Estimating optimal scale and technical efficiency in the Italian gas distribution industry

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Working Paper 6, 2003

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Abstract

The Italian gas distribution industry presents a high degree of fragmentation. However, the tendency of the market during the period comprised between 1970 and 1998 points out a concentration process. The available evidence supports the thesis that the local distributors have undertaken a process of enlargement of their scale size. This raises the question about the characteristics of returns to scale for such operators as well as the optimal scale at which they should operate. Returns to scale are analysed by means of DEA (Data Envelopment Analysis) methodology. The finding points out that the output space along which DMUs attain a high level of scale efficiency is very spread, so indicating an unexpected returns to scale characterisation. Only for smallest units the technology shows increasing returns, but such effect get rapidly exhausted in favour of a regime of constant returns to scale. The main policy conclusion is that an improvement of productivity can be reached by an intensification of the merging process involving local distributors operating at small scale. In addition, the mentioned concentration process appears as an "attainable" objective since the critical dimension allowing the exploitation of positive returns to scale is quite small.

Keywords: gas distribution industry, DEA, scale efficiency, most productive scale size.

JEL codes: L11, L23, L95.

1. Introduction

The purpose of this study is to examine the nature of returns to scale in the Italian gas distribution industry. The Italian context is peculiar with respect to other European countries because of its high fragmentation of supply that is provided by firms characterised by a highly heterogeneous scale size. This differentiation among firms in terms of operational size offers a suitable context for verifying the impact of scale effects on internal performance. In such a way it is possible to disentangle this latter from pure technical efficiency, providing answers to the question relating to the optimal dimension.

In Italy the regulatory reform was introduced by the decree 164/2000. In particular, the regulatory intervention proposed the complete liberalisation of the merchant functions while the distribution of gas services remained monopoly franchises, assigned by public tenders. The Authority establishes the regulated tariffs for the access to the network (Third Party Access system). The aim of the reform is to push firms towards an increasing efficiency considered as the only vehicle for attaining greater profits. In such a context the local distributors can take advantage from the economies deriving from a convenient scale size.

The dataset used at this proposal is represented by a panel composed of 46 units observed over the period from 1994 to 1999, that is before the liberalisation of the industry. The choice of the period depends upon the impossibility of conducing a comparison with the years following the regulatory intervention because of the introduction of new accounting rules. These latter are, in particular, related to the compulsory unbundling between the industrial function involved in the management of the network (*distribution*) and the merchant function involved in the relationship with the final customers (*sale*).

The methodological instrument employed is the Data Envelopment Analysis (DEA), a non parametric mathematical programming technique for estimating efficiency and returns to scale through the construction of a best practice frontier.

The paper unfolds as follows: section 2 provides a brief description of the structural and organisational aspects of the Italian gas distribution industry. Section 3 presents a review of the empirical studies dealing with scale problems in the energy sectors (gas and electricity). Section 4 describes the DEA methodology and the established returns to scale estimator. Section 5 points out the database. Empirical results are shown in section 6, while section 7 contains the conclusion and some policy implication.

2. Structure of the Italian gas distribution market

The gas distribution market in Italy presents a high degree of fragmentation. In 1999 the distribution service to final (domestic and industrial) customers was provided by 752 operators, a very large number, although in reduction if compared to the 810 gas distributors active in 1994 (Bernardini and Di Marzio, 2001). The explanation originates from historical reasons. The distribution phase has been, in general, carried out by local municipalities which directly provided the service into their own territories.

However, the delivered volumes are not as many fragmented as the providers of the service. The data point out that around 40% of the total volumes are supplied by 730 small and medium operators with size lesser than 100 million of cubic meters per year, while the 27% is delivered by the two main national operators (ITALGAS and CAMUZZI).

The tendency of the market during the period comprised between 1970 and 1998 points out a concentration process, as summarised in table 1, that indicates the number of firms holding one or more monopoly franchises. Focusing the attention to the 90s, it is noteworthy the reduction from 270 to 208 units occurred in the intermediate category (with a number of supply contracts from 2 to 10) and the sharp increase of 33%, from 94 to 125, in the number of firms holding more then 10.

Table 1: Fragmentation and concentration of the gas distribution market

	Number of franchises		
	1	*2-10*	*>10*
1970	194	153	10
1980	260	228	29
1990	392	270	94
1998	441	208	125

Source: Bernardini and Di Marzio (2001)

Table 2 presents further evidence confirming the concentration process. During the decade 1987-1998 the number of small firms (with customers comprised between 500 and 5,000 or less then 500) reduced, even if they continued to prevail in the distribution market. The percentages indicate a fall of around 5% in both the categories. On the other hand, the largest units have experienced a growth of their relative incidence, especially for the category of firms with customers ranging between 5,000 and 500,000 (from 31.3% to 39.9%).

Turning to the number of customers, it is possible to observe that its absolute amount declines for the lower categories while increases for the upper ones, although the relative shares show a generalised reduction, except for the main national operators.

In summary, the available evidence supports the thesis that the local distributors have undertaken an enlargement of their scale size even in the form of mergers and acquisitions, in order to consolidate their position on the market. The incentive to this growth process could be due to the exploitation of economies of scale in this particular service. The described process could also have been encouraged by the re-organisation of the public local services defined in the law 142/1990. Such political intervention has radically modified the previous forms of direct administration of public services in favour of more autonomous market-oriented organisations, such as limited or joint stock companies. During the period 1990-1998, the 76% of the municipal administrations that underwent re-organisation processes have assumed the form of publicly or privately-owned limited companies. The consequence has been a change in the behaviour of the firms that became more sensitive to the attainment of better efficiency conditions.

