Restructuring Public Transit Systems: Evidence on Cost Properties and Optimal Network Configuration from Medium and Large-Sized Companies

Carlo CAMBINI, Massimiliano PIACENZA, Davide VANNONI

Working Paper 4, 2006

Fondazione Collegio Carlo Alberto
Via Real Collegio, 30
10024 - Moncalieri (TO)
Tel: 011 670 5250
Fax: 011 6705089
info@hermesricerche.it
http://www.hermesricerche.it

Restructuring Public Transit Systems: Evidence on Cost Properties and Optimal Network Configuration from Medium and Large-Sized Companies

Carlo Cambini[a]
Massimiliano Piacenza[b]
Davide Vannoni[c]

March 2006

Abstract

This paper analyses the cost structure of a sample of Italian local public transport (LPT) companies operating in medium and large urban centres. The main focus is to identify the proper network configuration for the LPT service, by verifying the presence and the extent of *scale* and *density* economies. Technological characteristics of public transit systems are analysed by estimating both *variable* and *total* cost function models, which consider three alternative supply-oriented output measures, include *firm-specific* fixed effects, and allow for X-inefficiency to play a role through the estimation of a stochastic cost *frontier*. The evidence is remarkably robust across the different specifications which have been tested and shows the presence of short-run and long-run economies of scale, as well as of economies of network density, for both the average sample firm and for operators belonging to the highest percentile (large-sized companies). This suggests that, from a technological point of view, a proper LPT network design should at least include a large urban centre and should be extended so as to embrace the intercity service too, while a regulatory policy aimed at fragmenting the served area in various sub-networks would imply an efficiency loss.

Keywords: public transit systems, regulation, network configuration, scale and density economies, variable and total cost function.

JEL codes: L50, L92, R41

---

[a] Polytechnic of Turin, DISPEA, Corso Duca degli Abruzzi 24, 10129 Torino – ITALY.
Phone: +39-011-5647292; fax: +39-011-5647299; e-mail: carlo.cambini@polito.it.

[b] Italian National Research Council, Ceris-CNR, Via Real Collegio 30, 10024 Moncalieri (TO) – ITALY.
Phone: +39-011-6824929; fax: +39-011-6824966; e-mail: m.piacenza@ceris.cnr.it.

[c] University of Turin, Faculty of Economics, Corso Unione Sovietica 218 bis, 10124 Torino – ITALY.
Phone: +39-011-6706083; fax: +39-011-6706062; e-mail: davide.vannoni@unito.it.

1. Introduction

Historically many local public transport (LPT) firms in Europe enjoyed monopoly protection by means of non-tendered concessions. With very few exceptions, the financial performance of these firms has deteriorated for more than thirty years. Financial distress is partly explained by declining LPT patronage (lower shares in the private-public modality split) and fares permanently lower than average costs. However, an important role is also played by low and stagnant productivity, due to weak incentives for efficiency. In recent years, in order to introduce more efficiency, enhance productivity and reduce huge deficits, many EU-member countries (like Sweden, Finland, Germany, France and United Kingdom), put in place new industry reforms and introduced *competitive tendering* procedure in the assignment of franchised monopolies for the regional transportation services, including bus, underground and local trains.

In Italy, during the first half of the nineties, the Government devised a number of interventions aimed at improving the economic and financial situation of local public transport operators, that were on average benefiting from subsidies as high as to cover 71% of their operating costs. Since such measures failed to reach the goal of a structural readjustment of the balance-sheet accounts, a more radical reform was introduced with Law 549/1995 and implemented through the subsequent *Decreti Legislativi* 422/1997 and 400/99. The new regulatory framework shifts the programming of the services and the management of the subsidies from the national to the regional level, and increases the financial responsibility of both Local Authorities and LPT firms. These two actors are now required to sign a formal agreement (*service contract*) which clearly defines the rules that the provider of the service must obey and addresses important issues such as reimbursement and risk sharing schemes. The above measures, together with the reliance on competing tendering mechanisms for the allotment of service concessions, should be more effective in creating a more efficient and competitive environment in the LPT industry.

Competitive tendering (or competition *for* the market) is the main mechanism to create competitive pressure in a market where open competition between different transit operators is not possible or uneconomic (Klemperer, 2004). However, the implementation of tendering procedures is not so simple. Local authorities have to correctly define the optimal structure of a competitive tendering procedure in order to avoid negative effects for the whole local transport market and consequently for customers. The decision on the dimension of the service area to award, that is the *quantity* of service to tender, is probably the more important element that local governments should define in a tendering procedure. Local Authorities could decide to tender the transport services in their area on a route-by-route basis, splitting the whole area in sub-basins, aggregating local and intercity services or auctioning the entire network as it is. Obviously, a trade-off exists. On one hand, the smaller the area service is, for instance a bus line, the higher is the potential competition that can be generated in the tender because many operators will be able to participate in the tendering process. On the other hand, small service areas cannot guarantee an optimal exploitation of scale economies that could characterize the LPT service. This issue is particularly relevant for the opening of tendering procedures in big cities or metropolitan areas where, at least in principle, these economies could be exhausted at a particular size of the network.

In the present paper we analyse the cost structure of a sample of Italian LPT companies operating in medium and large urban centres. The main focus is to verify the presence of both *scale* economies (cost savings obtained through an increase in *both* the output and the service area) and *density* economies (reduction of average unitary cost obtained through an increase in the output *within* a given service area). Such an analysis allows us to identify the proper configuration of the network, which turns out to be useful both in the case in which Local Authorities choose to put the service in a tender and in the case in which they prefer to restructure the network while at the same time keeping the direct management of the LPT service. Depending on the findings on scale/density economies, the preferred strategy may lead to mergers and acquisitions in order to create larger-sized operators, or, alternatively, to divestitures of assets and fragmentation of the served area.

The remainder of the paper is organized as follows. Section 2 briefly reviews the international and Italian empirical literature on the cost structure of LPT sector. Section 3 presents the dataset and the different variables (output indicators, input prices and technical and environmental characteristics) used in the econometric analysis. Section 4 describes our empirical methodology and shows the main evidence on technological properties. Section 5 reports the results of some robustness checks, while section 6 concludes and highlights the implications for the regulatory policy.

2. Review of the literature

Several empirical studies have investigated the technological characteristics of TPL firms by estimating cost function econometric models. Table 1 reports the seminal contributions by Berechman (1987) and Windle (1988) and the main international and Italian studies carried out during the 90's and in the recent years. One can see that they differ in many respects:

i) the type of firms included in the sample (i.e. firms specialized in providing the urban service, firms specialized in providing the intercity service, or diversified firms offering both services);
ii) the choice of the output for the service provided (demand-oriented measures, such as passengers or passenger-kilometers; supply-oriented measures, such as bus-kilometers, seat-kilometers, or total-seat-kilometers);

iii) the inclusion among the explanatory variables of the size of the network, that allows to measure separately economies of network density and economies of scale;

iv) the decision to estimate a *long-run* cost function or the alternative choice of relying on a *short-run* cost function, which enables the computation of both short-run and long-run scale and network density economies;

v) the inclusion of hedonic characteristics, such as average commercial speed.

The findings generally point towards the presence of short-run economies of scale, while the long-run estimates give more uncertain results, especially for urban LPT systems. A common result is also the finding of considerable economies of network density. For what concerns the size of EU companies which have been analysed in the above studies, it is worthwhile to highlight that only the contribution by Matas and Raymond (1998) for Spain includes large LPT networks in the sample (i.e. the operators providing urban service in Madrid, Barcelona and Valencia, with 94, 35 and 22 millions of bus-kilometers, respectively), while all the other studies refer to small and medium firms.

