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Size, density and costs of network services - the case of the distribution of electricity in Italy

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The classical approach to the effects of territorial context in defining costs of distibution in network services (as the distribution of electric energy), often makes confusion between scale and density economies.

The consequence is a wrong definition of some variables and a misleading specification of the model. The result is a heavy underestimationf ot the role of the territorial context in shaping the curve of the average spatial cost of distribution.

A Translog function is used to estimate the role of territorial characteristics in defining costs.

We find, for the Italian case, that the share of cost due to a "non optimal territorial context" is about 40% on average (with a maximum of 68% in low density and scattered areas).

There is a trade off between a policy equalizing spatial prices and a choice of minimize costs in central areas.

1. Goals and method

The aim of this paper is to estimate the impact of territorial features on the costs of distributing electricity. For this purpose a distinction should be drawn between scale economies and density economies. The former concern technology, the latter relate to the characteristics of the service and of the territory. The evidence that the territory heavily influences distribution costs raises policy problems of especial importance in cases like Italy, which is now privatizing a distribution service operated (quasi-) monopolistically by ENEL. The results may also be applied to similar cases, like gas or water, where a service is 'networked' across a territory.

2. The data and the main variables

The database used concerns the 'ENEL zones' (ENEL is the National Electricity Board), these being the operational units engaged in the distribution of electricity in 1996. At that time ENEL was based on 147 zones which covered the entire national territory.

Besides ENEL, electricity is also distributed in Italy by numerous municipal enterprises, especially in urban centres. Consequently, the figures given do not refer to the total service in terms of users, power lines and employees, nor to its overall cost, because account is not taken of the municipal enterprises. However, the homogeneity of the distributing company means that the objective of determining whether the cost of the distribution service depends on the territorial characteristics.

2.1. Costs and the size of the market

In 1996, ENEL divided its **costs** into direct and indirect. The former include expenditure on personnel, the purchasing of materials, amortization, taxes and rents. The main items in the latter category are additional outlays, financial charges, and running costs not distributable among the various phases of service delivery.

The total direct distribution costs of the 147 zones amounted to 6,998.6 billion lire, of which 48.8% consisted of expenditure on personnel, 44.5% on amortization, and the remaining 6.5% of other costs (third-party services, general expenses, supplies and taxes).

In the literature, the **size** of an individual electricity company's market, or its utility distribution, is usually described in terms of the number of customers served or the number of GWh sold. The two variables yield very similar information (the coefficient of correlation is 0.81 for the database used here). Differences between the two variables may be due to the diversity of the types of customers served. Following the majority of studies on the subject, we use the number of customers served as the output variable. Out of a population of around 57 million people (as said, the figures are for 1996 and are summarized in Table 2.1), the 147 ENEL zones comprised 28.7 million customers, for an installed power capacity of 1,571 GW and a delivery capacity of approximately 164.5 TWh. The average size of a zone was 195 thousand customers (eight zones had more than 350 thousand customers).

Tabella 2.1 - *Statistics for the main variables*

	Minimum	Maximum	Sum	Average	St. Deviation
Total costs for a zone*	16,421	176,542	6,998,547	47,609	19,443
costs of network amortization*	7,488	73,760	3,115,724	21,195	8,322
personnel costs*	7,867	89,156	3,411,496	23,207	10,521
other costs*	888	13,626	471,327	3,206	1,739
Customers (thousands)	55.8	689.4	28,726.3	195.4	93.5
GWh	247	3,767	164,451	1,119	667
Employed power (MW)	2,700	37,316	1,571,339	10,689	5,558
Total km of power lines	939	16,489	991,529	6,745	2,550
Km of medium-tension lines	244	4,876	317,704	2,161	861
number of employees	124	1,087	45,185	307	132
Km power lines/employees	4.7	39.1	--	21.9	7.1
Km of power lines per 1000 customers	10.22	70.27	5508	37.8	13.22
Employees per 1000 customers	0.99	2.87	241.35	1.64	0.33
Amortization per Km of power line	2.0	9.1	--	3.14	0.93
Average pay of employees*	63.4	93.3	--	75.5	4.96
Population	92,152	2,645,322	57,369,371	390,267.8	n.d.
Density: inhabitants per sq km	37	8,919			
Territory indicator (T)	1	2,718	--	1.97	1.21

* millions of lire; number of cases (zones) = 147

2.2. The distribution network, employees and factor prices

As in many other studies, the length of the **distribution network** is the indicator used here to measure capital.

In 1996, the total length of the ENEL network was around 990 thousand km of power lines, with an average length per zone of 6,700 km. The length of the medium-tension network was just under one-third of the total (318 thousand km).

