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Regulatory and Environmental Effects on Public Transit Efficiency
A Mixed DEA-SFA Approach

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ABSTRACT. The aim of this paper is to account for the impact of statistical noise and exogenous regulatory and environmental factors on the efficiency of public transit systems in a DEA-based framework. To this end, we implement a three-stage DEA-SFA mixed approach based on Fried *et al*. (2002) using a 1993-1999 panel of 42 Italian public transit companies. This allows us to decompose input-specific DEA inefficiency measures into three components: exogenous effects, pure managerial inefficiency, and statistical noise. First, the initial evaluation of producer performance is carried out using conventional variable returns to scale DEA (Banker *et al*., 1984). Second, a SFA approach (Battese and Coelli, 1992) is used to regress single input slacks on subsidies regulation (cost-plus versus fixed-price contracts) and a set of environmental variables including network speed and user density. Finally, third stage re-runs DEA on inputs purged of both exogenous effects and statistical noise. Results are such that adjusting for the type of regulatory scheme, environmental conditions, and statistical noise increases average efficiency in the industry and reduces dispersion among firms. Furthermore, the implementation of fixed-price subsidies is found to enhance efficiency in the usage of "drivers" and "materials and services" inputs. Such a result sheds some light on the determinants of input-specific efficiency differentials in the industry, improving the existing evidence on mean overall cost efficiency (e.g. Gagnepain e Ivaldi, 2002; Piacenza, 2006). As a policy implication, it is confirmed the relevance of regula tion aimed at replacing cost-plus subsidization mechanisms with high-powered incentive contracts as well as improving operating conditions of public transport networks.

KEYWORDS: Public transit systems, Regulation, Environmental effects, Statistical noise, Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA)

JEL CODES: C44, D21, L50, L92, R41

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INTRODUCTION

This paper reconciles empirical contract theory applied to local public transport (LPT) industry with *Data Envelopment Analysis* (DEA)-based models incorporating policy and environmental effects and statistical noise. The main policy implication of our study is related to the assessment of the efficiency enhancing effect of "fixed-price" regulatory schemes as compared to "cost-plus" ones. Building upon previous literature on the topic dealing with the Italian case (Piacenza, 2006), the work is aimed at verifying the extent to which both regulation and other non-discretionary factors affect input-by-input inefficiency differentials in the industry. Furthermore, we pursue the analysis allowing for the presence of statistical noise, overcoming the limitation of DEA models due to their deterministic nature. Such an aim is motivated by the fact that inputs employed by local public transport suppliers can be rationalized at different extent. Hence, it is predictable that changes in regulation and/or environmental characteristics may induce higher slack reductions in the usage of more controllable inputs (e.g. labor) as compared to less controllable ones (e.g. fuel).

A crucial issue in the literature investigating the determinants of the production (or X-) inefficiency in LPT systems is the role played by non-discretionary characteristics in affecting local suppliers' performance. Due to the high degree of regulation, alternative subsidization mechanisms are indeed most likely to give rise, *ceteris paribus*, to inefficiency differentials across suppliers. Furthermore, it might well be the case of efficiency gaps induced by different network conditions (e.g. average commercial speed) that are not under the control of local operators. Hence, the design of producer performance evaluation procedures able to encompass external sources of inefficiency should be regarded as a major concern in efficiency analysis for the industry. In the light of this, we adopt a recently developed methodology within the line of research of DEA-based models (Fried *et al.*, 2002) incorporating exogenous (i.e. regulatory and environmental) effects and statistical noise.

Previous literature has dealt with the role played by different subsidization mechanisms in explaining inefficiency differentials among LPT operators, reaching the uncontroversial conclusion that the predictions from incentive theory (Laffont and Tirole, 1993) help explain differences in productive efficiency among firms. This stream of research includes the contributions by Kerstens (1996) and Gagnepain and Ivaldi (2002a, b) for the French urban transit industry, and by Dalen and Gomez-Lobo (1997, 2003) for Norway. More recently, Piacenza (2006) has investigated the LPT Italian case, controlling for the environmental characteristics of each network. His analysis is based on a panel data of firms managed under two regulatory schemes (i.e. cost-plus or fixed-price) and facing different levels of network commercial speed. The main conclusion is that – given similar network characteristics – firms under a fixed-price mechanism exhibit a lower distortion from minimum cost than operators subjected to a cost-plus regulation. Furthermore, to some extent the inefficiency differentials among companies are found to be due to differences in the network characteristics (commercial speed levels).

This study aims at investigating the impact of exogenous factors on the X-efficiency of the Italian LPT industry, within a DEA-based framework which takes also into account the presence of statistical noise. More precisely, we intend to provide a decomposition of input-specific DEA inefficiency measures into three components: environmental factors, pure managerial inefficiency, and random noise. Such a methodology proceeds in three steps. First, given a deterministic non-parametric reference technology for LPT operators consisting of four inputs (drivers, indirect employees, fuel, and materials and services) and one output (seat-kilometers) we run the initial performance evaluation using DEA. Second, a *Stochastic Frontier Analysis* (SFA) approach is adopted to regress stage-one input slacks on a set of regulatory and environmental variables. Finally, we rerun DEA on inputs quantities purged of both exogenous effects and statistical noise.

The remainder of the paper is organized as follows. Section 1 presents the main features of the Italian LPT industry. The focus will be on both the institutional context and the regulation of subsidies, in order to clarify the relevance of the research issue under investigation. Section 2 details the employed methodology, mainly referring to Fried *et al.* (2002). Section 3 deals with the presentation of the frontier model to be estimated, underlying the peculiarities of our empirical implementation. First, we concentrate on the specification of the deterministic non-parametric reference technology of service suppliers. Then, we discuss the relevance of the regulatory and environmental characteristics included in the estimated SFA regression equations and introduce the expected sings for the coefficients of variables used as proxies for subsidization mechanisms and other non-discretionary factors. Section 4 gives detail on the dataset used in the estimations. Results are reported in section 5 and section 6 concludes.