Focusing on the empirical evidence for Italy, Filippini *et al.* (2003) analyse in the years 1991-1997 a sample of 58 small-sized Italian TPL firms, which are compared with an analogous sample of Swiss operators (median bus-kilometers = 6.7 millions). The findings of the presence of considerable economies of scale for all size classes suggest a policy of mergers between adjacent firms operating in the same region.[1] In a similar vein, Fraquelli *et al.* (2004) found evidence in support of the existence of scale economies by using a sample of 45 small and medium-sized Italian firms observed in the years 1993-1999 (average bus-kilometers = 10 millions). The sample includes both specialized urban or intercity operators and diversified firms and the estimates point towards the presence of economies of scope too. Thus, the suggestion that LPT companies should become bigger operators by merging with neighbours is further qualified in the sense that it is preferable to end up with firms providing both urban and intercity services.

Both studies suggest that for small and medium towns the optimal size of the service area to be assigned as a franchised monopoly should not be confined within the borders of the municipality, as it has often been the case, but should embrace more urban centres as well as intercity routes. However, pending evidence on large LPT firms, it would not be correct to extend the above results so as to deny the possibility to assign, with separate tendering procedures, small allotments (such as a bunching of routes or sub-basins, or even single routes) in big cities or metropolitan areas like Rome, Milan, Genoa, Turin, Naples. If scale economies are exhausted at a particular size of the network, as highlighted by Mata and Raymond (1998) for large urban firms in Spain (see table 1), the correct policy suggestion could be to pursue a strategy of integration for small operators, while at the same time

---

[1] The above arguments are further developed by Cambini e Filippini (2003), with the aim of choosing the optimal size of the allotment to be put in a tender for the LPT service.

allowing for the fragmentation of the network in sub-basins in the case of big urban centres. The main purpose of the present work is to fill the above gap by using a sample of medium and large-sized public transit systems (average production size of about 27 millions of bus-kilometers, see table 3).

3. Dataset and descriptive statistics

Our dataset consists of a balanced panel of 33 Italian public-owned LPT firms which have been observed for years 1993-1999, for a total of 231 pooled observations. Our sample firms, which on aggregate are responsible for about 70% of the total sales of the sector, are fairly representative of the universe of large (12 firms with more than 1000 employees) and medium size (21 firms with a number of employees included between 400 and 1000) Italian operators[2]. As to the type of service, 12 firms are specialized in the urban service, 7 firms are specialized in the intercity service, and 14 are multi service firms. Finally, 12 firms are localised in the Northern Regions, while 11 and 10 operators are localised in Central and Southern Italy, respectively.

The information for the construction of the database has been gathered from different sources. The main economic and production data, as total costs, labour costs, fuel consumption, the number of bus-kilometers, passengers and buses have been extracted from the Directories and the Yearly Surveys published by ASSTRA, the nationwide trade organization of public-owned LPT companies. Disaggregated information about costs (energy, materials and services, capital) and about technical and environmental characteristics (different categories of workers, load capacity and average age of buses, average commercial speed, size of the network, measured either as transport routes or as extension of the served area) have been obtained through questionnaires sent to managers.

For what concerns the inputs, we collected information about labour costs, fuel and electricity costs, costs of capital and costs for material and services. In a short-run perspective, capital is treated as a quasi-fixed input and total operating costs are simple the sum of the costs of all the other inputs. The physical measure of the capital (K) is the number of vehicles in each firm's rolling stock. Since the relative age of the fleet is likely to influence the requirements of variable inputs (labour, fuel, materials and services) that are necessary to satisfactorily provide the service, we applied the following correction:

$$K_{it} = \text{(number of vehicles in the rolling stock)} \times (age_c / age_{it})$$

---

[2] Large LPT operators are: ARST (Cagliari), AMT (Catania), AMAT (Palermo), ATC (Bologna), CTP (Napoli), AMT (Genova), ATM (Torino), ANM (Napoli), ATM (Milano), ATAC (Roma), ATAF (Firenze), COTRAL (Roma). Medium LPT operators are: ASM (Brescia), TRA.IN (Siena), APT (Verona), ATC (La Spezia), ACT (Reggio Emilia), ACAP (Padova), GRTI (Avellino), TEP (Parma), AMAT (Taranto), SPT (Como), AMTAB (Bari), CPT (Pisa), ATCM (Modena), ATESINA (Trento), CTM (Cagliari), TT (Trieste), ARPA (Chieti), SAB (Bergamo), SATTI (Torino), CSTP (Salerno), ATL (Livorno).

where age_c is the average age of the fleet in the whole sample, and age_{it} is the average fleet age for firm i in year t.

The price of labour (P_L) is given by the ratio of total salary expenses to the average number of employees (drivers, maintenance workers and administrative staff). Fuel price (P_F) is computed as fuel costs divided by liters of diesel oil consumed[3]. Materials and services represent a residual input category, whose price (P_{MS}) has been obtained by dividing the relative cost by the number of seat-kilometers offered, under the reasonable hypothesis that such expenses are strictly related to the actual exploitation of the network.

As will be seen in the robustness section, we have estimated also a total cost function model. In such a case, the price of capital (P_K) has been computed by dividing the cost of capital by the number of buses in the rolling stock. The cost of capital has been estimated by using the information provided by the firms about the costs of purchasing new vehicles and considering an average life of 15 years.

For what concerns the outputs, as shown in the previous section, different measures have been used in the empirical literature on the cost structure of LPT firms. The final output, generally proxied by the variable passenger-kilometers (total passengers * average transport length), takes into consideration the effective exploitation of the service provided, but it is not completely under the control of the firm. For example, the cost of a trip, in terms of fuel and labour expenses, does not change if the bus is full or empty, and firms are required to provide the service also in periods in which the demand is very low (early in the morning or late in the night, or during holidays).

Since the focus of the paper is on the cost structure of LPT firms, and the service actually provided can be underestimated by relying on final output measures such as the number of passengers on a bus, we decided to rely on 'intermediate' output measures. The latter, being directly linked to the productive capacity that can be potentially exploited by customers, appear to be more appropriate in a cost analysis. We employ three different measures of output (Y):

- *bus-kilometers* (Y_{BK}), that is the total number of kilometers covered by all the buses in the rolling stock in a specific year;
- *seat-kilometers* (Y_{SK}) , which is obtained by multiplying the number of bus-kilometers by the average capacity of the vehicles in the rolling stock. By taking into account the average number of seats available in the buses, it allows a better evaluation of the size of the activity;
- *total seats-kilometers* (Y_{TSK}), which is obtained by the product between the total number of kilometers covered in one year and the total available seats (i.e. bus-kilometers times total seats or, equivalently, seat-kilometers times total number of buses). Such a measure, first

---

[3] For a few number of firms which utilize tramways, trolley-lines or railways and consume electricity, kilowatt-hours have been transformed into "equivalent liters" of diesel oil.

introduced by Gagnepain e Ivaldi (2002) and subsequently used by Fraquelli *et al.* (2004), takes into account the total load capacity and synthesizes three different components: the frequency of the service, the size of the network and the total stock of vehicles.

Technical and environmental variables are very important in this kind of studies, as they significantly affect both the level and the dynamic behaviour of operating costs. First, we include in the econometric cost model a variable controlling for the extension of the network (*N*). The latter represents the 'static' or potential dimension of the output measure, in the sense that the network can be exploited more or less intensively by the LPT operator by offering more bus-kilometers, or seat-kilometers, or total-seat-kilometers. In line with the empirical literature on *network utilities* (i.e. distribution of gas, water, electricity), the inclusion of a variable capturing the size of the network allows to distinguish network density economies (increase in the output, given the existing network) from scale economies (increase in both the output an the size of the network).[4] The proxy which has been chosen to measure the extension of the network is the area served by the LPT firm (square kilometers of served area), instead of the alternative total length of the network (number of routes times their average length). This will allow a better comparison between firms specialized in providing the service in urban centres (that are typically characterized by shorter and partially overlapping routes, which are moreover concentrated in a limited area), firms offering only intercity routes, and firms active in both services.