Many areas of similar size in terms of customers or population have very different lengths of network. This is because some of them serve urban centres, others cover more diversified territory comprising urban centres of different sizes and broad expanses of countryside. Consequently, the ratio between the length of of power lines and the number of customers – which measures capital intensity (K/Y) – varies considerably. In general, capital intensity correlates much more closely with the density of the territory than with the size of the market in terms of customers served.

In 1996 ENEL employed more than 45 thousand **workers** in its distribution service, with an average of 307 per zone. The number of employees depended closely on the amount of customers in a zone (the coefficient of correlation was 0.89).

In studies on distribution, the price of the **capital factor** is defined either as the unitary cost of capital or as amortization per unit of capital. Here the latter definition is used.

The price of the **labour factor** is often set equal to average pay per worker, and this practice is followed here. The price of the labour factor is very homogeneous in the Italian labour market.

2.3. The territory

In the literature, the **characteristics of the territory** are often approximated by density (customers per sq km, or inhabitants per sq km). Territories differ in terms of both their physical or geographical features and the different localization and settlement 'histories' of the population and its activities. The relation between the two dimensions – geographical and historical – has a number of complex aspects which should be clarified.

Often (Pred 1966), the factors that discriminate among territories concern initial advantages of physical or geographical type. These factors, which we label 'first nature' (Cronon 1991; Krugman 1993) can be approximated by such physical features as hilliness, closeness to/distance from the sea, average altitude, etc.

However, this does not entirely account for the difference among territories. Initial advantage tends to generate localization factors of another kind; existing locations exert considerable influence on subsequent ones, and once processes of concentration and densification have begun they are able to perpetuate themselves on their own ('second nature factors').

The resulting settlement of activity and population on the land is therefore due to a process with positive feedback: the population, enterprises and institutions choose locations with good access to markets, and these are exactly the locations that other enterprises have chosen. This process, which is cumulative in character, gives rise to non-deterministic equilibria resulting from historical processes and 'accidents'.

In the case of electricity distribution, where 'production' of the service takes place by extending the network across the territory (and not by transporting a good), density economies are particularly important. If the population (assumed for convenience to be uniformly distributed across the territory) of a particular distribution area increases in density, there is a much less than proportional increase in some or all of the production factors that constitute the 'network'. The consequent reduction of average costs is due to economies of density.

Economies of scale and density may coexist. If extending the area served by a distribution network brings about a reduction in average costs, this may also be due to more efficient use of capacity and to the presence of a factor whose use remains the same as size increases. These can be called spatial economies of scale (Filippini 1996) arising from the homogeneous growth of size and the area served.

The economies of scale described may also arise following densification of the distribution network. These are scale economies associated with variation in density, and it is necessary to know that both exist and distinguish them. An inability to do so may cause – as we shall see – poor specification of the model and ambiguous results.

Against this background, variable T correlated to D (density measured as inhabitants/sq km) was defined as an indicator of territorial features in the following manner:

$$T = \left(\frac{\mathrm{MAX(D)}}{\mathrm{D}}\right)^{\frac{1}{\log(\mathrm{MAX(D)}) - \log(\min(\mathrm{D}))}}$$

T assumes value 1 in the area of maximum density and value ***e*** in the area of minimum density. The average value of variable T is 1.97 (see Table 2.1), which shows that the 'average' zone is much less favoured, compared to dense territories.

2.4. The main variables classified according to size

Total costs (which comprise amortization costs, personnel costs and other costs) are closely correlated with size: the coefficient of correlation, r, is 0.90. Amortization costs and personnel costs are also closely correlated with size, and so too are other costs, but to a slightly lesser extent (r = 0.78).

The relation is much less clear-cut between the size of the zone and the total use of the **capital factor**, which is represented here by km of medium- and low-tension lines. The value of r is low (0.47).

There is a close relation (r = 0.89) between number of **employees** and size of the zone.

2.5. The main variables classified according to the characteristics of the land (T)

As we have seen, the **total costs** of distribution depend closely on size, but the relation with territorial characteristics is weak.

A similar result is obtained by analysing the relationship between **capital factor** (km of power lines), **labour factor** (number of employees) and territory. The total quantity of factors depends more on the level of output than on the nature of the territory. The values for the r statistic are low for both relations. The coefficient of correlation is negative because less dense areas are also of smaller size.

By contrast, the territory heavily influences the **average intensity in the use of the factors**, which is measured here by ‘km of power lines per 1000 customers’ (K/Y) and by ‘employees per 1000 customers’ (L/Y). The relation between these variables and the territory is very evident: as regards capital, the correlation ratio, r, between capital intensity (K/Y) and T is 0.77. The relation between labour intensity (L/Y) and territory is less strong (r = 0.54).

The **price of the labour factor** (average pay of employees) does not seem to be correlated with territorial variables.