All these arguments give rise the question about the optimal scale size at which firms should more conveniently operate. The following analysis will try to provide an answer by investigating the characteristics of returns to scale and verifying the presence of increasing, constant or decreasing returns areas within the output space.

Table 2: Structure of gas distribution market for number of customers

Category of customers	Firms		Customers		Customers/firm (000)
	No.	%	No.	%	
Year 1987					
> 500,000	2	0.3	2,934,321	27.3	1,467,161
50,000 – 500,000	29	3.9	3,853,486	35.9	132,879
5,000 – 50,000	232	31.3	3,104,177	28.9	13,380
500 – 5,000	370	49.9	815,236	7.6	2,203
< 500	108	14.6	22,831	0.2	211
Total	*741*	*100.0*	*10,730,051*	*100.0*	*14,481*
Year 1998					
> 500,000	4	0.5	6,418,235	40.1	1,604,559
50,000 – 500,000	41	5.6	4,560,715	28.5	111,237
5,000 – 50,000	293	39.9	4,231,982	26.5	14,444
500 – 5,000	331	45.1	756,747	4.7	2,286
< 500	65	8.9	19,235	0.1	296
Total	*734*	*100.0*	*15,986,914*	*100.0*	*21,781*

Source: Bernardini and Di Marzio (2001)

3. Empirical studies

Some empirical contributions on the economies of scale in the distribution activity of the public utilities are available in the literature.

An acquired point on this argument is the distinction between economies of density, with respect to output (volumes) and customers, and economies of scale. The economies of output density arise when the intensity of consumed volume per customer increases while the number of customers and the size of network system remains unchanged. The economies of customer density arise when volumes and number of customers increase proportionally holding unchanged the size of the network.

Economies of scale relate to the case in which volumes, customers and network increase at the same proportion.

Elasticity of scale directly affects the firm's maximal profit (Førsund and Hjalmarrson, 2002b). Moreover returns to scale are an important element to consider in valuating eventual merging between two or more adjacent distributors. In general, however, the characterisation of returns to scale in the gas distribution industry still remains unclear.

The characterisation of the technology in the energy sectors (gas and electricity) were largely investigated in the literature.

The technology underlying the gas distribution is analysed by Guldmann (1983, 1984, 1985); Kim and Lee (1996); Lee *et al.* (1999); Fabbri *et al.* (2000); Hollas *et al.* (2002). Guldman (1983) proposed the estimation of a neo-classical cost function to model the structure of the urban gas distribution. The empirical results allowed to assume the presence of weak economies of scale. The remaining Guldmann's contributions point out that economies of scale are not constant and the average costs vary with the market size and territorial concentration of the customers.

Kim and Lee used a hedonic cost function to model the distribution technology of the Korean gas industry over the period 1987-1992. They found that almost all of the firms were located in the increasing returns to scale region in the early period and gradually exhausted scale economies in the later period.

Lee *et a*l. compared the total factor productivity growth over time between US, Canada, France, Italy, Japan and Korea. In their cross-country analysis almost all of the firms result to operate under increasing returns to scale. Economies of scale appear a fundamental determinant of the average productivity in those countries with a premature industry. Instead, for the countries characterised by a mature natural gas industry technological progress is the main contributing factor for productivity growth.

Fabbri *et al.* proposed an empirical investigation of the Italian gas distribution industry by means of a long-term cost function. Their analysis highlights the important role of the morphologic and demographic variables in explaining costs differences and suggests the hypothesis of prevailing constant economies of scale.

Hollas *et al.* examined technical efficiency, economies of scale and efficiency changes for the US gas distribution utilities during the period 1975-1994 by means of Data Envelopment Analysis. As

regards economies of scale the results suggest that promotion of competition has generally moved gas distributors to excessive scale-down processes corresponding to a reduction in scale efficiency.
The technology underlying the electrical distribution is analysed by Clagget (1994); Kumbhakar and Hjalmarsson (1998); Bagdadioglu *et al.*(1996). Clagget's estimates show that Tennessee Valley Authority (TVA) distributors present increasing as well decreasing scale economies when physical volumes, number of customers and size of the service area change proportionally. Kumbhakar and Hjalmarsson focused on productive efficiency in Swedish retail electricity distribution using hedonic output(s) constructed from physical outputs and their qualities and network characteristics. The elasticity of scale is found to vary considerably across firms. Bagdadioglu *et al.* utilised DEA methodology to analyse the performance of public and private Turkish electric distributors. They found evidence of scale economies and firms appear symmetrically scale inefficient in both the increasing and decreasing returns regions.

4. DEA methodology

Knowledge of the nature of returns to scale is realised by applying DEA methodology (Charnes *et al.*, 1978). It consists in the identification of a non-parametric piecewise linear frontier representing the best practice in the transformation of a bundle of inputs into final outputs (the theoretical description of DEA is drawn heavily from Cooper *et al.*, 2000 and Thanassoulis, 2001).