Apart from the issue of the network, other aspects of the management of the service are different in a urban context as opposed to an intercity one. The former is generally characterised by larger buses, more frequent stops, and by a lower commercial speed (due to traffic congestion problems). These factors, together with the different type and density of users, affect the cost structure and the quality of the service. In order to take into proper account such a variability, we have added two service-specific dummies for intercity and diversified firms (*DINTC* and *DMIX*).

Finally, a variable checking for the average commercial speed of the network (*SP*) has been included among the regressors. For a specialized firm, it has been computed as the ratio between the total kilometers covered in one year and the total yearly hours of service of vehicles. For diversified firms, it is the weighted average of urban and intercity commercial speeds, using as weights the shares of kilometers covered by each type of service.

4. Cost function models

In this paper we estimate a translog specification of the cost function, due to its well known flexibility properties. In fact no restrictions are imposed on the characteristics of the underlying technology, and both the input substitution and the scale elasticities are allowed to

---

[4] See Braeutigam (1999) for more details.

vary with the size of the firm and with different input combinations. In order to check for the robustness of our results and to compare them with the ones coming from previous studies we have explored two different specifications of the cost function (a short-run cost function and a long run cost function), and, for each of them, we have used three different output measures (seats-kilometers, bus-kilometers and total seats-kilometers). In addition, each model has been estimated also by including fixed effects (a dummy for each firm), enabling us to show estimates of output and network coefficients which are not affected by firm specific characteristics. Table 2 summarizes the main features of the 12 specifications that have been tested.

The explanatory variables included in the econometric specification are output (Y, alternatively measured by the proxies *seat-km*, *bus-km*, or *total seat-km*), the quasi-fixed input (K, included only in the variable cost function specifications) and the prices of the following inputs: labour (P_L), fuel (P_F), materials and services (P_{MS}) and capital (P_K, included only in the total cost function specifications). Moreover, a time trend T has been added in all models, so as to capture the effect of technological progress, and *firm-specific* dummies DF_n have been included in fixed effects models.

Finally, we included among the regressors some technical and environmental variables in order to check for the high heterogeneity across our sample of firms. In all specifications, except the ones using total-seat-km as Y[5], we added the size of the network (N), the average commercial speed (SP), while in the models without firm specific dummies we inserted also two dummies that take into account the type of service provided, intercity service ($DINT$) or mixed service ($DMIX$), whose coefficients have to be interpreted as evidence of a different impact on costs as compared to the 'default' service (urban service).

Before estimation, all dependent variables (except for T and for the dummy variables) have been divided by their respective sample mean values.[6] In order to account for some possible distortions due to different technical and environmental characteristics of firms that are specialized in the intercity service or that provide an underground transport service, the analysis has been restricted also to sub-samples including urban and mixed LPT firms only and excluding two operators that during the years under observations had also subway transport facilities (namely, Milano ATM and Roma COTRAL). Table 3 presents the descriptive statistics for all the variables included in the different econometric cost models under estimation, for the restricted sub-sample of 25 firms (171 observations).

---

[5] N is not among the regressors in the four models that use total-seat-km as the output measure. Given the multiplicative nature of the latter (which can be read also as total load capacity × average frequency of the service × network size, see Gagnepain e Ivaldi, 2002 and Fraquelli *et al.*, 2004), the inclusion of N would have implied a sort of duplication of the impact of network characteristics on costs.

[6] This allows to interpret the first order coefficients as cost elastiticies (measured for the average firm in the sample) with respect to the different variables, cost elasticities which are.

The outcomes of the twelve models are similar for what concerns the impact on operating costs of the different variables, except for the two specifications that do not include firm-specific fixed effects and use bus-km as an output measure, whose results are unsatisfactory. The three outputs assume a different degree of exploitation of the network, with the bus-km measure representing a sort of *lower bound* and the total-seat-km measure representing an *upper bound.* Y_{TSK} is more suitable to analyse urban contexts, where it is appropriate to assume for all potential passengers (proxied by the number of total seats offered) an intensive exploitation of the service along the entire network. On the other hand, measures such as bus-km and seat-km assume that each vehicle circulates only once on the network, and are more suitable to depict firms providing (or providing also) intercity services, where the hypothesis of an intensive exploitation of the whole network on the part of customers is certainly less plausible.

As will be shown later on, our selection procedure suggests that the *variable cost model* which includes *firm-specific* fixed effects and uses *seat-km* as an output indicator, is best suitable to represent the cost structure of LPT firms. For such a model, the variable cost function reads as follows:

$$\begin{aligned}
\ln\left(\frac{VC}{P_{MS}}\right) &= \beta_0 + \beta_y \ln Y + \beta_N \ln N + \beta_k \ln K + \beta_{SP} \ln SP + \sum_i \beta_i \ln\left(\frac{P_i}{P_{MS}}\right) + \sum_i \beta_{iy} \ln\left(\frac{P_i}{P_{MS}}\right) \ln Y \\
&+ \sum_i \beta_{iN} \ln\left(\frac{P_i}{P_{MS}}\right) \ln N + \sum_i \beta_{iSP} \ln\left(\frac{P_i}{P_{MS}}\right) \ln SP + \sum_i \beta_{ik} \ln\left(\frac{P_i}{P_{MS}}\right) \ln K + \beta_{yN} \ln Y * \ln N \\
&+ \beta_{ySP} \ln Y * \ln SP + \beta_{yk} \ln Y * \ln K + \beta_{NSP} \ln N * \ln SP + \beta_{Nk} \ln N * \ln K + \beta_{SPk} \ln SP * \ln K \\
&+ \frac{1}{2}\beta_{yy}(\ln Y)^2 + \frac{1}{2}\beta_{NN}(\ln N)^2 + \frac{1}{2}\beta_{SPSP}(\ln SP)^2 + \frac{1}{2}\beta_{kk}(\ln K)^2 \\
&+ \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln\left(\frac{P_i}{P_{MS}}\right) \ln\left(\frac{P_j}{P_{MS}}\right) + \beta_t T + \sum_{n=1}^{N-1} \beta_n DF_n + \psi_{VC}
\end{aligned}$$

$$i,j \in \{L = \text{labour};\ F = \text{fuel}\}, \qquad [1]$$

where VC represents the variable costs, K represents the quasi-fixed input, DF_n is a dummy capturing the fixed-effect for firm n, and ψ_{VC} is a random noise reflecting the stochastic structure of the cost function. The normalisation of VC, P_L, P_F and P_K with respect to the input price P_{MS} ensures that the cost function is homogenous of degree one in input prices.

In order to improve the efficiency of the estimates, the cost function has been estimated jointly with the input cost-hare equations, which can be obtained by applying *Shephard's lemma* to equation [1]:

$$\frac{\partial \ln VC}{\partial \ln P_i} = \frac{\partial VC}{\partial P_i}\frac{P_i}{VC} = \frac{P_i x_i^D}{VC} = S_i \qquad i \in \{L, MS, F\} \qquad [2]$$

where x_i^D is the conditional demand of input i and S_i is its relative share on variable cost. Since the cost-shares must sum to 1 (*adding-up* condition), we have a system [1]-[2] with one equation which is linearly dependent on the others. We then dropped one equation, S_{MS}, and proceeded to estimate the remaining three equations by using Zellner's iterated SUR method (Zellner, 1962). The general expression of the *cost-share* equation, to be estimated jointly with the variable cost equation is the following:

$$S_i = \beta_i + \beta_{iy} \ln Y + \beta_{ik} \ln K + \sum_j \beta_{ij} \ln P_j + \beta_{iSP} \ln SP + \beta_{iN} \ln N + \psi_i \quad i \in \{L, F\}, j \in \{L, MS, F\} \qquad [3]$$

where ψ_i is a *random noise* reflecting the stochastic nature of input i's cost share.

