Società italiana di economia pubblica
XIV CONFERENZA
IL FUTURO DEI SISTEMI DI
WELFARE NAZIONALI TRA INTEGRAZIONE EUROPEA E DECENTRAMENTO REGIONALE
coordinamento, competizione, mobilità
Pavia, Università, 4 - 5 ottobre 2002

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pubblicazione internet realizzata con contributo della COMPAGNIA di San Paolo

società italiana di economia pubblica
dipartimento di economia pubblica e territoriale – università di Pavia

SCOPE AND SCALE ECONOMIES IN MULTI-UTILITIES: EVIDENCE FROM GAS, WATER AND ELECTRICITY COMBINATIONS

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Second draft, July 2002

Abstract

Within the recent debate on liberalisation of local public services, the paper investigates the cost properties of a sample of Italian public utilities providing in combination gas, water and electricity. The estimates from a Composite cost function econometric model (Pulley and Braunstein, 1992) are compared with the ones coming from other traditional functional forms such as the Standard Translog, the Generalized Translog, and the Separable Quadratic. The results highlight the presence of global *scope* and *scale* economies only for multi-utilities with output levels lower than the ones characterising the 'median' firm. This indicates that relatively small specialised firms would benefit from cost reductions by evolving into multi-utilities providing similar network services such as gas, water and electricity. However, the above positive impact is not confirmed for larger-scale utilities, suggesting that the recent diversification waves of leading companies could be explained by factors other than cost synergies. Thus, the welfare gains that can be reasonably expected from such examples of horizontal integration of giant firms, if any, are likely to be very low.

Keywords: Multi-Utilities, Scope and Scale Economies, Composite Cost Function.

JEL Code: L97, L5, L21, C3.

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1. Introduction

In the recent years there has been an increasing tendency for utilities to become providers of many network services. The British Gas Group (UK) is active in gas, telecommunications, and electricity, while RWE (Germany), apart from its oil and chemical divisions, provides electricity, gas, and waste management services. Endesa (Spain), Lyonnaise des Eaux (France) and its subsidiaries Electrabel and Tractebel (Belgium), Enron (USA), VEBA (Germany), just to cite some examples, combine electricity, gas, water and telecommunications. Italian firms do not represent an exception to this general horizontal integration trend. Enel (incumbent monopolist in the electricity market) and Edison (the largest private energy company) provide in conjunction electricity, water, gas and telecommunications services, while ENI (incumbent monopolist in the oil and gas industries) is active in gas, water and telecommunications.

One of the reasons of the emergence and growth of multi-utilities is to be found in the privatisation and liberalisation processes which at different paths all Governments of industrialised countries have been promoting in local public services. On the one hand, incumbent monopolists are looking for new opportunities of value creation by entering into new related sectors to counterbalance the loss in market share bring by the new more competitive scenario. On the other hand, new entrants are exploring the opportunity to provide services that were previously reserved to publicly owned national or local monopolies. Finally, such a diversification strategy may be appealing for private and public local utilities too. The latter may find it appealing to transform their structure into a multi-utility network partially as a reaction to the limited growth prospects of their core business, and partially because they tend to emulate the behaviour of large incumbent firms.

Another reason which pushes firms to diversify is the increasing convergence and relatedness among network markets. At the generation stage, gas will be the primary fuel of new power generation capacity, while at the distribution stage multi-utilities have already started to offer their services as bundled products.

This restructuring/reorganising of network service activities may have thus remarkable repercussions on the tariffs and on the quality of the service provided. By exploiting cost synergies among utility services, multi-product firms may be able to provide customers with a better service at a lower price. However, the possibility to sell bundles of products can increase the market power of diversified utilities and curb the ongoing competitive process together with its potential welfare benefits.

This paper addresses the above arguments by analysing the cost function of a sample of Italian utilities which were providers, in combination or as specialised units, of gas, water and electricity services in the years 1994, 1995 and 1996. Given the presence in the sample of specialised, two-output and three-output firms, we can investigate the presence of economies of scope for multiproduct utilities. Differently from the standard literature, which uses the Translog Cost Function or the Generalised (Box-Cox) Translog Cost Function, we test the advantage of using the Composite Cost Function model recently introduced by Pulley and Braunstein (1992), which appears to be more suitable for analysing cost properties of multi-product firms.

The remaining of the paper is organised as follows. Section 2 shortly reviews the theoretical literature on diversification and the few empirical studies addressing the phenomenon of diversified network utilities. Section 3 develops the Composite Cost Function model (Pulley and Braunstein, 1992) upon which is based the subsequent econometric analysis. Section 4 illustrates the main characteristics of our sample and shows some descriptive statistics concerning the variables included in the cost model. Section 5 presents the results of our estimates and Section 6 concludes.

2. Diversification of Utilities

Following Montgomery (1994), one can identify three main motivations behind corporate diversification strategies. The *resource theory* (Penrose, 1959) argues that firms enter new industries by building on their accumulated set of firm specific assets. The presence of indivisibilities in the use of such resources pushes firms to enter new related businesses when there are constraints to grow in the core activities. Moreover, the presence of transaction costs implies that assets are better exploited via the internalisation of new activities rather than by selling the excess amount on the market.

While according to the resource view diversification is a strategy which enables the exploitation of scope economies, the *agency view* sees diversification as driven by the desire to increase managerial power and prestige (Marris, 1964). Managers have an information advantage over shareholders and can use the cash generated in the firm to finance entry into new industries (Jensen's free cash flow hypothesis; Jensen, 1986), even if this does not add value to shareholders.

Finally, following the *market power view*, diversification allows firms to consolidate and increase their market power. Firms which operate in many industries may engage in anti-competitive practices such as cross-subsidisation, collusion with symmetrically diversified firms (Bernheim and Whinston, 1990), predatory behaviour and so on.

Utilities which combine activities such as gas, water, telecommunications and electricity use similar assets (wires, pipelines) and similar skills (management and network maintenance). Moreover, the joining of the respective customer bases brings synergies in the management of users (metering, billing, call centres), in advertising activities, and in administration costs. Finally, diversified firms should be in a better position in order to raise the funds required for financing their projected investments. However, since such utilities had been traditionally publicly owned companies, diversification strategies might be driven also by managerial attitude towards empire building, especially if managers have the free disposal of the rich amounts of cash flows accumulated in the past.

McGuinness and Thomas (1997) use the privatisation of water companies in the UK in 1989 as an event study to test the resource view of diversification. After privatisation, in fact, water companies had been allowed to undertake diversification strategies that were previously forbidden. While in early years after privatisation some utilities undertook unsuccessful adventures into hotel management, real estate activities, television franchising, other firms focussed on similar activities such as gas, electricity, waste management, and so on. The initial diversification moves, which were probably driven by mistakes in the allocation of resources and facilitated by the availability of cash resources inherited from the past, were followed by sudden divestitures, while the diversification towards related activities proved to be both lasting and successful. The authors argue that water firms had built upon existing core competencies by exploiting economies of scope (asset amortisation) and by improving their learning of managing network services (asset improvement through cross-utility learning), in accordance with the resource theory. Thompson (1999) uses the same event (privatisation of the UK water and electricity utilities) in order to test the free cash flow hypothesis. Consistently with the predictions of the theory, he finds that the level of non core activities in the years after the privatisation was significantly and positively related to the firm's availability of cash resources. He argues that this result is somewhat paradoxical, considered that privatisation is usually intended to improve firms' allocation of resources.