1. THE ITALIAN FRAMEWORK

The characteristic of universal service that Local Authorities usually attribute to LPT imposes the maintenance of low tariff levels. Thus the LPT operators have to face structural balance deficits, which need public subsidies to be refilled. A typical and critical issue for regulation Authorities is therefore to assure the economic and financial brake-even of LPT operators, but at the same time to minimize the waste of public funds.

In Italy (as in most of European Countries), during the '70s and the '80s costs of LPT firms have risen more than revenues. The first effort to face this problem has been implemented in the Law 151/1981, which provided for an ex ante definition of subsidy levels, yearly allocated to the National Transport Fund (NTF) and then assigned to the providers. The amount yearly allotted might act as a compensation to operators for providing services at a price lower than its costs. The remaining deficit should have been balanced by selling transport services. Despite this rule, both the high inflation rates (not taken into account in the centralized allotment) and the decrease of demand levels contributed to enhance firms' deficits and compelled the central Government to allocate ex-post funds. Notwithstanding this kind of cost-plus grant acted only as stopgap measures, and has been unable to readjust industry accounts.

In practice, before 1996 all LPT Italian providers received cost-plus reimbursements, characterized by the full recovery of budget losses by local authorities.[1] In this context, the firm bears neither industrial risk (risks on costs) nor commercial risk (risks on revenue). According with the new theory of regulation (Laffont and Tirole, 1993), in this situation the operator is not residual claimant for effort and so it has no incentives to produce efficiently. During the '90s radical regulatory changes have been introduced to improve both service efficiency and effectiveness. First the law 549/1995 established the abolition of the NTF (since 1996) and the allocation of the public funds responsibility to the Regions, who are in charge of the LPT programming as well. For this reason since 1996 some local authorities have introduced ex ante reimbursement mechanisms (fixed-price schemes), which provide different risk-sharing schemes between firm and local authority. Compared to cost-plus schemes, the companies subjected to fixed-price mechanisms face high-powered incentives towards a cost minimizing behavior.[2] Then the Legislative Decrees 422/1997 and 400/1999 provided a guide for transport system reform to be implemented by each Region.

The main purpose of the whole transport reform is to stimulate the recovery of LPT suppliers' productive efficiency, first by increasing the financial responsibility of all the subjects operating in the sector (local authorities and LPT firms). For this reason the transfers from the central government have been replaced with regional taxes, in order to encourage an efficient use of public local resources. The reform also provides for a clear distinction between programming and regulatory functions (assigned to

[1] European Commission (1998).

[2] It is worthwhile to underline that both cost-plus and fixed-price schemes are not optimal rules in the sense specified by the new theory of regulation. According to this approach, because of the presence of informational constraints, optimal mechanisms must solve the trade-off between the efficiency incentives typical of fixed-price schemes and the rent extraction properties of a cost-plus regulation. The complex problem of designing an optimal contract is beyond the scope of this study, as only fixed-price or cost-plus subsidization mechanisms are carried out at the present time in the Italian LPT industry.

public administrators) and the industrial management (assigned to LPT companies).

Secondly, the reform tries to introduce some competition "for the market" in the sector, by requiring competitive tendering procedures to allot LPT services. Competitive tendering in the assignment of franchised monopolies is the main mechanism to create competitive pressure when the open competition is not possible or is not economic. Therefore, if competition in the market is not feasible for technical reasons, the only way to enhance efficiency is to introduce competition for the market (Demsetz, 1968; Laffont and Tirole, 1993). Foreign experiences of competitive tendering in LPT sector have produced some positive effects both on productivity and cost savings (Cambini and Filippini, 2003). However, the adoption of tendering procedures is not so simple, local authorities having to correctly define the structure of a competitive tendering procedure in order to avoid negative effects for the whole LPT market and hence for customers.

Moreover the Law states that the relationships between the regulator and the LPT provider have to be outlined by means of a formal agreement: the 'service contract'. It should clearly name the service duties of the LPT company as well as the regulator/operator risk-sharing scheme and the ways to determine the amount of settlements. Each service contract has to have certain financial allotment in the regulator budget and to contain instruments to improve firms' efficiency. Anyway the transfer from the local authority has to be ex-ante defined, on the basis of expected operating costs (gross cost approach) or expected operating deficits (net cost approach), and the amount of actual costs (or deficits) has not to influence the level of subsidies (fixed-price contract).

One of the goal of the present paper is to investigate *input-by-input* whether public transit companies running under fixed-price regimes are more efficient than those operating under cost-plus schemes, due to stronger incentives to increase managerial effort, taking also into account firm-specific network characteristics. On the policy side, this investigation allows us to assess whether subsidization schemes recently introduced in Italy have proved suitable in order to recover efficiency, which is one of the goals pursued by the legislative reform, also highlighting the management areas where the rationalization attempt resulted more effective. In addition, we may extend previous evidence on the relevance of incentive theory and modern regulatory economics for the production analysis of public utilities.

2. ESTIMATION METHODOLOGY

Our approach is based on the three-stage methodology proposed by Fried *et al.* (2002), whereby we account for the impact of external conditions (regulatory and environmental factors) and statistical noise in a DEA-based producer performance evaluation framework. The aim is to identify three input-specific determinants of inefficiency – exogenous factors, pure managerial inefficiency and statistical noise – in the Italian LPT industry.

This section reviews Fried *et al.* (2002) methodology. Section 4 details the implementation of such methodology to our case study, focusing on the specification of nonparametric deterministic reference technology and on the modelling of regulatory schemes and other environmental variables involved in the analysis.