Table 4 shows the results of the econometric estimation of the system [1]-[3] for the full sample of 33 firms (231 observations), for the restricted sample of 31 operators without underground service (217 observations), and for the restricted sample of 25 urban and mixed operators (171 observations). Since the results are quite similar across sub-samples, we will discuss them only for the latter sub-sample.

Almost all the estimated coefficients are significantly different from zero and with the expected sign. The coefficient β_k is positive and significant, suggesting that LPT firms at the sample mean are characterized by excess capacities in terms of available buses in the rolling stock, and are not located on the optimal, long-run equilibrium path. This points towards the choice of a variable cost function specification. As to the fixed effects, a Wald test statistics strongly rejects the hypothesis that the coefficients on the 24 firm specific dummies are all equal to zero, and the same happens for the samples including 33 and 31 firms, respectively.

The estimates of β_L (0.72), β_F (0.08) and β_{MS} ($1-\beta_L-\beta_F$ = 0.20) are very close to the average sample values indicated in table 2[7]. Given the normalization procedure (see footnote 6), the values exhibited by β_y and β_N suggest that a 10% increase of both the output and the network size generate an increase of variable costs of about 4.8% and 1%, respectively. The estimates of β_{SP} = -0.61 and β_t = -0.002 show a statistically significant impact of both an increase in commercial speed and advances in technical progress in reducing costs.[8]

Since N has been included among the right hand side variables, it is possible to test for the presence of both density (*RTD*) and scale (*RTS)* economies. As to the former, they can be estimated by using the following expression:

---

[7] The share of the variable input i on variable cost can be easily computed from the shares on total costs as follows: $S_i^{VC} = S_i^{TC} / (S_L^{TC} + S_{MS}^{TC} + S_F^{TC})$. The average variable cost shares are then 73% for labor, 8% for fuel and 19% for materials and services.

[8] A distinctive feature of our dataset is the inclusion of LPT operators that provide different services (urban, intercity, or mixed). In order to fully exploit the richness of our database, we have estimated some variable cost function specifications which do not include fixed effects but include two dummies, relative to intercity and mixed operators, among the regressors (see table 2). The estimates of the coefficients β_{INT} and β_{MIX} and the computation of the corresponding cost elasticities suggest that firms specialized in the intercity service are characterised with lower costs as compared to firms specialised in providing urban services. Moreover, firms that are active in both markets reach even higher cost savings, a result that points towards the presence of scope economies.

$$SRTD = \frac{1}{\varepsilon_y} \qquad [4]$$

where ε_y is the cost elasticity with respect to output. As to the latter, it reads as follows:

$$SRTS = \frac{1}{\varepsilon_y + \varepsilon_N} \qquad [5]$$

where ε_N is the cost elasticity with respect to network size.

Both [4] and [5] have to be interpreted as short-run estimates, with the capital stock being fixed. The corresponding long-run estimates take into due account also the possibility to optimally modify the amount of quasi-fixed input. Following the formula proposed by Caves *et al.* (1981):

$$LRTS = \frac{(1-\varepsilon_k)}{(\varepsilon_y + \varepsilon_N)} \qquad [6]$$

$$LRTD = \frac{(1-\varepsilon_k)}{\varepsilon_y} \qquad [7]$$

where ε_k is the cost elasticity with respect to the quasi-fixed input.

The values of *SRTS* and *SRTD* for the average firm in the sample are 1.77 (standard error = 0.215) and 2.11 (s.e.= 0.214), respectively. These figures suggest that an increase of 10% of the supply of seat-km, being fixed the network size and the number of buses, would determine an increase in variable costs of about 5%. If the network size is allowed to increase by 10% too, variable costs increase of about 6%. The estimates of *LRTS* and *LRTD* are 1.44 (s.e.= 0.157) and 1.72 (s.e.= 0.144), respectively, and confirm the presence of both economies of scale and economies of network density. The estimates of density and scale economies for the full sample of 33 firms (*SRTS* = 2.01, *SRTD* = 2.18, *LRTS* = 1.65, *LRTD* = 1.79) and for the restricted sample of 31 firms (*SRTS* = 1.89, *SRTD* = 2.20, *LRTS* = 1.36, *LRTD* = 1.88) are quite similar to the ones previously shown, if we take into account that, given our normalization procedure, they are computed for hypothetical "average firms" whose sizes differ across samples. Overall, these results suggest that it is possible to reach considerable cost savings through a better exploitation of the network (*SRTD* and *LRTD*) and, where possible, through a simultaneous increase of both network size and the number of seat-km (*SRTS* and *LRTS*), both in the short and in the long run.

The Translog specification allows also to estimate scale economies for firms of a different size. Since the focus of the paper is on the technological properties of large LPT firms, table 5 presents the estimates of scale and density economies for firms belonging to different size classes, under the hypothesis that *N* and *K* increase proportionally with *Y* and that all the other explanatory variables are kept at their sample average values[9]. The first five

---

[9] That is to say that the cost elasticities are respectively computed as :

rows show that the estimates increase steadily with the size of the LPT firm. However, these figures can be considered good extrapolations only for intercity and mixed firms which, given the output and the stock of capital, are characterised by a network size which is remarkably larger as compared to the reality of urban LPT operators. In order to take into account the above asymmetry, the last five rows compute scale and density economies for firms which are extrapolations of an ‘average firm’ which is characterised by mean values of *Y* and *K*, but by a network size which is only one third of the sample mean.[10] For example, the values of the fourth row are good proxies for a firm like ATC Bologna, which is a mixed operator characterised with values of *Y*, *K* and *N* which are all twice the average values shown in table 3. In the same vein, the figures in the eighth row reflect the operating conditions of a firm like ATAF Firenze, which provides only the urban service, and is characterised by mean values of *Y* and *K* but a network size which is only one third of the average sample value.

5. Robustness analysis

As shown in table 2, we tested 12 different models, which vary according to the adopted output measure (Y_{BK}, Y_{SK} or Y_{TSK}), the inclusion of *firm-specific* fixed effects, the *short-run* or *long-run* specification. The estimates of density and scale economies confirm our prior belief that Y_{TSK} represents a sort of higher bound, while Y_{BK} is associated with the lowest values. For example, the results for the ‘average firm’ in the specification which includes *total seat-km* are the following: *SRTS* = 2.85 and *LRTS* = 2.37, while the results for the specification which uses *bus-km* as an output measure are respectively *SRTS* = 1.47 , *SRTD* = 2.00, *LRTS* = 1.40, *LRTD* = 1.89.

As shown in Braeutigam and Daughety (1983), equations [6] and [7] are correct if the underlying technology is homothetic or if *K* is at the optimal level. We have run a restricted model which satisfies homotheticity, under which computed scale and density economies for the average sample firm are equal to *SRTS* = 1.41 (s.e. = 0.15) , *SRTD* = 1.45 (s.e. = 0.12), *LRTS* = 1.31 (s.e. = 0.13), *LRTD* = 1.35 (s.e. = 0.08). While these figures confirm the presence of scale and density economies, albeit at a lower degree, homotheticity hypothesis is clearly rejected by LR tests (the log likelihood of the system of equations is only 1307.6), which are in favour of our full specification as in equation [1].