Turning towards a different empirical approach to the analysis of multi-product firms, the study of the dual cost function sheds some light on the presence and on the extent of economies of scope. Such an information is particularly useful to evaluate the future impact on the consumers (in terms of changes in the tariff levels) of recent waves of cross-utilities acquisitions. Moreover, empirical costing studies represent an important tool for assisting regulatory agencies in decision-making, as they provide guide-insights into policy questions such as optimal subsidisation or the design of competitive scenarios which are worth to be promoted in the future. Unfortunately, the econometric literature lacks of contributions which account for the joint provision of services such as gas, water, and electricity. Most studies of multiproduct firms in these sectors focus on the firm's presence at the different stages of the vertical chain (i.e generation, transmission, distribution for electricity) or in different segments of the market (residential users versus non residential users, high voltage versus low voltage)[1]. An exception is Sing (1987) who applies a Generalised Translog cost function to a sample of US combination gas and electricity utilities.[2] He found that the average combination utility was exhibiting diseconomies of scope, while other output combinations where associated with both economies and diseconomies of scope.

[1] See Kim (1987) for the water industry and Salvanes and Tjotta (1998) for electricity.
[2] For other earlier studies on gas-electricity combination utilities, see the references listed in Sing (1987).

Moreover, the results showed for the average firm product-specific economies of scale for electricity and product-specific diseconomies of scale for gas. The author concluded that "factors other than cost savings are responsible for the existence of combination utilities" (p.393). Some evidence on electricity-water combination utilities is available in Yatchew (2000). The author analyses the cost function of a sample of Canadian distribution electricity utilities using a semiparametric version of the Translog cost function model. He includes among the regressors a dummy for utilities diversified in other activities (mainly in water/sewage). The negative coefficient reported suggests the presence of economies of scope of the order of 7-10%.

To the best of our knowledge, this is the first attempt to study the cost function of utilities which provide simultaneously gas, water and electricity. Given the well known skepticism concerning the ability of Translog and the related Generalised (or Hybrid or Box-Cox) Translog functional forms to measure economies of scope in correspondence of zero output levels (see the discussion in the next section), we depart from Sing (1987) and Yatchew (2000) and apply the Composite specification firstly introduced by Pulley and Braunstein (1992). As it will be shown in Section 5, our analysis confirms the relative advantages of this functional form for the study of multi-product technologies.

3. The econometric cost function model

The availability of data on costs, outputs and inputs for Italian multi-utilities providing gas, water and electricity allows us to undertake a detailed study of the cost function in order to detect the presence of aggregate and product-specific economies of scale and scope. According to the well-known *Generalized Translog* (GT) *Specification* (Caves et al., 1980), the cost function is given by:[3]

$$\ln C = \alpha_0 + \sum_i \alpha_i Y_i^{(\pi)} + \frac{1}{2}\sum_i \sum_j \alpha_{ij} Y_i^{(\pi)} Y_j^{(\pi)} + \sum_i \sum_r \delta_{ir} Y_i^{(\pi)} \ln P_r + \sum_r \beta_r \ln P_r + \frac{1}{2}\sum_r \sum_l \beta_{rl} \ln P_r \ln P_l + \psi_C \quad [1]$$

[3] The subscript referring to individual observations has been omitted for convenience in the presentation.

where the superscripts in parentheses represent the Box-Cox transformation of outputs ($Y_i^{(\pi)} = (Y_i^{\pi} - 1)/\pi$ for $\pi \neq 0$ and $Y_i^{(\pi)} \to \ln Y_i$ for $\pi \to 0$). C refers to the long-run cost of production, Y_i refers to outputs (in our three-output case $i, j = G, W, E$), P_r indicates factor prices (in our two-input case $r, l = L, K$), and ψ_C is a random noise having appropriate distributional properties to reflect the stochastic structure of the cost model.

The associated input cost-share equations are obtained by applying the *Shephard's Lemma* to expression [1][4]

$$S_r = \sum_i \delta_{ir} Y_i^{(\pi)} + \beta_r + \sum_l \beta_{rl} \ln P_l + \psi_r \qquad [2]$$

where ψ_r is the error term relating to the cost-share r.

Setting $\pi \to 0$ in [1] and [2] yields the nested *Standard Translog* (ST) *Specification*, with all output terms in the cost function and in the corresponding cost-share equations assuming the usual logaritmic ($\ln Y_i$) form.[5]

For small values of π, the estimated GT function is a close approximation to the ST functional form. Due to its log-additive output structure, the latter suffers from the well-known inability to evaluate cost behavior when any output is zero.[6] This has been proved to yield unreasonable and/or very unstable values of the estimates for scope economies and product-specific scale economies (e.g., Pulley and Braunstein, 1992; McKillop et al., 1996).

To overcome the above problems, Pulley and Braunstein (1992) proposed as an alternative functional form for multi-product technologies the *Composite* (PB) *Specification*. The PB cost function originates from the combination of the log-quadratic input price structure of the ST and GT specifications with a quadratic structure for multiple outputs. This makes the model particularly suitable for the empirical cost analysis. The quadratic output structure is appropriate to model cost behavior in the range of zero output levels and gives the PB specification an advantage over the ST and GT forms as far as the measurement of both economies of scope and product-specific economies of scale

[4] Cost-shares are computed as $S_r = (X_r P_r)/C$. By Shephard's Lemma $X_r = \partial C/\partial P_r$, where X_r is the input demand for the rth input, so that $S_r = \partial \ln C / \partial \ln P_r$.

[5] In this case zero values for any of the three outputs are substituted by 0.000001.

[6] See Röller (1990a).

are concerned.[7] In addition, the log-quadratic input price structure can be easily constrained to be linearly homogeneous. The log-transformed PB cost function is written as[8]

$$\ln C = \ln[\alpha_0 + \sum_i \alpha_i Y_i + \frac{1}{2}\sum_i \sum_j \alpha_{ij} Y_i Y_j + \sum_i \sum_r \delta_{ir} Y_i \ln P_r] + \sum_r \beta_r \ln P_r + \frac{1}{2}\sum_r \sum_l \beta_{rl} \ln P_r \ln P_l + \psi_C \quad [3]$$

and the corresponding input cost-share equations are

$$S_r = \left(\sum_i \delta_{ir} Y_i\right)\left[\alpha_0 + \sum_i \alpha_i Y_i + \frac{1}{2}\sum_i \sum_j \alpha_{ij} Y_i Y_j + \sum_i \sum_r \delta_{ir} Y_i \ln P_r\right]^{-1} + \beta_r + \sum_l \beta_{rl} \ln P_l + \psi_r \quad [4]$$

Given the regularity conditions ensuring duality, the PB specification does not impose a priori restrictions on the characteristics of the below technology.[9] Thus, it is a flexible form in the sense of Diewert (1974). A more parsimonious and less general form is the *Separable Quadratic* (SQ) *Specification*, in which all terms δ_{ir} are set equal to 0. The SQ function, which is similar to the quadratic form used by Röller (1990b), allows to estimate the costs in the range of zero outputs, but has the disadvantage of imposing strong separability between outputs and inputs.