Consider I Decision Making Units (DMUs) - with $i = 1, \dots, I$ - each of them employing N inputs ($n = 1,\dots, N$) to produce M outputs ($m = 1, \dots, M$). DEA-based measures of the i^{th} producer performance – relative to the best-practise nonparametric frontier – has the limitation of neglecting two possible sources of inefficiency. First, DEA models are solely based on inputs and outputs data. However, the external conditions under which the i^{th} production is carried out can be relatively favorable/unfavorable – as compared to other firms in the comparison set – due to the positive/negative impact of any observable exogenous characteristics. Second, any other unobservable factors and omitted variables are also ruled out from the performance evaluation, the DEA framework being deterministic. Hence, accounting for neither of these non-discretionary differentials across firms belonging to the comparison set might lead to over/under-evaluated performances and misleading rankings.

A solution to such limitation is given by the adoption of SFA in order to decompose DEA input slacks into exogenous effects, managerial inefficiency and statistical noise (Fried *et al.*, 2002). We apply this approach to the Italian public transit systems.[3] Using data on observed inputs and outputs, a standard input-oriented variable returns to scale envelopment problem is solved for each i^{th} firm in the sample (Banker *et al.*, 1984):

$$\min_{\theta,\lambda} \quad \theta \qquad [1]$$

$$\text{subject to} \quad \theta x_i \geq X\lambda$$
$$\lambda Y \geq y_i$$
$$\lambda \geq 0$$
$$e^T \lambda = 1$$

where x_i is the i^{th} DMU (N x 1) non-negative vector of inputs; y_i is the i^{th} DMU (M x 1) non-negative vector of outputs; $\lambda = [\lambda_1, \ldots, \lambda_I]$ is an (I x 1) vector of intensity variables; $X = [x_1, \ldots, x_I]$ is an (N x I) matrix of input vectors in the comparison set; $Y = [y_1, \ldots, y_I]$ is an (M x I) matrix of output vectors in the comparison set; $e = [1, \ldots, 1]$ is a (I x 1) unit vector. The solution of the above linear programming problem in terms of non-negative and bounded to one optimal value θ allows to evaluate total slacks (radial plus non radial) for each input as the non-negative scalars:

$$s_{ni} = x_{ni} - X_n\lambda\,; \; n = 1,\ldots, N \text{ and } i = 1, \ldots, I. \quad [2]$$

Stage two involves the estimation of N stochastic frontier equations. In each of them the dependent variable is the n^{th} total input slack and the independent variables are the z non-discretionary regulatory and environmental variables. The aim is to purge slacks of external effects and statistical noise not accounted for in stage one, letting each of the exogenous characteristics producing a different impact across the SFA equations.[4] The N separate SFA regressions take the following form:

$$s_{ni} = f^n\left(z_i, \beta^n\right) + \upsilon_{ni} + u_{ni} \qquad [3]$$

where $z_i = [z_{1i}, \ldots, z_{Ki}]$ is a vector of K exogenous variables and β^n are unknown parameters to be estimated and ($\upsilon_{ni} + u_{ni}$) is a composite error term. The component $\upsilon_{ni} \sim (0, \sigma^2_{\upsilon n})$ represents *statistical noise*, while the one-sided truncated-normal error term $u_{ni} \sim N^+(\mu^n, \sigma^2_{un})$ reflects pure *managerial inefficiency*, with mean μ^n and variability σ^2_{un} across observed slacks of the n^{th} input. For the alternative assumption of half-normal distributed managerial inefficiency, we have instead $u_{ni} \sim N^+(0, \sigma^2_{un})$.

The *deterministic* feasible slack frontier term $f^n(z_i, \beta^n)$ captures the impact of observable external factors (regulation and environmental characteristics) on the stage-one slacks. Once statistical noise is accounted for, the *stochastic* feasible slack frontiers is given by the expression $f^n(z_i, \beta^n) + \upsilon_{ni}$, which indicates the minimum achievable slack in a noisy context. Under the alternative distributional assumptions on the inefficiency error term – truncated and half-normal distributions – the parameters to be estimated using a maximum likelihood (ML) technique are given by ($\beta^n, \mu^n, \sigma^2_{\upsilon n}, \sigma^2_{un}$) and ($\beta^n, \sigma^2_{\upsilon n}, \sigma^2_{un}$) respectively. Given the obtained estimates for β^n and υ_{ni}, *adjusted* input quantities (x^A_{ni}) are then evaluated:

$$x^A_{ni} = x_{ni} + \left[\max_i\left\{z_i\hat{\beta}^n\right\} - z_i\hat{\beta}^n\right] + \left[\max_i\left(\hat{\upsilon}_{ni}\right) - \hat{\upsilon}_{ni}\right] \qquad [4]$$

where the first term in square brackets force all firms to operate in the least favourable environment observed in the sample, while the second term in square brackets forces all firms to operate in the unluckiest situation observed in the sample. By doing so, distortions from the efficient usage of each input due to external factors and random noise, which are not under the control of LPT firms, are removed.

The final step of the analysis consists of reruning the DEA-based producer performance evaluation using data on adjusted inputs in order to reflect differences in firms' exogenous conditions. The comparison between initial and final DEA efficiency measures gives the understand-

[3] For a discussion on previous approaches attempting to incorporate environmental variables in DEA-like model, see Fried *et al.* (2002).

[4] The alternative strategy would be to estimate (M + N) regressions. For a discussion of advantages and disadvantages of both estimation strategies see Fried *et al.* (2002).

ing of the extent to which non-discretionary variables affect efficiency differentials, other things being equal.