In order to further check the robustness of our findings for long run economies, we have estimated a total cost function model, which uses *TC* as dependent variable and includes

---

$$\varepsilon_y = d\ln VC / d\ln Y = \beta_y + \beta_{yy}\ln Y + \beta_{yN}\ln N + \beta_{yk}\ln K$$

$$\varepsilon_N = d\ln VC / d\ln N = \beta_N + \beta_{NN}\ln N + \beta_{yN}\ln Y + \beta_{Nk}\ln K$$

$$\varepsilon_k = d\ln VC / d\ln K = \beta_k + \beta_{kk}\ln K + \beta_{yk}\ln K + \beta_{Nk}\ln N$$

[10] Thus, the rows at the top of the table refer to different sizes of a *mixed-type* LPT firm, while the bottom part of the table refers to different sizes of a *urban-type* LPT operator.

P_K among the regressors. The specifications of the cost function and of the corresponding cost-share equations read as follows:

$$\begin{aligned}
\ln\left(\frac{TC}{P_{MS}}\right) &= \beta_0 + \beta_y \ln Y + \beta_N \ln N + \sum_i \beta_i \ln\left(\frac{P_i}{P_{MS}}\right) + \beta_{SP} \ln SP + \sum_i \beta_{iy} \ln\left(\frac{P_i}{P_{MS}}\right) \ln Y \\
&+ \sum_i \beta_{iN} \ln\left(\frac{P_i}{P_{MS}}\right) \ln N + \sum_i \beta_{iSP} \ln\left(\frac{P_i}{P_{MS}}\right) \ln SP + \beta_{yN} \ln Y * \ln N \\
&+ \beta_{ySP} \ln Y * \ln SP + \beta_{NSP} \ln N * \ln SP + \frac{1}{2}\beta_{yy} (\ln Y)^2 + \frac{1}{2}\beta_{NN} (\ln N)^2 \\
&+ \frac{1}{2}\beta_{SPSP} (\ln SP)^2 + \frac{1}{2}\sum_i \sum_j \beta_{ij} \ln\left(\frac{P_i}{P_{MS}}\right) \ln\left(\frac{P_j}{P_{MS}}\right) + \beta_t T + \sum_{n=1}^{N-1} \beta_n DF_n + \psi_{TC}
\end{aligned}$$

$$i, j \in \{L = \text{labour}; F = \text{fuel}; K = \text{capital}\}, \qquad [8]$$

$$S_i = \beta_i + \beta_{iy} \ln Y + \sum_j \beta_{ij} \ln P_j + \beta_{iSP} \ln SP + \beta_{iN} \ln N + \psi_i \quad i \in \{L, F, K\}, j \in \{L, MS, F, K\} \qquad [9]$$

Similarly to the results of the short-run model, almost all coefficients are significantly different from zero and have the correct sign. The estimates of β_y e β_N suggest that an increase of 10% of both output and network size determine an increase of total costs of about 6.6% and 1.2%. Equations [4] and [5] are now to be interpreted as long-run estimates. The results are once more in favour of the presence of both economies of scale [RTS = 1/(0.661 + 0.117) = 1.29] and economies of network density (RTD = 1/0.661 = 1.51) for the average firm. Thus, a proportional increase of both seat-km and network size (for example a 10% increase) would bring a less than proportional increase in total costs (7.8%). A *fortiori*, an increase of 10% of seat-km, given the existing network, would determine a total cost increase of 6.6% only, with a saving in average unitary costs of about 3% [i.e. (1.066/1.1) – 1].

As a final robustness check we have estimated also a stochastic variable cost *frontier* model. One common critique to the studies which make use of total or variable cost functions concerns the underlying cost minimization hypothesis. The stochastic frontier approach (SFA), introduced by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977), allows to refine traditional production analysis so as to consider inefficiency and appears particularly appealing when estimating cost functions for regulatory purposes (e.g. for determining subsidies to public transit systems). In fact, regulators should define optimal policies using the performances of the most efficient observations as guidelines; they should therefore refer to technology estimates based on the best observed cost-output experience rather than on average cost relationships that standard regression techniques yield.

In order to control for the presence of individual cost inefficiency, we have estimated a "true fixed effect" stochastic frontier model with *firm-specific* heterogeneity included in the inefficiency distribution (Greene, 2004 and 2005). The model can be concisely expressed as follows:

$$C_{it} = \beta' x_{it} + v_{it} + u_{it}$$
$$\text{with } u_{it} \sim N^{+}(\mu_{it}, \sigma_u^2) \text{ and } \mu_{it} = \alpha_i + \delta' z_{it} \qquad [10]$$

where C_{it} and x_{it} are respectively the dependent - i.e. $\ln(VC/P_{MS})$ - and explanatory variables included in equation [1], v_{it} is a random noise ~ $N(0, \sigma_v^2)$, and u_{it} is a non-negative cost inefficiency component which has a truncated-normal distribution with mean μ_{it} and variance σ_u^2. Finally, we assume that μ_{it} depends on a set of explanatory variables z_{it} (in our specification we included average commercial speed *SP* and time trend *T*) and on *firm-specific* fixed effects (α_i). As compared to other traditional stochastic frontier formulations, in such a model the mean of the inefficiency distribution shifts in time but also has a *firm-specific* persistency term.[11]

The results are presented in table 7. Considering that in this case the estimates are relative to a single equation,[12] we note, not surprisingly, a loss of precision in the estimates of the input cost-shares (β_L = 0.64 and β_F 0.06). The computation of scale and density economies (*SRTS* = 2.06; *SRTD* = 2.26; *LRTS* = 1.36; *LRTD* = 1.71) are very similar to the ones resulting from the SUR estimation. As for the inefficiency component of model [10], the estimated average inefficiency for our sample (third last row of table 7) reveals a 5% of over-cost with respect to the minimum frontier level. Such a value is lower than the 12% obtained by Piacenza (2006), who estimated a stochastic cost frontier for a sample of Italian LPT operators of *smaller* size using the Battese and Coelli (1995) SFA specification. The difference may be partially due to the inclusion of *firm-specific* fixed effects in our model.[13] Table 7 reports also the values of parameters $\sigma \equiv (\sigma_v^2 + \sigma_u^2)^{1/2}$ and $\gamma \equiv \sigma_u^2/(\sigma_v^2 + \sigma_u^2)$, which are associated with the variances of the random noise v_{it} and the inefficiency term u_{it}. We note, in particular, that the estimate for γ is 0.858 (standard error = 0.332), implying that the vast majority of residual variation is due to departures from cost minimization objective.

6. Conclusions and regulatory implications

The paper show evidence of both scale and density economies for a sample of medium and large-sized Italian public transit systems. Such economies are present for the average firm as well as for companies belonging to the highest percentiles, independently of the type of service provided (i.e. urban, intercity or mixed). The overall findings, which are robust to different specifications of the cost function (a *variable* versus a *total* cost function model,

---

[11] The software used for the ML estimation of the stochastic cost frontier model [10] is LIMDEP Version 8.0. See chapter E-24 for full details and Greene (2004, 2005) for recent applications.

[12] System estimation (cost function and associated cost-share equations) is not allowed in LIMDEP using SFA routines.

[13] In fact, after having omitted the fixed effects α_i in the specification of μ_{it}, the mean of estimated inefficiencies raises up to 11%. Another explanation can be that Piacenza (2006) included among the regressors z_{it} a variable taking into account the different regulatory regimes (i.e. fixed-price versus cost-plus subsidization schemes).

considering or without considering the presence of *firm-specific* fixed effects), to the type of indicator used as an output measure (bus-km, seat-km, total seat-km), and to the inclusion of individual time-varying inefficiency terms (stochastic cost *frontier*), confirm also for large urban centres the results obtained by previous empirical literature for samples of French, Swiss and Italian public transit systems of smaller size. However, they are in contrast with the results by Matas and Raymond (1998), who found on a sample of Spanish companies that scale economies were exhausted after a certain threshold level.

