs given output and input prices. Production functions are often based on maximizing output given certain levels of inputs. Anyway, it should be noted that the

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[7] See Kumbhakar and Lovell (2000) for an extensive discussion.

discussion that follows, applies equally well to the efficiency measures based on production functions or any distance function for that matter.

Before turning to formal definitions of the studied efficiency measures, we lay out a simple presentation of a cost function (frontier) that can be used to identify the efficiency measures. A cost frontier is a function of output and input factor prices. Other output characteristics and environmental factors can also be included as independent variables. A general total cost frontier model with $M$ outputs, $N$ inputs and $K$ output characteristics can be written as:

$$C = f(q_1,...,q_M;w_1,...,w_N;z_1,...,z_K)\ , \qquad (1)$$

where $C$ is the total costs; $q_m$ ($m$=1, ..., $M$) are the outputs; $w_n$ ($n$=1, …, $N$) are the input factor prices; and $z_k$ ($k$=1, …, $K$) are output characteristics and other exogenous factors that may affect costs.

This chapter is organized in two sections. The first section provides the theoretical background for the concepts of economies of scale and scope and describes how these concepts can be used to explore the question of natural monopoly. Different concepts of productive efficiency including cost and technical efficiency will be described next.

## 2.1 Natural monopoly: economies of scale and scope

There is a great deal of literature dealing with the theoretical and empirical research in natural monopolies and their regulation. Panzar (1989) and Waterson (1987) provide surveys of the theoretical developments that are mainly attributed to the seminal research conducted by Baumol, Panzar et al. (1982).[8] Reviewing the most recent developments in this field, Joskow (2007) also provides a concise presentation of the theory of natural monopolies. As pointed out by Joskow citing Posner (1969) and Carlton and Perloff (2004), the natural monopoly does not refer to the actual number of suppliers in the market, but to an industry where the total production costs of a single firm is lower than that of several companies producing the same output. The concept of natural monopoly is therefore closely related to the economies of scope and scale in the production.

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[8] See also Sharkey (1982) for the origins of the natural monopoly.

In the simple case of single-output production, the necessary and sufficient condition for an industry to be a natural monopoly is the strict subadditivity of the cost function as expressed in the following inequality:

$$C(Q) < \sum_k C(q_k), \tag{2}$$

where $\sum_k q_k = Q$ and $k$=1, 2, .., $K$, with $K$ being the number of producers. This condition is generally associated with increasing returns to scale, which implies that the average costs of producing one unit can be decreased by increasing the output.[9] In other words, in a single-output case the existence of unexploited economies of scale indicates a natural monopoly. It should be noted however that economies of scale are only a sufficient (not necessary) condition for natural monopoly. Depending on the market demand in certain situations the subadditivity condition might hold even with diseconomies of scale, that is when the single firm's output is greater than the its optimal scale.[10] A main example is related to cases where the demand is greater than a monopolist's output at optimal scale but not sufficiently so in order for a second supplier to operate economically.

The subadditivity concept can be extended to multiple-output cases, by replacing the scalars $q_k$ with vectors in the multi-dimensional output space of dimension $M$, where $M$ is the number of outputs. As in the single-output case, the theory provides sets of sufficient conditions based on the cost structure. Basically the existence of multiproduct subadditivity requires a form of economies of scope in addition to economies of scale. Economies of scope can result from 'cost complementarity' across products namely, the property of a cost function in which increasing one output reduces the marginal cost of all other outputs, or from sharing the fixed costs among products. A readily available extension of economies of scope and scale to multiproduct cases is the definitions proposed by Baumol, Panzar et al. (1982). According to these definitions the

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[9] The returns to scale (RS) is usually defined as the proportional increase in output resulting from a proportional increase in all input factors, holding all input prices and output characteristics fixed (Caves et al., 1981). The RS has also been defined in terms of the effects on total costs resulting from a proportional increase in output, namely, as the inverse of the elasticity of total cost with respect to the output (Silk and Berndt, 2003).

[10] Optimal scale is defined as the output level at which the scale elasticity of costs is equal to one, thus implying the minimum average costs (Frisch, 1965; Chambers, 1988). At outputs lower than this optimal level, there are unexploited economies of scale.

degrees of 'global' economies of scale and scope are respectively given by the following equations:

$$SL = \frac{C(q_1, q_2, ..., q_M)}{\sum_{m=1}^{M} q_m \frac{\partial C}{\partial q_m}} = \frac{1}{\sum_{m=1}^{M} \frac{\partial \ln C}{\partial \ln q_m}} , \tag{3}$$

$$SC = \frac{\sum_{m=1}^{M} C(0,...,0, q_k, 0,...,0) - C(q_1, q_2, ..., q_M)}{C(q_1, q_2, ..., q_M)} . \tag{4}$$

Global (dis)economies of scale exist if *SL* is greater (smaller) than one and global (dis)economies of scope are present if *SC* is positive (negative). While *SL* is the global scale elasticity of costs measuring the degree of global returns to scale in a multiproduct firm, *SC* measures the relative additional cost that unbundling the production in independent single-product companies would incur. It is important to note that the existence of global economies of scale and scope is not a sufficient condition for natural monopoly. In fact, global economies of scale and scope might be due to synergies limited to certain products or specific combinations of them. In particular, the extension of natural monopoly to the multiproduct case requires a refinement of the concept of economies of scale that could be applied to a multidimensional output space.

The multiproduct economies of scale can be decomposed into two aspects. The first one is the concept of 'ray' economies of scale (increasing returns to scale) which implies ray subadditivity that is, declining average costs for varying quantities of a set of multiple outputs that are bundled in fixed proportions. This property can be formally written as:

$$C\left(q_1, q_2, ..., q_K \mid {}^{q_i}\!/_{q_K} = r_i ; i = 1,..,K\right) > \lambda C\left({}^{q_1}\!/_{\lambda}, {}^{q_2}\!/_{\lambda}, .., {}^{q_K}\!/_{\lambda} \middle| {}^{q_i}\!/_{q_K} = r_i ; i = 1,...,K\right), \tag{5}$$

where $\lambda$ and $r_i$ are positive constants. This condition is satisfied if the global scale economies exist namely, *SL* obtained from Equation (3) is greater than one.

The second definition is the product-specific economies of scale or 'declining average incremental costs.' This concept is based on the conversion of the multiproduct cost function into single-product functions defined for each one of the products. For any given product the single-output function is obtained by fixing all the outputs except that product. The incremental cost function is therefore defined as:

$$IC(q_k \mid \mathbf{q}_{-k}) \equiv C(q_1, q_2, \ldots, q_{k-1}, q_k, q_{k+1}, \ldots, q_K) - C(q_1, q_2, \ldots, q_{k-1}, 0, q_{k+1}, \ldots, q_K), \qquad (6)$$

where $\mathbf{q}_{-k}$ is an output vector obtained by fixing all products except product *k*, and the average incremental cost of product *k* is obtained by dividing the above function by $q_k$. The product specific economies of scale for product *k*, are defined on the basis of the incremental cost function of that product:

$$SL_k = \frac{IC(q_k \mid \mathbf{q}_{-k})}{\frac{\partial C}{\partial q_k} q_k}. \qquad (7)$$

Similar to the global (ray) economies of scale, the average incremental costs of product *k* is decreasing if $SL_k$ is greater than one.

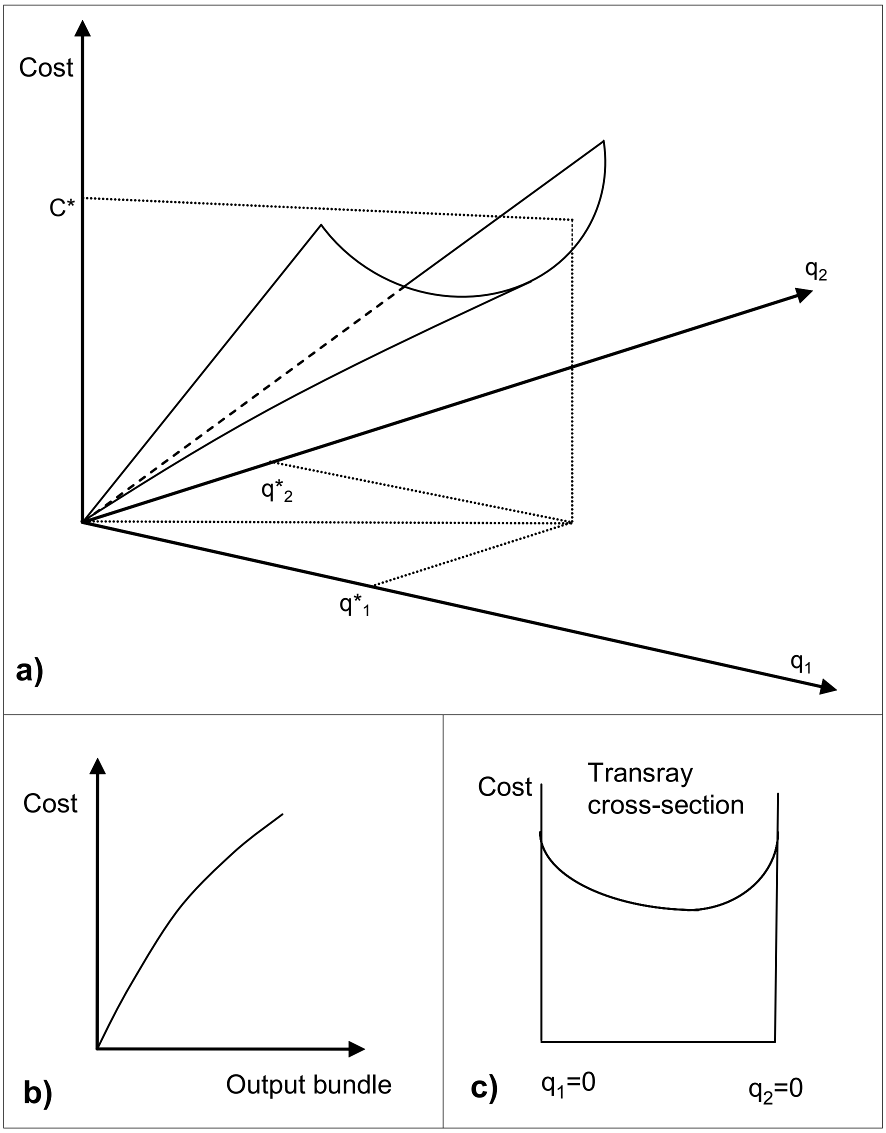
As it turns out the ray economies of scale might exist together with diseconomies of scope. In fact, a cost function might have strong ray economies of scale but at the same time certain products could show negative impact on the production costs of other outputs. In these cases, separating the production into several outputs might be more economical. Therefore, as far as subadditivity requirements are concerned the ‘trans-ray’ returns to scale matter as much as ray economies of scale. Technically speaking, the subadditivity ensured by declining ray average costs (ray economies of scale) combined with transray convexity along any hyperplane in the output space. Figure 1 illustrates a subadditive cost function that exhibits both features over all the output space in a two-product setup. The trans-ray cross section represents all combinations of outputs that have the same weighted sum $q_1 + \widehat{w} q_2 = \widehat{q}$ for any arbitrary values for $\widehat{w}$ and $\widehat{q}$. As shown in the figure, in a subadditive cost function, the average cost decreases as the output increases proportionally along a ray extended from origin. In addition, moving away from minimum costs (along any transray hyperplane) increases the costs.

The sufficient conditions for subadditivity can be specified in several ways. In general these conditions imply the presence of the economies of scope and scale. One useful set of sufficient conditions for natural monopoly (subadditivity) is the declining average incremental costs for all products, combined with the existence of weak scope economies (weak cost complementarity) across all product pairs. Intuitively, the former condition implies subadditivity in each product line whereas the latter implies the economic advantage of producing all the outputs together. Authors such as Mayo

(1984), Chappell and Wilder (1986) and Sing (1987) have used this approach to explore the issue of natural monopoly. The weak cost complementarity can be formally written as follows:

$$\frac{\partial^2 C}{\partial q_i \partial q_j} \leq 0; \quad \text{for all } i \neq j. \tag{8}$$

**Figure 1: An illustration of economies of scope in two-output production**



Another approach used by Evans and Heckman (1984) is based on a direct verification of the subadditivity condition as in Equation (2), based on the predicted costs for each one of the observed firms. This approach while having an advantage in that it closely simulates the actual situations, suffers however from the prediction errors entailed in the estimations.

As Panzar (1989) points out, the trans-ray convexity is a powerful condition which is difficult to verify and interpret. Therefore, a third approach for verifying the natural monopoly is by applying "local convexity conditions" that abstract from certain situations that are only of theoretical significance and have no practical importance. For instance, trans-ray convexity along any ray hyperplane is an unnecessary strong condition that can be hardly verified in a statistical set-up. In other words any non-convexity along a single hyperplane can violate this strong condition. In practice meaningful and feasible variation of outputs can occur only along certain directions, of which the most obvious in the two-output case would be $q_1 + \widehat{w} q_2 = \widehat{q}$ with $\widehat{w} = 1$.

In the empirical literature the trans-ray convexity condition is generally verified along one or several trans-ray hyperplanes. Many authors such as Braunstein and Pulley (1998) and Fraquelli et al. (2005) have asserted that the subaddivity condition can be verified by checking the strictly decreasing ray-average costs (ray economies of scale) plus trans-ray convexity at least along one cross section. The latter condition holds if the second-order own derivatives are positive and the second-order cross derivatives are negative (Baumol et al., 1982). The verification of these conditions is straightforward after the estimation of the multi-output cost function. Squires (1988) and Gordon et al. (2003) are among the authors who have used these conditions instead of a global convexity condition to verify subadditivity of costs, hence natural monopoly. Following this approach and for all practical purposes, the sufficient conditions for natural monopoly at output level $(q_1, q_2, ..., q_M)$ can be summarized as:

$$SL = \frac{C(q_1, q_2, ..., q_M)}{\sum_{m=1}^{M} q_m \frac{\partial C}{\partial q_m}} > 1; \quad \frac{\partial^2 C}{\partial q_i^2} \geq 0; \quad \frac{\partial^2 C}{\partial q_i \partial q_j} \leq 0; \quad \text{for all } i, j, \text{ with: } i \neq j. \qquad (9)$$

These conditions are generally difficult to satisfy at all sample points. A simple practical approach is to consider several representative mixes of outputs. For a translog cost function, the convexity conditions are more complicated, as they also involve the first-order derivatives as well as the quantities of outputs and costs. However, they can be simplified at the translog approximation point (usually sample median or mean) where the effect of the outputs will cancel out. In fact, the convexity conditions at the translog approximation point can be conveniently written as a function of translog cost function's coefficients. Therefore, at the translog approximation point, the subadditivity conditions in Equation (9) can be can be respectively written as:

$$
\begin{aligned}
& SL = \frac{1}{\sum_{m=1}^{M} \frac{\partial \ln C}{\partial \ln q_m}} > 1; \quad \frac{\partial^2 \ln C}{\partial \ln {q_i}^2} + \frac{\partial \ln C}{\partial \ln q_i}\left(\frac{\partial \ln C}{\partial \ln q_i} - 1\right) \geq 0; \\
& \frac{\partial^2 \ln C}{\partial \ln q_i \partial \ln q_j} + \frac{\partial \ln C}{\partial \ln q_i} . \frac{\partial \ln C}{\partial \ln q_j} \leq 0; \quad \text{for all } i, j, \text{ with: } i \neq j.
\end{aligned}
\qquad (10)
$$

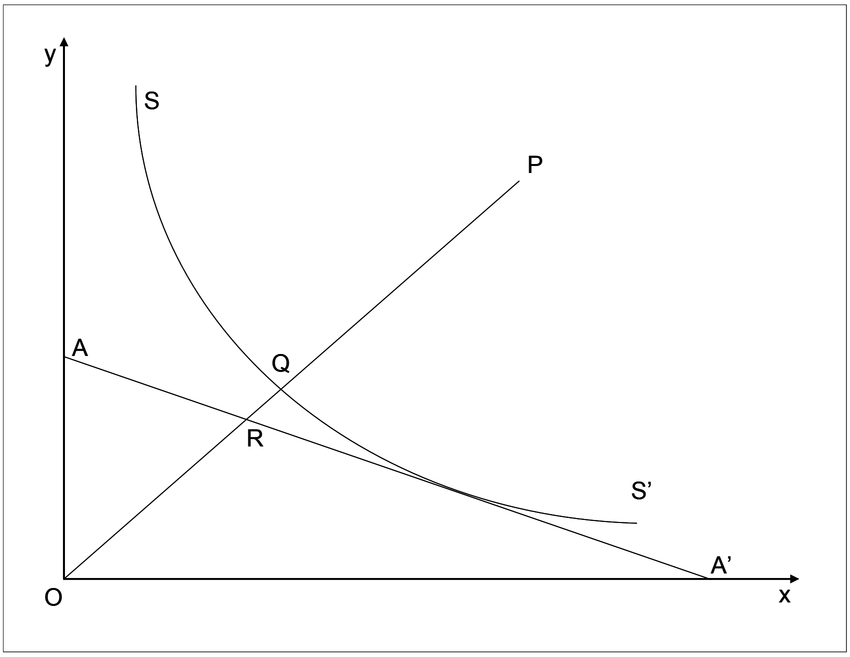
It should be noted that because of the statistical variation involved in the assessment of such multiple conditions, it is unlikely that all the conditions are satisfied in all the studied points and directions. While recognizing the difficulties in satisfying the mathematical conditions of convexity, many applied researchers (Fraquelli et al., 2005; Squires, 1988; Gordon et al., 2003) consider these conditions in light of their judgment regarding the practical importance of the estimated economies of scope (cost complementarities) and the economies of scale.