3. MODEL SPECIFICATION

3.1 Technology

In line with the mainstream of DEA and SFA literature, we adopt an input-oriented framework in the first DEA stage. This choice relies on the fact that firms are well-expected to minimise the use of inputs given the amount of output they provide.

A fundamental stage in any DEA assessment is the specification of a set of variables that correctly capture the underlying technology (Thanassoulis, 2001). The identification of a bundle of inputs used in the procurement of a bundle of corresponding outputs is thus needed. Environmental factors that might affect the efficiency of transformation of inputs into outputs are not considered at this phase, because they will be taken into account in the second SFA-based stage. With regards to the output measure, in principle one might try to estimate the efficiency conditions either in a demand or a supply-related framework. De Borger *et al*. (2002) point out that supply-related output indicators might be considered to a larger extent under the control of the management than the demand of transit service by passengers. It should be recognised that the decisions on the service level provision are not totally under the control of the firm because of the presence of regulatory constraints on the supply. However, it is reasonable to think that such constraints are the outcome of some negotiation process with the regulatory authorities. Thus, following Piacenza (2006) a supply-oriented framework is adopted in this study and a measure that captures the production capacity of the firms is needed.

Two alternative conventional output measures usually adopted in the public transit literature are the yearly vehicle-kilometres and the yearly seat-kilometres. The first one is calculated as the total number of vehicles in the fleet times the average distance yearly covered by each vehicle. The second one is calculated as the total number of vehicles in the fleet times the average size of the vehicles in terms of seats times the average distance yearly covered by each vehicle. The second output indicator seems to provide better information on the amount of the service as it takes into account the differentiation in size among firms' vehicles. Thus, we chose the latter (*SKM*) as our preferable output measure.

The conventional inputs used in the DEA frontier analyses are labour, fuel and other materials and services.[5] Labour has been included by splitting the number of workers in two categories: drivers (*emplDR*) and indirect employees (*emplIND*). The reason of this decomposition stands on the predominance of the cost of drivers as percentage of total labour cost. Thus, it might be interesting to investigate the conditions of use of this category of workers in isolation from non-drivers.[6] Fuel (*FUEL*) is measured as the total amount of yearly consumed litres of gasoline (or equivalent kilowatt-hours of energy). Other materials and services is a not homogeneous item. A physical measure is not available for this input, hence we chose to use the corresponding cost (*CMS*), opportunely deflated[7] so as to avoid any problem regarding changes in prices. The cost of materials and services has been derived by the balance-sheets of the firms as difference between the total operating expenditure and the costs of labour and fuel. It includes various types of costs within which the highest percentage belongs to the costs for maintenance and outsourced services. Table 1 reports descriptive statistics on output and inputs involved into the analysis.

[5] See De Borger *et al.* (2002) for a comprehensive review of the inputs most widely considered in the transit industry

[6] Although we will present the results on both the inputs, we will focus on drivers as they are the main source of costs for the firms.

[7] The deflator is the production price index.

Table 1: Descriptive statistics for output and input variables

Type of LPT system	*SKM* (10^6) [a]	*emplDR* [b]	*emplIND* [b]	*FUEL*(10^3 *litres*) [c]	*CMS*(10^6 €) [d]
Urban					
Mean	1,166	532	274	5,565	14,242
Standard Deviation	1,507	602	392	7,446	20,425
Minimum	48	23	4	233	435
1st quartile	246	133	42	1,269	3,943
Median	883	344	110	3,865	9,557
3rd quartile	1,199	595	307	6,299	14,164
Maximum	6,554	2,758	1,698	33,143	102,436
Variability index*	129%	113%	143%	134%	143%
Mixed					
Mean	1,062	507	212	4,999	16,254
Standard Deviation	973	535	310	4,397	18,939
Minimum	59	30	4	352	1,184
1st quartile	427	173	54	2,168	4,885
Median	891	369	97	4,120	9,704
3rd quartile	1,102	464	174	5,335	15,822
Maximum	3,909	2,290	1,323	18,103	86,427
Variability index	92%	106%	146%	88%	117%
Intercity					
Mean	820	335	163	4,035	9,285
Standard Deviation	578	288	258	2,667	6,064
Minimum	148	78	26	1,037	1,924
1st quartile	326	196	60	1,894	4,118
Median	735	250	79	3,673	7,753
3rd quartile	1,122	342	151	4,775	11,114
Maximum	2,043	1,339	1,307	10,500	24,536
Variability index	71%	86%	158%	66%	65%

* The variability index is computed as the ratio between standard deviation and mean.
[a] *SKM* = number of yearly seat-kilometers supplied.
[b] *emplDR* and *emplIND* = number of drivers and indirect employees, respectively.
[c] *FUEL* = litres of gasoline consumed.
[d] *CMS* = real value of yearly expenses for materials and services.

Following Fried *et al*. (2002), capital input has not been considered either as stock measure or as depreciation in the DEA model. Capital is a non-discretionary input, at least in the short-run, and the imposition of a quasi-fixed input in the minimisation DEA algorithm would have resulted in a significant shrinking of the set of peers so that each unit could have appeared as unique and with an efficiency score close to unity.[8] However, capital has been recovered as a control variable in the second SFA stage through the inclusion of size dummy variables, where size is measured in terms of the number of vehicles in the rolling stock. This solution allows us to avoid the difficult and inevitably imperfect construction of a time series of the replacement cost for capital, adjusted for taking into account inflation and/or revaluations. As during the period under investigation the majority of the firms undertook a reorganisation process passing from municipal firms to limited companies, the above-mentioned fixed assets revaluation could have represented a serious problem.

[8] See Coelli *et al*. (1998) and Thanassoulis (2001) for more details on the treatment of quasi-fixed inputs.