A transformation process can be based on the hypothesis of *constant returns to scale* (CRS), although in most general real life contexts it should be more appropriately assumed a *variable returns to scale* (VRS) technology. This occurs because the operational size under which a DMU operates can affect the average productivity. The main consequence is that a DMU should be better compared with similar DMUs in term of scale of production, especially when a large heterogeneity in size occurs. Alternatively, a small DMU, for instance, could result inefficient if compared to a larger one uniquely because of its scale property rather than pure intrinsic inefficiency. In such a way, the risk of putting forward erroneous judgements on efficiency determinants arises.

When using DEA an alternative occurs in the identification of inefficiency. It is possible to minimise the use of inputs given the outputs or to maximise the outputs given the inputs. As regard utility services, such as gas distribution, the output is linked to the local demand while the costs saving appears to be a more rationale managerial objective. For such reasons, the paper will analyse the efficiency conditions using an input-oriented projection model.

Given N DMUs ($j=1,...N$) producing S outputs ($r=1,...,S$) using M inputs ($i=1,...,M$), the efficiency DEA score for a DMU j_0 under VRS and input-oriented hypotheses can be estimated by solving the following linear programme in envelopment form:

$$
\begin{aligned}
&\text{Min } \theta_{j_0}^{VRS} \\
&\text{s.t.} \\
&\sum_{j=1}^{N} \lambda_j y_{rj} - y_{rj_0} \geq 0 \qquad r = 1,\ldots,S \\
&\theta_{j_0}^{VRS} x_{ij_0} - \sum_{j=1}^{N} \lambda_j x_{ij} \geq 0 \qquad i = 1,\ldots,M \\
&\sum_{j=1}^{N} \lambda_j = 1 \\
&\lambda_j \geq 0 \quad j = 1,\ldots,N, \quad \theta_{j_0}^{VRS} \textit{ free.}
\end{aligned}
\qquad [1]
$$

Here the non-negative λ-weights measure the contribution of selected Pareto-efficient DMUs to the definition of a reference point for the inefficient unit j_0. The convexity constraint $\sum_{j=1}^{N} \lambda_j = 1$ imposes of assessing the efficiency under VRS. The optimal solution of [1], $\hat{\theta}_{j_0}^{VRS}$, is non negative and less than 1, being equal to unity when full efficiency in the use of inputs occurs. The measure ($1-\hat{\theta}_{j_0}^{VRS}$) represents the potential radial reduction in inputs, given the output, until the inefficient point is projected on a surface of the linear piecewise frontier.

In figure 1 the input-oriented frontier, in a simplified single-output single-input model, is constructed using both CRS and VRS technology. The areas to the right of the two frontiers represent the production possibility sets (PPS) under both the assumption of returns to scale. They are composed by all the points feasible in principle, given the production technology, but affected by inefficiency.

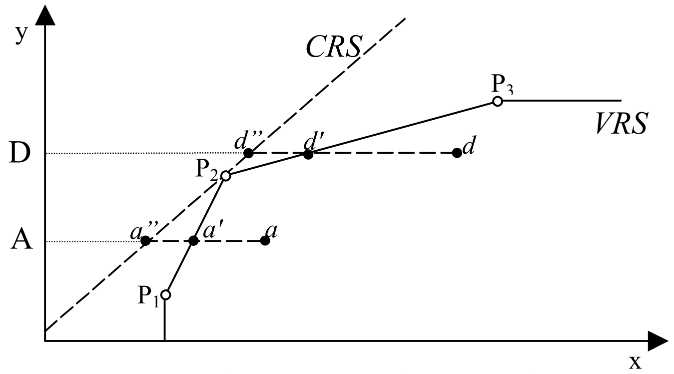

Figure 1: CRS and VRS frontiers

Points *a* and *d* are inefficient and their input-oriented path of projection individualizes referent points *a'* and *d'* on VRS frontier and *a"* and *d"* on CRS frontier. The unique difference between *a"* and *a'* or *d"* and *d'* is due to control for scale. The ratios A*a"*/A*a'* and D*d"*/D*d'* represent the measure of scale efficiency ($\hat{\theta}_{a}^{SE}$ and $\hat{\theta}_{d}^{SE}$), while the ratios A*a*'/A*a* and D*d*'/D*d* identify the pure technical input efficiency ($\hat{\theta}_{\mathrm{a}}^{\mathrm{VRS}}$ and $\hat{\theta}_{\mathrm{d}}^{\mathrm{VRS}}$) which is exclusively attributable to managerial effort. The shape of the VRS piecewise boundary is closer to the observed inefficient points so that efficiency scores under VRS result higher than corresponding CRS measures. The rationale for this is that CRS measures incorporate a scale inefficiency while VRS measures do not.

The difference occurring between points *a* and *d* is that they are characterised by opposite scale properties. Point *a* is radially projected on an increasing returns to scale facet of the VRS frontier while point *d* is radially projected on a VRS surface where locally decreasing returns to scale hold.