## 2.2 Efficiency concepts

Farrell's (1957) efficiency concepts are still the basic definitions in use today. The fundamental assumption of Farrell was the possibility of inefficient operations, immediately pointing to a *frontier production function* concept as the benchmark, as opposed to a notion of *average performance* underlying most of the previous econometric literature on the production function. The basis of Farrell's measures is the radial contraction/expansion relating inefficient observed points with reference points on the production or cost frontier. Farell (1957) proposed that efficiency consists of two components: technical efficiency and allocative efficiency. The former reflects the ability of a firm to minimize input utilization as to produce a given amount of output. The latter reflects the ability of a firm to use inputs in optimal proportions, given their respective prices and the production technology. Together, these two measures represent an overall efficiency measure also known as cost efficiency. An illustration of the

Farrell efficiency measures in the input space, is shown in Figure 2 (Farrell's original figure).

**Figure 2: An illustration of Farrel's efficiency concept**



The definitions of the various efficiency concepts using the inefficient production plan P are based on the distances relative to the theoretical frontier unit located at the isoquant SS'. These definitions are as follows. Technical efficiency: inputs needed at best practice to produce given outputs relative to observed input quantities, keeping observed input ratios; OQ/OP. Allocative efficiency: costs of producing observed output at observed factor prices, assuming technical efficiency, relative to minimized costs at the frontier; OR/OQ. Overall efficiency: costs of producing observed output if both technical efficiency and price efficiency are assumed relative to observed costs; OR/OP=(OQ/OP) (OR/OQ).

Inefficiency in production may result, therefore, from two different sources: deficiency in the adopted technology or its implementation (technical inefficiency) and suboptimal allocation of resources (allocative inefficiency). Cost inefficiency subsumes these two concepts and can be measured by input or output oriented measures.[11] The

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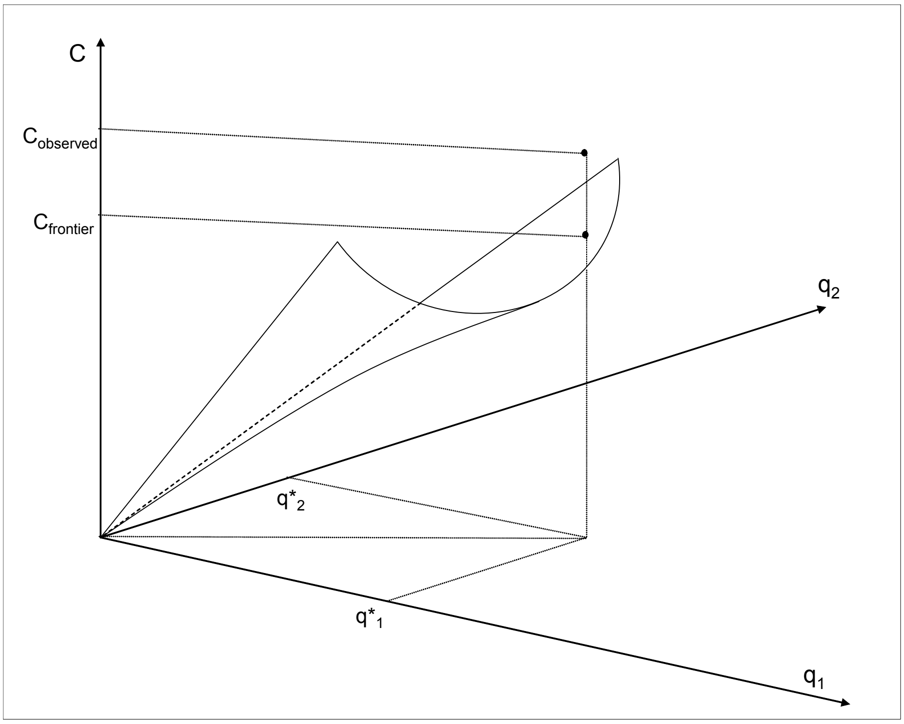
[11] See Russel (1998) for a discussion of different measures of productive efficiency.

estimation of a production function allows the analysis of the technical efficiency, whereas the estimation of a cost function allows the analysis of cost efficiency. Moreover, by estimating a cost function together with the factor share equations and making certain assumptions it is also possible at least theoretically to derive measures of technical efficiency from a cost function, thus decomposing the overall (in)efficiency into two components respectively due to allocative and technical inefficiency.[12]

One of the commonly used measures of cost inefficiency is the deviation from minimum costs to produce a given level of output with given inputs prices. This measure is an input-oriented measure that does not include the inefficiencies due to suboptimal scale or scope of production. Overall cost inefficiency of a given company, as presented before, is the resultant of the allocative and technical inefficiencies. In Figure 3 we illustrate a situation where a company producing two outputs $q_1^*$ and $q_2^*$, shows a level of cost that is not on the cost frontier (surface). The ratio between $C_{observed}$ and $C_{frontier}$ is a measure of cost inefficiency.

**Figure 3: An illustration of cost inefficiency in a multi-output context**



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[12] See Kumbhakar and Lovell (2000) for a discussion of this approach and the potential difficulties in its empirical implementation.

# 3 Estimation of Efficiency

Generally, in the empirical literature on the measurement of productive efficiency you can find empirical studies estimating a cost function or a production function. Moreover, there are two streams of this empirical literature. On one side we have studies that estimate a cost function using for instance OLS or more sophisticated econometric methods. In this case it is implicitly assumed that all the companies operate on the cost frontier, i.e. the observed differences across firms are due to omitted variables and random noise rather than cost inefficiency. From the estimation of this cost function it is then possible to calculate the level of scale and scope (in)efficiency of the companies. The estimation of this type of cost function can be based on the OLS estimation of a parametric cost function, usually expressed in logarithms:

$$ln\ C_i = f\,(\boldsymbol{q_i}, \boldsymbol{w_i}) + \varepsilon_i. \ , \tag{11}$$

where C is total cost incurred by company $i$, $f()$ is the cost function, $\boldsymbol{q}$ is a vector of outputs, $\boldsymbol{w}$ is a vector of input prices, and $\varepsilon_i$ is the stochastic error term. The efficiency of parameter estimates can be improved by estimating the cost function along with the factor share equations implied by Shephard's Lemma. Because, according to theory, certain parameters in the cost function are identical to certain parameters in the share equations, additional degrees of freedom are gained without the need to estimate any additional parameters. The input share equations take the following form:

$$S_{ji} = g\,(\boldsymbol{y_i}, \boldsymbol{w_i}) + \varepsilon_{ij\,i} \quad , \tag{12}$$

where $S_{ji}$ is share cost incurred by company $i$ for input $j$, $g()$ is the input share function, $\boldsymbol{y}$ is a vector of outputs, $\boldsymbol{w}$ is a vector of input prices, and $\varepsilon_{ji}$ is the stochastic error term. The cost system is usually estimated using the iterative Zellner's technique (Zellner, 1962) for seemingly unrelated regressions (SUR). This allows for the possibility that there may be a correlation between the disturbance terms of the cost and share equations for each observation, but that such correlation does not exist across observations within a given equation. As the share equations sum to one, an equation must be omitted from the system to implement SUR. However, using the iterative Zellner technique, the resulting estimates are equivalent to maximum likelihood estimates (Kmenta and Gilbert, 1970), and they are invariant to which share equation is deleted (Barten, 1977).

On the other side, in the empirical literature we have studies that assume that not all the companies are cost efficient. In this case researchers estimate the best practice cost frontier that allows the calculation of the level of scale, scope and cost inefficiency of the companies. The adopted approach in this stream of literature, often referred to as the 'frontier' approach, consists of a variety of methods that will be discussed in the next section. While being mainly tailored for the identification of cost or technical efficiency, most of these methods can also be used to estimate scale and scope economies. In this chapter, after a brief review of the frontier models especially the econometric approaches, it is argued that the unobserved heterogeneity could distort the estimation results both regarding the measures of cost-efficiency as well as scope and scale economies. The chapter's second section (Section 3.2) describes how panel data models could be used to improve the analysis in order to provide more reliable conclusions and more effective regulation instruments.

## 3.1 Frontier methods

The methods used for measuring technical, allocative and cost inefficiency are commonly referred to as frontier approaches. There are several frontier methods to estimate the efficiency of individual firms. Two main categories are non-parametric methods originated from operations research, and econometric approaches, which are the approaches considered in this study.[13] Murillo-Zamorano (2004) provides an account of advantages and shortcomings of each one of these methods. In non-parametric approaches like Data Envelopment Analysis (DEA), the frontier is considered as a deterministic function of the observed variables but no specific functional form is imposed.[14] Moreover, non-parametric approaches are generally easier to estimate and can be implemented on small datasets. Perhaps these are the main reasons that the non-parametric approach especially DEA is the most commonly used in practice.[15]

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[13] See Coelli et al. (2005) and Simar (1992) for an overview of non-parametric approaches and Kumbhakar and Lovell (2000) for a survey of parametric methods.

[14] See Coelli et al. (2003) for more details on DEA.

[15] The efficiency estimates in most of the non-parametric methods are based on the distance from a frontier which is obtained by a linear programming solution to an optimization problem (e.g. cost minimization) given a series of linear constraints to ensure all the observations lie on the feasible side of the frontier (e.g. above the cost frontier). Although the frontier is assumed to be deterministic, its shape can be quite flexible. Both variable and constant returns to scale can be accommodated. Even the common convexity restrictions can be relaxed in some of these methods such as the Feasible Disposable

Parametric methods on the other hand, allow for a random unobserved heterogeneity among different firms but need to specify a functional form for the cost or production function. The main advantage of such methods over non-parametric approaches is the separation of the inefficiency effect from the statistical noise due to data errors, omitted variables etc. The non-parametric methods' assumption of a unique deterministic frontier for all production units is unrealistic. Another advantage of parametric methods is that these methods allow statistical inference on the significance of the variables included in the model, using standard statistical tests. In non-parametric methods on the other hand, statistical inference requires elaborate and sensitive re-sampling methods like bootstrap techniques.[16]

A detailed comparison between parametric and non-parametric approaches is beyond the scope of this study. Recognizing that the latter category, particularly DEA, has become popular among electricity regulators, we assert that the econometric approaches such as stochastic frontier models have a clear advantage when it comes to data with specific structure such as repeated observations over time from several companies (panel data) or grouped or clustered data. In such cases the stochastic element of the frontier can be readily adapted to account and exploit the panel structure of the data. In this study we will argue that the regulators can benefit from the increasing availability of panel data to improve the efficiency estimates. Therefore, the use of panel data models is a central issue here, which naturally leads us to adopt a parametric approach that can accommodate panel data extensions.

Apart from a few exceptions, all parametric methods consider a stochastic frontier. Thus, this group of methods is known as Stochastic Frontier Analysis (SFA). The main exception with a deterministic frontier is the Corrected Ordinary Least Squares (COLS) method.[17] In this approach the inefficiencies are defined through a constant shift of the OLS residuals (*cf.* Greene, 1980). As the entire stochastic term is considered as inefficiency, the frontier remains deterministic. In SFA models, on the other hand, the residuals are decomposed into two terms, a symmetric component representing statistical noise and an asymmetric one representing inefficiency. This approach is due

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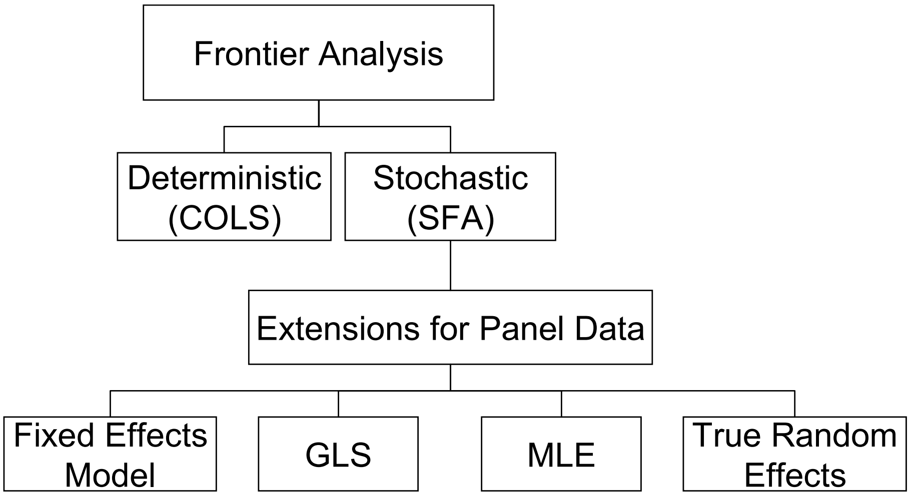
Hull (FDH) approach.

[16] These methods are available for rather special cases and have not yet been established as standard tests. See Simar and Wilson (2000) for an overview of statistical inference methods in non-parametric models.

[17] This frontier model has been developed by Greene (1980) based on Richmond (1974)'s Corrected Ordinary Least Squares method.

to Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). Figure 4 presents a general classification of parametric efficiency measurement methods.

**Figure 4: Efficiency measurement using econometric methods**



The COLS, the simplest parametric method, while being a deterministic frontier method, can be considered as the basis of many stochastic frontier models. The COLS approach is based on the OLS estimation of a parametric cost function, usually expressed in logarithms:

$$ln\ C_i = f\,(\boldsymbol{q_i}, \boldsymbol{w_i}) + \varepsilon_i \quad , \qquad (13)$$

where $C_i$ is the actual costs incurred by company $i$, and $f()$ is the cost function; and $\varepsilon_i$ is the stochastic error term. After correcting this term by shifting the intercept such that all residuals $\varepsilon_i$ are positive, the COLS model can be written as:

$$\ln C_i = f\,(\mathbf{y}_i, \mathbf{w}_i) + \min(\varepsilon_i) + u_i \text{, with } u_i = \varepsilon_I - \min(\varepsilon_i) >= 0, , \qquad (14)$$

where $u_i$ is a non-negative term representing the firm's inefficiency. The cost-efficiency of firm $i$ is then given by: $Eff_i = \exp(u_i)$.

The main shortcoming of this method is that it confounds inefficiency with statistical noise: the entire residual is classified as inefficiency, thus the cost frontier is deterministic. In the stochastic frontier model the error term is composed of two uncorrelated parts: The first part $u_i$, is a one-sided non-negative disturbance reflecting the effect of inefficiency, and the second component $v_i$, is a symmetric disturbance capturing the effect of noise. Usually the statistical noise is assumed to be normally distributed, while the inefficiency term $u_i$ is assumed to follow a half-normal distribution.[18] The SFA model can be written as:

$$ln\ C_i = f\,(\boldsymbol{y}_i, \boldsymbol{w}_i) + u_i + v_i\,. \tag{15}$$

This model with a normal-half-normal composite error term can be estimated using Maximum Likelihood Estimation method. Similarly the cost-efficiency of firm $i$ is given by: $Eff_i = \exp(u_i)$.

Here we focus on stochastic cost frontier models, that is, the deterministic frontier models like COLS as well as non-parametric models are excluded. In stochastic frontier models, the cost frontier is specific to each firm. Therefore, the cost frontier represents the expected locus of the minimum costs of all firms. With certain assumptions on the distribution of the two error components ($u_i$ and $v_i$) stochastic cost frontier methods can distinguish between these two components.[19] The inefficiency measure of a given firm is therefore the ratio between its observed costs and its corresponding frontier costs. It should be noted that the inefficiency estimation requires a certain interpretation of the stochastic terms in the model. In the frontier literature, starting from the original models (Aigner et al., 1977; Meeusen and van der Broek, 1997), it is commonly accepted that the skewed stochastic term with a certain distribution represents inefficiency. Carree (2002) discusses some of the implications of such distribution assumptions. For instance a half-normal distribution through its zero mode, implies that any company is most likely to be completely efficient. Moreover, implicit in this model is the assumption that inefficiency is uncorrelated with all exogenous variables and also with the idiosyncratic variations reflected in the symmetric error term.

The deterministic part of the cost function usually accounts for price and output variation among different companies. However, a considerable part of the cost differences among individual companies could be due to differences in external factors such as network and environmental characteristics. In practice, only some of these factors are observed. Moreover, some of these factors such as network complexity are

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[18] Other extensions of this model have also considered exponential and truncated normal distributions for the inefficiency term. See for instance Battese and Coelli (1992).

[19] Notice that in deterministic models like COLS, there is no need for any distribution assumption.

not easily measurable. The importance of accounting for heterogeneity of companies in efficiency analyses has been highlighted in several studies (*cf.* Greene, 2004, 2005a; Farsi, Filippini and Greene, 2006; Farsi, Filippini, Kuenzle, 2005).

The original stochastic frontier model (Aigner et al., 1977) includes a stochastic term for all the omitted variables. However, the key assumption is that the overall effect of these variables follows a normal distribution over the sample points. This is a necessary assumption for a consistent estimation of the frontier's parameters. This restriction can be partly relaxed with panel data models. The following section provides a selective review of panel data extensions of stochastic frontier models.

Before turning to the next section we would like to explore the difficulties encountered in measuring the productive efficiency in efficiency estimation, which have been pointed out in several studies. Jamasb and Pollit (2003) and Fraser (2003) report substantial variations in estimated efficiency scores and rank orders across different approaches (parametric and non-parametric) and among different econometric models applied to a cross sectional sample of European power distribution utilities. More or less similar discrepancies have been reported by Estache et al. (2004) and Farsi and Filippini (2004, 2005) in two samples of power distributors respectively from Switzerland and South America.[20] This problem is especially important for in most cases, there is no clear criterion for choosing a unique method among several legitimate models. Moreover, the efficiency estimates could have great financial consequences for the regulated companies and therefore, their reliability is crucial for an effective regulation system. In particular, if the efficiency estimates are sensitive to the benchmarking method, a more detailed analysis to justify the adopted approach is required. For instance, Bauer et al. (1998) have proposed a series of criteria that can be used to evaluate if the efficiency levels obtained from different approaches and models are mutually "consistent", that is, lead to comparable efficiency scores and ranks. However, in many cases because of a considerable discrepancy, these criteria are not satisfied.

In their comparative analysis of a sample of generating companies, Kopp and Smith (1980) conclude that the differences in efficiency estimates are related to the estimation method rather than the adopted functional form of the production frontier.

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[20] Other authors like Horrace and Schmidt (1996), Street (2003) and Jensen (2000) reported substantial errors and inconsistency problems in the estimation of individual efficiency scores in cross sectional data from other industries.