The **price of the capital factor** (amortization per km of power line) is instead much more sensitive to the features of the territory. The relation is an inverse one, because unitary amortizations are higher in dense areas with complex and tight networks. Rural areas seem to have less ‘cared-for’ networks than urbanized and dense areas. Also the type of technology used (overhead power lines or underground cables) changes.

Finally, a classic problem in the specification of the model is the **substitutability of the production factors**. Descriptive analysis of the data does not yield decisive evidence. The ratio between K and L displays a sufficiently linear pattern (with the exception of metropolitan areas), which may signify both a Leontiev technology, i.e. with quasi-fixed coefficients, and a technology with substitutability and quasi-stable relative prices.

3. Analysis of the literature

3.1. Some cases in the literature

Studies on the distribution costs of electrical power often seek to ascertain the existence of economies of scale in the delivery of the service and of an efficient scale in the company and the organization of its activity.

The studies by Christensen and Greene (1976), Neuberg (1997), Roberts (1986), Giles and Wyatt (1993) and Filippini (1996) use this approach. Roberts (1986) and Giles and Wyatt (1993) also analyse economies of density in order to establish the actual economies of scale.

Roberts (1986) starts from a different definition of scale economies. He gives three definitions for what he calls “economies of density and size” connected with relative variation in costs with change in, respectively, ‘output density’ (customer density and size of the area remaining equal), ‘customer density’ (output per customer and geographical size of the area remaining equal) and ‘size of the area’ (the other two variables remaining equal). Using a translog and the cost function, Roberts states that, in the USA, reductions in the average cost derive from an increase in consumption by existing customers (growth of output density) but not from an increase in the number of customers served.

Filippini (1996) analyses the presence of economies of scale and economies of plant utilization in the case of electricity distribution in Switzerland. The database is a panel of 39 municipal enterprises for the period 1988-91. Filippini defines output as the quantity of electricity sold, and capacity as employed power (a measure for the service's 'capacity'). According to Filippini, the use of power as a variable indicative of capital, closely correlated with the growth of output, may give rise to problems of multicollinearity in the case of panel data. He concludes that it is relatively certain that economies of scale exist at every size level.

Other studies in similar contexts have used power as a proxy for capital in order to ascertain the existence of utilization economies (and over-capacity diseconomies).

3.2. Two recent studies on Italy

Scarpa (1998) estimated scale economies in distribution. On the basis of a Cobb-Douglas production function, and using the same database as this study, Scarpa regressed total cost on the variables of price and output, using both the 'customers served' (Y) variable and the 'electricity sold' (GWh) variable as indicators of output. The price of the labour factor (p_L) was defined as the ratio between labour costs and number of employees for each zone. The price of the capital factor was defined – following Filippini (1996) – as the ratio between amortization costs and employed power.

The zone costs not explained by the previous relation were regressed on structural and territorial variables: the size of the area (A), the ratio between the total number of connections and disconnections and the number of customers served (IntCL), the total number of connections and disconnections (Int), the average duration of interruptions in the service (DUR).

From the results obtained Scarpa infers the presence of scale economies.

Our own estimation of Scarpa's (1998) equations shows that, in Italy, the costs due to the territory range from less than 1% to 12% according to the zone, with an overall average of around 3% of total costs.

The aim of the study by Gullì (2000) is to separate efficient management from the effects of exogenous factors related to structural features like size and the characteristics of the territory.

As regards output, Gullì maintains that the most representative variable for a costs analysis, is the number of customers served.

Owing to the homogeneity of management (there is only one company), Gullì excludes the prices of the production factors capital and work, because differences in those prices are due to structural not corporate conditions. This enables him to use a linear non-logarithmic regression. As regards the characteristics of the territory, Gullì hypothesises that these are translated into density economies described by the length of the medium-tension power lines.

Gullì's conclusion is that there are no substantial economies of scale at the operational level of the zone. Instead, there are substantial economies of density, although diseconomies may arise in very dense areas because of the complexity of the network.

4. The model

Many of the results in the literature seemingly suggest that the territory plays a relatively residual role in the definition of costs. This conflicts with the descriptive analysis of the data conducted in the previous section, which showed that the use of the factors (both labour and, especially, capital) depends substantially on the characteristics of the territory.

The former result is obtained when the territory is considered to be a variable unconnected with technology and the use of the factors, as in Figure 4.1.