The empirical evidence suggests that public transport operators can benefit from cost savings by increasing, within a specific service area, the number of seat-km supplied (density economies), and that their costs increase less than proportionally with proportional increases in both output level and network size (scale economies). From a policy point of view, it is thus worth to pursue a strategy of mergers between neighbouring companies, and in particular between urban and intercity operators, so as to create firms that, by offering a mixed service, can also exploit potential scope economies existing between the two types of public transport (Fraquelli *et al*., 2004, Piacenza, 2006).

More delicate is however the issue of the definition of the network object of tendering mechanisms. The econometric results suggest that tenders should embrace large transport networks, including both urban and intercity services, and that in the case of metropolitan areas the allotment should be relative to the entire network. However, even if in this case the integrity of the network is maintained and economies of scale and density are fully exploited, the design of the tendering procedure presents some disadvantages. Firstly, the complexity of the services would probably increase the organization costs of the tendering procedure. Moreover, the potential number of bidders would be relatively low, since it is difficult for small companies to provide the whole LPT service in a big city. Therefore, potential benefits from competition for the market would be lower. On the contrary, reducing the area to award (i.e. dividing a metropolitan area in sub-basins or subsets of routes) increases the number of potential bidders in each set and thus enhances the competitive pressure in the tendering process. In addition, the possibility of tendering small units, without loss of integration, permits the Local Authority to compare operators' performance simultaneously (*yardstick* competition), even if the exploitation of scale economies is inevitably reduced. Thus, the final decision of Local Authorities should balance all the above mentioned effects in taking their choice on the optimal area size for the competitive tendering mechanism. As a matter of fact, at least for big towns, it is possible to think of separating *ex ante* the allotments to be put in different tenders, running separate tenders without introducing any participation constraints, and leaving the market free to give signals of the effective presence of scale economies. Such an option could represent also a valid empirical test for the econometric results shown in the present work.

7. References

Aigner D., Lovell K. C. A. and Schmidt P. G., "Formulation and Estimation of Stochastic Frontier Production Function Models", *Journal of Econometrics*, 6, 1977, 21-37.

Bhattacharyya A., Kumbhakar S. C. and Bhattacharyya A., "Ownership Structure and Cost Efficiency: A Study of Publicly Owned Passenger-Bus Transportation Companies in India", *Journal of Productivity Analysis*, 6, April 1995, 47-61.

Battese G. E. and Coelli T. J., "A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data", *Empirical Economics*, 20, 1995, 325-332.

Berechman J., "Cost Structure and Production Technology in Transit: An Application to Israeli Bus Transit Sector", *Regional Science and Urban Economics*, 17, 1987, 519-534.

Braeutigam R., "Learning About Transport Cost", *Techniques of Transportation Analysis*, 1999, 57-97.

Braeutigam R. and Daughety A. F., "On the Estimation of Returns to Scale Using Variable Cost Functions", 1983, 11, 25-31.

Cambini C. and Filippini M., "Competitive Tendering and Optimal Size in the Regional Bus Transportation Industry: An Example from Italy", *Annals of Public and Cooperative Economics*, 2003, 74(1), 163-182.

Caves D.W., Christensen L.R., and Swanson J.A. (1981), "Productivity Growth, Scale Economies and Capacity Utilization in U. S. Railroads", *American Economic Review*, vol. 71, 994-1002.

Dalen D. M. and Gomez-Lobo A., "Yardsticks on the Road: Regulatory Contracts in the Norwegian Bus Industry", *Transportation*, 30, 2003, 371-386.

Fabbri D., "La stima di frontiere di costo nel trasporto pubblico locale: una rassegna e un'applicazione", *Economia Pubblica*, 3, 1998, 55-94.

Fazioli R., Filippini M. and Prioni P., "Cost Structure and Efficiency of Local Public Transport: The Case of Emilia Romagna Bus Companies", *International Journal of Transport Economics*, 3, 1993, 305-324.

Filippini M., Fazioli R. and Künzle M., "Valutazione dell'efficienza delle compagnieimprese di bus italiane e svizzere", in *L'efficienza nei servizi pubblici*, Banca d'Italia, Roma, Luglio 2003, 175-214.

Filippini M. and Prioni P., "The Influence of Ownership on the Cost of Bus Service Provision in Switzerland. An Empirical Illustration", *Applied Economics*, 2003, 35(6), 683-690.

Fraquelli G., Piacenza M. and Abrate G., "Regulating Public Transit Networks: How Do Urban-Intercity Diversification and Speed-up Measures Affect Firms' Cost Performance?", *Annals of Public and Cooperative Economics*, 2004, 75(2).

Gagnepain P., “Structures Productives de l'Industrie du Transport Urbain et Effets des Schemas Reglementaires”, *Economie et Prevision*, 135, 1998, 95-107.

Gagnepain P. and M. Ivaldi, “Incentive Regulatory Policies: the Case of Public Transit Systems in France”, *RAND Journal of Economics*, 33(4), 2002, 605-629.

Greene W., “Distinguishing between Heterogeneity and Inefficiency: Stochastic Frontier Analysis of the World Health Organization’s Panel Data on National Health Care Systems”, *Health Economics*, 2004, 13, 959-980.

Greene W., “Reconsidering Heterogeneity in Panel Data Estimators of the Stochastic Frontier Model”, *Journal of Econometrics*, 2005, 126, 269-303.

Jha R. and Singh S. K., “Small Is Efficient: A Frontier Approach to Cost Inefficiencies in Indian State Road Transport Undertakings”, *International Journal of Transport Economics*, 2001, 28(1), 95-114.

Klemperer P., *Auctions: Theory and Practice*, Princeton University Press, 2004.

Levaggi R., “Parametric and Non-Parametric Approach to Efficiency: The Case of Urban Transport in Italy”, *Studi Economici*, 49(53), 1994, 67-88.

Matas A. and Raymond J. L., “Technical Characteristics and Efficiency of Urban Bus Companies: The Case of Spain”, *Transportation*, 25, 1998, 243-263.

Meeusen W. and van den Broeck J., “Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error”, International Economic Review, 18, 1977, 435-444.

Piacenza M., “Regulatory Contracts and Cost Efficiency: Stochastic Frontier Evidence from the Italian Local Public Transport”, *Journal of Productivity Analysis*, 25(3), 2006 forthcoming.

Windle R. J., “Transit Policy and the Cost Structure of Urban Bus Transportation”, in J.S. Dogson and N. Topham eds., *Bus Deregulation and Privatization*, Averbury: Aldershot, 1988.

Zellner A., “An Efficient Method of Estimating Seemingly Unrelated Regressions (SUR) and Tests for Aggregation Bias”, *Journal of the American Statistical Association*, 57, 1962, 348-368.