Similarly in this study, we argue that a major part of these discrepancies is related to the specification of unobserved factors and the model's assumptions required for distinguishing those factors from efficiency differences. In particular, this paper explores how some of the recently developed panel data models can be used to explain some of these discrepancies and attempts to provide a guideline for a better utilization of benchmarking methods.

As opposed to cross-sections, in panel the repeated observation of the same company over time allows an estimation of unobserved firm-specific factors, which might affect costs but are not under the firm's control. Individual companies operate in different regions with various environmental and network characteristics that are only partially observed. It is crucial for the regulator to distinguish between inefficiency and such exogenous heterogeneity. Several recently developed models such as Greene (2004; 2005a,b), Farsi, Filippini and Kuenzle (2005), Alvarez, Arias and Greene (2004) and Tsionas (2002) have addressed this issue using alternative panel data models. Some of these models have proved a certain success in a broad range of applications in network industries in that they give more plausible efficiency estimates.[21] These results raise an important question as to what extent the sensitivity problems can be solved by using panel data and the adapted frontier models. This question is especially important in the multi-utility sector, in which the companies operate in multiple networks, entailing several network-specific heterogeneity dimensions.

## 3.2 Panel data extensions of stochastic frontier models

The frontier model in (15) can be re-written for panel data using subscripts subscripts $i$ and $t$ respectively representing the firm and the operation year:

$$ln\ C_{it} = f\,(\mathbf{y}_{it}, \mathbf{w}_{it}) + u_{it} + v_{it}. \qquad (16)$$

Typically, it is assumed that the heterogeneity term $v_{it}$ is normally distributed and that the inefficiency term $u_{it}$ has a half-normal distribution that is, a normal distribution truncated at zero:

$$u_{it} \sim \left|N(0,\sigma_u^2)\right|, \quad v_{it} \sim N(0,\sigma_v^2). \qquad (17)$$

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[21] See respectively Saal, Parker and Weyman-Jones (2007), Farsi, Filippini and Greene (2006), Farsi, Filippini and Kuenzle (2006) and Farsi, Filippini and Greene (2005) for applications in water distribution, electricity networks, bus transport and railroads.

This model is based on the original cost frontier model proposed by Aigner, Lovell and Schmidt (1977). The firm's inefficiency is estimated using the conditional mean of the inefficiency term as proposed by Jondrow et al. (1982) that is: $\mathrm{E}\left[u_{it} \middle| \hat{\varepsilon}_{it}\right]$, where $\varepsilon_{it} = u_{it} + v_{it}$.

It should be noted that the inefficiency estimation requires a certain interpretation of the stochastic terms in the model. In the frontier literature, starting from Aigner et al. (1977), it is commonly accepted that the skewed stochastic term with a certain distribution represents inefficiency. Carree (2002) discusses some of the implications of such distribution assumptions. For instance a half-normal distribution through its zero mode, implies that any company is most likely to be completely efficient. Moreover, implicit in this model is the assumption that inefficiency is uncorrelated with all exogenous variables and also with the idiosyncratic variations reflected in the symmetric error term. The first use of panel data models in stochastic frontier models goes back to Pitt and Lee (1981) who assumed that the inefficiency term $u_{it}$ is constant over time, that is: $u_i \sim \left|N(0, \sigma_u^2)\right|$. Pitt and Lee (1981)'s model is different from the conventional random-effect model in that the individual-specific effects are assumed to follow a half-normal distribution. Important variations of this model were presented by Schmidt and Sickles (1984) who relaxed the distribution assumption and used the Generalized Least Squares (GLS) estimator, and by Battese and Coelli (1988) who assumed a truncated normal distribution. In cases where the individual firm effects ($u_i$) are correlated with the explanatory variables, the estimated parameters may be biased. Schmidt and Sickles (1984) proposed a fixed-effects approach to avoid such biases.

All the above models are basically analogous to conventional panel data models with the difference that the individual effects are interpreted as inefficiency rather than heterogeneity. A main shortcoming of these models is that any unobserved firm-specific heterogeneity that is constant over time, can be captured in the individual effects, thus considered as inefficiency. In the distribution sector that is characterized by strong unobserved network and environmental factors across firms, this could be a very restrictive assumption.

In more recent papers the random effects model has been extended to include time-variant inefficiency. Cornwell, Schmidt and Sickles (1990), Kumbhakar (1990), and Battese and Coelli (1992) are the important contributions that consider a time function to account for variation of efficiency. In particular Cornwell and his coauthors propose a model that considers a flexible function of time with parameters varying among firms.

These models have been extensively used in the literature. A common feature of all these models is that they do not fully separate the sources of heterogeneity and inefficiency at the firm level. Kumbhakar (1997) proposes a model that accommodates firm-specific variances in a heteroscedastic error term. An alternative approach is to consider two separate stochastic terms for efficiency and firm-specific heterogeneity. Theoretically, a stochastic frontier model in its original form (Aigner, Lovell and Schmidt, 1977) can be extended to panel data models, by adding a fixed or random effect in the model. There are a few papers that have explored this possibility. The first development can be attributed to Kumbhakar (1991) who proposed a three-stage estimation procedure to solve the model with time- and firm-specific effects.[22] Similarly, Heshmati (1998) has used a two-step procedure in a random-effect framework to separate the firm-specific effects from efficiency differences. However, all these papers use a multi-step estimation procedure. Polachek and Yoon (1996) attempted to estimate a panel data frontier model with firm dummies using a one-step procedure. Greene (2005b) discussed the numerical obstacles that have apparently delayed such a development.

Greene (2005a,b) proposes numerical solutions for both models with random and fixed effects, which he respectively refers to as “true” fixed and random effects models.[23] Some of these models have been successfully used in electricity distribution networks (Farsi, Filippini and Greene, 2006), as well as other public service sectors (*cf.* Farsi, Filippini and Kuenzle, 2005; Farsi, Filippini and Greene, 2005). These models can be written by adding a firm-specific stochastic term ($\alpha_i$) in the right-hand-side of Equation (16), hence:

$$ln\ C_{it} = f\,(\boldsymbol{y}_{it}, \boldsymbol{w}_{it}) + \alpha_i + u_{it} + v_{it}, . \qquad (18)$$

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[22] See also Heshmati and Kumbhakar (1994) and Kumbhakar and Hjalmarsson (1995) for two applications of this model. Note that in the latter paper, it is assumed that both time- and firm- specific effects are part of inefficiency.

[23] The name “true” is chosen by Greene (2005b) to show that the model keeps the original frontier framework and the extension is done only by including an additional heterogeneity term.

The term ($\alpha_i$) is an *i.i.d.* random component in random-effects framework, or a constant parameter in fixed-effects approach. Such models have an important advantage in that they allow for time-variant inefficiency while controlling for firm-level unobserved heterogeneity through fixed or random effects. The main difficulty of these models is that they are numerically cumbersome.

Another problem arises when the firm-specific effects are correlated with the explanatory variables. In such cases, the random effects (RE) estimators are affected by heterogeneity bias,[24] but the fixed effects (FE) model while being consistent regarding the cost frontier slopes, usually overestimates efficiency variations. Moreover, there is an important practical problem with the FE model in that it requires the estimation of a large number of parameters, which limits its application to reasonably long panels with sufficient within-firm variation. Generally, in short panels the fixed effects are subject to considerable estimation biases, which directly reflect in the inefficiency scores.[25]

Therefore in many cases these models do not provide a unified approach for estimating cost frontier and inefficiencies. An exception is one of the models proposed by Cornwell, Schmidt and Sickles (1990),[26] which extends on Hausman and Taylor (1981)'s instrumental variable methodology. This model however requires that a sufficient number of explanatory variables be uncorrelated with random effects. Farsi, Filippini and Kuenzle (2005) have proposed an alternative specification of the Schmidt and Sickles (1984)'s random effect model, that controls for the correlation between firm-specific effects and explanatory variables. This model draws upon Mundlak (1978)'s formulation of a 'within' estimator in the random effects framework. When applied to the conventional random-effects model, the resulted GLS estimator is identical to the FE estimator, thus unbiased. The inefficiency estimates are however adjusted for the correlation with exogenous variables. As shown by Farsi, Filippini and Kuenzle (2005), a similar method can be applied to other frontier models such as Pitt and Lee (1981) or the Greene (2005a,b)'s true random-effects model to decrease the

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[24] The term 'heterogeneity bias' has bee used by Chamberlain (1982) to refer to the bias induced by the correlation between individual effects and explanatory variables in a general RE model.

[25] See Greene (2005a,b) for more details. This author considers a panel of 5 years as a short panel.

[26] Notice that this model is different from those authors' other model discussed earlier.

heterogeneity bias.[27] The argument is based on an analogy with a GLS model that can be transformed to a 'within' (fixed-effects) estimator. However, in frontier models with an asymmetric residual term, Mundlak's specification is not equivalent to the corresponding fixed-effects model.

# 4 Background and Previous Literature

In Switzerland's energy sector, there is a certain tendency that local utility companies operate in both electricity and gas distribution as well as in the provision of water. Given the importance of multi-utilities in Switzerland, there are two issues that deserve attention from a public policy standpoint. First, given the ongoing reforms in the EU and the upcoming regulatory changes in Switzerland, it is important to understand whether the multiproduct operation of distribution utilities is sustainable. In order to answer this question, one has to explore the issue of natural monopoly in multi-utilities. Secondly, it is important that the regulators can induce and improve the productive efficiency of these multi-utilities by using adequate incentive regulation methods and eventually develop a benchmarking tool for measuring their performance. This issue has a special relevance in the eve of first implementation of reform measures in Switzerland on the one hand due to the increasing public scrutiny of public utilities, and on the other hand, because of the methodological challenge of an adequate benchmarking analysis in the presence of strong heterogeneity as in the case of Swiss multi-utilities.

After a brief overview of the structure and regulation of energy and water distribution networks in Switzerland, this chapter surveys the previous empirical studies of the utilities around the world. While the primary focus is on the multi-output utilities the studies related to single-output distribution networks are also discussed in three separate groups respectively for electricity, gas and water networks.

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[27] This argument is based on an analogy with a GLS model that can be transformed to a 'within' (fixed-effects) estimator. However, in frontier models with an asymmetric residual term, Mundlak's specification is not equivalent to the corresponding fixed-effects model.

## 4.1 Energy and water distribution sectors in Switzerland

The energy and water distribution sectors in Switzerland consist of fragmented markets characterized by a strong heterogeneity across the 3,023 communities. With a total of 940 electricity utilities, 124 gas companies and 2,995 water distributors Switzerland's energy and water sector is characterized by its staggeringly large number of distributors with a prevalence of small and medium size companies (*cf.* Dymek and Glaubitz (2003), VSG (2007) and Föllmi and Meister (2005)). Multi-utilities play an important role in all three sectors. In general, there is a certain tendency that local utility companies operate in both electricity and gas distribution as well as in the provision of water. This horizontal integration strategy allows the local multi-utility companies to save on costs by exploiting the economies of scope and to provide customers with an integrated set of services.

Table 1 provides a brief description of the structure of the electricity, gas and water distribution sectors in Switzerland. The market share of each type of utility is given as the fraction of end-use consumption and also as the number of utilities operating in the sector. These shares are based on a sample of total 175 utilities including 127, 80 and 95 companies respectively operating in electricity, gas and water sectors. Unfortunately, no detailed data are available for all multi-utilities. However, it has to be noted that the distributors included in the sample while representing a small fraction of the total companies operating in the country, supply a major part of energy markets amounting to about 88, 93 and 41 percent of national consumption in electricity, gas and water respectively. Of course, we are aware that this table is not representative of the production structure of the small utilities and multi-utilities.

**Table 1: The structure of the Swiss energy distribution utilities by sector**

| Sector: | Electricity | Gas | Water |
|---|---|---|---|
| Total number of distributors operating in Switzerland (2005) | 940 | 124 | 2’995 |
| Total energy distributed in Switzerland (2005) | 57’330 GWh | 33’589 GWh | 929 Mio. $m^3$ |
| Number of companies included in the sample | 127 | 80 | 95 |
| Share of national end-user consumption distributed by the utilities included in the sample | 88% | 93% | 41% |
| Share of end-use consumption in the sample (*percentage of companies in the sample*) | | | |
| E: Specialized in Electricity | 65%<br>(*36%*) | - | - |
| G: Specialized in Gas | - | 24%<br>(*21%*) | - |
| W: Specialized in Water | - | - | 14%<br>(*4%*) |
| EG: Electricity and Gas distributors | 1%<br>(*3%*) | 1%<br>(*4%*) | - |
| EW: Electricity and Water distributors | 4%<br>(*20%*) | - | 13%<br>(*39%*) |
| GW: Gas and Water distributors | - | 3%<br>(*11%*) | 2%<br>(*5%*) |
| EGW: Horizontally integrated utilities | 30%<br>(*41%*) | 72%<br>(*64%*) | 72%<br>(*52%*) |

Sources: BFE (2006), Dymek and Glaubitz (2003), Föllmi and Meister (2005), SVGW (2005), VSG (2007).

A seen in Table 1, while the majority of electricity companies are specialized single-product firms, the share of specialized companies in water and gas sectors is relatively limited. The data also suggest that the specialized companies in the electricity sector are likely to be relatively large utilities. As the table shows, the share of double-output utilities is relatively low, especially in the gas sector. Overall, the numbers listed in the table indicate that the fully horizontal integrated utilities have a major share across all three sectors.

During the last two decades the introduction of high levels of competition in the electricity and gas sectors of several EU-member countries has raised the general question of the necessity of unbundling services of utility companies. The regulatory reforms have been so far toward a separation of activities in the form of functional, legal or ownership unbundling, which are often believed to lower the entry barriers and boost competition, particularly in the electricity sector. However, the importance of the potential synergies through ‘horizontal’ integration has been recognized in the recent European regulatory recommendations.

According the EU policy directive all the utilities with fewer than 100,000 customers can be exempt from any functional unbundling requirement. The distinction of small and large companies is based on the relative insignificance of scope economies in large companies that exploit scale economies. Such discriminative policies allow small companies to benefit from other synergies than scale economies. Although Switzerland does not belong to the European Union, the Swiss unbundling requirements upcoming in the near future, will probably reflect those discussed in the European directives. Moreover, since Switzerland is among the European countries with a large number of small companies in its energy sector, it is very likely that the prevalence of multi-utilities in will remain a main characteristic of the Swiss energy sector in the future.

In this study it is assumed that there is no functional separation between distribution and supply functions. While being possibly unrealistic in some EU countries, this assumption closely reflects Switzerland’s actual situation and most probably, its future development. As most of the distribution companies in Switzerland are relatively small with only a few companies having more than 100,000 customers, with a likely adoption of policies similar to those of EU, the distribution and supply are likely to remain integrated in the future.

The liberalization of the electricity and gas markets in Switzerland is not as advanced as in the neighboring EU countries. A first attempt to reorganize the Swiss electricity market was made in 2002 with the “Electricity Market Law” (EMG) that has been closely rejected in a national referendum.[28] A new possibility to liberalize the electricity markets is the federal law for electricity distribution (StromVG). This legislation predicts measures to liberalize the market in two stages, with the first stage (to take effect in 2008) providing free choice of provider for large-scale consumers (more then 100 MWh per year) and a second stage (envisaged in five years, if approved in through referendum) to extend the measures to all consumers. The new legislation also commits the vertically integrated electricity utilities to a minimum level of unbundling that ensures separate accounting for electricity generation as well as an

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[28] The voting outcome was 52.6%.against the adoption of the new laws. For more information about the regulatory reforms see OECD (2006) and Vaterlaus and Wild (2001).

‘informational’ unbundling. The latter measure requires a strict confidentiality within companies, prohibiting the flow of sensitive economic information across different services such as distribution and generation.

The efforts to deregulate the Swiss gas market are relatively weaker than those in the electricity market. This is in contrast with the ongoing reforms in the EU which has liberalized the gas market parallel to the electricity sector. In 2003, following their own initiative the Swiss gas distributors have agreed to open third-party access to the high-pressure sectors of their networks, leading to a partial liberalization. This agreement (*Rohrleitungsgsetz*) requires the operator of high-pressure lines to arrange contracted transmission for a third party provided that it is technically and economically feasible and a reasonable compensation is offered. The agreement also provides an accounting unbundling between distribution and transmission. However, such agreements have been considered as inadequate and not aligned with the European market (BFE (2007)). In fact since July 2004 the EU commercial consumers can freely choose their gas distributors and this benefit has been extended to all consumers from July 2007. As for unbundling, the EU reforms require a complete unbundling for gas utilities with more than 100,000 customers.

Water supply and distribution in Switzerland is under the authority of local communities. Overall there are about 3,000 water providers serving the 3,023 Swiss communities. The industry is vertically integrated that is, extraction, filtering and distribution are conducted by a single utility. These companies have formed regional partnerships to ensure water safety the security of supply. The neighboring reservoirs and local networks are connected and the capacity gaps can be covered using commercial exchange between independent companies (*cf.* Föllmi, R. and U. Meister (2005)). If the actual policy debates in Switzerland are considered as a guide, it is unlikely that the Swiss water industry undergo any measures toward market liberalization and competition in the near future. However, the water utilities will be inevitably influenced by the ongoing reforms in gas and electricity industries especially as many water utilities are also involved in those two sectors.

## 4.2 Review of previous literature

The empirical studies of multi-utilities are limited to a few papers. To the knowledge of the authors there is hardly any study that explores the cost efficiency of multi-utilities. The studies usually provide separate analyses of efficiency for electricity, gas and water sectors. There are however, a few studies on the economies of scope and scale in multi-utilities. The rarity of efficiency studies in multi-utilities could be related to strong heterogeneity among the multi-utilities. The analysis of efficiency relies on an important assumption of a reasonable uniformity of production technology across the analyzed production units. Multi-utilities are often considered as several production units with more or less independent technologies. Any reliable performance measurement based on comparison among the companies should account for such heterogeneity. Another reason might be related to the differences in regulatory practice between electricity, gas and water distributions. In the presence of independent regulation systems for the three sectors, one might find easier to decompose a multi-utility company to separate production units with single outputs. Thanks to accounting unbundling these units can be analyzed together with single-output companies that produce the same output. However, it should be noted that because of the presence of the economies of scope such an approach would distort the cost-efficiency measures in favor of multi-utility firms.