Figura 4.1 – *The 'classic' approach to estimation of costs of the territory*

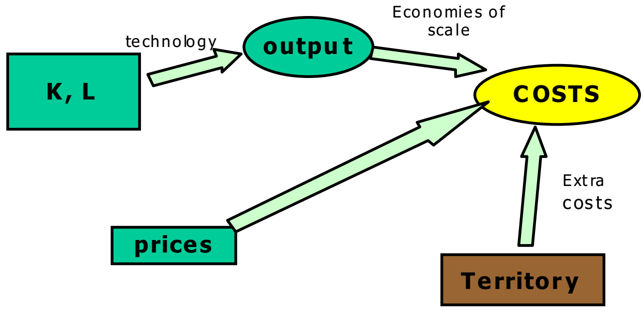
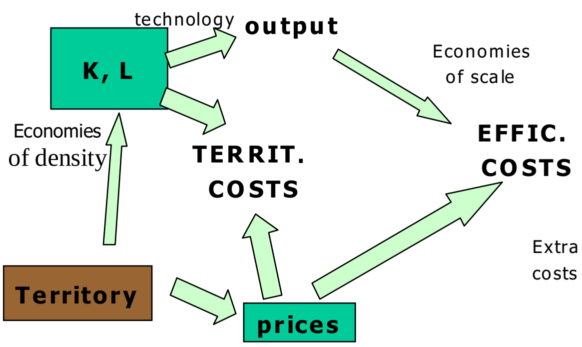


Figura 4.2 – *The 'territorial' approach to the estimation of costs*



The approach used here is illustrated by Figure 4.2, which contrasts with Figure 4.1 by highlighting economies of density and their influence on the technological variables and the use of the factors.

The aim of the analysis that follows, therefore, is to estimate the component of territorial extra costs with respect to an efficient situation; by 'efficient costs' is meant those that should exist in an 'optimal' territory taken as the benchmark case. In an 'optimal' territory, the quantity of factors used will be 'efficient'; in a sub-optimal one it is necessary to add factors to deal with relative diseconomies due to the territory. In the production function, the 'efficient' capital and labour factors are hypothesised as being connected to the actual ones (K and L) according to the following relation:

[*i*] $K = K_E \cdot f_1(T);\ L = L_E \cdot f_2(T)$

In the 'optimal' situation obviously,

[*ii*] $K = K_E,\ L = L_E$, i.e. ($f_i(T=1)=1$; (i = 1, 2))

In the production function, actual output is yielded by the 'efficient' factors:

[*iii*] $Y = f(K_E, L_E) = f(K, L, g(T))$ $\left(\frac{\partial g}{\partial T} < 0\right)$

The model may now be generalized by means of a translog cost function, and by admitting substitutability among the factors, the dependence of some variables on the territorial context, and hypotheses of the non-homotheticity and non-homogeneity in the output of the production function. The empirical model is a translog approximation of the cost function which takes the following form:

[4.1]
$$\ln CT = \alpha_0 + \sum_i \alpha_i \ln p_i + \frac{1}{2}\sum_i\sum_j \gamma_{ij}(\ln p_i \ln p_j) + \alpha_Y \ln Y + \frac{1}{2}\gamma_{YY}(\ln Y)^2 + \\ + \sum_i \gamma_{iY}(\ln p_i \ln Y) \quad (i,\ j = 1,\ 2)$$

where it is assumed that $\gamma_{ij} = \gamma_{ji}$.

In order to introduce the variable describing the territory into [4.1], we assume that:

- function [4.1] refers to the 'efficient' description of the output and capital price variables (where the term 'efficient' is used for a technology associated with an 'optimal' territory):
- the variables in [4.1] may therefore be substituted with the 'measured' variables that take account of the territory; in particular:

[4.2] $\ln Y_E = \ln Y + z \ \ln T$

[4.3] $\ln p_{K_E} = \ln \overline{p}_K - \gamma_p \ln T$

With these latter two relations and after some steps, [4.1] becomes:

[4.4]
$$\ln CT = \alpha_0 + \alpha_L \ln p_L + \alpha_K \ln p_K + \frac{1}{2}\gamma_{LL}(\ln p_L)^2 + \frac{1}{2}\gamma_{KK}(\ln p_K)^2 + \\ + \gamma_{LK} \ln p_L \ln p_K + \alpha_Y \ln Y + \frac{1}{2}\gamma_{YY}(\ln Y)^2 + \gamma_{LY} \ln p_L \ln Y + \\ + \gamma_{KY} \ln p_K \ln Y + \alpha_T \ln T + \frac{1}{2}\gamma_{TT}(\ln T)^2 + \gamma_{LT} \ln p_L \ln T + \\ + \gamma_{KT} \ln p_K \ln T + \gamma_{TY} \ln T \ln Y$$

Associated with [4.4] are the following two equations relative respectively to the share of labour cost in the total (S_L) and to the share of capital cost in the total (S_K); equations that have been derived by applying Shepard's lemma to [4.4]:

[4.5] $$S_L = \alpha_L + \gamma_{LL} \ln p_L + \gamma_{LK} \ln p_K + \gamma_{LY} \ln Y + \gamma_{LT} \ln T$$

[4.6] $$S_K = \alpha_K + \gamma_{KK} \ln p_K + \gamma_{LK} \ln p_L + \gamma_{KY} \ln Y + \gamma_{KT} \ln T$$

Since the function must be homogeneous of degree 1 in prices, the following constraints must be imposed:

$$\sum_i \alpha_i = 1 \quad \sum_i \gamma_{ij} = \sum_j \gamma_{ji} = \sum_i \sum_j \gamma_{ij} = 0 \qquad \sum_i \gamma_{iY} = 0 \quad \text{and} \quad \sum_i \gamma_{iT} = 0$$

After imposing the constraints and defining p = p_L/p_K, [4.4] becomes:

[4.7] $$\ln\left(\frac{CT}{p_K}\right) = \alpha_0 + \alpha_L \ln p + \frac{1}{2}\gamma_{LL}(\ln p)^2 + \alpha_Y \ln Y + \frac{1}{2}\gamma_{YY}(\ln Y)^2 + \gamma_{LY} \ln p \ln Y + \\ + \alpha_T \ln T + \frac{1}{2}\gamma_{TT}(\ln T)^2 + \gamma_{LT} \ln p \ln T + \gamma_{TY} \ln T \ln Y + \theta\, DUMSUD$$

where DUMSUD is a dummy variable introduced to take account of differences between northern and southern Italy in the use – in particular – of the labour factor.

In estimation of the model, equation [4.7] is used together with the equation relative to the share of labour cost in the total (SL), which after the constraints have been imposed becomes:

[4.8] $$S_L = \alpha_L + \gamma_{LL} \ln p + \gamma_{LY} \ln Y + \gamma_{LT} \ln T$$

5. The results of the analysis

5.1. Estimation of the cost function[1]

The translog function does not impose *a priori* constraints on the possibility of substitution among the factors and allows economies of scale and density to vary with the level of output and with the characteristics of the territory. The cost function is estimated together with the factor demand equations (cost shares). In the initial specification of the model, the constraints of symmetry and of homogeneity of degree 1 in factors prices are imposed. These constraints make one of the cost share equations redundant, so that the system estimated consists of the cost function and the cost share relative to the labour factor (equations [4.7]-[4.8])[2].

Table 5.1 gives the results of estimation of three specifications of the model, of which the second and third are obtained by imposing successive restrictions on the first specification.

The likelihood ratio test was used to verify the validity of these successive restrictions.

Model 1 is the non-restricted specification against which the other specifications are compared. The results are set out in Table 5.2. Analysis of the results of the empirical verification shows that neither the hypothesis of separability between factor prices and output (model 2), nor the hypothesis that the coefficients γ_{YY} and γ_{TT} are nil (model 3), can be rejected. Inclusion in the model of the quadratic terms relative to output and the territory, in fact, creates problems of multicollinearity among the variables.

Tabella 5.1 - *Estimation of the cost function (1996)* [a]

Coefficients	model 1	model 2	model 3
α	1.8116 (1.0078) [b]	1.9781 (1.118)	1.4371 (3.815)
α	0.4749 (7.2714)	0.3996 (10.223)	0.3998 (10.903)
α	0.5251 (8.0408)	0.6007 (15.368)	0.6003 (16.374)
γ	0.07874 (5.7239)	0.0768 (5.639)	0.0762 (5.824)
γ	0.07874 (5.7239)	0.0768 (5.639)	0.0762 (5.824)
γ	-0.07874 (-5.7239)	-0.0768 (-5.639)	-0.0762 (-5.824)
α_Y	0.8858 (1.4305)	0.8760 (1.426)	1.0921 (15.138)
γ	0.0475 (0.4346)	0.0408 (0.375)	
γ	-0.0138 (-1.3523)		
γ	0.0138 (1.3523)		
α	3.5442 (2.9711)	3.6228 (3.062)	3.5373 (6.675)
γ	-0.1264 (-0.2163)	-0.1801 (-0.301)	
γ	-0.1916 (-6.7887)	-0.1745 (-6.674)	-0.1748 (-6.898)
γ	0.1916 (6.7887)	0.1745 (6.674)	0.1748 (6.898)
γ	-0.3605 (-2.0638)	-0.3828 (-2.191)	-0.3867 (-3.846)
θ	0.1324 (5.3992)	0.1324 (5.410)	0.1305 (5.405)
$\tilde{R}^2$ [c]	0.9338	0.9329	0.9327
constraints	none	1	3
log likelihood	366.7200	365.6854	365.4868

[a] : Use was made of FIML iterative estimation procedures. These are invariant with respect to the cost share equation, which was omitted from the estimation.
[b] : The *t* statistics associated with the coefficients estimated are given in brackets.
[c] : This statistic corresponds to an R^2 measure *generalized* to the system (Berndt, 1991, p.468).