Table 1. Main empirical literature estimating cost functions for public transit systems

	Type of firm and country	Model	Output	Network	Hedonic variables	Main Results*
INTERNATIONAL STUDIES						
Berechman (1987)	Complete urban and intercity transport industry, Israel	Translog, total cost	vehicle-kms/ passenger-trips			*SE*
Windle (1988)	91 US urban bus companies	Translog, total and variable cost	passenger-miles	number of route miles	commercial speed	*SE* ; *DE*
Bhattacharyya *et al.* (1995)	32 Indian state-run bus companies	Translog, total cost	passenger-kms			*SD*
Matas and Raymond (1998)	9 urban bus companies, Spain	Translog, total cost	vehicle-kms	network lenght		*SE* for small and medium firms but *SD* for large firms; *DE*
Gagnepain (1998)	60 urban bus companies, France	Translog, variable cost	vehicle-kms	network lenght	commercial speed	*SE* ; *DE*
Jha and Singh (2001)	9 Indian state-run road companies	Translog, total cost	passenger-kms	network lenght		both *SE* and *SD*
Gagnepain and Ivaldi (2002)	59 urban bus companies, France	Cobb-Douglas, variable cost	total seats-kms			*SE*
Dalen and Gomez-Lobo (2003)	142 urban bus companies, Norway	Extended Cobb-Douglas, variable cost	vehicle-kms	network density, dispersion	industrial characteristics of served area	*SE*
Filippini and Prioni (2003)	34 Swiss regional bus companies	Translog, total cost	vehicle-kms/ seat-kms	network lenght, number of stops		*SE* ; *DE*
ITALIAN STUDIES						
Fazioli *et al.* (1993)	40 intercity bus companies, Emilia Romagna	Translog, total cost	seat-kms	network lenght		*SE* ; *DE*
Levaggi (1994)	55 urban bus companies	Translog, variable cost	passenger-kms	network lenght	commercial speed	*SE* and *DE* in the short-run but *SD* and *DD* in the long-run
Fabbri (1998)	9 intercity and urban bus companies, Emilia Romagna	Translog, variable cost	vehicle-kms			*SE*
Cambini e Filippini (2003)	58 urban, mixed and intercity bus companies	Translog, total cost	vehicle-kms	network lenght		*SE* ; *DE*
Fraquelli *et al.* (2004)	45 urban, mixed and intercity bus companies	Translog, variable cost	total seats-kms		commercial speed	*SE*
Piacenza (2006)	44 urban, mixed and intercity bus companies	Translog, variable cost	seat-kms		commercial speed	*SE*

* *SE* (*SD*) = scale (dis)economies; *DE* (*DD*) = density (dis)economies

Table 2. Alternative specifications of the translog cost function model

Output measure	without *firm-specific* FIXED EFFECTS		with *firm-specific* FIXED EFFECTS	
	TOTAL cost	VARIABLE cost	TOTAL cost	VARIABLE cost
SEAT-KM	Includes: P_k, N, SP, $DINT$, $DMIX$[a]	Includes: K, N, SP, $DINT$, $DMIX$[a]	Includes: P_k, N, SP, *firm-specific* dummies	Includes: K, N, SP, *firm-specific* dummies
BUS-KM	Includes: P_k, N, SP, $DINT$, $DMIX$	Include: K, N, SP, $DINT$, $DMIX$	Includes: P_k, N, SP, *firm-specific* dummies	Includes: K, N, SP, *firm-specific* dummies
TOTAL SEAT-KM	Includes: P_k, SP, $DINT$, $DMIX$	Includes: K, SP, $DINT$, $DMIX$	Includes: P_k, SP, *firm-specific* dummies	Includes: K, SP, *firm-specific* dummies

[a] $DINT$ ($DMIX$) = dummy equal to 1 for intercity (mixed) companies; P_k = price of capital, K = capital expressed in physical units; N = squared kilometers of served area; SP = average network speed.

Table 3. Summary statistics of the variables included in the different cost function models

Sample: 25 LPT companies	Mean	St. dev.	Min	Max
VC[a] (10^3 €)	88,112	126,096	19,660	732,809
TC[a] (10^3 €)	94,640	132,544	23,312	770,615
Y_{BK}[b] (millions)	21	23	7	127
Y_{SK}[b] (millions)	2,156	2,702	635	14,656
Y_{TSK}[b] (millions)	2,412,650	6,534,472	131,580	40,126,996
N (km^2 of served area)	1,669	1,493	116	5,001
SP (kms / hour of bus service)	19.10	5.38	10.09	33.00
K[c]	545	530	172	2,997
P_L (10^3 € / worker)	38.72	3.48	29.59	47.38
P_F (€ / liter of diesel oil)	0.59	0.07	0.36	0.82
P_{MS} (€ / seat-km)	0.01	0.00	0.00	0.01
P_K (10^3 € / bus)	12.31	1.31	8.19	15.18
S_L (labour cost-share)	0.67	0.08	0.48	0.85
S_F (fuel cost-share)	0.07	0.01	0.03	0.10
S_{MS} (material cost-share)	0.17	0.06	0.06	0.36
S_K (capital cost-share)	0.09	0.02	0.04	0.16

Sample: 33 LPT companies	Mean	St. dev.	Min	Max
Y_{BK}[b] (millions)	27	33	7	159
Y_{SK}[b] (millions)	2,828	4,234	557	20,170
Y_{TSK}[b] (millions)	4,578,009	11,984,970	10,000	58,998,876

[a] Variable cost (VC): sum of labour, fuel, and materials & services expenses; Total cost (TC):): sum of labour, fuel, materials & services, and capital expenses.

[b] Output: Y_{BK} = bus-kilometers; Y_{SK} = seat-kilometers; Y_{TSK} = total-seat-kilometers.

[c] Capital (K): number of vehicles in the rolling stock weighted by an average-fleet-age index.

Table 4. SUR estimates of the translog *variable cost function* [1]

Regressor [a]	FULL SAMPLE (33 LPT companies)		RESTRICTED SAMPLE 1 (31 LPT companies)		RESTRICTED SAMPLE 2 (25 LPT companies)	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
Constant	25.473***	(0.049)	25.227***	(0.053)	25.776***	(0.088)
$\ln Y_{SK}$	0.458***	(0.038)	0.455***	(0.039)	0.475***	(0.048)
$\ln N$	0.039	(0.050)	0.074	(0.051)	0.091**	(0.046)
LnSP	-0.376***	(0.050)	-0.477***	(0.054)	-0.609***	(0.070)
LnK	0.180***	(0.035)	0.145***	(0.033)	0.185***	(0.038)
$\ln P_L$	0.711***	(0.004)	0.715***	(0.003)	0.722***	(0.003)
$\ln P_F$	0.081***	(0.001)	0.082***	(0.001)	0.078***	(0.001)
$\ln P_L \ln Y_{SK}$	-0.041***	(0.008)	-0.041***	(0.009)	-0.040***	(0.009)
$\ln P_F \ln Y_{SK}$	0.003	(0.003)	0.004	(0.003)	0.006**	(0.003)
$\ln P_L \ln N$	0.010***	(0.003)	0.013***	(0.004)	0.010**	(0.004)
$\ln P_F \ln N$	-0.002**	(0.001)	-0.004***	(0.001)	-0.005***	(0.001)
$\ln P_L \ln SP$	-0.115***	(0.011)	-0.143***	(0.014)	-0.158***	(0.019)
$\ln P_F \ln SP$	0.041***	(0.004)	0.053***	(0.004)	0.060***	(0.005)
$\ln P_L \ln K$	0.054***	(0.009)	0.050***	(0.009)	0.049***	(0.010)
$\ln P_F \ln K$	-0.006**	(0.003)	-0.005*	(0.003)	-0.006**	(0.003)
$\ln Y_{SK} \ln N$	0.004	(0.019)	0.008	(0.023)	0.002	(0.032)
$\ln Y_{SK} \ln SP$	0.076	(0.048)	0.059	(0.061)	0.093	(0.078)
$\ln Y_{SK} \ln K$	0.035	(0.034)	0.050	(0.035)	0.076*	(0.040)
$\ln N \ln SP$	-0.207***	(0.032)	-0.237***	(0.040)	-0.284***	(0.044)
$\ln N \ln K$	-0.011	(0.017)	-0.022	(0.019)	-0.027	(0.021)
$\ln SP \ln K$	0.051	(0.058)	0.122*	(0.073)	0.210**	(0.106)
$\ln Y_{SK}{}^2$	-0.087**	(0.043)	-0.137**	(0.059)	-0.192**	(0.075)
$\ln N^2$	-0.011	(0.032)	0.0001	(0.032)	-0.028	(0.033)
$\ln SP^2$	0.741***	(0.138)	0.897***	(0.192)	1.177***	(0.229)
$\ln K^2$	0.029	(0.037)	0.042	(0.038)	0.035	(0.046)
$\ln P_L \ln P_F$	-0.037***	(0.003)	-0.042***	(0.005)	-0.036***	(0.004)
$\ln P_L{}^2$	0.177***	(0.004)	0.182***	(0.005)	0.176***	(0.005)
$\ln P_F{}^2$	0.049***	(0.003)	0.055***	(0.005)	0.049***	(0.004)
T	-0.001	(0.001)	-0.001	(0.001)	-0.002**	(0.001)
Observations	231		217		171	
System Log-lik	1,769.9		1,675.1		1,376.8	

[a] Dependent variable: *VC*; estimates of *firm-specific* fixed effects not reported.