*Studies of multi-utilities*

As far as the economies of scale and scope are concerned the studies of multi-utilities *per se* are limited to few papers:[29] Mayo (1984) and Sing (1987) in electricity and gas distribution and Fraquelli, Piacenza and Vannoni (2004), Piacenza and Vannoni (2004) and Farsi, Fetz and Filippini (2007b) in electricity, gas and water sectors. Mayo (1984) and Chappell and Wilder (1986) estimate a quadratic cost function for two cross sectional data sets from the US electricity and gas distribution sectors. Mayo (1984) reports scope economies only for small companies, whereas Chappell and Wilder (1986) conclude significant scope economies over most of output ranges. Sing (1987),

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[29] We exclude studies of scale and scope economies that pooled multi-utilities' units together with single-output companies. An interesting example is Yatchew (2000) who applied a semi-parametric model to a 3-year panel data set of Canadian electricity distributors. While focusing on scale economies he uses a dummy variable to assess the economies of scope from joint distribution of water and electricity.

also using a cross-sectional data set including 108 US electricity and gas distributors, estimates a generalized translog cost function with a Box-Cox transformation for outputs. In addition to the factor prices of labor, capital and fuel, he includes the customer density as an output characteristic. While reporting diseconomies of scope for the sample mean Sing (1987) finds scope synergies for certain output combinations, without any clear pattern with respect to the outputs magnitude.

The relatively recent papers by Fraquelli, Piacenza et al. (2004) and Piacenza and Vannoni (2004) use data from 90 Italian electricity, gas and water distributors over 3 years. However the data is pooled across the years and no panel data models are applied. They compare different functional forms such as the translog cost function with a small value transformation, the generalized translog, the separable quadratic and the composite cost function introduced by Pulley and Braunstein (1992). They conclude that economies of scope exist but their statistical significance can only be asserted over small outputs. A summary of the above studies and their main results is presented in Table 2. As we can see, panel data econometric methods has rarely been utilized to date. The short panels used in the recent studies by Fraquelli, Piacenza et al. (2004) and Piacenza and Vannoni (2004) probably have not allowed the authors to account for unobserved heterogeneity and correlation in the error terms.

## Table 2: Summary of previous empirical studies of multi-utilities

| | Mayo (1984) | Chappell and Wilder (1986) | Sing (1987) | Fraquelli et al. (2004) | Piacenza and Vannoni (2004) | Farsi et al. (2007b) |
|---|---|---|---|---|---|---|
| Data | Cross-section (1979, US) | Cross-section (1981, US) | Cross-section (1981, US) | Pooled (1994-96, Italy) | Pooled (1994-96, Italy) | Panel data (1997-2005, Switzerland) |
| Functional form | Quadratic and flexible fixed costs quadratic | Quadratic | Generalized translog | Translog, generalized translog, separable quadratic and composite | Translog, generalized translog, separable quadratic, composite and general form (Pulley and Braunstein (1992)) | Quadratic |
| Model | OLS | OLS | SUR | NLSUR | NLSUR | GLS, RCM |
| Output | Electricity and gas distribution | Electricity and gas distribution | Electricity and gas distribution | Electricity, gas and water distribution | Electricity, gas and water distribution | Electricity, gas and water |
| Factor prices | Labor, fuel | - | Labor, capital, fuel | Labor, other inputs | Labor, other inputs | Labor, capital, fuel |
| Other characteristics | - | - | Customer density | - | - | Customer density |
| Economies of scope | Exist only for small companies (+0.77%), for large companies diseconomies (up to -11.7%) | Exist over most of the output ranges, +12% for small, -10% for largest companies | Output combinations of both scope economies and diseconomies, no economies of scope for the mean output (-7.2%) | Exist, but significant only for companies producing less than the median output | Exist with all the models except with the translog cost function. For the median output between 16 and 64% | Exist over most of the output ranges, except for largest companies |
| Economies of scale | Product-specific economies of scale for gas over all outputs, for electricity only for small companies | Global and product-specific economies of scale exist | Product-specific economies of scale for electricity, diseconomies for gas | Exist, but significant only for companies producing less than the median output | All the models show economies of scale except the translog model | Global economies of scale exist over virtually all outputs |

A relevant study in the case of Switzerland has been conducted by Farsi, Fetz and Filippini (2007b). In that paper the cost structure of a panel data set form 87 electricity, gas and water utilities has been analyzed using a quadratic cost function. The goal of this paper was mainly to estimate the economies of scale and scope and not to estimate the level of cost efficiency of these multi-utilities. The model specification includes three outputs (the distributed electricity, gas and water), customer density and four input factor prices (labor, capital, electricity and gas). The econometric analysis has been based on a random effect GLS model and a random coefficient specification (RCM). In the latter model the intercept and main coefficients of output and customer density are assumed to follow a normal distribution across individual companies. All other coefficients are considered as constant parameters. Farsi, Fetz and Filippini (2007b) report significant economies of scope and scale over a great majority of the

Swiss multi-utilities. A summary of their estimates of scale and scope economies in several sample representative points is provided in Table 3.

**Table 3: Summary of the estimates of the economies of scope and scale reported by Farsi, Fetz and Filippini (2007b)**

| | Economies of Scope | | Economies of Scale | |
|---|---|---|---|---|
| Representative sample point | GLS | RCM | GLS | RCM |
| 1. Quintile | 0.37 | 0.27 | 1.24 | 1.17 |
| 2. Quintile | 0.22 | 0.16 | 1.14 | 1.09 |
| Median | 0.17 | 0.12 | 1.10 | 1.07 |
| 3. Quintile | 0.11 | 0.07 | 1.07 | 1.04 |
| 4. Quintile | 0.03 | -0.003 | 1.06 | 1.03 |

The estimates are obtained from a quadratic cost function estimated for 622 observations from 87 companies (from 1997 to 2005).

As it can be seen in the table, in the upper tail of the distribution, namely large companies, both economies of scope and scale are practically close to zero. For instance the values estimated at the 4th quintile suggest that scale economies are limited to a few percentage points and the scope economies are practically non-existent. These results suggest that the utilities that are close to the optimal size (economies of scale close to 1), thus do not have much unexploited economies of scale, cannot reduce costs by additional economies of scope. The findings reported by Farsi, Fetz and Filippini (2007b) suggest however, that the scope economies could be considerable in small and medium-size companies. As Table 3 indicates, more than half of the utilities included in the sample, benefit from more than 10 percent scope economies. For small companies the potential cost savings could reach 20 to 30 percent. These results imply that unbundling multi-utilities could result in considerable additional production costs.

As discussed earlier, the empirical studies of technical and cost efficiency in energy utilities have been limited to those that consider the sectors separately. It is however important to review this literature by sector. In fact there is a close similarity both in methodology and policy applications, between these studies and an analysis of efficiency in multi-utilities. The difference is more related to the included companies and the assumption about the production technologies. There is also a great body of literature that has applied non-parametric methods to utilities especially electricity distributors.[30] Because of their limitations discussed in the previous chapter the non-parametric studies are excluded here.

### *Studies of the electricity sector*

Parallel with the relative advancement of regulatory reforms in the electricity sector, there are also a larger number of efficiency studies on that sector compared to gas and water industries.[31] Rossi and Ruzzier (2000) provide an overview of the regulatory applications of efficiency measures in the electricity sector. Here we review a selected number of studies that have used the stochastic frontier method.[32] Two interesting recent examples are Hirschhausen et al. (2006) and Hattori et al. (2006) who used both parametric and non-parametric approaches to study the efficiency of electricity distribution companies. Both studies use the translog functional form for their parametric approach. In the former study a production function has been estimated using a cross section of 307 German distributors, whereas the latter provides a comparative analysis using a cost function applied to a panel data set of 21 electricity distributors from UK and Japan. Hirschhuasen et al. (2006) specify labor and capital as well as energy losses as input, and the distributed electricity as output. They also include an index representing the network's customer density and the peak load in one of their alternative specifications. Using an input-oriented distance function to measure the technical efficiency, they find that returns to scale play only a minor role limited to very small utilities and that the customer density has a negative impact on efficiency, while the peak load has not significant effect. The authors also provide evidence suggesting a higher productive efficiency for East Germany compared to the western part. The latter finding has been explored and confirmed in another study (Hess and Cullmann, 2007) that used the same data.

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[30] Edvardsen and Førsund (2003) is an interesting example of the application of non-parametric methods in the benchmarkin of electricity distribution utilities. See also Jamasb and Pollitt (2001, 2003) for a brief review of a part of this literature applied to the electricity industry.

[31] The electricity sector probably also witnesses a stronger criticism against using benchmarking in regulatory practice. See for instance, Shuttlewoth (2003) and Irastorza (2003).

[32] We also exclude a number of studies that analyzed the productivity growth. A recent example is Granderson (2006) who used a translog cost function combined with input share equations to decompose the TFP growth in the US electricity generation into three components related to scale, technical change and efficiency gains.

Hattori et al. (2006) use a total cost function with customers and distributed electricity as outputs.[33] They but do not include input factor prices which implies a simplifying assumption asserting that (real) input prices are constant across companies. Pooling the data across the years (1985-1998), those authors do not consider the panel aspect of their data. Their findings suggest a lower efficiency for Japanese utilities and a higher productivity gain in the UK utilities, which the authors associate to relatively tight regulatory system in the UK. Another international comparison has been reported by Hattori (2002) between the US and Japanese electricity distribution sectors. Hattori also applies a pooled cross-sectional model to a panel data set from 21 utilities from 1982-1997. Hattori considers translog input distance function with two separate output variables for residential and industrial customers and two input factors (labor and capital), and includes load factor and customer density in his model specification. Hattori's findings suggest that the Japanese sector has on average a more efficient production.

Kumbhakar and Hjalmarsson (1998) and Burns and Weyman-Jones (1996) are two other applications of stochastic frontier models in electricity distribution. While the former uses an input requirement function the latter considers a cost function. In particular Kumbhakar and Hjalmarsson (1998) is an interesting study in that it use a *sequential* frontier model, that is for estimating efficiency in any given year the observations after that year are excluded from the analysis. Moreover it provides a concise review of the relevant empirical studies before its publication. Focusing on the differences across utilities with different ownership structures, the authors use a panel data set consisting of a large number of Swedish utilities from 1970 to 1990 but do not consider the panel data structure in their econometric specification. They use a translog functional form with a single output and include the transformer capacity as a measure of capital stock. Their findings suggest the existence of economies scale and technical progress, and a higher efficiency for private-owned companies as opposed to public firms.

Burns and Weyman-Jones (1996) on the other hand, used several panel data models for estimating the efficiency of 12 distributors over a 13 year period. They use a translog cost function with delivered electricity and number of customers as output and

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[33] Hattori et al. refer to their cost function as an 'input' function with a single monetary input measured as the company's total expenditure.

capital and labor as input. The customer density and maximum load have been included as explanatory variables. The authors show a relatively good stability of the efficiency ranking regardless of the adopted assumption imposed on the distribution of the inefficiency term. Their findings also indicate significant economies of scale.

Overall, there are two main points that we could observe in the empirical studies dealing with the efficiency in power distribution. First, the importance of observed variations across companies has been recognized in most of these studies. Electricity distribution utilities operate in networks with different shapes and various degrees of complexity, which directly affect the costs. As discussed by Roberts (1986), Salvanes and Tjϕota (1994) and Thompson (1997), the cost function should take into account differences in network characteristics and other variables that have an impact on costs but are in principle, beyond the firm's control. Ignoring these factors might result in biased estimates of cost function coefficients and thus the economies of scale and scope due to heterogeneity bias. Moreover, some of these omitted factors could be captured by the stochastic term representing inefficiency, thus produce a distorted and often misleading picture of cost-efficiency penalizing utilities that operate in more complex environments. Most of the studies have accounted for some of these cost drivers through output characteristics such as load factor,[34] network length, area size and customer density. The problem that is hardly recognized in the literature is the difficulty in accounting for some of these factors such as network complexity because they are generally not available in the data and are often too complicated to measure using a single variable.

Secondly, there are not many studies that have taken advantage of panel data models. As discussed in the previous chapter, panel data can be helpful in accounting for such unobserved factors through firm-specific stochastic effects. Farsi, Fetz and Filippini (2007a) have explained the potential advantages of panel data models and their usefulness in regulation practice. In addition to Burns and Weyman-Jones (1996), several authors such as Wild (2001), Filippini and Wild (2001), Farsi and Filippini (2004) and Filippini et al. (2004) have used conventional panel data models to estimate cost-efficiency of electricity distributors. However, all these studies have assumed that the efficiency is time-invariant. Farsi, Filippini and Greene (2006) is among the few

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[34] The load factor captures the impact of the intensity of use on costs. See Foreman-Peck and Waterson (1985) for a discussion of the role of load factor in cost models.

exceptions that used alternative panel data models that can separately account for time-variant inefficiency term and firm-specific heterogeneity. The rarity of panel data models in this literature can be partly explained by the scarcity of the data in this field and partly because of econometric problems that such models could entail. For instance, as pointed out by these authors (Farsi and Filippini, 2004) conventional panel data models could have a poor performance in estimating efficiency and more elaborate models such as those proposed by Greene (2005a,b) could be numerically cumbersome.

Another limitation is related to the availability of panel data models for systems of equations that use input factor demand (share) equations to improve the model's statistical performance. Combining share equations with a stochastic frontier model in a panel data framework can create a complex error structure (Greene, 1997), the econometric solution to which remains to be developed (Kumbhakar and Lovell, 2000). The main problem is the fact that the allocative inefficiencies enter the demand equations, thus complicate the error structure of the system of equations. Obviously the above problem does not extend to non-frontier models, which can be estimated using a system of Seemingly Unrelated Regression equations with random-effects GLS specification (*cf.* Baltagi, 2001).[35] Therefore, abstracting from cost-efficiency and as far as the economies of scope and scale are concerned, in principle panel data models can be used with system of equations. However, to our knowledge the available statistical packages do not provide such a possibility.

*Studies of the gas sector*

The literature on econometric estimation of cost or production functions in gas distribution companies is scarce. As pointed out by Casarin (2007), this can be partly explained by the fact that several gas companies rarely co-exist in the same country and inter-country comparisons are generally difficult because of great differences across the countries regarding the configuration of the industry. Hollas and Stansell (1988)[36] are probably the first authors who analyzed this industry by modeling technical and allocative inefficiency. Their method allows identifying the relative efficiency of

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[35] It should be noted that some authors have combined a fixed effect main cost equation with share equations without individual effects. An example is the Jara-Diaz et al. (2003) paper.

[36] See Hollas and Stansell (1994) for a similar application to estimate the economic efficiency of public and private gas distribution utilities.

different types with respect to each other, but it does not provide any firm-specific inefficiency estimate. Hollas and Stansell (1988) applied a behavioral translog profit function to a cross sectional data set including 64 privately owned gas distribution from the US. In their specification, they include output, the price of fuel, labor price, customer density and the fixed capital input measured in daily throughput capacity of the distribution system as well as price 'shifters' for four types of companies..

Kim and Lee (1996) highlight the importance of accounting for output characteristics in estimating a translog cost function for 7 Korean gas distributors operating over 6 years. In addition to the labor price and the unit price of pipeline, they include the customer density, the average 'customer size' measured as average consumption and the 'supply rate' measured as the actual number of customers divided by the potential number of customers. Bernard et al. (1998) consider the load factor and the network length as major cost drivers that should be included as output characteristics. The latter authors used a Box-Cox cost function on a cross section of 131 Canadian companies.

Granderson and Linvill (1999) and Granderson (2000) used an eleven-year panel of 20 U.S. interstate natural gas transmission companies to produce a benchmark for regulation. As inputs, they specify labor, fuel, the weight of the transmission pipelines, and the capacity of compressor station and estimate a translog cost frontier by a random effects GLS model (Schmidt and Sickles, 1984). They also used DEA to get non-parametric estimates of inefficiency and compare the results. Although the results show that when using the non-parametric approach, the inefficiency estimates are lower, the inefficiency ranking stays more or less the same.[37]

Fabbri et al. (2000) estimated a total distribution translog cost function for 31 Italian companies observed during two years. They use the yearly average cost per employee as labor price, the book-value of equipment divided by the length of the distribution network as capital price and the price of material and services is calculated as the residual expenses divided by network length. Output is measured as the volume of gas delivered and the number of customers. Their specification also includes the ratio of network length to the number of customers, share of urban population, the average altitude of the service area, and dummy variables for ownership differences and time

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[37] This result is generally consistent with those reported by Carrington et al. (2002) who used the DEA approach and a translog input distance function to estimate efficiency of gas distribution companies.

effects. Their results suggest a more cost efficient production in private firms. These authors also found that the economies of scale are not significant at the output levels in the data. On the other hand, economies of density appear to be considerable. These results are in line with most of the findings reported in other studies.

Rossi (2001) estimated a stochastic frontier production function using the approach suggested by Battese and Coelli (1992). Rossi used the network length as a proxy for capital input, and the number of employees as the labor input. In addition, the concession area, the ratio of residential sales to total sales and the maximum demand are considered as the environmental variables. The number of customers is used as a single output. In one of his specifications the results suggest significant diseconomies of scale, but another model's results do not reject the hypothesis of optimal scale.

Carrington et al. (2002) have used both DEA and COLS as well as the stochastic frontier approach to estimate the technical efficiency of a sample of 59 gas distribution utilities from the US and Australia. They used a translog input distance function with three outputs namely, the delivered gas and the numbers of residential and other customers. Carrington et al. (2002) provide an example of the application of international benchmarking by the regulators to set the price caps.

A relevant study in Switzerland's case is Farsi, Filippini and Kuenzle (2007) who studied the cost efficiency in the Swiss gas distribution sector. They have used a Cobb-Douglas total cost function which includes gas output as well as area size, customer density and number of customers. Using a 5-year panel data set of 26 companies and using several panel data models they showed that the efficiency estimates could be sensitive to the econometric specification. They also distinguish between economies of scale and economies of density in line with Caves et al. (1984, 1985).[38] Their findings suggest the presence of considerable economies of density but weak or insignificant economies of scale in the Swiss gas distribution sector.