3.2 Regulation and environmental factors

As stated above, any efficiency comparison should not neglect the external conditions under which firms operate. Such characteristics might create advantages or disadvantages for the firms so that the efficiency scores might result heavily affected. In other words, a high/low efficiency score might be attributed to a favourable/not favourable action of exogenous variables rather than to the actual effort/inadequacy of the managers. Hence, the resulting ranking of the firms should be viewed as a very preliminary one, requiring an adjustment to embody the impact of exogenous variables. These variables cannot be included as inputs or outputs, being out of the control of the management.

We consider two exogenous sources of efficiency differentials across LPT suppliers: the regulatory policy context and the environmental non-discretionary characteristics. In the following we provide microeconomic insights on the variables included into the analysis in order to capture both sources of inefficiency, discussing their expected effects on each considered input.

All firms in the sample experienced a change in the regulation during the period under investigation. The decentralisation of the financial responsibility at a regional level has increased the power of the regions in selecting service areas to be subsidised. Furthermore, local public authorities gradually abandoned previous cost-plus schemes based on a full ex-post coverage of the losses, adopting risk-sharing fixed-price schemes which allow for a rent and at the same time are expected to stimulate the firms to a better performance through a tighter control on the inputs.

The impact of regulatory schemes has been analysed by Kerstens (1996) for France under a DEA framework. In particular, the author verified that the efficiency scores under different non-parametric frontier specifications are more related to high-powered incentive schemes if seat-kilometres are used as output variable. Gagnepain and Ivaldi (2002a, b) and Dalen and Gomez-Lobo (1997) assessed the impact of fixed-price policy on the managerial effort for French and Norwegian bus industries using a structural cost function model based on a principal-agent framework. They empirically demonstrated that the fixed-price policy dominates cost-plus schemes and that the underlying yardstick mechanism can help the regulator to reduce the lack of information on the firm's cost structure. Finally, Dalen and Gomez-Lobo (2003) and Piacenza (2006) analysed the effects of the adoption of high-powered incentive schemes of subsidization respectively for Italy and Norway within the SFA framework proposed by Battese and Coelli (1995). Both studies shed some light on the effectiveness of risk-sharing contracts (yardstick and fixed-price type of regulation) in enhancing efficiency. So we expect that the introduction of fixed-price schemes will increase the level of efficiency and reduce the slacks in the use of the resources, at least for those inputs that are more suitable for rationalisation, such as drivers and costs of materials and services. Regulation (*REG*) is included in our model as a dummy variable that assumes, for each firm, value 1 after the introduction of a fixed-price contract and 0 otherwise.

Non-discretionary characteristics include variables linked to network features – namely, average commercial speed and population density – as well as to other environmental factors outside the control of the managers, such as average fleet age, operational size and technological change (Dalen and Gomez-Lobo, 2003; Piacenza, 2006).

Average commercial speed (*SPEED*) is a well-recognised relevant network characteristics for several reasons and is commonly used as a proxy for congestion costs. As average speed declines, due to higher congestion or lack of preferential lanes, the number of vehicles per kilometre is expected to increase together with the number of engaged drivers. Furthermore, more frequent stop and go or prolonged stops due to highly busied routes are likely to enhance fuel consumption. Finally, lower network speeds imply higher maintenance or repairmen costs due to more accidents.[9] Summarizing, we postulate a positive effect of higher average speed on technical efficiency trough a reduction of the slacks for drivers, fuel and materials and services, whereas the impact on indirect workers is ambiguous.

Population density (*DENS*) has been calculated as population per squared kilometre in the transport service provided area. Like average speed, population density might be interpreted as a measure of congestion, and so reducing ef-

[9] In fact, if average network speed reduces, the probability that an accident occurs is higher, even if perhaps the gravity of accidents will be softened.

ficiency. On the other hand, this variable could affect the way the network is designed, with more or less stops along the lanes, and to some extent contribute to increase technical efficiency. Hence, following Kerstens (1996), we do not pose *a priori* expectations on the effect of density variable on the input slacks.

Average fleet age (*AGE*) is a variable that reflects average age of the transit vehicles. To the extent newer buses are more spacious than older ones, one could expect the newer the buses the smaller the number of vehicles in the fleet and consequently the number of drivers. However, this is a merely empirical consideration. Less ambiguous effects might be found with regards to fuel and costs of materials and services. Indeed, a higher age could be reasonably associated with more frequent drawbacks and higher maintenance and repairmen costs. On the other hand, as suggested in Boame (2004), newer vehicles might result in a reduction of familiarity with them, thus both increasing the number of accidents and extending holding time in the workshop. Furthermore, newer vehicles might be thought as more fuel-saving. Generally, we expect a reducing impact of average fleet age on fuel and other costs slacks.

A time trend (*TR*) is included to account for any technological change. Although technical progress is a usual hypothesis, no *a priori* could be forecast, especially within a input-by-input framework. Since the second stage is a SFA-based one, *TR* variable is interpreted to capture only technological shifts, and not changes in managerial performances, which are embodied in the one-sided distributed inefficiency component specified in the Battese and Coelli (1992) SFA approach.

Operational size is categorized through dummy variables (*dBUS1*, *dBUS2*, *dBUS3* and *dBUS4*). Four groups are considered and categorized on the basis of the quartile values in the number of vehicles. The *dBUS1* category includes the smallest firms while the *dBUS4* category includes the largest ones. The *dBUS1* dummy variable has been dropped so as the parameters of other categories give us a measure of how slack-relative inefficiency changes if size moves upward. It could be argued that local governments are particularly careful in promoting the use of public transit services in the presence of higher congestion. This is the case, for instance, of large urban networks, where traffic congestion can result in highly critical conditions of circulation in peak-load periods, with social reflections (e.g. worsening of the quality of life due to strong air and acoustic pollution) that alert local governments. Therefore, in order to meet peak-load problems, more congested networks will be likely to receive proportionally higher subsidies for sustaining the investments in public transit service. The final result could be an excess endowment of vehicles with respect to the optimal rolling stock and an overuse of the fleet with respect to the potential demand. This would consequently bring about an excessive use of inputs for the largest and more congested networks, especially for those inputs that are more directly linked with the circulation of the vehicles, such as drivers, fuel and material and service costs. It is therefore of interest to assess the impact of the investments' subsidization policy, as proxied by fleet size dummy variables, on the efficient use of the inputs.