A further restriction of the model which would turn it into a Cobb-Douglas specification is not admissible on the basis of the likelihood ratio test (see the bottom row of Table 5.2).

Model 3 is taken as the reference model for both the description of the results (although reference will sometimes be made to models 1 and 2) and the simulations set out in the next section.

Tabella 5.2 - *Likelihood ratio test among the various specifications of the model*

model	log-likelihood	$-2\ln\lambda$ statistic	degrees of freedom	critical value $\chi^2_{0,95}$
model 1	366.7200			
model 2	365.6854	2.0692	1	3.84
model 3	365.4868	2.4664	3	7.82

Cobb- Douglas	330.7771	71.8858	6	12.59

The results of the estimations are satisfactory. The three specifications of the model account for more than 93% of the generalized variance of the system's dependent variables.

A positive variation of T (i.e. a worsening of the territory's characteristics) increases the share of capital costs $(\gamma_{KT} > 0)$ and decreases the share of the labour cost.

One notes a significant relation between size and density $(\gamma_{TY} < 0)$: the areas of largest size in terms of output are also dense (low T), and this explains the negative value of the coefficient; the increase in the costs associated with a non-dense territory (high T) is attenuated by non-large size.

The Allen partial substitution elasticity was calculated (σ_{LK}) as well as the elasticity of factor demand to price $(\eta_L \text{ e } \eta_K)$. The results are given in Table 5.3.

Tabella 5.3 - *Elasticity of substitution among factors and elasticity to price*

	model 1		**model 2**		**model 3**	
	range	**average**	***range***	**average**	***range***	**average**
σ_{LL}	M 0.6850 m 0.6727	0.6832	M 0.69525 m 0.6826	0.6936	M 0.69525 m 0.68255	0.6936
η_L	M –0.2713 m –0.3711	-0.3263	M –0.2732 m –0.3746	-0.3312	M –0.2730 m –0.3746	-0.3312
η_K	M –0.3115 m –0.4015	-0.35695	M –0.3187 m –0.4094	-0.3624	M –0.3186 m –0.4095	-0.3624

As required by the theory, we also controlled for monotonicity and the quasi-concavity of the cost function estimated. The positive values of the cost shares estimated ensure that the function is monotonically increasing, and the negative signs of η_L (-0.33 around the average, with a range from –0.27 to –0.37) ensure that the Hessian of the second derivatives of the cost function with respect to prices respects the condition of quasi-concavity of the function.

The elasticity of substitution among factors, σ_{LK}, is 0.69 on average (model 3). Its value varies very little among observations and is also very similar in models 1 and 2. It is a relatively high value. In dense areas there is an increase in the average prices of both capital and labour, although the former increases to a much greater extent. The relative price thus becomes more favourable to the labour factor. On the other hand, the intensity of capital and labour decreases in dense areas compared to those dispersed by economies of density. The decrease is much more marked for the capital factor. This accounts for the 'factual' result of a certain amount of substitutability among the factors, although in our opinion this is due more to the characteristics of the territory (which guide choices in factor endowment) than to the underlying basic technology.

Price-elasticity of the factors is negative and displays, as expected, low price-elasticity of demand for the factors, which is slightly less for labour (η_L = -0.33: model 3) than for capital (η_K = -0.36: model 3).

5.2. Economies of scale and density

If:

[5.1] $$\varepsilon_C = \frac{\partial \ln C}{\partial \ln Y}$$

Using notation similar to Roberts (1986), we may write:

[5.1b] $$\varepsilon_C = \frac{\partial \ln C}{\partial \ln Y} = \varepsilon_{CY} + \varepsilon_{CT}\frac{\partial \ln T}{\partial \ln Y}$$

ε_{CY} is the elasticity of costs to output, when the territorial context remains unchanged. It is a short-run elasticity of costs to output. Its reciprocal measures short-run ‘pure’ economies of scale similar to the economies of size described by Roberts (1986).

ε_{CT} is the sensitivity of costs to a variation in the territorial context, keeping the number of customers constant (loss of density). Finally, $\frac{\partial \ln T}{\partial \ln Y}$ is the variation in the territorial context consequent on a size increase (size growth is accompanied by a variation in density except in the special case of homothetic growth).