*** Significant at the 1% level, ** significant at the 5% level, * significant at the 10% level (two-tailed Student test).

Table 5. Estimates of short-run and long-run economies of scale (*SRTS*, *LRTS*) and economies of network density (*SRTD*, *LRTD*) by scaled values of the average production (at the average input prices) [a]

Scaling procedure [b]			*SRTS*	*LRTS*	*SRTD*	*LRTD*
λ_y	λ_k	λ_N				
1/3	1/3	1/3	1.33	1.21	1.67	1.51
			(0.147)	(0.125)	(0.186)	(0.158)
1/2	1/2	1/2	1.47	1.28	1.80	1.58
			(0.129)	(0.101)	(0.157)	(0.122)
1	1	1	1.77	1.44	2.11	1.72
			(0.215)	(0.157)	(0.214)	(0.144)
2	2	2	2.22	1.68	2.53	1.92
			(0.590)	(0.422)	(0.535)	(0.365)
3	3	3	2.62	1.90	2.86	2.07
			(1.056)	(0.731)	(0.896)	(0.599)
1/3	1/3	1/9	1.28	1.13	1.67	1.47
			(0.182)	(0.156)	(0.248)	(0.214)
1/2	1/2	1/6	1.41	1.19	1.81	1.53
			(0.167)	(0.131)	(0.224)	(0.180)
1	1	1/3	1.68	1.32	2.12	1.66
			(0.199)	(0.126)	(0.238)	(0.149)
2	2	2/3	2.09	1.52	2.54	1.85
			(0.462)	(0.290)	(0.487)	(0.289)
3	3	1	2.44	1.69	2.88	2.00
			(0.811)	(0.508)	(0.811)	(0.484)

[a] Estimated asymptotic standard errors in parentheses.

[b] Parameters λ_y, λ_k and λ_N refer to the coefficients used to scale down (λ = 1/9, 1/6, 1/3, 1/2, 2/3) and up (λ = 2, 3) the average values (λ = 1) of output (Y_{SK} = 2,156 millions of seat-kilometers), capital (K = 545 vehicles weighted by the fleet age) and network size (N = 1,669 squared kilometers of served area), respectively.

Table 6. SUR estimates of the translog *total cost function* [8] - 171 observations

Regressor [a]	Coefficient	Standard error
Constant	25.790***	(0.088)
$\ln Y_{SK}$	0.661***	(0.036)
$\ln N$	0.117**	(0.047)
$\ln SP$	-0.689***	(0.073)
$\ln P_L$	0.663***	(0.004)
$\ln P_F$	0.071***	(0.001)
$\ln P_K$	0.086***	(0.001)
$\ln P_L \ln Y_{SK}$	0.007	(0.005)
$\ln P_F \ln Y_{SK}$	0.003**	(0.001)
$\ln P_K \ln Y_{SK}$	-0.012***	(0.002)
$\ln P_L \ln N$	0.010**	(0.004)
$\ln P_F \ln N$	-0.006***	(0.001)
$\ln P_K \ln N$	0.007***	(0.001)
$\ln P_L \ln SP$	-0.188***	(0.021)
$\ln P_F \ln SP$	0.057***	(0.005)
$\ln P_K \ln SP$	0.031***	(0.006)
$\ln Y_{SK} \ln N$	-0.005	(0.031)
$\ln Y_{SK} \ln SP$	0.154***	(0.051)
$\ln N \ln SP$	-0.188***	(0.038)
$\ln Y_{SK}{}^2$	0.028	(0.049)
$\ln N^2$	0.007	(0.032)
$\ln SP^2$	0.742***	(0.191)
$\ln P_L \ln P_F$	-0.025***	(0.004)
$\ln P_L \ln P_K$	-0.039***	(0.007)
$\ln P_K \ln P_F$	-0.012***	(0.003)
$\ln P_L{}^2$	0.194***	(0.011)
$\ln P_F{}^2$	0.048***	(0.003)
$\ln P_K{}^2$	0.050***	(0.006)
T	-0.002***	(0.001)
System Log-likelihood	1,942.08	

[a] Dependent variable: *TC*; estimates of *firm-specific* fixed effects not reported.

*** Significant at the 1% level, ** significant at the 5% level (two-tailed Student test).

Table 7. ML estimates of the translog *variable cost frontier* [10] - 171 observations

Regressor [a]	Coefficient	Standard error
Constant	25.357***	(0.057)
$\ln Y_{SK}$	0.442***	(0.100)
$\ln N$	0.090*	(0.046)
$\mathrm{Ln} SP$	-0.547***	(0.168)
$\mathrm{Ln} K$	0.087*	(0.050)
$\ln P_L$	0.644***	(0.086)
$\ln P_F$	0.063	(0.090)
$\ln P_L \ln Y_{SK}$	-0.258	(0.219)
$\ln P_F \ln Y_{SK}$	-0.094	(0.216)
$\ln P_L \ln N$	-0.061	(0.073)
$\ln P_F \ln N$	0.187***	(0.066)
$\ln P_L \ln SP$	0.348	(0.405)
$\ln P_F \ln SP$	-1.043***	(0.383)
$\ln P_L \ln K$	0.270	(0.188)
$\ln P_F \ln K$	-0.108	(0.196)
$\ln Y_{SK} \ln N$	0.025	(0.049)
$\ln Y_{SK} \ln SP$	-0.048	(0.227)
$\ln Y_{SK} \ln K$	0.327***	(0.123)
$\ln N \ln SP$	-0.353***	(0.078)
$\ln N \ln K$	0.048	(0.056)
$\ln SP \ln K$	-0.019	(0.246)
$\ln Y_{SK}{}^2$	-0.644***	(0.207)
$\ln N^2$	-0.030	(0.033)
$\ln SP^2$	1.207***	(0.465)
$\ln K^2$	-0.202*	(0.113)
$\ln P_L \ln P_F$	-0.009	(0.551)
$\ln P_L{}^2$	0.016	(0.590)
$\ln P_F{}^2$	0.048	(0.549)
T	-0.001	(0.003)
Mean inefficiency [exp(u)-1]	0.051	
$\sigma = (\sigma_v{}^2 + \sigma_u{}^2)^{1/2}$	0.036***	(0.004)
$\gamma = [\sigma_u{}^2/(\sigma_v{}^2 + \sigma_u{}^2)]$	0.858***	(0.332)

[a] Dependent variable: *VC*; estimates of individual cost inefficiencies and of coefficients of explanatory variables for inefficiency (average network speed, time trend, *firm-specific* fixed effects) not reported.

*** Significant at the 1% level, * significant at the 10% level (two-tailed Student test).