Numerous studies in DEA literature attend to the identification of scale economies (Färe *et al.*, 1983; Banker *et al.*, 1984; Banker, 1984; Banker and Thrall, 1992; Coelli *et al.*, 1998; Kerstens and Vanden Eeckaut, 1999). The method adopted in the present work is based on the dual programme to model [1] (Banker *et al.*, 1984; Banker, 1984). Let u_r and v_i be the non-negative shadow prices of the input and output constraints in [1] and u_0^{in} be the unrestricted shadow price of the convexity constraint (Førsund and Hjalmarsson, 2002a,b). Then the dual value-based DEA model is:

$$
\begin{aligned}
& Max \quad \mathrm{p}_0 = \sum_{r=1}^{S} u_r y_{rj_0} + u_o^{in} \\
& s.t. \\
& \sum_{i=1}^{M} v_i x_{ij_0} = 1 \\
& \sum_{r=1}^{S} u_r y_{rj} - \sum_{i=1}^{M} v_i x_{ij} + u_o^{in} \le 0 \qquad \mathrm{j} = 1,\ldots,\mathrm{N} \\
& \mathrm{u_r} \ge 0, \;\; \mathrm{v_i} \ge 0, \;\; u_0^{in}\, free \qquad \mathrm{r} = 1,\ldots,\mathrm{S} \quad \mathrm{i} = 1,\ldots,\mathrm{M}
\end{aligned}
\tag{2}
$$

The methodology consists in the inspection of the sign of the shadow price u_0^{in}. Given the inequality constraints and the objective function in [2] it derives that u_0^{in} has an upper bound of 1 and a lower bound of minus infinity.

As largely outlined in DEA literature, returns to scale characterise locally the production frontier so that they can be solely computed with respect to originally efficient DMUs or radial projections of inefficient DMUs belonging to the PPS. Nevertheless, the treatment of the returns to scale is different according to the cases.

As regards inefficient DMUs the shadow price u_0^{in} is, in general, unique and the nature of returns to scale well-defined (Førsund and Hjalmarsson, 2002b). This occurs because the radial projections are interior points of the supporting hyperplanes of the VRS boundary. So a radial projection point exhibits increasing returns to scale if $u_0^{in} > 0$, decreasing returns to scale if $u_0^{in} < 0$ and constant returns to scale if $u_0^{in} = 0$.

As regards Pareto-efficient DMUs a problem of multiple optimal solutions arises. This fact can be better appreciated turning to the previous figure 1. The efficient point P_2, for instance, lies on the edge point that separates two linear facets characterised by different scale regimes. The multiplicity of the facets which the originally efficient DMUs belong to generates alternative optimal solutions for u_0^{in}.

Banker and Thrall (1992) provided a generalisation of this method for dealing with the presence of multiple optimal solutions, by means of the identification of the maximal and minimal admissible values of u_0^{in}, allowing the identification of the nature of returns to scale for such DMUs.

Finally, following Førsund and Hjalmarsson (1996), the scale elasticity for the input-oriented projection point of a generic DMU j_0 is estimated as:

$$\varepsilon\left(y_{j_0}, \hat{\theta}_{j_0}^{VRS} x_{j_0}\right) = \frac{\hat{\theta}_{\mathrm{j}_0}^{VRS}}{\hat{\theta}_{\mathrm{j}_0}^{VRS} - u_0^{in}} \quad .$$

Even in this case, the presence of multiple solutions provides the existence of upper and lower bounds for ε (Löthgren and Tambour, 1996). In Banker and Thrall (1992) can be, once again, found the extension of the method aimed to solve the alternative solutions problem. At least for originally inefficient DMUs, an elasticity parameter equal to 1 indicates that the scale is technically optimal, that is the average productivity is maximal. Values greater than 1 indicate that the radial projection is on a facet of the VRS boundary where locally increasing returns to scale hold, while values comprised between 0 and 1 correspond to decreasing returns to scale.

5. Description of the sample

5.1 Input and output variables

Data are available on a sample of 46 gas distributors observed over the period 1994-1999, that is before the introduction of the liberalisation act, yielding a whole sample of 276 individual observations. The data have been taken from the database managed by CERIS that collects the balance sheets of firms providing public services and includes both economic and technical information. The Italian gas distribution system has not been subjected in these years to radical regulatory reforms so as to justify the pooling treatment of the panel. The yearly productivity growth on the same period has been quite low (+0.22%), as found in Fraquelli and Erbetta (2003).

Coherently with the aim of analysing the characteristics of scale our sample presents a high heterogeneity in scale size, including both large and small distributors. The sample adopted in this study represents around the 62% of the total amount of the delivered gas and around the 60% of the total number of served customers. The significance of the sample is reinforced if it is considered that gas industry in Italy is extremely fragmented among a large number of firms, whose most part operate at a very small size. Unlikely for smallest operators the availability of data is much more problematic. Nevertheless, our sample is representative from a scale size viewpoint, as the descriptive statistics in table 1 below will show.

The choice of inputs and outputs is a crucial point as input-output correspondences have to respect a relationship of exclusivity and exhaustiveness between the two sets of variables (Thanassoulis, 2001). The data used in this work are divided into *input* variables, *output* variables and *categorical* variables that try to capture the environmental characteristics of the firms.

The input variable adopted in the present study is the overall operating and capital expenditure (*COST*) including costs for materials, labour, maintenance, other services and the cost of capital. Costs for purchasing gas from the national transportation company (SNAM) has been excluded. The exclusion is due to the fact that, during the considered period, gas was purchased at regulated prices out of the managerial control.