An indicator of ***scale economies with unchanged territorial structure*** (consider a zone which acquires customers increasing its area proportionally) is therefore:

[5.2] $$\text{SCALA} = \frac{1}{\varepsilon_{CY}}$$

An indicator of **‘pure’ economies of density**, i.e. of economies arising from variation in territorial characteristics, keeping the number of customers constant, is:

[5.3] $$\text{EDENS} = \frac{1}{\varepsilon_{CT}\frac{\partial \ln T}{\partial \ln Y}}$$

This is interesting as an indicator of the opportuneness of defining more territorially compact zones, bearing in mind, however, that defining smaller zones means abandoning the less attractive parts of the territory and therefore generating problems of equity in service delivery.

Finally, an overall indicator of ***economies of scale and density***, which are interdependent, is:

$$\text{[5.4]} \qquad SD = \frac{1}{\varepsilon_{CY} + \varepsilon_{CT} \frac{\partial \ln T}{\partial \ln Y}},$$

in which 'pure' economies of scale are added to those of density ($\frac{\partial \ln T}{\partial \ln Y} > 0$), or, vice versa, the former are attenuated or eliminated by the latter ($\frac{\partial \ln T}{\partial \ln Y} < 0$).

Table 5.4 sets out the values of the three indicators for models 1, 2 and 3 presented above. In order to estimate SD (overall economies of scale and density), hypothesised was the worst case of a size increase associated with a proportional loss of density.

Tabella 5.4 - *Elasticity of scale and density*

	model 1		**model 2**		**model 3**	
	range	**average**	***range***	**average**	***range***	**average**
SCALE	M 1.42 m 0.88	1.19	M 1.46 m 0.89	1.22	M 1.42 m 0.92	1.21
EDENS	M 9.45 m 3.55	5.72	M 10.13 m 3.56	5.85	M 9.9996 m 3.599	5.78
SD*	M 1.10 m 0.77	0.98	M 1.13 m 0.78	1.00	M 1.12 m 0.82	0.996

* If size growth is associated with a proportional decrease in density

5.3. Cost differentials due to the configuration of the territory

The calculation of the share of total costs due to the territory (q_T) was performed by estimating the costs that would have been sustained in an 'optimal' territorial context (T=1), with the other zone characteristics remaining the same. This amounted to setting all the elements in which T appears in [4.7] to zero. In this optimal territorial context, the zone costs would not have been actual costs, but 'efficient' ones (CTE_i).

Thus, defining:

$$\text{[5.5]} \qquad \ln Q = \ln CT - \ln CTE = \alpha_T \ln T + \frac{1}{2}\gamma_{TT}(\ln T)^2 + \gamma_{pT} \ln p \ln T + \gamma_{TY} \ln T \ln Y$$

because $q_T = \frac{CT - CTE}{CT} = 1 - \frac{CTE}{CT}$ one obtains:

$$\text{[5.6]} \qquad q_T = 1 - \frac{1}{Q}$$

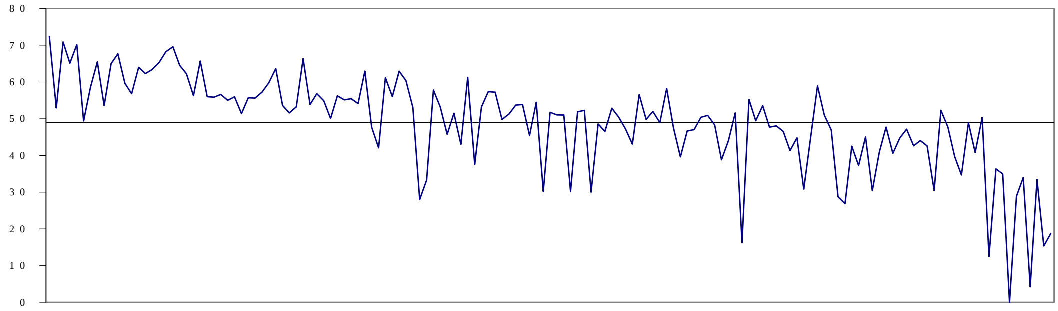
The results are given in Table 5.5. Overall, it emerges than 48% of costs on average are due to the configuration of the territory. In less favoured areas, this proportion exceeds 2/3 of costs. The three models yield very similar results. Also the distribution of the cost shares due to the territory in the various zones ordered by customer size shows substantially the same results. The share of territorial costs is related to size (number of customers), since there is a correlation between the latter and the characteristics of the territory.