Finally, we introduced in our model dummy variables aimed at representing the specialised (urban transport, *dURB* and intercity transport, *dINTC*) or diversified typology of service (both urban and intercity transport, *dMIX*). This latter distinction seems to have a strong role in explaining cost differentials across firms (Fraquelli *et al.*, 2004; Piacenza, 2006). Urban and intercity companies typically provide the LPT service under very different operational conditions, especially in terms of congestion of the covered area. The *dURB* dummy variable has been dropped so as the parameters allow us to measure the overuse of inputs with respect to the urban networks. These dummies could overlap with average speed, as both are linked to congestion, but it is likely that average speed can not be the unique distinctive feature among typologies of service. Thus we decided to maintain the service-specific dummies in order to capture as much as possible the above mentioned differences in the operational context. In any case, we do not put any *a priori* on these variables.[10]

[10] It should be noted that Fraquelli *et al.* (2004) and Piacenza (2006) shed some light on higher potential cost savings of the mixed firms. These studies, however, use a cost function approach and do not allow therefore for an input-by-input decomposition.

4. DATA DESCRIPTION

The dataset used in the following analysis consists of a balanced panel of 42 Italian public-owned LPT companies which have been observed during the period 1993-1999, for a total of 294 pooled observations.

Our sample firms are fairly representative of the universe of Italian public transit systems and includes 6 small-sized operators (less than 150 workers), 19 medium-sized (151-550 workers), and 17 large-sized (more than 550 workers). As for the type of service provided, 15 firms mostly operate in the urban context, 10 firms are specialized in the intercity service, and the remaining 17 have activities in both compartments (multi-service or *mixed* firms). As for geographical distribution, 23 operators are located in the Northern Regions and 19 provide LPT service in Central and Southern Italy. Finally, as far as the subsidization mechanisms are concerned, around twenty-four percent of observations (71 cases) relate to fixed-price regulatory schemes, while around seventy-six percent (223 cases) refer to transit systems under cost-plus reimbursement rules.

The information for the construction of the database has been gathered from different sources. The main economic and production data – as supplied seat-kilometres, total number of workers, fuel consumption, rolling stock size, total operating cost – have been extracted from the Yearly Surveys published by ASSTRA, the nationwide trade organization which associates the public-owned LPT companies. Disaggregated information concerning technical and environmental characteristics (i.e. different typologies of workers, fleet age, average commercial speed, population density) and cost categories (labor, fuel, materials and services) have been obtained through questionnaires sent to firms' managers. In order to investigate the impact of regulation on the efficient use of each input, we needed information on the subsidization practice for the Italian public transit systems. To this end, we also included a question on the reimbursement mechanism (fixed-price or cost-plus) adopted by the competent local authority (Region, Province or Town Council).

5. RESULTS

The results of the first DEA stage, obtained separately by service category, are shown in Table 4 below, which accommodates the comparison with the DEA-adjusted scores from the third stage. These preliminary unadjusted DEA scores indicate a mean efficiency level around 93% for the urban firms against a mean value of 85-86% for the mixed and intercity LPT systems. Furthermore, it is noteworthy the lower variance of the efficiency scores for the urban category. Overall, this evidence implies that urban transit firms are closer to the efficiency frontier than their intercity and mixed counterparts and differentials among companies in the former case are less marked. However, these efficiency scores are far to be reliable, as they do not take into account exogenous factors that might affect firms' performance.

Table 2 reports the results from second stage SFA input-by-input regressions. Within each equation all the firms from different service category have been gathered and the estimates have been then controlled for the effect type of network Exogenous regulatory and environmental factors are included as non-discretionary determinants of input slacks, while the managerial inefficiency component u_{ni} has been modelled according to the time-variant specification proposed by Battese and Coelli (1992). This model assumes $u_{nit} = u_{ni} e^{[-\eta(t-T)]}$, where η is a parameter to be estimated, t is the present year and T is the final year of the observed period. In obtaining maximum likelihood estimates of slack equations (3) the variance of the aggregated error (υ_{ni} + u_{ni}) is parameterized as $\sigma_n^2 = (\sigma_{\upsilon n}^2 + \sigma_{un}^2)$ and $\gamma = \sigma_{un}^2 / \sigma_n^2$ (for each equation n = 1, …, N). Thus, γ represents the proportion in the total error variance that is attributable to managerial inefficiency component. A likelihood ratio (LR) test for this structural parameter is also carried out and it provides an insight on whether or not pure managerial inefficiency can be neglected from the analysis. In our specification we also assume the inefficiency terms to be i.i.d. distributed as half-normal random variables.[11]

[11] This assumption is corroborated by the fact that the truncated-normal hypothesis is rejected by the LR test. Moreover, the results do not change substantially according to the chosen assumption.