Because of the high capital intensity characterising this industry, *COST* variable has been computed including a measure of the cost of capital represented by depreciation. This latter suffers from high variability along time and for this reason seemed to misrepresent the actual contribution of capital[1]. The treatment of the depreciation variable has been carried out in two stages. In the first stage capital values were corrected starting from the amount of fixed assets of the year immediately before revaluation and adding the successive yearly investments. In such a way a new sequence of capital values was built up allowing to avoid the break point represented by balance sheet revaluation. In the second stage a convenient rate of depreciation has been applied to the sequence of capital values, calculated as average of the rates holding before revaluation took place.

Data were then deflated through the ISTAT production price index by industry with basis 1995 in order to eliminate the corruption due to changes in prices of factors[2].

The output variables used are the number of customers (Y_1) and the delivered volumes (Y_2) as usually found in numerous works on the efficiency of public utilities.

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[1] Almost half of the observed companies has been subjected to a revaluation of their fixed assets, especially when they underwent transformation in legal form, as stated in the law 142/90. This fact produced some problems in the definition of a homogeneous time series.

[2] In regard of cost of capital the yearly depreciations have been firstly multiplied by a deflator with basis 1999 derived from Centrale dei Bilanci (2001) and successively corrected by the ISTAT price index. This procedure is due to the

Finally, the length of network (*LN*) has been included in our study as categorical variable, in order to capture the different behaviour of firms operating under particular degree of customers concentration, as in the cases of urban and rural areas.

5.2 *Descriptive statistics*

Table 3 summarises some descriptive statistics relative to the sample. The main evidence is that DMUs are spanned over a very wide output space, that includes a high variety in scale size, as shown by the coefficients of variation, calculated as ratio between standard deviation and mean values. The results show a standard deviation being three times the average value of each variable.

All the outputs appear positively correlated with *COST* variable. The corresponding index is in all cases approximately equal to 1 so indicating a high explanatory power of the dynamic of operating and capital expenditures. The high variety that characterises the length of network confirms the heterogeneity of the environment contexts at which the firms operate, reflecting the state of the Italian gas distribution system.

Notice finally that the distance between the third quartile and the maximal value is due to the presence in our sample of ITALGAS, that is the main national public-owned distributor.

Table 3: descriptive statistics

	Min	1st quartile	3rd quartile	max	mean	var. coeff.	Correlation index
Y_1 (*no. customers*)	2,708	18,344	111,357	4,458,000	19,3348	3.15	0.996
Y_2 (*mil. of cubic meters*)	6.0	41.5	193.8	7,100.0	301.3	3.12	0.991
Y_3 (*km of network*)	39.4	253.3	1,064.8	3,6271.0	1,661.2	2.97	0.983

5.3 *Economies of scale and density*

The economic efficiency is theoretically decomposed in scale efficiency and technical efficiency. Scale efficiency is related to the economies that arise when all outputs (volumes and customers) and network increase proportionally. Technical efficiency under VRS assumption, instead, indicates the internal managerial ability to maximise the economic performance leaving out of consideration the operational scale. Technical efficiency can be affected by economies of density with respect to output and customers.

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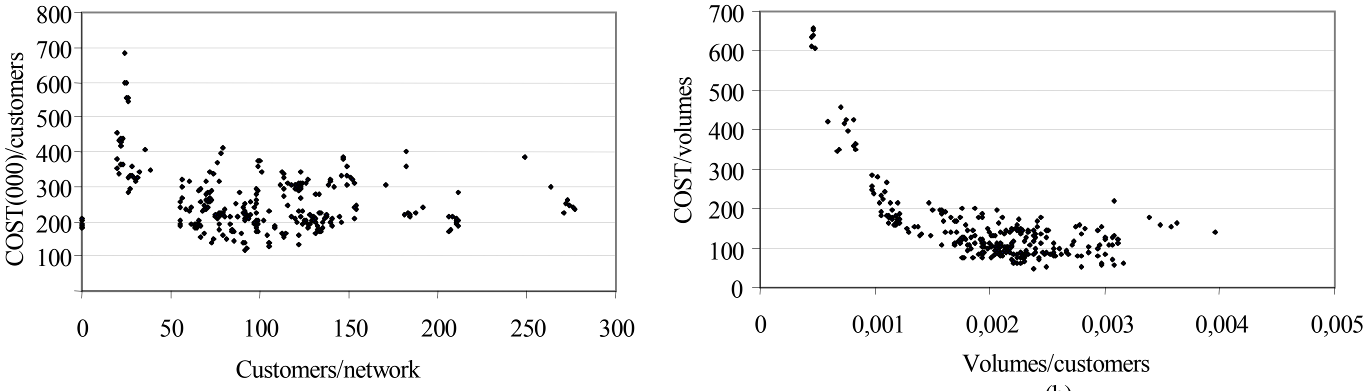
nature of capital variable, characterised by a stratification over time of the investments. In such a way is has been possible to express the depreciation in an homogeneous monetary power.

Figure 2 shows the dynamic of the average cost corresponding to an increase of customers per kilometre of network (a) and of volumes per customer (b). The average cost with respect to customers confirm the presence of economies of customer density while the average cost with respect to delivered volumes confirm the presence of economies of output density. For what it concerns figure 2a the median of the ratio costumers/network is around 100 and this value has been used for discriminating between DMUs characterised by high and low customer density.



(a) (b)

Figure 2: Economies of output and customer density

Anyway both output and customer density are environmental characteristics out of managerial control that necessitate of specific treatments.