Another interesting study in the gas sector is Casarin (2007) who explores the economies of vertical integration of transmission, distribution and supply to end-use consumers. Casarin considered a generalized multi-product translog variable cost function for an 8-year panel data set consisting of 92 observations from gas companies

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[38] See also Farsi, Filippini and Kuenzle (2006) for another application in public transport, that distinguishes economies of scale from economies of density.

in Argentina and the UK. While considering three inputs namely, capital, material and labor, he estimated a system of equations including the labor input share equation, but did not consider the panel aspect of the data. While providing evidence of economies of scale for small companies, his findings suggest that the returns to scale are constant for large utilities such as those operating in the UK. More interestingly, Casarin (2007)'s results indicate diseconomies of vertical integration between different stages of production, favoring particularly the separation of the transmission stage from distribution.

*Studies of the water sector*

There are a large number of papers that explored the company-level data in the water industry. Here a selection of these studies will be reviewed. Antonioli and Filippini (2001) used a variable cost function to analyze the cost structure of a panel data set of 32 Italian water distributors. Using a Cobb-Douglas functional form, they considered the volume of delivered water as the output and labor, capital and energy as input. They also controlled for the number of customers and the length of the main network as output characteristics. Considering stochastic frontier models with several econometric specifications, the authors highlight the sensitivity of efficiency estimates. The paper's findings suggest the existence of economies of output and customer density, but no economies of scale in the short-run.

Using the fixed effects framework proposed by Schmidt and Sickles (1984), Sabbioni (2007) studies the cost-efficiency of water and sewerage utilities in Brazil. Sabbioni's findings indicate considerable economies of scale suggesting that regional companies are more economical than the municipal provision of water and sanitary services. These results are consistent with the evidence reported by Garcia and Thomas (2001), suggesting an efficiency improvement by merging local utilities to water districts. The latter authors apply a translog variable cost function to a 3-year panel data set from 55 water utilities operating in France. They apply GMM and within estimators to solve a system of regression equations that integrate two input share equations with a variable cost equation. Their findings also indicate that the variable cost function is increasing in capital stock measured as stocking and pumping equipments, which the authors interpret as an indication of excess capacity for water distributors.

Using a stochastic frontier approach with an input distance function, Mugisha (2007) analyzes the performance of 15 public water and sewerage utilities operating over a 6-year period in Uganda. The adopted econometric specification is based on Battese and Coelli (1995) with a truncated normal distribution for the efficiency term and a translog function that includes delivered water and number of connections as output and the network length, number of employees and the operating expenses as input. The author provides some evidence that the financial incentives can improve the technical efficiency even in companies managed within the public administration.

Aubert and Reynaud (2005) is another study that has used Battese and Coelli (1995)'s model to explored the impact of different regulation regimes on efficiency of water utilities. Considering a translog variable cost function, the authors analyze a 3-year panel of 211 water utilities operating in Wisconsin. Similarly they consider the distributed water and the number of customers as two separate outputs, and labor, capital and electricity as input. Their findings suggest that the efficiency depends partly upon the regulation scheme. While overall, the price-cap system is favored over rate-of-return regulation, there is a wide variation in relative efficiency within each regime.

Sauer and Frohberg (2007) use a non-linear cost function namely, a symmetric generalized McFadden functional form, to estimate the allocative efficiency of a cross-sectional data set of 47 German water utilities operating in rural areas. The authors use the supplied water as a measure of output and labor, capital, electricity and the chemicals used for water treatment as input. They also control for the number of connections and the network length as output characteristics. Their findings indicate that the allocative efficiency depends on the utility's size, with large utilities scoring a better labor and energy efficiency while favoring small utilities for chemical efficiency.

Saal and Parker (2006) applied a translog input distance function to an 11-year panel data set including 29 privatized UK water companies, some of which provide sewerage services in addition to water supply. Pooling the data across the years, the authors used a stochastic frontier model in line with Aigner et al. (1977) to estimate the efficiency and returns to scale. They show that estimations based on a joint frontier for water-only companies and water-and-sewerage companies distort the efficiency estimates. Saal and Parker (2006) conclude that a joint specification for the two types of company is inappropriate, mainly because of the problem of zero output values in distance functions. In an extension of that study Saal et al. (2007) focus on the 10 utilities that provide both services and augment the sample span to a 16-year period. The adopted econometric specification is based on the ‘true’ fixed effect frontier model proposed by Greene (2005b). The authors assert that benefiting from a relatively long panel data allowed a reliable identification of firm-specific fixed effects.

Saal et al. (2007) focus on the impact of privatization and the new price cap regulation on the productivity growth in the industry and the contributions resulting from technical progress, efficiency improvements and changes in scale. They consider the physical supplied water and the sewerage load as well as the number of connections with water and sewerage customers as four separate outputs, and capital stock and non-capital costs as two inputs. They also adjust the physical outputs by a measure of quality. The paper’s findings suggest that while technical progress improved after privatization, the productivity growth did not. The authors attribute this to the efficiency losses that companies might have undergone to implement the technological advances and their excessive scale that could have contributed negatively on productivity growth.

Another relevant paper is Filippini et al. (2008) that applies a series of panel data models such as Greene’s (2005a,b) true fixed effects model to study the cost efficiency and the economies of scale in the Slovenian water distribution utilities over the 1997-2003 period. Their results point to significant cost inefficiencies in the sector. However, the inefficiency estimates and individual rankings differ across various cost frontier models. While favoring the results obtained from the true fixed effects model, the authors associate this lack of robustness to different models’ assumptions to separate unobserved heterogeneity from inefficiency. Filippini et al. (2008) distinguish between the economies of density through an increase in density without changing the network size and the economies of scale resulting from extending outputs and network size. They report fairly robust results indicating the presence of the economies of scale for small-sized utilities, but significant economies of output density and customer density in a majority of the studied companies.

## 5 Empirical Analysis

With a panel data analysis of a sample of 34 multi-utilities operating over a nine-year period, and also referring to another recent study on the economies of scope and scale, the cost structure of the energy and water distribution networks in

Switzerland has been analyzed. The cost efficiency of the multi-utilities included in the sample has been estimated using elaborate stochastic frontier models that could account for unobserved heterogeneity across different networks and locations. This chapter reports the empirical analysis conducted in this project. Section 5.1 describes the data and the adopted model specification. The econometric specification is presented in Section 5.2. The regression results are presented in Section 5.3. The results with respect to cost-efficiency and scale/scope economies are discussed separately in the following two sections.

## 5.1 Data and model specification

The data used in this study includes financial and technical information from a sample of electricity, gas and water companies that have operated in Switzerland between 1997 and 2005. The data have been mainly collected from the annual reports. Information on the size of the firm's distribution area is from the "Arealstatistik 2002" published by the Federal Statistical Office and the "Preisüberwacher". The original data set covers about 90 companies that have operated in the sample period (1997 to 2005). These companies cover about 42% of total electricity, 67% of total gas and 22% of total water distribution in Switzerland. That sample includes multi-utility firms as well as specialized companies in electricity, gas and water sectors and several double-output utilities, but excludes companies with more than 10% self-generation of total electricity distribution.[39]

Since the focus of this study is on the horizontal integrated multi-utilities, we focused on a subsample of the data used by Farsi, Fetz and Filippini (2007b), including observations from 34 companies. Moreover, as pointed out by Saal and Parker (2006) assuming a similar cost frontier among multi-output companies and specialized utilities is not a realistic assumption and might cause considerable distortion in efficiency estimates and ranking. Because the primary purpose of this analysis is the estimation of cost-efficiency, we did not pool the multi-utilities with specialized companies. This strategy has a shortcoming in estimating the economies of scope which relies on the prediction of costs in specialized companies as well. If such companies are excluded from the sample, the estimation errors might increase, because of the extrapolation

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[39] See Farsi, Fetz and Filippini (2007b) for more details about the data.

required for out-of-sample prediction. However, there are two reasons that we preferred to concentrate on utilities that have positive output values in electricity, gas and water sectors.

First, as we have seen in the previous section, the evidence of the economies of scope has been documented in a previous study (Farsi, Fetz and Filippini, 2007b). Secondly, the natural monopoly hypothesis can be supported by the existence of cost complementarity across different outputs. It should be noted that compared to cost-complementarity, the existence of economies of scope generally entails a weaker condition.[40] Because the economies of scope as estimated from Equation (4) might be driven partly from significant fixed costs that could be implicitly captured in the cost function's estimation, whereas cost complementarity given by Equation (8), is a marginal condition that does not rely on the existence of the fixed costs. As opposed to economies of scope testing complementarity condition can be based on multi-output companies without any zero output. Moreover, excluding zero outputs from the observations allows the utilization of the translog model without resorting to arbitrary approximation or Box-Cox transformation which limits the possibility of using elaborate panel data models.[41]

The final sample used in this analysis consists of an unbalanced panel data set including observations from 34 multi-utilities during the nine-year period spanning from 1997 to 2005. The sample represents about 60% of the integrated multi-utilities in Switzerland. According to our estimates based on the available information (Table 1), the multi-utilities included in the sample cover about half of the national electricity and gas consumption provided by multi-utilities and about a fifth of the water distributed by multi-utilities. Overall, these companies cover approximately 13% of electricity, 38% of gas and 14% of water distribution in the entire country.

The model specification is based on a cost function with three outputs namely, the distributed electricity, gas and water and four input factors that is, labor and capital as well as the electricity and gas inputs. As in Sing (1987) customer density is introduced as a service area characteristic. This variable should capture, at least partially, the cost impact of the heterogeneity of the service area of the companies. In fact, differences in networks and environments influence the production process and

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[40] See Pulley and Humphrey (1993) for more details.

[41] For more details about the problem of zero values in these models see Frasi, Fetz, Filippini (2007c).

therefore the costs. Obviously, the heterogeneity of the service area cannot be summarized into a single variable. However, the available data do not allow for any other environmental or network characteristic that is reasonably independent of the included explanatory variables. Given the risk of multi-collineraity in the translog function, especially in the second-order terms, we preferred to retain a relatively simple specification. Thus, some of these characteristics are inevitably omitted from the cost function specification. As we see later these omitted factors are represented by firm-specific stochastic components in the adopted panel data econometric models.

Assuming that the firm minimizes cost and that the technology is convex, the adopted total cost function can be written as:

$$C = C(q^{(1)}, q^{(2)}, q^{(3)}, r, w^{(0)}, w^{(1)}, w^{(2)}, w^{(3)}, D_t)\,, \tag{19}$$

where $C$ represents total costs; $q^{(1)}$, $q^{(2)}$ and $q^{(3)}$ are respectively the distributed electricity, gas and water during the year, $w^{(0)}, w^{(1)}, w^{(2)}$ and $w^{(3)}$ are respectively the input factor prices for capital and labor services and the purchased electricity and gas; $r$ is the customer density measured by the number of customers divided by the size of the service area measured in square kilometers; and $D_t$ is a vector of year dummies that represent technical change and other year-to-year variations with the first year of the sample (1997) as the omitted category.[42] The technical change is assumed to be neutral with respect to cost minimizing input ratios, that is, it is represented by a cost shift that does not alter the optimal input bundles.

In addition to the above specification, we have tried several other specifications particularly, a model that includes the size of the service area and the number of customers as two output characteristics. However, these analyses indicated certain discrepancy in the signs and statistical significance of some of the coefficients, which can be associated with multicollinearity problems mainly because of the strong correlation between outputs and number of customers and area size. Therefore, we decided to include the ratio of these two variables as the customer density. We recognize the fact that by including the customer density, we cannot distinctively

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[42] In cost function estimations it is common to use a linear trend for technical progress. However, as we will see later our regressions suggest that the time-variation of costs is not linear. These variations can be explained by many unobserved factors (such as changes in collective labor contracts or seasonal composition of the demand) that change uniformly across companies.

estimate the economies of density, a concept used to describe the effect of changes in output with the network characteristics being fixed (Caves et al., 1985; 1984). As opposed to the economies of density, for the scale economies it is usually assumed that, as the production scale increases, all outputs and network characteristics vary at the same proportion (Caves et al., 1981). As shown in Farsi, Filippini and Kuenzle (2007, 2006), the economies of density are generally greater than the economies of scale. Here, the estimation of the economies of scale are based on changes in outputs that involve an extension in spatial characteristics such as area size, but more or less retaining the same customer density. Therefore, by limiting the potential economies of scale to those extensions with constant customer density, the adopted model to some extent, understates the economies of scale.

The variables for the cost function specification were constructed as follows. Total costs ($C$) are calculated as the total expenditures of the energy and water distribution firms in a given year. The outputs $q^{(m)}$ are measured by the total quantity delivered to the customers. The measurement units are GWh for electricity and gas and million cubic meters for water. Input prices are defined as factor expenditures per factor unit. Following Friedlaender and Chiang (1983), the capital price ($w^{(0)}$) is calculated as residual cost (where residual cost is total cost minus labor and electricity and gas purchases) divided by the network length. For the multi-utilities, the prices were weighted by the share of the residual costs in each sector to the total residual costs in all sectors (see also Fraquelli, Piacenza et al. (2004) for this approach). Labor price ($w^{(1)}$) is defined as the ratio of annual labor costs to the total number of employees as full time equivalent. As data on full time equivalent was not available for 40 companies and taking the number of employees including part time workers would underestimate the labor price, a correction was done by taking the mean with the labor price of the companies within the same canton. The electricity and gas prices ($w^{(2)}, w^{(3)}$) are defined as the expenditures of purchasing the input factors divided by the amount purchased (in MWh).

Table 4 provides a descriptive summary of the variables included in the model. All the costs and prices are adjusted for inflation using consumer price index and are measured in year 2000 Swiss Francs (CHF). As can be seen in the table, the sample shows a considerable variation in costs and all three outputs.

**Table 4: Descriptive statistics (237 observations from 34 companies)**

| Variable | | Unit | Minimum | Median | Mean | Maximum |
|---|---|---|---|---|---|---|
| $C$ | Total cost | Mio. CHF | 11.20 | 41.10 | 77.60 | 503.00 |
| $q^{(1)}$ | Electricity distribution | GWh | 38.78 | 126.89 | 293.23 | 2'023.59 |
| $q^{(2)}$ | Gas distribution | GWh | 28.82 | 226.34 | 512.60 | 4'294.20 |
| $q^{(3)}$ | Water distribution | Mio. $m^3$ | 0.78 | 2.45 | 5.28 | 33.35 |
| $r$ | Customer density | Customers/ $km^2$ | 44.35 | 298.33 | 387.57 | 1'554.09 |
| $w^{(0)}$ | Capital price | CHF/ km | 11'853 | 31'167 | 38'385 | 234'796 |
| $w^{(1)}$ | Labor price | CHF/ employee | 77'789 | 106'466 | 107'851 | 146'816 |
| $w^{(2)}$ | Electricity price | CHF/ MWh | 44.6 | 107.4 | 105.9 | 163.5 |
| $w^{(3)}$ | Gas price | CHF/ MWh | 16.6 | 28.4 | 29.3 | 63.2 |

Following Christensen et al. (1973) we use a translog model which is probably the most widely used the functional form in empirical studies of cost and production functions (Caves et al., 1980).[43] This flexible functional form is a local, second-order approximation to any arbitrary cost function. The approximation point is usually set at the sample mean or median. Here the approximation point has been set at the sample median. Compared to the mean, the median values are less affected by outlier values. The translog form does not impose any restrictions on the elasticity of substitution and allows the economies of scale to vary with the output level. In order to avoid the excessive number of parameters we have considered a homothetic cost function in which the interaction terms between input price variables and output variables are excluded.[44] By excluding such interactions we assume that the variations in input prices can influence the extent of the economies of scope and scale only through fixed costs, that is, through a shift in the cost function. In other words, marginal costs particularly cost complementarities and scale elasticities do not depend upon input prices. This is a valid assumption to the extent that scope and scale economies primarily depend on the technological characteristics of the production. In any case insofar as the input prices remain in a reasonable range, the potential changes in the shape of the cost function

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[43] See Griffin et al. (1987) for a discussion on the criteria used for the choice of the functional form.

[44] We evaluated the possibility of applying a non-homothetic translog form. However, the relatively large number of parameters created certain numerical problems in some of the econometric models, especially the true random effects model that requires a simulated likelihood maximization method. This is perhaps related to problems due to the model's over-identification and perhaps multicollinearity as suggested by the lack of significance and counter-intuitive signs for some of the main variables.

appear to be of minor importance compared to other approximations entailed by the fucntional form.

It is generally assumed that the cost function is the result of cost minimization given input prices and output and should therefore satisfy certain properties. Mainly, this function must be non-decreasing, concave, linearly homogeneous in input prices and non-decreasing in output (Cornes, 1992). These conditions can be tested based on the estimation results. However the linear homogeneity in input prices can be imposed by normalization of prices namely, by dividing the costs and all factor prices by one common factor price referred to as numeraire (*cf.* Farsi, Fetz et al., 2007; Featherstone and Moss, 1994; Jara-Diaz, Martinez-Budria et al., 2003). Here we used the capital price as the numeraire.

The translog approximation to the cost function given in Equation (19) can therefore be specified as:

$$\begin{aligned}\ln(\frac{C_{it}}{w_{it}^{(0)}}) = & \sum_{m}\alpha^{m}\ln q_{it}^{(m)} + \alpha^{r}\ln r_{it} + \sum_{k}\beta^{k}\ln\frac{w_{it}^{(k)}}{w_{it}^{(0)}} + \frac{1}{2}\sum_{m}\alpha^{mm}\left(\ln q_{it}^{(m)}\right)^{2} \\ & + \sum_{m(m\neq n)}\sum_{n}\alpha^{mn}\ln q_{it}^{(m)}\ln q_{it}^{(n)} + \frac{1}{2}\alpha^{rr}\left(\ln r_{it}\right)^{2} + \sum_{m}\alpha^{rm}\ln q_{it}^{(m)}\ln r_{it} \\ & + \frac{1}{2}\sum_{k}\beta^{kk}\left(\ln\frac{w_{it}^{(k)}}{w_{it}^{(0)}}\right)^{2} + \sum_{k(k\neq l)}\sum_{l}\beta^{kl}\ln\frac{w_{it}^{(k)}}{w_{it}^{(0)}}\ln\frac{w_{it}^{(l)}}{w_{it}^{(0)}} + \sum_{t}\delta^{t}D_{t} + \alpha^{0} \ ,\end{aligned} \tag{20}$$

where parameters $\alpha^{m},\beta^{k},\alpha^{mn},\beta^{kl},\delta^{t}$ and $\alpha^{0}$ ($m,n,k,l=1,2,3;t=1998,...,2005$) are the regression coefficients to be estimated; and all second-order parameters $\alpha^{nm}$ and $\beta^{kl}$, satisfy the symmetry conditions ($\beta^{kl}=\beta^{lk};\alpha^{mn}=\alpha^{nm}$).