There are not many received studies which employed the PB specification when examining economies of scale and scope. After the pioneering application

[7] Baumol et al. (1982) recommend such a structure because it is able to measure the characteristics of multi-product technologies without prejudging their presence.

[8] In the original specification proposed by Pulley and Braunstein (1992) the composite model includes an additional constant term β_0 and other price-output interactions ($\Sigma_i \Sigma_r \mu_{ir} Y_i \ln P_r$) different from those entering via the output structure. Since the authors encountered problems in the estimation of the complete model, they decided to delete β_0 and the terms involving μ_{ir}. Following Pulley and Braunstein (1992) and the subsequent studies by McKillop et al. (1996), Braunstein and Pulley (1998) and Bloch, Madden and Savage (2001), our empirical analysis is based on this more parsimonious version as reported in equation [3].

[9] To be consistent with cost minimization, [1] and [3] must satisfy symmetry ($\alpha_{ij} = \alpha_{ji}$ and $\beta_{rl} = \beta_{lr}$ for all couples i, j and r, l) as well as the following properties: *a*) non-negative fitted costs; *b*) non-negative fitted marginal costs with respect to outputs; *c*) homogeneity of degree one of the cost function in input prices ($\Sigma_r \beta_r = 1$ and $\Sigma_l \beta_{rl} = 0$ for all r, and $\Sigma_r \delta_{ir} = 0$ for all i); *d*) non-decreasing fitted costs in input prices; *e*) concavity of the cost function in input prices. Symmetry and linear homogeneity in input prices are imposed *a priori* during estimation, whilst the other regularity conditions are checked ex-post.

by Pulley and Braunstein to the U.S. banking sector, only two contributions on the U.S. (Braunstein and Pulley, 1998) and Australian (Bloch, Madden and Savage, 2001) telecommunication industries and a study of the cost structure of Japanese banks (McKillop et al., 1996) have appeared in the literature.

In this paper we estimate a composite cost function for the Italian gas, water and electricity utilities and we test for the presence of scope and scale economies and pairwise cost complementarities between outputs. Following Pulley and Braunstein and McKillop et al., we will assess the relative advantages of the PB form with respect to the alternative ST, SQ and GT specifications in the context of measuring cost properties of multi-product firms.[10]

3.1. Measures of scale and scope economies

Assume the multi-product cost function to be represented by $C = C(Y;P)$, where $Y = (Y_G, Y_A, Y_E)$ and $P = (P_L, P_K)$. Following Baumol et al. (1982), local measures of global and product-specific scale and scope economies can be easily defined. *Global* or *aggregate scale economies* are computed via

$$SL(Y;P) = \frac{C(Y;P)}{\sum_i Y_i MC_i} = \frac{1}{\sum_i \varepsilon_{CY_i}} \qquad [5]$$

where $MC_i = \partial C(Y;P)/\partial Y_i$ is the marginal cost with respect to the *i*th output and $\varepsilon_{CY_i} = \partial \ln C(Y;P)/\partial \ln Y_i$ is the cost elasticity of the *i*th output.

The above measure describes the behavior of costs as all outputs increase by strictly the same proportion. However, since product mixes rarely remain constant as output changes, additional dimensions of scale behavior can be

[10] Pulley and Braunstein (1992) suggest for the PB and SQ specifications to transform both sides of the cost function. In particular, in order to enlarge the set of plausible empirical specifications, they propose to estimate $C^{(\phi)} = [C(Y, P)]^{(\phi)} + \psi_C$ where (ϕ) refers to a Box-Cox transformation. The optimal value of ϕ can be found either *i*) by searching over a grid of given ϕ values and judging on the basis of the sum of squared errors (SSE) or *ii*) by direct estimation, resorting to standard non-linear least squares routines. Using approach *ii*), the authors found that the optimal value of ϕ was –0.14, while McKillop et al. who relied on the grid-search approach, found that ϕ*'s* in the range of 0.7-1.3 were balancing relatively high log-likelihood values with the highest degree of satisfaction of regularity conditions. Braunstein and Pulley (1998) and Bloch et al. (2001), on the other hand, did not apply the transform-both-sides procedure but directly estimated equation [3] which corresponds to setting ϕ equal to zero. By following approach *i*) we found that ϕ = 0.23 was

measured by product-specific scale economies indicators. These latter show how costs changes as the output of one or two products changes with the quantities of other products held constant. *Product-specific economies of scale* for the couple of products (i, j; $i \neq j$) are defined by

$$SL_{ij}(Y;P) = \frac{IC_{ij}}{Y_i MC_i + Y_j MC_j} = \frac{IC_{ij}}{[\varepsilon_{CY_i} + \varepsilon_{CY_j}]\, C(Y;P)} \qquad [6]$$

where $IC_{ij} = C(Y;P) - C(Y_{-ij};P)$ represents the incremental cost of the couple (i, j), and $C(Y_{-ij};P)$ is the cost of producing all the other products different from i and j.

The degree of scale economies specific to the product i are finally

$$SL_i(Y;P) = \frac{IC_i}{Y_i MC_i} = \frac{IC_i}{\varepsilon_{CY_i} C(Y;P)} \qquad [7]$$

where $IC_i = C(Y;P) - C(Y_{-i};P)$ is the incremental cost relating to the ith product and $C(Y_{-i};P)$ is the cost of producing all outputs except the ith one. Returns to scale defined by expressions [5], [6] and [7] are said to be increasing, constant or decreasing as $SL(Y; P)$, $SL_{ij}(Y; P)$ and $SL_i(Y; P)$ are greater than, equal to, or less than unity, respectively.

The second relevant concept in understanding the cost structure of multi-product firms is that of scope economies. The latter appear when the cost of joint production of a given output set is less than the sum of the "stand-alone" production costs of subsets of outputs. In other words, scope economies (diseconomies) are reflected into cost savings (cost disadvantages) associated with the joint production of many outputs. When there are neither economies nor diseconomies of scope the production process is said to be non-joint, so that productive inputs are completely specialized by product and there are no strong interdependencies among the costs of different outputs.[11] The measure of *global* or *aggregate scope economies* for our three-utility case can be computed via

associated with the highest log-likelihood value. Since the estimates were very similar to the $\phi = 0$ case (see Section 5), our final choice was to adopt the simpler specification of equation [3].

[11] See Kim (1987).

$$SC(Y;P)=\frac{\left[C(Y_G,0,0;P)+C(0,Y_A,0;P)+C(0,0,Y_E;P)-C(Y;P)\right]}{C(Y;P)} \qquad [8]$$

with $SC(Y; P) > 0$ (< 0) denoting global economies (diseconomies) of scope.

Product-specific economies of scope for output *i* are

$$SC_i(Y;P)=\frac{\left[C(Y_i;P)+C(Y_{-i};P)-C(Y;P)\right]}{C(Y;P)} \qquad [9]$$

where $C(Y_i; P)$ is the cost of producing only output *i*, and $SC_i(Y; P) > 0$ (< 0) indicates a cost disadvantage (advantage) in the "stand-alone" production of output *i*.[12]

Finally, it is also possible to assess the degree of economies of scope for couples of outputs under the assumption that the production of the remaining output is zero. Formally, scope economies for the couple of products (i, j; $i \neq j$) are defined by

$$SC_{ij}(Y_{ij};P)=\frac{\left[C(Y_i;P)+C(Y_j;P)-C(Y_{ij};P)\right]}{C(Y_{ij};P)} \qquad [10]$$

with $C(Y_{ij}; P)$ denoting the cost of producing the outputs *i* and *j* alone.