As regards economies of output density, the simultaneous presence of Y_1 and Y_2 allows to treat these economies as endogenous. In fact, given the output Y_2, the efficiency of those DMUs with a high number of customers, and then with low output density, increases while the efficiency of those DMUs with a low number of customers, and then a high degree of output density, decreases[3].

With regards economies of customer density two possible solutions can be proposed.

The first one is more practical and suggests the consideration of the variable *LN* as output so as to DMUs with high network extension and then low customer density are allowed to increase their score efficiency, while the opposite would occur for DMUs that take advantage from higher density effect.

The second one, instead, is based on the use of a density measure, calculated as ratio between customers and length of network, as categorical variable (Banker and Morey, 1986; Charnes *et al.*, 1994; Thanassoulis, 2001). This control for density lies upon the *a priori* assumption that higher the number of customers for each kilometre of network higher the productivity advantage would be.

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[3] In order to isolate the output density effect it would be necessary to run a DEA model based on one output (volumes) and one input. A similar model, however, seems not admissible in practice, because of the consequent lack of discrimination among firms, and in theory, given the well established use in the literature of two output models.

The main insight is that DMUs that enjoy a higher advantage in term of average productivity by virtue of density effects, could not be taken as referent points for DMUs that are less advantaged, while the inverse is admissible (Thanassoulis, 2001).

This latter solution seemed more appropriate and has been adopted in this study because of its stronger theoretical background an also because it seemed more correct to use *LN* as categorical variable rather than as output itself. In order to implementing this procedure, the sample has been split into two subsets of DMUs (S_d, with d = 1 and 2), the first one corresponding to the less advantaged and the second one corresponding to the more advantaged units. The comparison between more advantaged and less advantaged DMUs by virtue of potential density effect has been limited by modifying the constraints of [2], so that the linear programming for a generic DMU j_0 belonging to subset d becomes:

$$
\begin{aligned}
& Max \quad \mathrm{p}_0 = \sum_{r=1}^{S} u_r y_{rj_0} + u_o^{in} \\
& s.t. \\
& \sum_{i=1}^{M} v_i x_{ij_0} = 1 \\
& \sum_{r=1}^{S} u_r y_{rj} - \sum_{i=1}^{M} v_i x_{ij} + u_o^{in} \le 0 \qquad \mathrm{j} \in \bigcup_{\mathrm{k}=1}^{\mathrm{d}} \mathrm{S_k} \\
& \mathrm{u_r} \ge 0, \;\; \mathrm{v_i} \ge 0, \;\; u_0^{in}\, free \qquad \mathrm{r} = 1,\dots,\mathrm{S} \qquad \mathrm{i} = 1,\dots,\mathrm{M}
\end{aligned}
\qquad [3]
$$

6 Empirical results

Efficiency scores and returns to scale parameters have been estimated using two models. Both the models use Y_1 and Y_2 as output variables and *COST* as input variable. The second one, however, introduce the technique of categorical variables in order to take into consideration the role of the economies of customer density.

The mean values of VRS pure technical efficiency (TE) and scale efficiency (SE) are represented in table 4.

Table 4: Technical and scale efficiency (average values)

	Model 1	Model 2
VRS pure TE	63.40	66.15
VRS pure TE (1st quartile)	57.13	65.90
VRS pure TE (2nd quartile)	53.49	54.30
VRS pure TE (3rd quartile)	58.91	59.89
VRS pure TE (4th quartile)	85.15	85.65
SE	83.51	80.27

The average value of technical efficiency is around 63% in model 1 and around 66% in model 2. The average scores are quite low so indicating a lack of competition among distributors. The scale component is, instead, characterised by an efficiency level of 80-83%. Due to the high variability in scale size, the observations has been grouped into quartiles, calculated on the basis of the number of customers. In both the models the first 75% of the DMUs lies below 60% of pure technical efficiency while the latter 25% presents values of 80-83%. This latter result, however, should be treated with caution because the group of greatest units could benefit of high technical efficiency uniquely because of a lack of comparison with other DMUs. In fact, when few firms operate spot at very high scale size, in absence of an adequate comparison with other DMUs they assume a high score efficiency as DEA uses them as best practice points.

The passage from model 1 to model 2 points out an average increase in pure technical efficiency of 3%, which is particularly significant for the first quartile (9%). This gives rise questions on the role played by the effect of customer density. The firms serving few customers are likely to operate under low density of network that bestows a productivity disadvantage with respect to firms operating under higher density conditions. The increasing in efficiency observed for model 2 reveals the penalisation in which low density firms have been incurred when compared with high density firms.

This latter point is better clarified in table 5 where the separation between low density and high density DMUs is presented.