Tabella 5.5 – *Share of costs due to the territory on total costs*

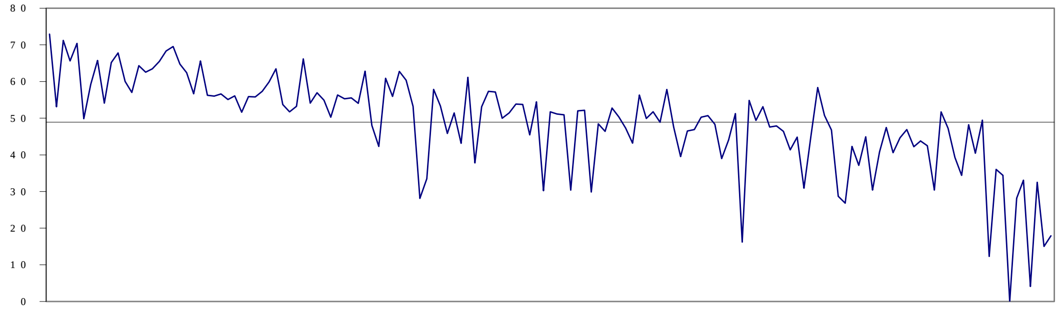
model	average percentage incidence	max
model 1	48.95%	72.43%
model 2	48.91%	72.92%
model 3	47.48%	72.41%

Figura 5.1 – *Percentage shares of the costs of the territory on the of the zone costs and average value (the zones are ordered in increasing size)*

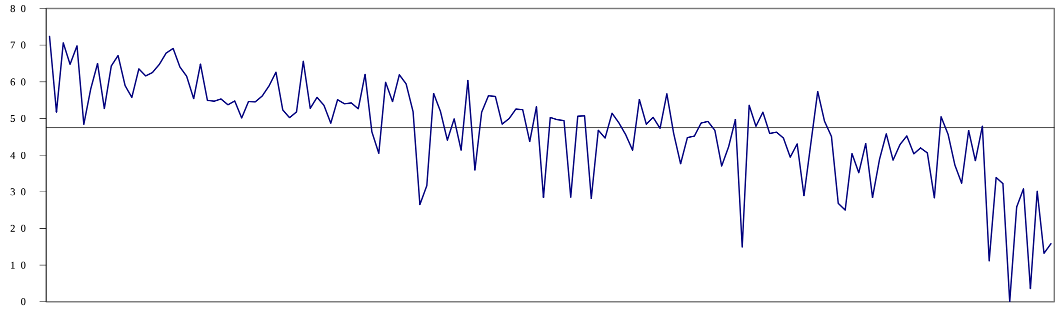
i) model 1



ii) model 2



iii) model 3



6. Concluding remarks and policy considerations

Italy is now introducing competition between utilities in the electricity distribution service. The documents of the authority that supervises this service recognize that it is characterized by different costs according to the geographical area in which it operates, and that these differences may depend on the differing organization of the utilities or on the differing characteristics of users and the territory served.

Debate is in progress on the most suitable system to equalize the utilities by compensating for the differences in costs due to factors not directly under their control.

The aim of this paper has been to contribute to this debate. It has shown that the territorial configuration heavily influences the electricity distribution service. Differences among dense and compact areas compared to disadvantaged areas, in terms of average costs, may be of various orders of magnitude. A territory with non-optimal features is penalized in terms of economies of density and, normally, scale as well, because less dense areas are usually also small ones in terms of number of users. From a factual point of view, the two types of economies are interconnected in that territorial configuration is the cause of both the economies of density and the economies of scale that can be exploited (in certain territorial contexts, moreover, the latter can only be exploited at the expense of the former).

Highlighting the supplementary costs due to the territory may suggest – as regards the equalization of service supply – policies for customer concentration. However, the saving on costs would be off-set by the cost of abandoning both the territory (with the deterioration consequent on this) and the economic activities connected therewith. ‘Design’ of the service and of networks, however, should bear in mind the different opportunities, costs or benefits associated with them.

APPENDIX A - The variables used

Y	Number of LT and MT customers (/ 1.000)
GWh	Medium- and low-tension energy sold
L	Number of employees
K	Length in km of the distribution network
KmLinee_MT	Length in km of the medium-tension network
AMM	Amortization costs (millions of lire)
CL	Total cost of personnel (millions of lire)
OC	Other costs: third-party services, general expenses, supplies and taxes (millions of lire)
CT	Amortization costs + labour cost (millions of lire)
CTOT	Total costs: amortization + labour cost + other costs (millions of lire)
D	Inhabitants per km^2 (1996 values) (D)
T	Characteristics of the territory (calculated using D)
SUP	Surface areas of the zones (in km^2)
p_K	Amortization cost per km di power lines
p_L	Average pay per employee
DUMSUD	*Dummy* for southern Italy: 1 for distribution zones located in the South; 0 for the others
INT_K	Km of power lines per 1000 customers
INT_L	Employees per 1000 customers
S_L	Share of labour costs on total costs
S_K	Share of amortization costs on total costs

Footnotes

1 The estimates were performed using the Eviews 3.1 econometric package produced by Quantitative MicroSoftware.

2 Appendix A contains the definitions of the variables used.

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