It can be helpful to report a relationship which summarizes the links between scale and scope economies:

$$SL(Y;P)=\frac{\gamma_i SL_i(Y;P)+(1-\gamma_i)SL_{-i}(Y;P)}{1-SC_i(Y;P)} \qquad [11a]$$

for all $i = (G, W, E)$. $SL_{-i}(Y;P)$ is the measure of product-specific economies of scale for the set of outputs other than *i* and $\gamma_i=\frac{\varepsilon_{CY_i}}{\sum_i \varepsilon_{CY_i}}$. According to equation [11a], the degree of global scale economies depends on both product-specific scale economies and product-specific economies of scope. In particular, if $SC_i > 0\,(SC_i < 0)$, the degree of global scale economies is greater (lower) than the weighted average of product-specific scale economies. Another useful formula

[12] In our three outputs case, the measure of product-specific economies of scope for the couple (i, j) is identical to the one for the remaining good *k* ($SC_k = SC_{-ij}$):

for disaggregating the factors that contribute to form the measure of global scope economies is the following:

$$SC(Y;P)=\left(\sum_i SL_i(Y;P)\varepsilon_{CY_i}+\sum_i SC_i(Y;P)\right)-1 \qquad [11b]$$

Thus, global scope economies depend on the joint play of product-specific economies of scale (weighted by the output cost elasticities) and product-specific economies of scope.

As an additional check for the presence of scope economies in utilities which combine the provision of gas, water and electricity, we also compute *pairwise cost complementarities*.[13] For a twice continuously differentiable cost function, cost complementarities are present at Y' if

$$CC_{ij}(Y';P)=\frac{\partial^2 C(Y';P)}{\partial Y_i \partial Y_j}<0, \qquad i\neq j \qquad [12]$$

for all $Y' \in [0,Y]$. Equation [12] states that cost complementarities between two products are present when the marginal cost of producing one output decreases as the quantity of the other good is increased.

4. Data description

Our dataset refers to a balanced panel of 90 Italian municipal utilities operating in the gas, water and electricity sectors over the period 1994-1996, for a total of 270 *pooled* observations.

The sample composition by output mix and firm size is presented in Table 1. 39 firms are specialised utilities (19 gas-specialized, 16 water-specialized, 4 electricity-specialized), 37 have activities in two sectors (31 gas-water combinations, 1 gas-electricity combinations, 5 water-electricity combinations), and the remaining 14 are multi-utilities which jointly provide the three services. As for firm size, measured in terms of average number of employed workers in

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$$SC_k(Y;P)=SC_{-ij}(Y;P)=SC_{ij}(Y;P)=\frac{[C(Y_{ij};P)+C(Y_{-ij};P)-C(Y;P)]}{C(Y;P)}.$$

[13] Baumol et al. (1982) have shown that a multi-product cost function characterized by weak cost complementarities over the full set of outputs up to the observed level of output exhibits scope economies.

1996, the sample includes 30 small-sized companies (less than 50 workers), 42 medium-sized units (51-250 workers), and 18 large operators (more than 250 workers).

Data on costs, output quantities and input prices are obtained by integrating the information available in the annual reports of each company with additional information drawn from questionnaires sent to managers. Long-run cost (C) is the sum of labor and capital costs of the firm. The three output categories are: cubic meters of gas (Y_G); cubic meters of water (Y_W); and kilowatt hours of electricity (Y_E). Productive factors are labor and capital. The price of labor in each utility (P_L) is given by the ratio of total salary expenses to the number of employees. For multi-utilities price is obtained by computing a weighted average of prices in each sector, with weights being the labor cost shares of each service on the total labor cost. Capital price (P_K) is obtained by dividing residual expenses (including energy, materials, services and depreciation costs) by the length of the network (expressed in kilometers). For multi-utilities the average price of capital is obtained by following the same procedure used for labor. Summary statistics are provided in Table 2.

5. Estimation and empirical results

All the specifications of the multi-product cost function are estimated jointly with their associated input cost-share equations.[14] Because the two share equations sum to unity, to avoid singularity of the covariance matrix the capital share equation (S_K) was deleted and only the labor equation (S_L) was included in the systems. Before the estimation, all variables were standardized on their respective sample medians. Parameter estimates were obtained via a non-linear GLS estimation (NLSUR), which is the non-linear counterpart of the Zellner's iterated seemingly unrelated regression technique. This procedure ensures estimated coefficients to be invariant with respect to the omitted share equation (Zellner, 1962). Assuming the error terms in the above models are normally distributed, the concentrated *log-*

[14] For the GT and PB models, for instance, this leads to the estimation of systems [1]-[2] and [3]-[4].

likelihood for the estimated *cost function* and related *labor-share equation* can be respectively computed via[15]

$$\ln L_C = -\sum_{t=1}^{T} \ln C_t - \frac{T}{2}[1 + \ln(2\pi)] - \frac{T}{2}\ln\left[\frac{1}{T}\sum_{t=1}^{T}\hat{\psi}_{C\,t}^{2}\right] \qquad [13a]$$

$$\ln L_{S_L} = -\frac{T}{2}[1 + \ln(2\pi)] - \frac{T}{2}\ln\left[\frac{1}{T}\sum_{t=1}^{T}\hat{\psi}_{L\,t}^{2}\right] \qquad [13b]$$

where t is the single observation (t = 1, …, 270), $\hat{\psi}_C$ and $\hat{\psi}_L$ are the estimated residuals of the two regressions, and ($-\Sigma_t \ln C_t$) is the logarithm of the Jacobian of the transformation of the dependent variable from C_t to $\ln C_t$ ($J = \prod_{t=1}^{T} J_t$ with $J_t = |\partial\psi_{C\,t} / \partial C_t| = 1/C_t$). Similarly, the concentrated *system log-likelihood* is defined by:

$$\ln L_{(C,S_L)} = \ln J - \frac{T}{2}\left[2(1 + \ln(2\pi)) + \ln|\Omega|\right] \qquad [14]$$

where J is the Jacobian of the transformation of $(C_t, S_{L\,t})$ to $(\ln C_t, S_{L\,t})$, and Ω is the (2×2) matrix of residual sum of squares and cross products for the system, with the *pq*th element of Ω, Ω_{pq}, equal to $\frac{1}{T}\sum_{t=1}^{T}\hat{\psi}_{p_t}\hat{\psi}_{q_t}$ and p, q = C, S_L.

The summary results of the NLSUR estimations for the ST, GT, SQ, and PB models are presented in Table 3.[16] In the first row the value of the Box-Cox parameter (π) for the GT specification is positive (0.13) and significantly different from zero (t-ratio = 4.62). The small value of π suggests that, being a close approximation to the standard translog form, the GT model would suffer from the same drawbacks of the ST specification when used to estimate cost properties of multi-product firms. The following five rows present the estimates of cost

[15] See Greene (1997), Chapters 10 and 15.