Table 5: Low and high economies of customer density

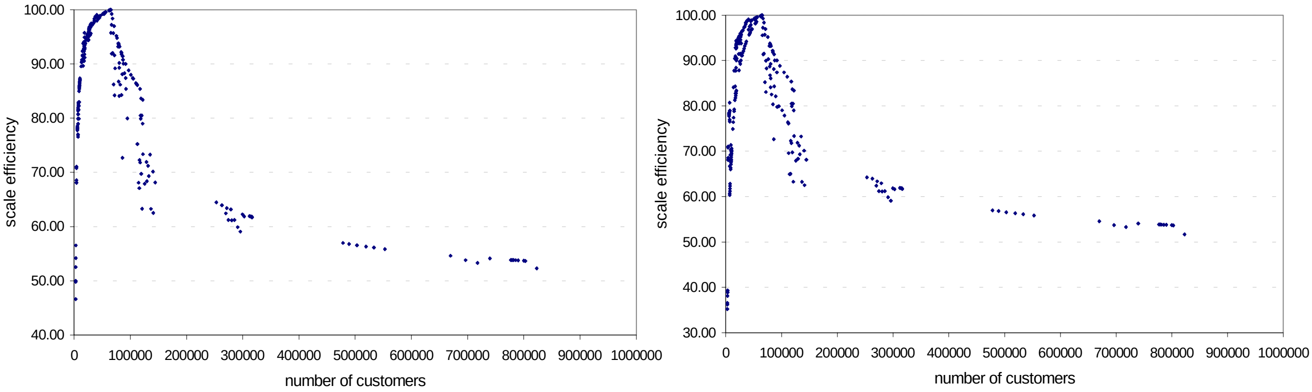
	Model 1		Model 2	
	TE	SE	TE	SE
Low density	60.60	86.94	66.11	80.46
High density	66.19	80.08	66.19	80.08

Table 5 points out two important insights. Firstly, in model 2 the pure technical efficiency increases of 5.5 points and scale efficiency decreases of 6.5 points with respect to model 1. Such evidence implies that if density effect is neglected, the results tend to misrepresent the actual decomposition of the overall efficiency. Indeed, in model 1 a share of the scale efficiency has, in reality, a technical nature. Model 2, imposing that the disadvantaged low density DMUs can not feature as referent peers for high density DMUs, is able to provide a more correct representation of the contribution of the two sources of efficiency. Secondly, it is noteworthy that the behaviour of both the categories is very similar in model 2. Once the effect of customers density has been taken into consideration and the efficiency assessments relative to the two groups are made comparable, their managerial behaviour as well as their scale effect do not show significant divergences.

The evaluation of the scale efficiency allows to identify the output space areas where decreasing or increasing returns hold as well the optimal scale at which a gas distributor should operate in order to maximise its average productivity (MPSS, *Most Productive Scale Size*).

In figure 3 scale efficiency has been plotted against a scale variable identified by the number of served customers. The shape of the curve is regular, showing increasing returns before approximately 65,000 customers and decreasing returns after this threshold[4]. The optimal scale is univocally determined and corresponds to 65,000 customers in both the models. Notice moreover that almost the half of the observations show a scale efficiency greater than 90%.

The same analysis conducted with respect to delivered volumes provided an optimal scale corresponding to approximately 150 millions of cubic meters .



a) Model 1

b) Model 2

Figure 3: identification of optimal scale , DRS and IRS areas

The regulatory act (Decree 164/2000), establishing some circumstances that permit to benefit of the delay of the public tender for the franchise assignment, indicates respectively a higher threshold as regards customers (100,000 units) and a lower threshold as regards volumes (100 millions of yearly cubic meters) with respect to the optimal scale found out in our study.

The analysis of elasticity of scale can contribute to the comprehension of the scale properties. Elasticity of scale (ε_{jo}) measures the relative marginal increases in all outputs corresponding to a relative marginal increase in input. A value of elasticity greater than 1 indicates increasing returns to scale. A value of elasticity lesser than 1 indicates decreasing returns to scale. Finally a value of elasticity equal to 1 indicates that the DMU operate at optimal scale.

In figure 4 the values of elasticity have been plotted against the number of customers[5].

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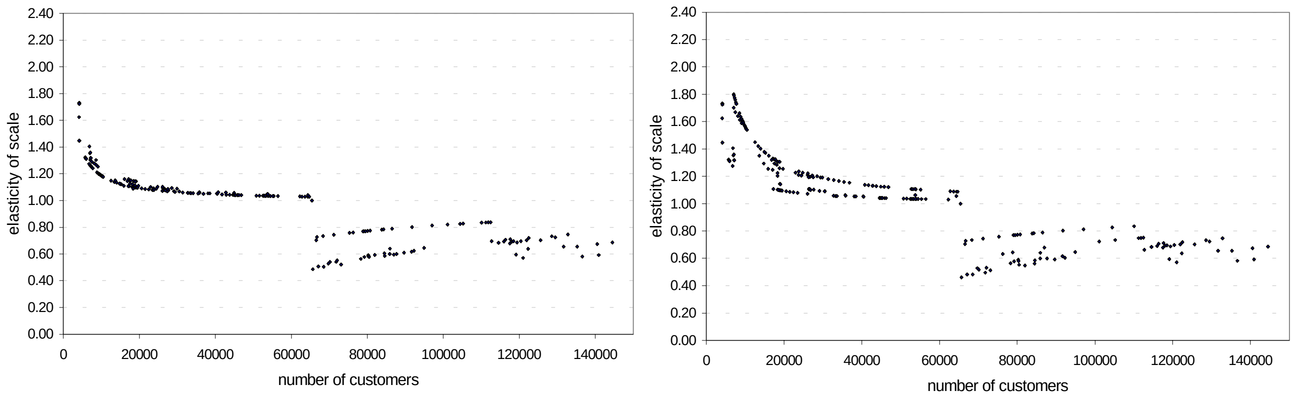
[4] The horizontal axis has been truncated at 1,000,000 customers but the curve maintains its regularity even for greater scale sizes.