## 5.2 Econometric methods

The general econometric specification of the cost function in (20) can be written as:

$$
\begin{aligned}
\ln\left(\frac{C_{it}}{w_{it}^{(0)}}\right) = & \sum\nolimits_{m} \alpha^{m} \ln q_{it}^{(m)} + \alpha^{r} \ln r_{it} + \sum\nolimits_{k} \beta^{k} \ln \frac{w_{it}^{(k)}}{w_{it}^{(0)}} + \frac{1}{2} \sum\nolimits_{m} \alpha^{mm} \left(\ln q_{it}^{(m)}\right)^{2} \\
& + \sum\nolimits_{m(m \neq n)} \sum\nolimits_{n} \alpha^{mn} \ln q_{it}^{(m)} \ln q_{it}^{(n)} + \frac{1}{2} \alpha^{rr} \left(\ln r_{it}\right)^{2} + \sum\nolimits_{m} \alpha^{rm} \ln q_{it}^{(m)} \ln r_{it} \\
& + \frac{1}{2} \sum\nolimits_{k} \beta^{kk} \left(\ln \frac{w_{it}^{(k)}}{w_{it}^{(0)}}\right)^{2} + \sum\nolimits_{k(k \neq l)} \sum\nolimits_{l} \beta^{kl} \ln \frac{w_{it}^{(k)}}{w_{it}^{(0)}} \ln \frac{w_{it}^{(l)}}{w_{it}^{(0)}} \\
& + \sum\nolimits_{t} \delta^{t} D_{t} + \alpha^{0} + \alpha_{i} + u_{it} + v_{it} \ ,
\end{aligned}
\tag{21}
$$

where subscripts *i* and *t* denote the company and year respectively; $\alpha_i$ is a firm-specific effect; $u_{it}$ is an asymmetric stochastic term that captures the time-variant inefficiency and $v_{it}$ is a symmetric term representing random noise and statistical errors.

We have considered four variations of the above model. These models are summarized in Table 5. The first model (Model *I*) is a random effects model in line with Schmidt and Sickles (1984). The model is estimated using the Generalized Least Squares (GLS) method. The specification includes a firm-specific random effect $\alpha_i$, and a random noise term $v_{it}$, which are both assumed to be identically and independently distributed (*iid*) with any arbitrary distribution. In this model, the inefficiency is assumed to be constant over time, namely the term $u_{it}$ in Equation (21) is set equal to zero. A given company *i*'s inefficiency is considered as the difference between its estimated random effect $\alpha_i$ and that of the firm with the "best performance" namely, the minimum estimated random effect min($\alpha_i$).

The GLS model benefits from certain robustness in that no specific distribution assumption is imposed, except for the usual assumption that the random terms are uncorrelated with the explanatory variables. However, the very construction of this model implies that companies are compared to a single, fully efficient firm that has the lowest observed costs after adjusting for explanatory variables and allowing for random noise. This could be an unrealistic assumption that only one company is completely efficient. Moreover, there is always a probability of wrong identification of a single "best" company because of some special unobserved factor or some measurement error. In which case the efficiency estimates will be completely distorted. The advantage of imposing a distribution assumption on efficiency attenuates at least partly such seriously misleading outcomes. A commonly used distribution in the literature is the half-normal distribution which is obtained by a zero-mean normal distribution truncated at zero. This distribution assumption that dates back to the original frontier models (Aigner et al., 1977; Meeusen and van der Broek, 1997), implies that full efficiency is the most frequent outcome located at the mode of the distribution.

**Table 5: Econometric specifications of the stochastic cost frontier**

| Stochastic term | *Model I*<br>**GLS**<br>**(Schmidt-Sickles)** | *Model II*<br>**ML**<br>**(Pitt-Lee)** | *Model II*<br>**ML**<br>**(Battese-Coelli)** | *Model IV*<br>**True RE**<br>**(Greene)** |
|---|---|---|---|---|
| Firm-specific effect $\alpha_i$ | $\alpha_i \sim iid\ (0, \sigma_\alpha^2)$ | $\alpha_i \sim \mathrm{N}^+(0, \sigma_\alpha^2)$ | 0 | $\alpha_i \sim \mathrm{N}(0, \sigma_\alpha^2)$ |
| Time-varying inefficiency $u_{it}$ | 0 | 0 | $u_{it} =$<br>$u_i \exp\{-\eta(t\text{-}T)\}$<br>$u_i \sim \mathrm{N}^+(0, \sigma_u^2)$ | $u_{it} \sim \mathrm{N}^+(0, \sigma_u^2)$ |
| Random noise $v_{it}$ | $v_{it} \sim iid\ (0, \sigma_v^2)$ | $v_{it} \sim \mathrm{N}\ (0, \sigma_v^2)$ | $v_{it} \sim \mathrm{N}(0, \sigma_v^2)$ | $v_{it} \sim \mathrm{N}(0, \sigma_v^2)$ |
| Inefficiency estimate | $\hat{\alpha}_i - \min\{\hat{\alpha}_i\}$ | $\mathrm{E}\left[\alpha_i \middle| \hat{\omega}_{i1}, \hat{\omega}_{i2}, \ldots\right]$<br>with $\omega_{it} = \alpha_i + v_{it}$ | $\mathrm{E}\left[u_{it} \middle| \hat{\varepsilon}_{it}\right]$<br>with $\varepsilon_{it} = u_{it} + v_{it}$ | $\mathrm{E}\left[u_{it} \middle| \hat{r}_{it}\right]$<br>with<br>$r_{it} = \alpha_i + u_{it} + v_{it}$ |

The half-normal distribution not only provides a relatively solid benchmark performance observed in a relatively large number of cases, it is also more consistent with the economic theory. In fact the half-normal distribution implies that higher levels of inefficiency have lower incidence. This is aligned with the theory that predicts the prevalence of rational and cost-minimizing behavior and considers the non-optimal performance as sporadic and rare outcomes. Following this assumption in the other three models, we assume a half-normal distribution for inefficiency.

Model *II* is a random effects model proposed by Pitt and Lee (1981). Similar to the first model, the efficiency is assumed to be constant over time ($u_{it}$=0). As opposed to Model *I* that does not impose any distribution, here the stochastic terms are assumed to follow a composite normal-half-normal distribution: The firm-specific effect $\alpha_i$ that represents (time-invariant) inefficiency, follows a half-normal distribution, and the random noise $v_{it}$ is simply a normal variable with zero mean. This model is estimated using the maximum likelihood method. In line with Kumbhakar and Lovell (2000) we will refer to this model as the maximum likelihood (ML) model. The firm's inefficiency is estimated using the conditional mean of the inefficiency term proposed by Jondrow et al. (1982),[45] that is: $\mathrm{E}\left[\alpha_i \left|\hat{\omega}_{i1}, \hat{\omega}_{i2}, ..., \hat{\omega}_{iT}\right.\right] = \mathrm{E}\left[\alpha_i \left|\bar{\omega}_i\right.\right]$, where hat symbol ^ is used to indicate the post-estimation predicted value; $\omega_{it} = \alpha_i + v_{it}$; and $\bar{\omega}_i = \frac{1}{T}\sum_{t=1}^{T} \hat{\omega}_{it}$.

The assumption of the firm's inefficiency being constant over time can be relaxed by assuming a parametric form for such variation. A commonly used functional form is the exponential decay function proposed by Battese and Coelli (1992). Model *III* is based on one of the specifications proposed by those authors. In this model the inefficiency is defined as $u_{it}=u_i\exp\{-\eta(t-T)\}$, where $u_i$ is a firm-specific stochastic term, $T$ is the end period and $\eta$ is a positive constant to be estimated. The adopted functional form implies that a given company $i$ starts with an initial level of inefficiency of $u_{i0}=u_i\exp(\eta T)$, that declines over time with an exponential rate of $\exp(-\eta)$ per period, reaching $u_{iT}=u_i$ at the end of the sample period.[46] This specification, while recognizing individual differences in efficiency, assumes a similar improvement rate for all companies. The firm-specific heterogeneity term $\alpha_i$ in Equation (21), is set equal to zero. Battese and Coelli (1992, 1995) have proposed variations of this model with different distributions for $u_i$, including truncated normal distribution. In this study we assume a half-normal distribution. This model is also estimated using the maximum likelihood method. The firm's inefficiency is estimated using the conditional mean of the inefficiency term, namely: $\mathrm{E}\left[u_{it} \left|\varepsilon_{it}\right.\right] = \mathrm{E}\left[u_i \left|\hat{\varepsilon}_{i1}, \hat{\varepsilon}_{i2}, ..., \hat{\varepsilon}_{iT}\right.\right]\exp\{-\eta(t-T)\}$, where the hat symbol ^ indicates the post-estimation value and $\varepsilon_{it}= u_{it}+ v_{it}$.

In both models *I* and *II*, it is assumed that all the unobserved differences across firms that do not vary over time are related to inefficiency. Model *III* relaxes the time-invariance assumption by imposing a deterministic form of evolution that is uniform among all companies. In all three models, all the unobserved differences that cannot be captured by the random noise ($v_{it}$) are assumed to be due to inefficiency. As we have seen in the previous chapter this could be a restrictive assumption in network industries especially in multi-utilities, which might entail a considerable cost variation through

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[45] See also Greene (2005a).

[46] Note that a more general notation $T_i$ is usually used for the end of sample period ($T$) that can be specific to company. Here we dropped the subscript for simplicity.

unobserved factors that vary from one network to another but are more or less constant over time and cannot be changed by the management. For example, the complexity of the distribution network determined by the morphology of the territory. This means that in these cases we are confounding inefficiency with unobserved heterogeneity.

Model *IV* allows for a separate stochastic term that captures the time-invariant unobserved heterogeneity. This model is the 'true random effects' frontier specification proposed by Greene (2005a,b), which extends the original frontier model (Aigner et al., 1977) in a panel data framework with random effects. In addition to the normal-half-normal composite term, a firm-specific stochastic term. The stochastic components $\alpha_i$, $u_{it}$ and $v_{it}$ respectively represent the firm-specific random effect, inefficiency term and random noise: $\alpha_i \sim N(0,\sigma_\alpha^2)$, $v_{it} \sim N(0,\sigma_v^2)$ and $u_{it} \sim N^+(0,\sigma_u^2)$. This model is estimated using Simulated Maximum Likelihood (SML) method. We use quasi-random Halton draws to minimize the potential sensitivity of the results to simulation process. Number of draws has been fixed to 1000. Our sensitivity analysis using several options suggested that the estimation results are not sensitive when the number of draws is higher than a few hundred. The inefficiency is estimated using the (simulated) conditional mean of the inefficiency term ($u_{it}$) given by $\mathrm{E}\left[u_{it}|\hat{r}_{it}\right]$, where $r_{it}=\alpha_i+u_{it}+v_{it}$ is the regression residual. The above conditional expectation is also calculated by Monte Carlo simulations.[47]

With two heterogeneity terms, Model *IV* is expected to provide a better distinction between inefficiency and other unexplained variations. This advantage is especially important in network industries, in which a significant part of unobserved differences is due to time-invariant factors. All the adopted models assume that the stochastic terms namely, cost-efficiency and unobserved heterogeneity are independent from each other and are both uncorrelated with the explanatory variables included in the model. There are several methods to relax these assumptions. For instance the correlation between firm-specific effects and explanatory variables can be allowed by Mundlak's specification (Farsi, Filippini and Greene, 2005; Farsi, Filippini and Kuenzle; 2005) or the impact of explanatory variables on efficiency can be modeled by specifying the truncation point of the normal distribution as a function of observed

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[47] See Greene (2005b) for more details. A general discussion of the SML estimation method is also provided by Greene (2007).

factors (Kumbhakar et al., 1991; Battese and Coelli, 1995) or as a general functional form (Wang and Schmidt, 2002). However, such elaborations can only be achieved through more complicated and often arbitrary assumptions that might compromise the clarity of the original assumptions and make the interpretations more difficult. Moreover, including explanatory variables in several forms in the model specification could cause over-identification and multi-collinearity. Such problems could bias the estimated coefficients or lower their accuracy, and eventually cause misleading estimates of the economies of scope and scale as well as cost-efficiency. Finally, most of these “refinements” cannot be combined with the true random effects model. The latter model provides an already rich structure of the stochastic terms and should provide a realistic picture of efficiencies in the case of multi-utilities.

## 5.3 Results

Table 6 lists the regression results of the cost frontier analysis, using the four alternative models as presented in Equation (21) and Table 5. The estimated coefficients of the first-order terms generally have the expected signs and are statistically significant across all models. Given that all the variables except the dummy variables are in logarithmic form, these coefficients can be directly interpreted as elasticities. The coefficients of first-order output variables represent the cost elasticities with respect to the corresponding outputs at the sample median. These coefficients indicate that the marginal costs of electricity distribution are considerably higher than those of gas and the latter are considerably higher than the costs of water distribution.

## Table 6: Estimation results

| | *Model I*<br>**GLS (Schmidt-Sickles)** | *Model II*<br>**ML (Pitt-Lee)** | *Model III*<br>**ML (Battese-Coelli)** | *Model IV*<br>**True RE (Greene)** |
|---|---|---|---|---|
| $\alpha^1$ (Electricity output) | 0.505 ** (.053) | 0.460 ** (.069) | 0.418 ** (.063) | 0.527 ** (.020) |
| $\alpha^2$ (Gas output) | 0.317 ** (.032) | 0.298 ** (.041) | 0.245 ** (.045) | 0.258 ** (.012) |
| $\alpha^3$ (Water output) | 0.092 ** (.039) | 0.178 ** (.053) | 0.212 ** (.047) | 0.146 ** (.015) |
| $\alpha^r$ (Customer density | 0.064 ** (.027) | 0.043 (.038) | 0.026 (.037) | 0.007 (.009) |
| $\beta^1$ (Labor price) | 0.242 ** (.057) | 0.229 ** (.054) | 0.236 ** (.058) | 0.201 ** (.027) |
| $\beta^2$ (Electricity price | 0.326 ** (.059) | 0.317 ** (.051) | 0.333 ** (.052) | 0.370 ** (.033) |
| $\beta^3$ (Gas price) | 0.234 ** (.043) | 0.243 ** (.039) | 0.223 ** (.038) | 0.215 ** (.024) |
| $\alpha^{11}$ | 0.646 ** (.197) | 0.368 * (.221) | 0.218 (.193) | 0.231 ** (.086) |
| $\alpha^{22}$ | 0.234 ** (.055) | 0.154 * (.080) | 0.067 (.071) | 0.093 ** (.023) |
| $\alpha^{33}$ | 0.287 ** (.141) | 0.042 (.176) | 0.186 (.167) | 0.089 * (.052) |
| $\alpha^{rr}$ | 0.019 (.061) | -0.063 (.095) | -0.233 ** (.089) | -0.146 ** (.026) |
| $\alpha^{12}$ | -0.273 ** (.086) | -0.182 * (.105) | -0.048 (.091) | -0.099 ** (.041) |
| $\alpha^{13}$ | -0.327 ** (.149) | -0.124 (.158) | -0.214 (.148) | -0.133 ** (.058) |
| $\alpha^{1r}$ | -0.215 ** (.070) | -0.220 ** (.097) | 0.074 (.104) | -0.119 ** (.030) |
| $\alpha^{23}$ | -0.002 (.059) | 0.049 (.072) | 0.051 (.068) | 0.037 (.026) |
| $\alpha^{2r}$ | 0.123 ** (.059) | -0.002 (.079) | -0.147 * (.080) | -0.065 ** (.027) |
| $\alpha^{3r}$ | 0.085 * (.050) | 0.120 (.081) | 0.104 (.076) | 0.122 ** (.020) |
| $\beta^{11}$ | 0.419 (.279) | -0.031 (.270) | 0.051 (.248) | 0.384 ** (.121) |
| $\beta^{22}$ | 0.695 ** (.205) | 0.524 ** (.172) | 0.565 ** (.167) | 0.758 ** (.110) |
| $\beta^{33}$ | -0.243 ** (.120) | -0.291 ** (.106) | -0.278 ** (.110) | -0.217 ** (.108) |
| $\beta^{12}$ | -0.701 ** (.221) | -0.419 ** (.197) | -0.460 ** (.189) | -0.724 ** (.102) |
| $\beta^{13}$ | 0.294 ** (.147) | 0.422 ** (.137) | 0.386 ** (.136) | 0.351 ** (.096) |
| $\beta^{23}$ | -0.096 (.135) | -0.154 (.118) | -0.156 (.115) | -0.136 (.092) |
| $\delta^{1998}$ | -0.004 (.019) | -0.005 (.015) | 0.011 (.016) | -0.005 (.032) |
| $\delta^{1999}$ | -0.003 (.020) | -0.002 (.016) | 0.028 (.019) | -0.005 (.021) |
| $\delta^{2000}$ | -0.015 (.021) | -0.013 (.018) | 0.035 (.024) | -0.006 (.025) |
| $\delta^{2001}$ | -0.014 (.023) | -0.015 (.020) | 0.049 * (.029) | -0.012 (.022) |
| $\delta^{2002}$ | -0.037 * (.021) | -0.036 ** (.018) | 0.036 (.030) | -0.040 * (.022) |
| $\delta^{2003}$ | -0.041 * (.021) | -0.044 ** (.018) | 0.039 (.033) | -0.039 * (.023) |
| $\delta^{2004}$ | -0.064 ** (.023) | -0.069 ** (.020) | 0.032 (.038) | -0.067 ** (.024) |
| $\delta^{2005}$ | -0.059 ** (.026) | -0.065 ** (.023) | 0.046 (.043) | -0.073 ** (.022) |
| $\alpha^0$ | 7.164 ** (.029) | 6.989 ** (.032) | 6.917 ** (.046) | 7.120 ** (.019) |
| $\sigma_\alpha$ | .053 | 0.217 ** (.034) | | 0.114 ** (.005) |
| $\sigma_u$ | | | 0.210 ** (.039) | 0.081 ** (.030) |
| $\sigma_v$ | .054 | 0.054 ** (.003) | 0.052 ** (.003) | 0.024 ** (.006) |
| $\eta$ | | | 0.048 ** (.015) | |
| logL | Not Applicable ($R^2$=0.982) | 296.785 | 299.355 | 303.786 |

** and * refer to 5% and 10% significance levels respectively. Standard errors are given in parentheses.

Approximately, the results suggest that by adding electricity output by 10 percent, the total costs will increase by about 5 percent on average, but the same relative increase in other outputs will raise the company's total costs by about 2.5 to 3 percent for gas and only about 0.9 to 2 percent for water output. These predictions vary slightly across different models. Many of the second-order terms are also statistically significant, implying that the assumption of constant elasticities is unrealistic. The coefficients of the squared output terms ($\alpha^{11}$, $\alpha^{22}$, $\alpha^{33}$) are positive and mostly significant across all models. This suggests that a marginal increase in a given output increases the cost elasticity of that output. Therefore, as expected, the (product-specific) economies of scale are decreasing in output.