[16] The software used for the estimation is the NLSUR procedure of LIMDEP Version 7. Since we are working on a panel data in which each firm is observed over a period of three years, we had to choose whether to add to the model a fixed effect for every year or eventually a time-trend variable. To tackle this issue we performed Wald tests after having included in the model the time dummies for 1994 and 1996 or a time-trend variable. At the usual confidence levels, both the null hypotheses of constancy of the intercept over time and of not significant time-trend effect could not be rejected. Thus we opted for a simple regression based on the pooled observations.

elasticities with respect to outputs and factor prices for the 'median' firm.[17] The latter are very easy to recover from the GT and ST models, in that $\varepsilon_{CY_i} = \alpha_i$, while S_r is simply the estimate of β_r (see equations [1] and [2]). In the PB and SQ models the computation of output and factor-price cost elasticities is more cumbersome:

$$\varepsilon_{CY_i} = \frac{\alpha_i + \sum_j \alpha_{ij}}{\alpha_0 + \sum_i \alpha_i + \frac{1}{2}\sum_i \sum_j \alpha_{ij}} \qquad [15]$$

$$S_r = \beta_r + \frac{\sum_i \delta_{ir}}{\alpha_0 + \sum_i \alpha_i + \frac{1}{2}\sum_i \sum_j \alpha_{ij}} \qquad [16]$$

While the four estimated cost function models seem to perform similarly with respect to labor and capital-price elasticities (S_L ranges from 0.22 to 0.28), the estimates for the output elasticities show a greater variability, with ST and GT specifications according more weight to gas (ε_{CY_G} = 0.45 and 0.36 respectively) and SQ and PB models according more weight to electricity (ε_{CY_E} = 0.47 and 0.49 respectively).

By looking at the summary statistics, one can observe that the R^2 for the cost function ranges from 0.77 (ST model) to 0.86 (SQ model), while the R^2 for the labor-share equation ranges from 0.30 (SQ model) to 0.53 (PB model).[18] The lower ability of the SQ specification to fit the observed factor-shares is not surprising given that it assumes a strong separability between inputs and outputs. McElroy's (1977) R^2 (R_*^2) can be used as a measure of the goodness of fit for the NLSUR system. The results suggest that the fit is higher for the separable quadratic (R_*^2 = 0.80) and composite (R_*^2 = 0.79) specifications as compared to the ST (R_*^2 = 0.70) and GT (R_*^2 = 0.71) functional forms.

[17] The *median* firm (the point of normalization) corresponds to an hypothetical firm operating at a median level of production for each output and facing median values of the input price variables.
[18] A similar pattern can be observed by looking at the log-likelihood values of the cost and labor-share equations, as well as by comparing their estimated SSE.

The pairs SQ-PB and ST-GT are nested specifications, so that standard likelihood ratio (LR) hypothesis testing based on system log-likelihoods can be applied to see which model adjusts better observed data. The LR statistics leads to reject the ST specification in favor of the GT model (critical ${}_{0.001}\chi^2_{(1)}$ = 6.63; computed $\chi^2_{(1)}$ = 16.36). Similarly, the null hypothesis that PB and SQ models are equally close to the true data generating process is rejected in favor of the PB specification (critical ${}_{0.001}\chi^2_{(3)}$ = 11.34; computed $\chi^2_{(3)}$ = 36.40).

Since GT and PB are non-nested (or to be more precise overlapping) models, we cannot perform traditional LR selection test. However, the general procedure developed in Vuong (1989) for choosing among strictly non-nested and overlapping models can be easily applied. According to the latter, the standard LR statistics is normalized by

$$\hat{\omega}_T = \left[\sum_{t=1}^{T} (\hat{\psi}'_{\mathrm{PB}\,t} \Omega^{-1}_{\mathrm{PB}} \hat{\psi}_{\mathrm{PB}\,t} - \hat{\psi}'_{\mathrm{GT}\,t} \Omega^{-1}_{\mathrm{GT}} \hat{\psi}_{\mathrm{GT}\,t})^2 \right]^{\frac{1}{2}} \qquad [17]$$

where $\hat{\psi}_t$ is for each observation the (2 × 1) column vector of the estimated residuals from the cost function and labor-share equation $\begin{pmatrix} \hat{\psi}_{C\,t} \\ \hat{\psi}_{S_L\,t} \end{pmatrix}$ and Ω is the estimated covariance matrix. Following Gasmi, Laffont and Vuong (1992), we adjusted the Vuong's statistic to take into account the fact that the GT specification has one more parameter (π) than the PB one. Among the various correction factors proposed by the literature[19], we choose the one according the lowest penalty for the number of estimated parameters (Hannan and Quinn, 1979): $\mathrm{HQ} = -1/2\,(g-h)\ln\ln T$, where g and h are the numbers of parameters in PB and GT and T is the number of observations.[20] The final adjusted normalized LR statistic is then[21]

[19] See Gasmi et al. (1992), page 286.
[20] In our case the value of HQ is equal to 0.86.
[21] This resulting statistic is asymptotically normally distributed under the null hypothesis of equal fit. Thus, given a critical value z from the standard normal distribution at some significance level, we cannot reject H_0 if the normalized LR statistic is smaller than z in absolute value. On the other hand, if the normalized LR statistic is smaller (higher) than – z (+ z), we conclude that GT (PB) model is significantly better.

$$\text{AVLR} = \frac{\text{LR}}{\hat{\omega}_T} + \text{HQ} = \frac{2(\ln L_{\text{PB}} - \ln L_{\text{GT}})}{\left[\sum_{t=1}^{T} (\hat{\psi}'_{\text{PB}\,t}\Omega_{\text{PB}}^{-1}\hat{\psi}_{\text{PB}\,t} - \hat{\psi}'_{\text{GT}\,t}\Omega_{\text{GT}}^{-1}\hat{\psi}_{\text{GT}\,t})^2\right]^{\frac{1}{2}}} - \frac{1}{2}(g-h)\ln\ln T$$

[18]

where $\ln L_{\text{PB}}$ and $\ln L_{\text{GT}}$ are the computed values of the system log-likelihood for PB and GT, respectively, as defined by equation [14]. The value for the AVLR statistic reported in the last row of Table 3 indicates that the composite model provides a better description of data for the Italian multi-utilities than the alternative generalized translog functional form.

The relative advantages of the composite specification can be appreciated also by comparing the measures of global economies of scale and scope provided by the four estimated models. The last row of Table 4 shows the estimate of global economies of scale calculated for the median firm:. According to the ST and GT models (for which $SL = 1/\sum_i \alpha_i$) the estimates are 0.94 and 1.30 respectively, but only the latter is significantly different from 1. For the PB and SQ models global scale economies can be computed via the following expression:

$$SL = \frac{\alpha_0 + \sum_i \alpha_i + \frac{1}{2}\sum_i \sum_j \alpha_{ij}}{\sum_i \alpha_i + \sum_i \sum_j \alpha_{ij}} \qquad [19]$$

The results are 1.10 and 1.13 respectively, but only the latter figure is statistically different from 1. Thus, while for the SQ and GT specifications there appear to be increasing global returns to scale at the median firm level, according to PB and ST models the hypothesis of constant returns to scale cannot be rejected.