[5] The horizontal axis has been truncated at 150,000 customers but the curve maintains its regularity even for greater scale sizes.



a) Model 1

b) Model 2

Figure 4: elasticity of scale

Figure 4 shows strong evidence of increasing returns to scale for smallest units, followed by a flattering of the curve in correspondence of, approximately, 20,000 customers[6]. This evidence suggests that there exists a wide range of units operating at *quasi*-most productive scale size. As consequence it can be observed that the optimal scale does not reduce to a single point but it stretches over a bounded interval characterised by constancy of returns to scale. This finding is consistent with the evidence of prevailing constant economies of scale found out in Fabbri *et al.* (2000).

The upper bound of this *quasi*-most productive scale size area is well delineated. For values of output greater than 65,000 customers a dramatic decrease of elasticity occurs. This latter evidence depends heavily upon the adopted technique. As it is well known, the VRS efficient frontier is represented by a piece-wise linear boundary. Within each surface the marginal product remains constant. The shift from one to another surface causes a break down of marginal productivity and consequently a discontinuity of the scale elasticity curve. Figure 4 brings evidence of a radical change in marginal productivity after the attainment of the optimal scale size level[7]

Using delivered volumes as output, the shape of scale elasticity is unchanged. In this case the area where it is possible to observe a constancy of the returns to scale is comprised between 40 and 150 millions of cubic meters.

These findings can be better appreciated by means of a simulation. In fact, scaling up and down the average firm (respect to volumes, number of costumers and operating costs), it is possible to generate a sequence of virtual observations characterized by different scale sizes but equal

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[6] The points corresponding to VRS efficient DMUs have been excluded because of the multiplicity of optimal solutions.

[7] It is worth to give notice that the elasticity of scale moves up to 1 as soon as output increases. This evidence has to be treated with caution because its explanation depends upon technical rather than economic reasons. Given the way the

operational attributes. DEA has been running starting from a panel composed by real and virtual observations. These latter are inefficient by construction so that to do not modify previous DEA frontier.

Table 6 presents the estimates of the elasticity of scale. For the smallest firms (below 10% of the average firm) the returns to scale are very strong and exhaust rapidly. Successively it is possible to observe a more gradual decreasing in the elasticity parameter. Notice, finally, the strong break down of the elasticity between 30% and 40% of the average firm, that is when the optimal scale size is overran.

Table 6: Elasticity of scale

Observations	Volumes (mil. of cubic meters)	Number of customers	Elasticity of scale
3% average firm	9.0	5,801	1.320
5% average firm	15.1	9,667	1.192
10% average firm	30.1	19,335	1.096
20% average firm	60.3	38,670	1.048
30% average firm	90.4	58,005	1.032
40% average firm	120.5	77,339	0.764
average firm	301.3	193,348	0,746

7 Conclusions and policy remarks

The Italian gas distribution industry presents a high degree of fragmentation. More than 700 operators provide the service to final customers. They operate at very different scale sizes and this fact could arise questions about the most convenient dimension. The regulatory act 164/2000 indirectly provides an indication of 100,000 customers and 100 millions of cubic meters as output values compatible with a regime of optimal scale size.

The purpose of this study has been to estimate the characteristics of technical and scale efficiency of the Italian gas distributors. DEA methodology has been adopted in order to construct an efficient boundary against which to measure the degree of efficiency of the involved units.

The results of our study can be summarised as follows.

1) The level of the technical efficiency is equal, on average, to 63-66%. This means that the same levels of output could be provided using the 63-66% of the original amount of input. This score

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VRS boundary is built up, as soon as output increases the average product converges towards marginal product so yielding the return to 1 of the elasticity curve.

of efficiency seems very low so indicating a lack of competition within the distribution system. Therefore the evidence suggests a strong need of regulatory rules that can replicate competitive conditions. The scale efficiency is higher and equal to, on average, 80-83%.

2) The inclusion in the model of the effect of customer density permits to evaluate the degree of penalisation suffered by low density DMUs. When low density DMUs are directly compared with high density DMUs DEA tends to underestimate technical efficiency and overestimate scale efficiency to a significant extent, so providing a wrong decomposition of the overall efficiency.
3) Optimal scale is attained at around 65,000 customers and 150 millions of cubic meters. These results do not fully match the indication putted forward by the regulator. However, it is interesting to note that a wide range in output space there exists where *quasi*-most productive scale size is attained. Increasing returns to scale become rapidly exhausted and after around 20,000 customers and 40 millions of cubic meters the curve of scale elasticity flats on unitary value.

From a regulatory viewpoint our main conclusion is that the search of better productivity conditions could be based on merging processes that involve the smallest units serving less than 20,000 customers or delivering less than 40 millions of cubic meters, that is the lower bounds of the area where *quasi*-constant returns to scale hold. Given the extreme fragmentation of the service on the Italian territory, this merging process could contribute to substantially reduce the existing number of distributors. Governmental interventions should encourage the concentration process that has already took place during the 90s. Indeed, the recent liberalisation of the gas industry seems addressed to grant a strategic valence to the scale set up.

Finally, since the critical size required to exploit economies of scale is not so large and substantially inferior to the optimal dimension, the concentration process in the distribution gas industry can be viewed as a very “attainable” objective.

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