Table 2: SFA parameters estimates of input slack equations

Variable	*slack-emplDR*			*slack-emplIND*			*slack-FUEL*			*slack-CMS*		
	Coefficient	*t-stat*	*p-value*	*Coefficient*	*t-stat*	*p-value*	*Coefficient*	*t-stat*	*p-value*	*Coefficient*	*t-stat*	*p-value*
SPEED	-1.898	-2.46	0.014	-1.839	-3.10	0.002	-21.210	-3.33	0.001	-53.956	-1.39	0.164
DENS	-0.007	-1.14	0.255	0.004	1.08	0.279	-0.020	-0.39	0.697	-0.027	-0.08	0.932
AGE	-1.444	-0.87	0.385	0.419	0.36	0.719	20.949	1.35	0.177	138.475	1.48	0.138
REG	-17.817	-2.09	0.036	0.110	0.02	0.987	-95.203	-1.15	0.252	-776.511	-1.95	0.052
TR	7.816	3.54	0.000	-2.159	-1.21	0.227	-53.870	-2.19	0.029	223.943	1.56	0.118
dBUS2	14.460	1.16	0.247	11.786	1.24	0.215	138.483	1.28	0.201	482.460	0.79	0.427
dBUS3	51.739	3.69	0.000	27.187	2.63	0.008	434.319	3.28	0.001	1,922.477	2.90	0.004
dBUS4	12.282	0.83	0.405	31.338	2.78	0.005	421.073	2.97	0.003	1,114.470	1.54	0.123
dINTC	46.039	2.43	0.015	49.606	3.42	0.001	400.607	2.07	0.038	665.922	0.66	0.509
dMIX	67.757	3.80	0.000	39.486	3.29	0.001	852.339	5.44	0.000	2,243.988	2.85	0.004
η	0.270	11.18	0.000	-0.048	-1.27	0.203	-0.077	-2.17	0.030	0.154	2.94	0.003
γ	0.436	4.40	0.000	0.689	9.12	0.000	0.835	17.87	0.000	0.429	3.16	0.000
LR test $\gamma = 0$	249.322		0.000	84.595		0.000	121.198		0.000	89.308		0.000
Wald χ^2 test	52.050		0.000	21.09		0.020	60.02		0.000	24.89		0.006
observations	294			294			294			294		
log-likelihood	-1,618.554			-1,490.153			-2,208.112			-2,712.801		

The coefficients for *SPEED* variable appear to be highly significant, with the exception of *CMS* input, and show the expected negative sign. This implies that an increase in the average network speed would reduce the input slacks. Such a conclusion, which reconciles with the findings obtained by Piacenza (2006), could be of particular interest for the regulatory authority. In fact, any intervention concerning the local mobility aimed at favouring traffic flows (such as the introduction of traffic-lights or round-bounds), as well as improving the programming of bus lanes, could have a significant impact on congestion costs and, through this way, on efficiency conditions.

The impact of *DENS* variable is not statistically significant and shows alternation in sign. So we can conclude that it does not affect the performance of LPT firms in our sample. Notice that this result does not create particular problems of interpretation, as we had not imposed any *a priori* on the effect of this exogenous variable on input slacks.

The parameter associated with the *AGE* variable is generally not significant, but it become to some extent marginally significant with regards to *CMS* input. Besides, it shows the expected sign. This would imply that the older the rolling stock, on average, the higher the excess expenses for maintenance and repairmen. The investigation of the sign also matches with our assumption about the *FUEL* input, even though in this case the t-statistic might not be considered marginally significant. Notice that the *AGE* coefficient for the *emplDR* input slack does not present the positive sign we have supposed; however, the t-test strongly reject the hypothesis of statistical significance.

The policy *REG* variable matches our predictions for *emplDR* and *CMS* inputs. The sign of the associated parameter is negative, thus indicating a reduction in the slack as a consequence of the introduction of highly-powered (fixed-price) subsidization contracts. The risk-sharing underlying mechanism seems to have worked successfully, by forcing LPT firms to reduce the overuse of drivers and the excess cost for material and services. It is worthwhile to remark that drivers and material and service expenses can be better rationalized than other inputs (indirect employees and fuel), so the change in the regulatory practice succeeded in promoting rationalization where it resulted more plausible. This result confirms previous evidence on the effectiveness of incentive subsidies in reducing production inefficiency already obtained in Kerstens (1996), Gagnepain and Ivaldi (2002a, b), Dalen and Gomez-Lobo (1997; 2003) and Piacenza (2006). Moreover, it extends the latter by investigating the effects of different regulatory practices at single input level.

As expected, the dummies associated with the largest size categories (*dBUS3* and *dBUS4*) have a positive and generally significant impact on the input slacks. This means that if the firm size grows up, the efficiency conditions worsen. As already stated, this result might be associated with the subsidization practice of the most congested networks. Our interpretation is that the conspicuous subsides to investments addressed to these LPT systems in order to meet local governments' social goals have actually brought about an overcapitalisation problem. This excess endowment of rolling stock has induced firms to provide service beyond the actual request of the users with detrimental effects on efficiency. However, reconciling the efficiency reasons with social goals is not a simple exercise, and, to a certain extent, some degree of production inefficiency might be accepted if a good compromise can be found to make the service more effective.

The coefficients for the types of service (*dINTC* and *dMIX*) are in general highly significant and exhibits positive signs, implying that intercity and diversified LPT companies are intrinsically affected by a higher inefficiency than firms operating in urban contexts. This is difficult to interpret, as the urban networks are usually characterised by a higher degree of traffic congestion and so they are expected to be less efficient. However, it is possible that other environmental factors beyond congestion act and they are able to impact on efficiency conditions. In any case, our results contrast with the evidence put forward by Fraquelli *et al.* (2004) and Piacenza (2006) of arising economies of scope for diversified public transit systems.