If the estimates of *SL* are not dramatically different across models, the results for global economies of scope show a much greater variability. In the ST specification the median firm exhibits scope diseconomies of the order of -75%, while the GT model suggests the presence of economies of scope of the order of 63.5%. Finally, for the SQ and PB functional forms *SC* is equal to 0.19 and 0.12, respectively.

As argued in Section 3, the ST cost model, as well as the GT specification for small values of the Box-Cox parameter (in this case π = 0.13), often provide unreasonable and/or very unstable estimates of scope economies when outputs are set near to zero. In order to tackle this issue, Table 4 tests the stability of the estimates of global scope economies for the four models when, instead of setting $Y_i = 0$, firms are assumed to produce a small positive share of the median output (εY_i). Thus, for example, the fourth row ($\varepsilon = 0.01$) corresponds to the following measure of so-called '*quasi*'-scope economies: $QSC(\varepsilon) = [C(0.01Y_G, 0.01Y_W, 0.98Y_E) + C(0.01Y_G, 0.98Y_W, 0.01Y_E) + C(0.98Y_G, 0.01Y_W, 0.01Y_E) - C(Y_G, Y_W, Y_E)] / C(Y_G, Y_W, Y_E)$, and so on.[22] It is easy to notice that, while the SQ and PB models provide very stable estimates, in the ST model $QSC(\varepsilon)$ ranges from –0.75 to –0.01 and in the GT model it switches from negative values to positive values (when $\varepsilon > 0.01$).

The preference for the composite specification on the basis of statistical fit and as a result of LR based statistics performed in both nested and non-nested frameworks is thus further strengthened by the better ability of quadratic models in measuring global scope economies. In the remaining of the paper we will then focus on the PB functional form in carrying out the empirical tests concerning scope and scale economies.[23]

5.1. *Global economies of scale and scope*

Table 5 reports the estimates for global scale and scope economies evaluated at the output sample medians, $Y^* = (Y^*_G, Y^*_W, Y^*_E)$, and at ray expansions and contractions of Y^*. More precisely, we consider the following output scaling: $\lambda Y^* = (\lambda Y^*_G, \lambda Y^*_W, \lambda Y^*_E)$, with outputs ranging from one fifth ($\lambda = 0.2$) to five times ($\lambda = 5$) the values observed for the 'median' firm. The positive estimates for *SC* suggest the presence of economies of scope.[24] The latter, which amount to 33%

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[22] The general formula for '*quasi*'-scope economies in our three-outputs case is $QSC(\varepsilon) = [C(\varepsilon Y_G, \varepsilon Y_W, (1\text{-}2\varepsilon)Y_E) + C(\varepsilon Y_G, (1\text{-}2\varepsilon)Y_W, \varepsilon Y_E) + C((1\text{-}2\varepsilon)Y_G, \varepsilon Y_W, \varepsilon Y_E) - C(Y_G,Y_W,Y_E)] / C(Y_G,Y_W,Y_E)$.

[23] The estimated PB cost function also satisfies *each* of the output and price regularity conditions at 90 percent of the sample data points. More precisely, fitted costs are always non-negative and non-decreasing in input prices (fitted factor-shares are positive at each observation). Concavity of the cost function in input prices is satisfied everywhere in the sample (the Hessian matrix based on the fitted factor-shares is negative semi-definite). Fitted marginal costs with respect to each output are non-negative for 244 observations on 270.

[24] This indicates that combination utilities are benefiting from cost savings arising from sharable inputs such as, for instance, meter reading, billing, accounting and engineering services.

for relatively small multi-utilities, progressively decrease for larger multi-product firms (12.6% in correspondence of $\lambda = 1.5$). For utilities characterized by output vectors larger than $3Y^*$, global economies of scope are again increasing. However, a close inspection at the standard errors of the point estimates reveals that only the first three (and marginally the fourth) estimates are significantly different from zero at the 5% confidence level. Consequently, we have to conclude that for multi-utilities bigger than the sample median ($\lambda Y > Y^*$) neither economies nor diseconomies of scope can be ascertained.

Turning towards global economies of scale, all estimates are larger than one and significantly different from zero (except for the $\lambda = 5$ case). However, only the figures for $\lambda < 1$ are significantly different from one, revealing the presence of *increasing returns to scale*. For multi-utilities larger than the median firm, the hypothesis of constant returns to scale cannot thus be rejected. Similarly to what observed for global scope economies, global scale economies are decreasing from 1.21 to 1.10 when λ passes from 0.2 to 1.

Summarizing, there is evidence that small multi-utilities benefit from cost reductions of the order of 13%-33% with respect to specialised utilities. Moreover, by increasing the dimension up to the median, multi-product utilities may obtain moderate reductions of average costs. Notwithstanding the estimates for firms larger than the sample median would still suggest the presence of both economies of scope and scale, the large values of the standard errors force us to conclude that the cost benefits of diversification disappear in such output region.

5.2. Product-specific scope economies, cost complementarities and product-specific scale economies

Tables 6 and 7 look at more depth into the contribution of each product or couples of products in determining the above global scope and scale economies results. Product-specific economies of scope are very similar across products and range from 0.17 for small utilities to 0.05-0.09 for the ‘median’ firm. Since gas and water exhibit slightly higher values, it is not surprising that the estimate of product-specific scope economies for the pair gas-water (SC_{GW}) are higher (14%-30%) than the other pairwise output combinations (gas-electricity and water-electricity, which lie in the range of 5%-21%). Again, the standard errors indicate that only the figures up to $\lambda = 0.67$ ($\lambda = 0.33$ for SC_E and $\lambda = 1.5$ for SC_{GW}) can be considered as significantly different from zero. The above estimates suggest then that, for a utility already operating into water and electricity, the diversification into gas would generate cost savings of the order of 17% for small units and of 9% for units producing two-third of the water and electricity provided by the median firm. Slightly lower cost savings can be enjoyed by gas-water combination utilities that decide to diversify into electricity, and by gas-electricity combination utilities that decide to enter the water industry. The figures in the last three columns indicate that, with respect to two specialised producers, two-output firms would enjoy cost savings of the order of 14%-30% in the case of gas-water combinations, and 7%-21% in the case of the other output pairs[25]. In contrast with the above findings, for firms larger than the sample median we cannot reject the hypothesis that SC_i and SC_{ij} are equal to zero, for all i's and for all (i, j) pairs except (G, W).

The analysis of cost complementarities (CC_{ij}; $i, j = G, W, E$, with $i \neq j$) provides further evidence on the cost advantage (or disadvantage) enjoyed by a utility which decides to diversify into two or more services. Under this empirical test, we investigate pairwise how an increase in the level of one of the three services will affect the marginal cost of producing the other ones. Unlike scope economies, which assess if it is less or more costly to provide jointly two or three services at all, cost complementarities are 'local' properties because they describe how the cost function behaves in the neighborhood of an observation or set of observations. Given the functional form of the PB model, CC_{ij} exclusively depends on the second order cross-outputs coefficients, α_{ij}, and on the input price levels. Thus, the latter being fixed at their sample medians, we have a unique estimate for the cost complementarities calculated at different scaled valued of the median outputs. The three values are reported in the last row of Table 6. Given the close relationship with the cross-output coefficients, none of the three estimates is statistically different from zero. So, no robust inference about the presence of cost complementarities in multi-utilities can be made on the basis of these results.