As we see in Table 6 the output cross-interaction terms ($\alpha^{12}$, $\alpha^{13}$, $\alpha^{23}$) are mostly negative across the models. In particular, the cross effect between electricity and other two outputs (gas and water), is statistically significant. This suggests that the multi-utilities with higher electricity output have a relatively low marginal cost for distributing water and gas. This cost complementarity also applies to companies with high gas or water output, which according to the estimation results, have lower marginal cost fro electricity output. The results show however that the cost complementarity between gas and water outputs (as shown by coefficient $\alpha^{23}$) is not statistically significant. If we interpret this is a zero effect, this result suggests that the marginal cost of distributing gas (water) is not related to the volume of water (gas) output. This is a weak form of cost complementarity, implying that the marginal costs of one output will not increase in the amount of the other output.

As for the effect of customer density, the results show that the first order term is positive but statistically insignificant in most models. This suggests that the effect at the median company is probably not important. However, the mostly negative coefficient of the square term ($\alpha^{rr}$) suggests that higher densities could have a decreasing effect on costs. At first impression, this can be considered as counter-intuitive because increasing the customer density may be economical in low-density areas, but could create extra costs in congested areas. However, the statistically significant interaction terms between customer density and outputs, suggest that the density has a strongly non-linear effect depending on the output combination across the three services.

For instance the interaction term with electricity output ($\alpha^{1r}$) is mostly negative and significant, suggesting that the marginal cost of electricity output is lower in networks with higher customer density. This cannot be said for gas and water outputs. Especially the corresponding interaction term for water distribution ($\alpha^{3r}$) is mostly on the positive side, suggesting that an increase in customer density will increase the marginal cost of water distribution. These results can be related to different costs of network connection for various outputs, and also different amount of extra cables and pipes required for the provision of greater volumes of electricity, gas and water, depending on the actual customer density. For instance, in a dense and crowded area providing more electricity might be handled easier than a considerable increase in gas and water output. Moreover, connection of new customers to electricity networks is probably less costly than that of water and gas distribution networks.

The coefficients of the first-order terms of input prices are an indicator of the share of each factor price at the sample median.[48] Based on the regression results, the shares of labor, electricity and gas inputs respectively amount to about 22, 33 and 23 percent of the total costs. These numbers are comparable to the sample mean of the observed factor shares which is 12, 35 and 17 percent of the company's total costs, respectively for labor, electricity and gas inputs. As we see the share of electricity and gas expenses are quite close the average observed values. The remaining costs have been considered as 'capital' costs that are 36 percent on average, but about 22 percent from the regression results. Therefore in the model, the share of labor costs is overstated compared to that of the residual capital costs.

We explored if the estimated cost functions satisfy the theoretical properties implied by cost-minimization. As shown by the positive coefficients of the first order terms (Table 6), all the estimated cost functions are non-decreasing in output and input prices at the approximation point (sample median). However, our calculations showed that the Hessian matrix defined by the second derivatives of the translog cost function with respect to log of input prices, is not negative semi-definite. The violation of this

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[48] Note that in translog form, any statement about sample points other than the approximation point (here, sample median), should consider the second-order terms in addition to the main effects.

necessary condition[49] for concavity might be considered as an indication that the concavity in input prices is not satisfied. This result can be explained by the fact that the multi-utilities are probably not as sensitive to price changes as the textbook economic theory might predict. Theoretically the companies are expected to substitute labor with capital or capital with energy in response to changes in the relative prices. However, in practice these substitutions are not feasible in many cases. For instance if the relative price of electricity increases compared to gas, the companies cannot substitute electricity input with gas input, because these inputs are mainly determined by the demand side.

In any case, even if we consider the lack of concavity in input prices as an indication that the companies do not fully minimize their costs the estimated cost functions can be useful to study the marginal effects of different factors on costs and also to compare the companies' performance. In such cases, as pointed out by Bös (1986) and Breyer (1987), functions based on cost optimization can still be used as 'behavioral' cost functions and can be helpful in studying the firms' behavior. Moreover, we should keep in mind that we are estimating a cost frontier function, which allow the possibility that some companies do not minimize their costs.

## 5.4 Cost efficiency

The estimates of inefficiency scores obtained from the four models are summarized in Table 7. As expected, compared to all other models, the True RE model's estimates provide generally lower inefficiency. According to this model the multi-utilities have on average about 6 percent excess costs compared to the fully efficient production whereas the other models predict from 18 to 21 percent excess cost on average. The median inefficiency for the True RE model is about 5%, while being about 20% for all other models. It should be noted that the True RE model's estimates do not include the persistent inefficiencies that might remain more or less constant over time. To the extent that there are certain sources of inefficiency that result in time-invariant excess costs, the estimates of the True RE model should provide a reasonable lower bound for the companies' inefficiency. On the other hand, in all the three other

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[49] As pointed out by Diewert and Wales (1987), even with a negative semi-definite Hessian matrix for the translog cost function, the costs might be concave with respect to input prices. So applying such a condition on the coefficient matrix of a translog cost function is too strong for concavity in input prices.

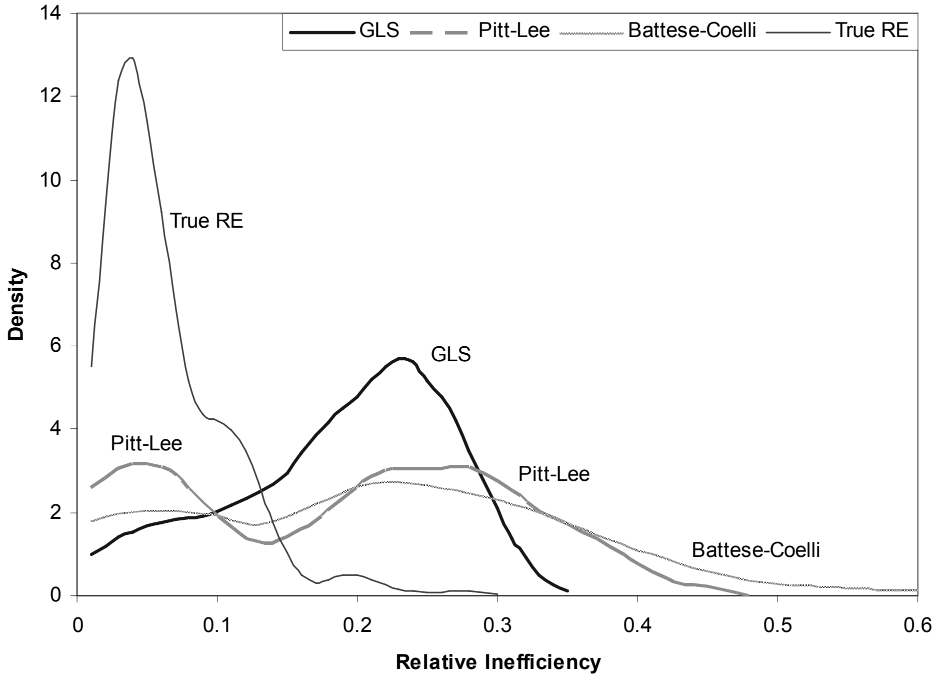
models, it is assumed that all the time-invariant cost differences due to exogenous heterogeneity are accounted for by the observed explanatory variables included in the model, and whatever remains can be interpreted as inefficiency. Therefore, the overall estimates of inefficiency obtained from these models can be considered as a kind of upper bound for the actual level of inefficiency in the sector.

**Table 7: Descriptive summary of inefficiency estimates**

| | *Model I*<br>**GLS (Schmidt-Sickles)** | *Model II*<br>**ML (Pitt-Lee)** | *Model III*<br>**ML (Battese-Coelli)** | *Model IV*<br>**True RE (Greene)** |
|---|---|---|---|---|
| Mean | 0.184 | 0.183 | 0.216 | 0.063 |
| Std. Deviation | 0.079 | 0.119 | 0.143 | 0.043 |
| Minimum | 0.000 | 0.013 | 0.014 | 0.010 |
| 1st Quartile | 0.144 | 0.060 | 0.075 | 0.031 |
| Median | 0.202 | 0.207 | 0.214 | 0.050 |
| 3rd Quartile | 0.251 | 0.275 | 0.303 | 0.082 |
| Maximum | 0.303 | 0.401 | 0.699 | 0.277 |

The distribution of the inefficiency estimates in the sample is depicted in Figure 5. The distribution densities have been smoothed using Kernel density method. As seen in the figure the extent of inefficiency in the True RE model is considerably narrower than in other models. Moreover, the distribution of the GLS estimates suggest a negative skewness, which contradicts the usual assumption of positive skewness in cost-inefficiencies. Moreover, both Models *II* and *III* indicate a tendency toward a bimodal distribution, which goes against the underlying half-normal distribution assumption in these models. These peculiar patterns might be indicative that the econometric specification of the error term in the first three models could be insufficient to capture the inefficiencies in a coherent way. This can be explained by unobserved cost differences that are not due to inefficiency but to other external factors.

**Figure 5: Distribution of inefficiency estimates**



In order to explore if the efficiency estimates provide a consistent ranking pattern across different modes, we studied the correlation coefficients between these estimates. Table 8 provides the correlation matrix of inefficiency scores across the four models. The results suggest a high positive correlation among the first three models. There is however a relatively low correlation between each one of these models and the True RE model. The Spearman rank correlation matrix shows slightly lower correlation in general but confirms the above pattern namely low correlation between Model *IV* and the other three models, and high correlation among the latter models. This result suggests that even if we are only interested in efficiency ranking rather than the numerical level of inefficiency, using the inadequate model can give a misleading ordering of individual companies.

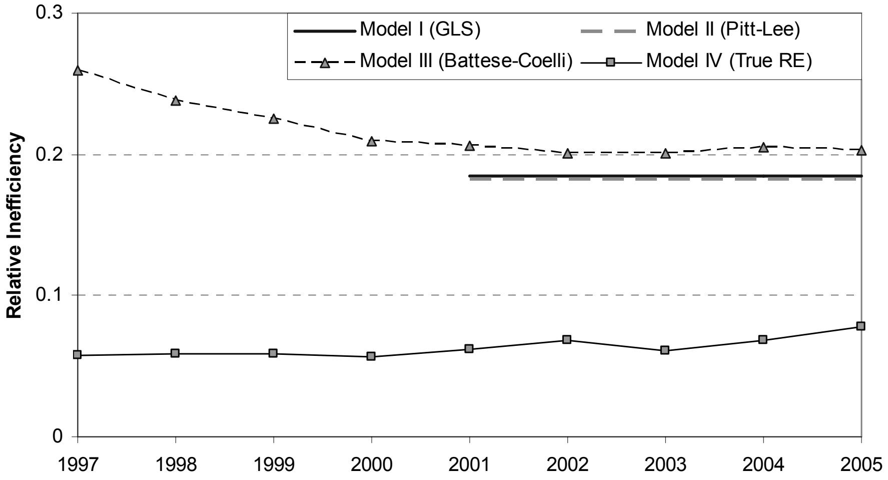
**Table 8: Pearson correlation matrix between inefficiency estimates**

| | *Model I*<br>**GLS (Schmidt-Sickles)** | *Model II*<br>**ML (Pitt-Lee)** | *Model III*<br>**ML (Battese-Coelli)** | *Model IV*<br>**True RE (Greene)** |
|---|---|---|---|---|
| *I* | 1 | 0.863** | 0.715** | 0.124* |
| *II* | | 1 | 0.793** | 0.140** |
| *III* | | | 1 | 0.128** |

** and * refer to 5% and 10% significance levels respectively.

The variation of the sector's average estimated inefficiency over time is depicted in Figure 6: The evolution of average inefficiency in the sector. In Models *I* and *II* the efficiency is assumed to be constant over time, whereas Model *III* assumes a exponential decrease with time for all companies. According to the latter model, the sector's inefficiency has decreased from 26% in 1997 to about 20% in 2005. This amounts to a statistically significant improvement of 0.7 percentage points per year in the sector's average inefficiency. However, this has not been confirmed by the True RE model which suggests a slight increase in inefficiency from about 6% in 1997 to about 8% in 2005. This contrasting result could be explained by the fact that Model *III* by construction assumes a monotonous rise or fall in efficiency that is implicit in the underlying exponential function described in Table 5. Model *IV* on the other hand, has an important advantage in that it does not assume any deterministic form for the evolution of efficiency. The variation of efficiency for individual firms will be discussed later.

## Figure 6: The evolution of average inefficiency in the sector

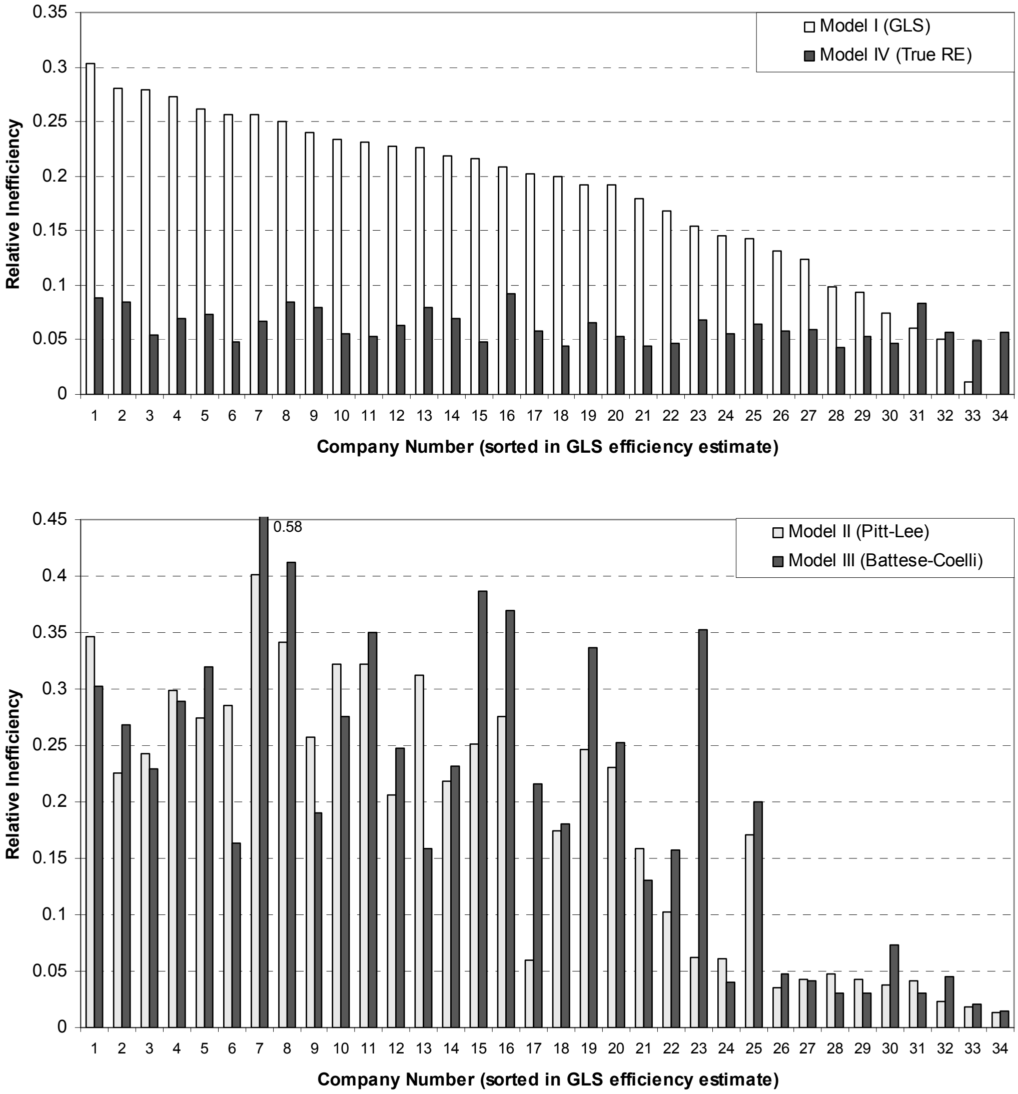


Comparing the efficiency scores at the firm level can be helpful for understanding the differences across models and eventually adopting the "right" specification. Figure 7 illustrates the average inefficiency score for the 34 included firms in the study. The upper plot compares GLS and True RE models, whereas the lower panel depicts the scores resulted from the two other models. The companies are ordered in terms of their efficiency estimates based on Model *I* with the fully efficient company at the right side. Assuming that the individual effects in the GLS model provide a good picture of unobserved firm-specific factors that are constant over time, and also assuming that the True RE model can best describe the actual inefficiencies, which should be time-variant, the upper panel of the figure can be used to compare the two effects for each firm. As it can be seen, in a large majority of the firms, the cost effect of heterogeneity is more than twice as that of inefficiency. Noting that the above assumptions are perfectly plausible, this implies that an inadequate model might lead to totally misleading results regarding both overall efficiency and at the firm-level.