[25] Following Equation [9], the cost savings are to be intended with respect to the sum of the costs incurred by a specialised firm producing good i and a two-products firm producing the other two

Anyway, the signs of CC_{GW}, CC_{GE} are impressive of the presence of cost synergy from offering gas-water and gas-electricity combinations, respectively, confirming our evidence on pairwise scope economies. On the other hand, the positive sign for CC_{WE}, which implies cost anticomplementarities between water and electricity services and clash with the presence of weak scope economies highlighted above, is highly not significant.[26]

Turning towards product-specific economies of scale, all the estimates in Table 7 (except some figures included in the last row, $\lambda = 5$) are significantly different from zero but not significantly different from one. Thus, there is no evidence of either product-specific economies of scale or product-specific diseconomies for each good i and for each couple (i, j)[27].

Equations [11a] and [11b] are useful to summarize the relationship between global scale and scope economies, on the one hand, and product-specific scale and scope economies, on the other hand. From expression [11a], global scale economies emerge if there are product-specific scope economies and/or increasing product-specific returns to scale. Our results show that the overall increasing returns to scale found for small multi-utilities are mainly due to the presence of product-specific economies of scope. In a similar vein, equation [11b] shows that global economies of scope are due to both product-specific economies of scale and to the sum of product-specific economies of scope. Again, it is the latter factor that drives our findings of global economies of scope for firms smaller than the sample median.[28]

6. Conclusions

In the recent years many utilities have followed diversification strategies by entering into similar network services, giving rise to a new business model known as multi-utility. This paper analyses the cost structure of a sample of firms

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goods.

[26] The t-ratio of the related parameter, α_{WE}, is indeed extremely low.

[27] See Fabbri and Fraquelli (2000) for a study of Italian gas distributors and Fabbri, Fraquelli and Giandrone (2000) for an analysis of cost structure of Italian water utilities. As to electricity, Table 1 shows that our sample includes only 24 firms, most of which are only distributors.

[28] When we apply the "transform-both-sides" procedure and use the best estimate of $\phi = 0.23$ (see note 9) we obtain results very similar to the ones reported above. The only remarkable difference

operating, as specialised units or as combination utilities, in gas, water and electricity sectors. The empirical strategy departs from Standard Translog (ST) and Generalised Translog (GT) specifications, and focuses the attention on the Composite Cost Function model (PB) recently introduced by Pulley and Braunstein (1992). The latter, by combining a log-quadratic input price structure with a quadratic structure for multiple outputs, are more suitable to investigate the presence of economies of scope.

Our results show the existence of global and product-specific economies of scope, as well as of global returns to scale, for multi-utilities smaller than the 'median' firm (producing about 71 million m^3 of gas, 11 million m^3 of water and 221 million kwh of electricity). For larger units, notwithstanding the estimates point to the presence of both aggregate economies of scale and scope, the high standard errors are such that the hypotheses of constant return to scale and of null advantages from diversification cannot be rejected.

The policy implications that can be drawn for this preliminary set of results are straightforward. Smaller-scale local utilities can reduce their costs by evolving into multi-utilities providing network services such as gas, water and electricity. To this respect, the gas-water pair is the one associated with the highest cost advantage. The efforts of municipalities to transform into multi-utility networks are then to be encouraged, considered the likely reduction in the tariff levels and the further benefits that users could enjoy as long as competition in the market (or for the market) is spurred.

However, for firms larger than the median the above positive impact is not borne out by our data, which means that the recent diversification waves of big companies might well respond to managerial and/or market power motivations. Keeping into account the fact that local public services have not yet been fully privatized/liberalized in most countries, one has at best to be cautious in expecting large welfare gains from such giant diversification moves.

is that global and product-specific economies of scope are significantly different from zero for the 'median' firm too.

Table 1. Sample structure: number of utilities by product mix and firm size*

	Total	Small units	Medium-small units	Medium-large units	Large units
Mono-product					
Gas	19	12	5	1	1
Water	16	5	3	6	2
Electricity	4	2	0	0	2
Two-product					
Gas & Water	31	6	9	9	7
Gas & Electricity	1	0	0	0	1
Water & Electricity	5	2	1	1	1
Three-product					
Gas, Water & Electricity	14	3	3	4	4
Total	90	30	21	21	18

* Size classes were constructed on the basis of the number of workers (n.w.) employed by firms: *small* for n.w. ≤ 50; *medium-small* for n.w. ∈ [51, 100]; *medium-large* for n.w. ∈ [101, 250]; *large* for n.w. > 250.

Table 2. Summary Statistics

	Mean	Std. dev.	Min	Median	Max
Total Cost (10^6 Italian lire)	72,542	135,357	1793.05	31,265	860,570
Output					
Gas (10^6 cubic meters)	94.54	179.10	4.60	71.20	1,287.00
Water (10^6 cubic meters)	18.86	52.72	0.31	10.55	435.26
Electricity (10^6 kilowatt hours)	163.87	621.58	2.30	221.24	4,535.60
Input prices					
Price of capital (10^6 Italian lire)	44.61	28.21	4.10	43.40	115.09
Price of labor (106 Italian lire)	73.32	9.48	50.41	71.59	104.13
Cost shares					
Capital share (10^6 Italian lire)	0.76	0.14	0.38	0.80	0.99
Labor share (10^6 Italian lire)	0.24	0.14	0.01	0.20	0.62

Table 3. NLSUR estimation: Standard Translog (ST), Generalized Translog (GT), Separable Quadratic (SQ), and Composite (PB) cost function models [a]

	ST MODEL	GT MODEL	SQ MODEL	PB MODEL
Box Cox parameter (π)	-	0.1276 (0.0276)	-	-
Output and factor price elasticities [b]				
ε_{CY_G}	0.4487 (0.0418)	0.3620 (0.0504)	0.2158 (0.0249)	0.2524 (0.0620)
ε_{CY_W}	0.2981 (0.0446)	0.2015 (0.0450)	0.2350 (0.0239)	0.1701 (0.0445)
ε_{CY_E}	0.3195 (0.0676)	0.2078 (0.0579)	0.4724 (0.0328)	0.4855 (0.0487)
S_K	0.7683 (0.0251)	0.7589 (0.0257)	0.7823 (0.0109)	0.7176 (0.0165)
S_L	0.2317 (0.0251)	0.2411 (0.0257)	0.2177 (0.0109)	0.2824 (0.0165)
Cost function				
Log-likelihood	-234.40	-227.75	-167.79	-169.88
R^2	0.7742	0.7851	0.8622	0.8600
SSE [c]	102.20	97.28	62.39	63.36
Labor share				
Log-likelihood	234.85	233.68	196.58	249.85
R^2	0.4749	0.4705	0.3028	0.5297
SSE	2.7755	2.7990	3.6853	2.4859
System log-likelihood	5.47	13.65	48.74	85.14
Goodness of fit [d]	0.6958	0.7113	0.8014	0.7926
LR test statistic	GT vs. ST: LR = 16.36	-	PB vs. SQ: LR = 36.40	-
AVLR test statistic [e]	-	PB vs. GT: AVLR = 6.40	-	-

[a] Estimated asymptotic standard errors in parentheses.
[b] The values are computed at the median firm. The coefficient subscripts are G = gas, W = water, E = electricity, K = capital, L = labor.
[c] Sum of squared errors.
[d] The goodness-of-fit measure for the NLSUR systems is McElroy's (1977) R^2.
[e] See Vuong (1989) and Gasmi et al. (1992). The AVLR statistic is distributed as a $N(0,1)$.

Table 4. Estimates of global scope, quasi-scope and global scale economies for the ST, GT, SQ, and PB models (at the medians of the output and input price variables)*

	ST MODEL	GT MODEL	SQ MODEL	PB MODEL
Quasi-scope estimates**				
ε = 0.0 (scope)	-0.7533	0.6350	0.1933	0.1236
	(0.0625)	(0.2455)	(0.0665)	(0.0928)
ε = 0.0001	-0.8855	-0.0535	0.1932	0.1236
	(0.0319)	(0.2872)	(0.0665)	(0.0928)
ε = 0.001	-0.8581	-0.0840	0.1929	0.1236
	(0.0357)	(0.24780)	(0.0664)	(0.0926)
ε = 0.01	-0.7405	-0.0191	0.1893	0.1235
	(0.0509)	(0.2069)	(0.0651)	(0.0904)
ε = 0.03	-0.6063	0.0766	0.1817	0.1232
	(0.0630)	(0.1842)	(0.0623)	(0.0857)
ε = 0.05	-0.5112	0.1427	0.1744	0.1228
	(0.0693)	(0.1722)	(0.0597)	(0.0813)
ε = 0.07	-0.4336	0.1948	0.1673	0.1225
	(0.0733)	(0.1635)	(0.0573)	(0.0771)
ε = 0.09	-0.3671	0.2380	0.1605	0.1221
	(0.0760)	(0.1567)	(0.0549)	(0.0732)
ε = 0.15	-0.2117	0.3343	0.1419	0.1206
	(0.0803)	(0.1420)	(0.0487)	(0.0629)
ε = 0.20	-0.1191	0.3887	0.1283	0.1191
	(0.0817)	(0.1339)	(0.0443)	(0.0559)
ε = 0.33	-0.0104	0.4491	0.1013	0.1140
	(0.0822)	(0.1249)	(0.0357)	(0.0430)
Global scale estimates	0.9379	1.2965	1.1327	1.1025
	(0.0711)	(0.1564)	(0.0635)	(0.0728)

* Estimated asymptotic standard errors in parentheses.

* Coefficient $\varepsilon \in [0, 0.33]$ has been used to split the median production of the three-outputs among firms, so as to generate configurations ranging from three fully mono-product specialized firms (ε = 0.0) up to three firms each one producing 1/3 of the median value for each output (ε = 0.33). Since it is impossible to evaluate the ST model when ε = 0.0, following Pulley and Braunstein (1992) we used ε = 0.000001 instead.

Table 5. Estimates of global economies of scope and scale for the PB model by scaled values of the median outputs (at the median prices)*

	GLOBAL SCOPE (SC)	GLOBAL SCALE (SL)
Scaling procedure:		
λ = 0.20	0.332 (0.070)	1.207 (0.049)
λ = 0.33	0.223 (0.053)	1.138 (0.033)
λ = 0.67	0.142 (0.063)	1.100 (0.046)
λ = 1 (median outputs)	0.124 (0.093)	1.103 (0.073)
λ = 1.5	0.126 (0.145)	1.126 (0.123)
λ = 3	0.189 (0.333)	1.254 (0.370)
λ = 5	0.325 (0.685)	1.586 (1.297)

* Estimated asymptotic standard errors in parentheses. Parameter λ refers to the coefficient used to scale down (λ = 0.20, 0.33, 0.67) and up (λ = 1.5, 3, 5) the median values of the three outputs.

Table 6. Estimates of product-specific scope economies and cost complementarities for the PB model by scaled values of the median outputs (at the median prices)*

PRODUCT-SPECIFIC SCOPE	SC_G	SC_W	SC_E	SC_{GW}	SC_{GE}	SC_{WE}
Scaling procedure:						
$\lambda = 0.20$	0.171 (0.036)	0.167 (0.035)	0.164 (0.037)	0.298 (0.054)	0.197 (0.043)	0.210 (0.043)
$\lambda = 0.33$	0.120 (0.031)	0.113 (0.026)	0.109 (0.035)	0.215 (0.043)	0.133 (0.038)	0.137 (0.034)
$\lambda = 0.67$	0.089 (0.048)	0.074 (0.033)	0.065 (0.058)	0.152 (0.042)	0.082 (0.055)	0.071 (0.040)
$\lambda = 1$ (median outputs)	0.089 (0.074)	0.067 (0.049)	0.052 (0.088)	0.144 (0.059)	0.068 (0.083)	0.045 (0.058)
$\lambda = 1.5$	0.106 (0.116)	0.071 (0.077)	0.047 (0.138)	0.159 (0.091)	0.065 (0.128)	0.026 (0.089)
$\lambda = 3$	0.189 (0.270)	0.113 (0.177)	0.060 (0.308)	0.263 (0.216)	0.087 (0.275)	-0.001 (0.183)
$\lambda = 5$	0.345 (0.561)	0.198 (0.366)	0.096 (0.603)	0.466 (0.462)	0.136 (0.503)	-0.023 (0.317)

COST COMPLEMENTARITIES	CC_{GW}	CC_{GE}	CC_{WE}
$\lambda = 1$ (median outputs)	-3.016 (2.435)	-0.076 (0.290)	0.138 (1.295)

* Estimated asymptotic standard errors in parentheses. In the SC_i, SC_{ij} and CC_{ij}, the i, $j = G$, W, E refer to the outputs 'cubic meters of gas', 'cubic meters of water', and 'kilowatt hours of electricity', respectively.

Table 7. Estimates of product-specific scale economies for the PB model by scaled values of the median outputs (at the median prices)*

PRODUCT-SPECIFIC SCALE	SL_G	SL_W	SL_E	SL_{GW}	SL_{GE}	SL_{WE}
Scaling procedure:						
$\lambda = 0.20$	0.993 (0.013)	1.002 (0.002)	1.006 (0.019)	1.010 (0.009)	1.006 (0.010)	1.004 (0.015)
$\lambda = 0.33$	0.988 (0.022)	1.003 (0.003)	1.011 (0.032)	1.018 (0.015)	1.010 (0.017)	1.006 (0.025)
$\lambda = 0.67$	0.976 (0.044)	1.005 (0.007)	1.022 (0.066)	1.037 (0.033)	1.021 (0.037)	1.013 (0.052)
$\lambda = 1$ (median outputs)	0.962 (0.069)	1.009 (0.011)	1.034 (0.102)	1.059 (0.054)	1.033 (0.058)	1.020 (0.081)
$\lambda = 1.5$	0.939 (0.111)	1.014 (0.019)	1.053 (0.163)	1.095 (0.095)	1.052 (0.095)	1.032 (0.131)
$\lambda = 3$	0.849 (0.296)	1.041 (0.076)	1.125 (0.400)	1.250 (0.357)	1.125 (0.257)	1.080 (0.342)
$\lambda = 5$	0.625 (1.114)	1.163 (0.878)	1.272 (0.957)	1.717 (2.163)	1.284 (0.729)	1.191 (0.936)

*Estimated asymptotic standard errors in parentheses.

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