Another observation from Figure 7 is the fact that except a few companies all Models *I*, *II* and *III* provide comparable efficiency levels and ranks. In particular, these models are useful to rank the individual firms in terms of costs in excess of "legitimate" expenses due to observed output characteristics and input prices. As shown in this figure and through their strong correlation seen earlier, these three models can be used to identify in reasonably robust way, the individual companies that are excessively and persistently more costly than other firms. In contrast the efficiency estimates from True

RE model are relatively small, and practically cannot distinguish the individual firms based on their average performance over the sample period. However, as we see later this model is probably more useful when the variations over time are of interest.

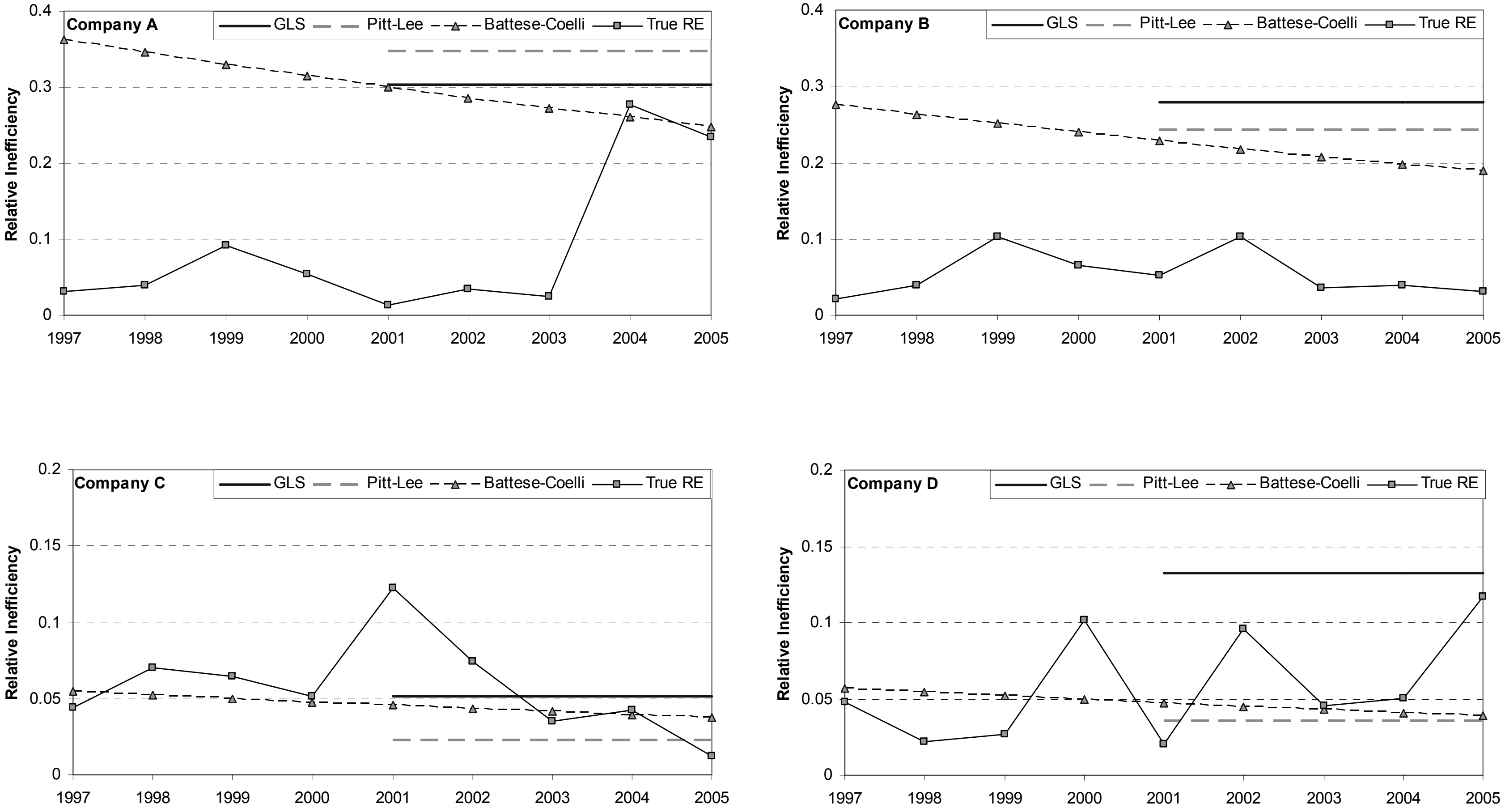
**Figure 7: Distribution of inefficiency scores for individual firms**



The diagrams provided in Figure 8 show the evolution of efficiency in four companies in the sample. The first company (company A) has the poorest efficiency based on Model I and based on the other models respectively ranked 33, 26 and 33 (among the 34 companies included in the sample). As shown in the upper left diagram in Figure 8, Model *III* suggests that this company has significantly improved its performance through a decrease of about 11 percentage points in inefficiency. However, the True RE model indicates that this company has been quite efficient until 2003, but showed a sudden increase in inefficiency in 2004.

Company B (the upper right diagram in Figure 8) is also a rather inefficient company based on Models *I* to *III* that rank it as 32nd, 21st and 19th respectively. This company has an above average rank of 12th based on Model *IV*. As shown in the figure, the latter model suggests that this company had only two years of weak performance with an inefficiency score of about 10% and in all other years, the company has been relatively efficient. The other two companies (C and D) shown in the lower diagrams are chosen from the firms that showed a good performance according to Models *I* to *III*. Especially Company C has ranked 3rd according to the first two models and 8th and 15th respectively for Models *III* and *IV*. As shown in the figure, the True RE model suggests that this company has been improving substantially since 2002, a process that is not detected in other models. Finally, Company D is an interesting example that is ranked, 9th, 4th, 9th and 18th according to Models *I* to *IV* respectively. According to the first three models, this company has a good performance, but the True RE model detects a peculiar pattern of efficiency fluctuation in this company. In particular, this model suggests a deterioration of efficiency performance in the last two years of the sample period, a performance that the regulator might be interested to identify.

**Figure 8: The evolution of efficiency in four individual companies**



## 5.5 Natural monopoly

Table 9 provides the estimates of economies of scale at several representative sample points. These estimates are obtained by the application of Equation (3) to the presented in Equation (21). The representative sample points are based on the sample quartiles in output and customer density. The first observation on this table is that all models point to the existence of the economies of scale virtually at all output levels. The coefficient of the global economies of scale at the sample median (translog approximation point) varies from 1.07 to 1.14 depending on the model. This implies significant unexploited economies of scale in the majority of the multi-utilities included in the data. In particular, the models suggest that at a typical multi-utility, increasing outputs by say 10% will result in a proportional decrease of average costs by about 0.7 to 1.4 percent.

**Table 9: Estimates of economies of scale at representative sample points**

| | *Model I*<br>**GLS (Schmidt-Sickles)** | | | *Model II*<br>**ML (Pitt-Lee)** | | | *Model III*<br>**ML (Battese-Coelli)** | | | *Model IV*<br>**True RE (Greene)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Output Quartile | Density Quartile<br>1st | 2nd | 3rd | Density Quartile<br>1st | 2nd | 3rd | Density Quartile<br>1st | 2nd | 3rd | Density Quartile<br>1st | 2nd | 3rd |
| 1st | 1.06 | 1.06 | 1.07 | 1.02 | 1.09 | 1.17 | 1.22 | 1.20 | 1.17 | 1.05 | 1.10 | 1.14 |
| 2nd | 1.09 | 1.09 | 1.10 | 1.00 | 1.07 | 1.14 | 1.17 | 1.14 | 1.12 | 1.03 | 1.07 | 1.12 |
| 3rd | 1.15 | 1.15 | 1.16 | 0.99 | 1.05 | 1.12 | 1.11 | 1.09 | 1.06 | 1.02 | 1.06 | 1.10 |

- The 1st, 2nd and 3rd output quartiles are respectively specified as follows: $\{q^{(1)}, q^{(2)}, q^{(3)}\}$= {99, 118, 1.9}; {127, 226, 2.4}; {226, 471, 6.4}. The quartiles of customer density are respectively: 165, 298 and 546. The measurement units are the same as those described in Table 4.

The results in Table 9 also suggest that the amount of unexploited economies of scale decrease with the firm's global size. This pattern can be observed in all models except the GLS model. The latter model suggests a counter-intuitive pattern in which the scale economies increase with output. Another observation is the fact that the economies of scale vary with the company's customer density. While the models are slightly different in this respect, a dominant pattern can be observed. The companies with higher customer density can achieve relatively higher savings by extending. It should be noted that in all the above statements about the economies of scale, it is implicitly assumed that in the process of extension the customer density remains constant.

The existence of global economies of scale suggests that the ray average costs are strictly decreasing. Hence, one of the conditions of natural monopoly is satisfied. The second requirement for natural monopoly is related to trans-ray convexity, which as we saw in Chapter 2, can be verified using the second-order derivatives of the cost function with respect to outputs. As shown in Table 6, the output square terms ($\alpha^{11}$, $\alpha^{22}$, $\alpha^{33}$) are positive and statistically significant across all models, indicating that the second-order own derivatives are positive. Table 6 also shows that the output cross-interaction terms ($\alpha^{12}$, $\alpha^{13}$, $\alpha^{23}$) are mostly negative across the models. Interestingly in all the cases that the coefficient has a positive sign, the effect is statistically insignificant. Therefore, the regression results verify that all the second-order cross derivatives in tranlog function are negative or at least non-positive. This is an indicative evidence of convexity, which should however be checked without logarithmic transformation, namely using the requirements given in Equation (10).

We have checked the conditions of convexity in translog form at the approximation point (here the sample median) as in Equation (10). The results differ across the models. However, the evidence of pair-wise cost-complementarity remains satisfied in virtually all models at least for some pairs of the outputs. Overall, the above results indicate the existence of weak cost-complementarity and strong ray economies of scale. In line with Gordon et al. (2003) we consider this as a suggestive evidence of subadditivity (natural monopoly) for all practical purposes.

In order to further explore the question of natural monopoly we also estimate the product-specific economies of scale as defined in Equation (7). The translog function estimated in this study does not allow a direct estimation of incremental costs as in Equation (6). Such quantities are identified more easily from a quadratic cost function such as the one estimated by Farsi, Fetz and Filippini (2007b). Given that virtually all the multi-utilities included in this study are also included in that paper's sample, the output coefficients obtained from that analysis, can be directly used to estimate the incremental costs and the product-specific economies of scale for the multi-utility sector studied here.

Using the regression results reported in Farsi, Fetz and Filippini (2007b) and Equations (4), (6) and (7), we have estimated the economies of scope and the three product-specific economies of scale for electricity, gas and water outputs respectively. We focused on the GLS model from that paper, which is similar to the GLS model (Model *I*) used here, but with a quadratic functional form. The estimations have been conducted at several representative sample points with respect to output and customer density. These results generally confirm the existence of natural monopoly, through considerable economies of scope and relatively low but significant product-specific economies of scale. The relative weakness of the product-specific economies of scale should be considered in view of the fact that the theoretical conditions of natural monopoly generally rule out the presence of product specific fixed costs. As pointed out by Panzar (1989), the extent of natural monopoly is enhanced by increases in fixed costs, which favor a single company over several firms. Therefore, the trans-ray convexity condition is somewhat too strong for verifying natural monopoly. In particular, in verifying the condition of declining average incremental costs, ignoring the product-specific fixed costs obviously results in an understatement of product-specific economies of scale through underestimated incremental cost at the numerator of Equation (7). In view of the above discussion, both approaches provide suggestive evidence of the existence of natural monopoly in Swiss multi-utilities.

## 6 Conclusions

This study is an analysis of the cost structure of the Switzerland’s multi-utilities operating in the distribution of electricity, gas and water. The issues addressed in the study involve two important and inter-related questions for the regulation of this industry. First, what is the optimal structure of the multi-utility sector regarding the degree of separation and independence of different services, and secondly, how can the productive efficiency of the companies be ensured through incentive regulation and benchmarking? In order to answer the first question it is important to identify if and to what extent the industry can be characterized as a natural monopoly. If the economies of scope and scale are not significant, the optimal solution will be the horizontal unbundling of services to separate distributors for electricity, gas and water. In this case, each of the three sectors will be subject to its own regulatory systems, and the productive efficiency of each type of distributor will be monitored and incentivized by separate and independent mechanisms. Price-cap regulation of electricity distributors or yardstick competition between water distributors are two examples of such mechanisms.

However, if the multi-utility sector is a natural monopoly, the combined provision of electricity, gas and water will be optimal. In which case, it is necessary to develop reliable methods of benchmarking such to ensure the productive efficiency of the local monopolies through a regulation system. In general, the benchmarking of utilities with a similar output is relatively easier than that of multiple-output companies. The multi-utilities that operate in several different sectors, are characterized by a strong unobserved heterogeneity, therefore the measurement of their performance poses an important challenge for the regulators. The answer to the unbundling question is therefore inter-related to the availability of reliable estimates of efficiency posed in the second question. This study is an attempt to responding in the above questions.

At the first stage, this study reviews the theoretical background and general methods of identifying natural monopoly characteristics as well as the estimation of productive efficiency particularly cost-efficiency. After a brief discussion of the methodological difficulties in efficiency estimation, the recent panel data extensions to the conventional econometric methods have been reviewed. It is shown through several studies reviewed in this report, that these recent developments can be helpful to achieve more reliable estimates of inefficiency in presence of unobserved and omitted factors. The previous studies have used some of these methods in single-network distributors such as electricity and gas. However to our knowledge there is no reported empirical application in the multi-utility sector.

At a second stage, this study provides an extensive empirical study to explore the two questions mentioned above. First, reviewing the empirical evidence reported in previous studies both at national and international levels, we argue that the multi-utility sector in Switzerland benefits from considerable economies of scope, which would be lost if the case of horizontal unbundling. There are only a few studies that address the issue in the multi-utility sector. Therefore the reviewed studies include both the studies of separate sectors and combined provision of two or three energy products. In particular one of the studies that deal with the multi-utility sector in Switzerland has been emphasized. The empirical evidence in general favors the presence of the economies of scope at least for a considerable fraction of companies and output levels.

Moreover, most studies provide evidence of scale economies both in multi-utilities and in the single-output case for electricity, water and gas.

At the end, this study provides an analysis of the cost structure of 34 Swiss multi-utilities operating from 1997 to 2005. Using a translog cost function and several econometric specifications this analysis indicates the presence of unexploited global scale economies in the majority of the companies included in the sample. The results also indicate significant cost complementarities between the distribution of electricity and the two other outputs, and a weak complementarity between gas and water. Combined with the empirical evidence reported in previous papers, these results suggest that the Swiss multi-utility sector benefits from significant economies of scope and scale. Moreover, the hypothesis of natural monopoly has been explored using two different approaches. The results provide suggestive evidence that the Switzerland's multi-utility sector is a local natural monopoly.

Together with previous findings reported in the literature, the results of this study indicate that the economies of scope and cost complementarities exist in a majority of the multi-utilities, suggesting that additional costs could result from unbundling the multi-utility services. In the actual situation many companies avoid these additional costs through combining different outputs. The savings associated with scope economies are more considerable for small companies, especially because these companies do not take advantage of the economies of scale as much as their larger counterparts.

With the application of several stochastic frontier models, the inefficiency scores of the 34 companies included in the data, have been estimated and compared across different econometric models. The results suggest that the efficiency estimates are sensitive to the econometric specification of unobserved factors through the model's stochastic components. Recently developed panel data models such as True Random Effects frontier model (Greene, 2005b) can be useful to at least partly, disentangle the unobserved firm specific heterogeneity from the inefficiency estimates. The present analysis explores the difficulties involved in the estimation of efficiency in multi-utilities. The results indicate that an inadequate model could provide a misleading picture of the efficiency both at an aggregate level and for individual firms.

While highlighting the potential problems in benchmarking multi-utilities, this study shows that adequate panel data models can be used to identify the inefficient companies and determine to certain extent, which part of their excess costs has been persistent and which part has varied over time. Combining several frontier models also allows two types of inefficiency estimates: a "lower bound" estimate that includes only the transient part of the firm's excess costs assuming that all persistent cost differences are due to unobserved factors rather than poor efficiency performance, and an "upper bound" that associates all the firm-specific unaccounted cost differences to their productive efficiency and neglects the effect of external unobserved factors. Both estimates could be useful for the regulator, as they can use them to identify the companies that are persistently more costly than others and those that have high time-variant inefficiency. The regulator should perform further detailed and possibly case-by-case studies to assess to what extent the excessive costs of the former group can be associated with productive inefficiency and identify the potential external factors and peculiarities that might have caused such excessive costs.

The policy implications of this study can be summarized as follows: First, regarding the issue of unbundling, the results of this study suggest that the horizontal unbundling of the distribution utilities in separate electricity, gas and water distributors would entail considerable additional costs due to the companies' inability to exploit the economies of scale and scope across the sectors. It should be noted however, that keeping separate accounts for different services i.e. accounting unbundling does not retain companies from using the synergies and can be helpful for enhancing the transparency of companies' operation and improving the effectiveness of the regulator's activities. Secondly, the indicative evidence of natural monopoly together with the strong evidence of the unexploited economies of scale, suggest that side-by-side competition should not be promoted in the multi-utility sector. Third, large and integrated multi-utilities can benefit from the economies of scale. Therefore, provided a strong and independent regulatory system that can monitor prices and ensure productive efficiency, the results of this study provide suggestive evidence in favor of mergers and acquisitions in multi-utilities. Finally, the results indicate that the Swiss multi-utilities might have slight to moderate cost-inefficiencies. Therefore, it is crucial to ensure the cost efficiency of local monopolists by implementing incentive regulation systems and appropriate benchmarking methods.

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