After having controlled for the effects of regulation and environmental characteristics, it is worthy to analyse more in details the input-by-input managerial inefficiency component (u_{ni}). The second stage SFA regressions provide more reliable measures of the pure managerial efficiency by purging DEA slacks of the impact of exogenous effects. Furthermore, the adopted SFA methodology is able to account for the effects of statistical noise that can be purged from original DEA scores as well. The observation of the γ parameter suggests that the impact of pure managerial inefficiency appears substantially limited, at least for drivers and material and service costs, for which only about 43% of the aggregate error term variability is due to inefficiency. This evidence outlines the non negligible role played by statistical noise as determinant of the input slacks. In addition, the LR test rejected the null hypothesis that γ equals to zero, leading to the conclusion that even if regulatory and environmental factors other than noise exert a strong impact, they are unable to completely explain the whole variability observed in the estimated input slacks. A significant component, particularly relevant, for indirect employees and fuel whose values of γ are remarkably higher (0.689 and 0.835 respectively) still remains attributable to discrepancies among managerial performances.

As for the parameter η, it is significantly different from zero except for *emplIND*, and its sign is positive for *emplDR* (0.270) and *CMS* (0.154). The latter result means that inefficiency term is decreasing over time. The yearly decrease in inefficiency would then be equal to around 23.6% in the first case and 14.3% in the second case. This reduction could seem a quite strong result. The interpretation could be searched in the gradual transformation of the organisational status the public transit systems were subjected to during the years under investigation. In fact, all the units changed their governance model from *municipal firms* to *limited companies*. This decision imposed by the legislator was not unexpected by the managers and the change drew a significant increase of the autonomy in the firms' conduct. The above mentioned process did not take place suddenly and at the same time for all the companies. On the contrary, the process has been gradual and involved many steps with a straight negotiation between Local Authorities and LPT operators. Nevertheless, this process could have changed the firms' flair and increased the liability of the managers, which in turn stimulated the endeavour to come up to an inefficiency reduction path, by a rationalization mainly of drivers and material and service costs. It is worthwhile to underline that this trend of production efficiency during the observed years is distinguished from technological change, which is captured by the time variable *TR* in the slack function specification.[12] Notice, in particular, that production efficiency for drivers and materials and services showed a progressive improvement during time, while technological change seems to have been subjected to a regress. In fact, the sign of parameter associated to *TR* is positive, even though for *CMS* the parameter is only marginally significant.

Once accounted for the impact of regulatory and environmental factors, the third stage has been carried out using the algorithm (4) for adjusting the inputs data. Table 3 shows, for each input categorised by typology of service, the distribution of the observations between favourable and unfavourable external conditions and statistical noise (lucky versus unlucky conditions). The discriminatory average values have been calculated as the fitted values of the exogenous impact and the noise. The high coefficients of variation for external factors and variances for noise reveal that a non negligible part of the observation benefited from a highly favourable exogenous context and good luck as well as has been disadvantaged by exogenous conditions and bad luck. Therefore a correction for taking into account these effects is needed.

Finally, following Fried *et al*. (2002), the advantaged firms have been aligned with the most disadvantaged ones. In other words the input data for the more advantaged firms have been increased to the extent their advantage could be completely absorbed, thus putting all the firms in the same condition. In such a manner the problematic presence of negative inputs could be avoided. Re-running DEA separately for each category of service gives rise to new adjusted efficiency coefficients no longer affected by exogenous non controllable factors and random noise. The comparison between original and ad-

[12] In a more general context we estimated also a SFA model with temporal dummies instead of a time trend. The result remained unchanged.

justed DEA scores is showed in Table 4. As expected, the mean efficiency arises for all types of service, and especially for intercity and diversified firms that were more affected by intrinsic inefficiency. Moreover, the dispersion around the average appears reduced as consequence of the exclusion of part of the heterogeneity among operators. By aligning the firms on the less favourable conditions, a large part of the observations were put in a better light as demonstrated by the higher number of upward movements of the scores with respect to downward movements.

Anyway, it should be noted that if we observe the minimum adjusted DEA efficiency scores large bags of inefficiency remain reaching the extreme values (13.8%) for intercity networks.

Table 3: Impact of regulatory and environmental factors and statistical noise on input slacks

	Input	*Favourable external conditions*	*Non favourable external conditions*	*Coefficient of variation*	*Lucky situation*	*Unlucky situation*	*Sigma*
		# under mean	*# over mean*		*# under mean*	*# over mean*	
Intercity networks	*emplDR*	34	33	3.330	34	33	34.74
	emplIND	30	37	1.889	42	25	45.65
	FUEL	36	31	8.090	32	35	192.62
	CMS	36	31	2.762	32	35	903.12
Mixed networks	*emplDR*	63	59	0.582	64	58	62.47
	emplIND	55	67	1.710	61	61	31.72
	FUEL	56	66	0.483	61	61	504.88
	CMS	56	66	0.560	76	46	2725.99
Urban networks	*emplDR*	56	49	2.686	55	50	24.70
	emplIND	51	54	1.271	48	57	21.79
	FUEL	55	50	1.425	53	52	195.47
	CMS	57	48	1.617	54	51	1590.78

Table 4: Original (*orig*) and adjusted (*adj*) DEA efficiency scores

	Urban networks		*Mixed networks*		*Intercity networks*	
	DEA-adj	*DEA-orig*	*DEA-adj*	*DEA-orig*	*DEA-adj*	*DEA-orig*
Mean efficiency	98.75	93.11	99.09	85.45	97.90	86.46
Minimum	91.95	73.01	93.24	64.72	86.20	48.20
1st quartile	98.07	87.97	98.87	77.99	97.03	77.33
2nd quartile	99.48	95.33	99.79	83.32	99.66	93.27
3rd quartile	100.00	100.00	100.00	97.51	100.00	100.00
Variance	1.74	7.13	1.41	10.33	3.60	15.75
# efficient units	40	30	49	22	30	19
# downward shifts	8		7		2	
# movements from the frontier	6		7		2	
# upward shifts	73		100		48	

CONCLUSIONS

The main methodological issue this paper has investigated concerns the scope for avoiding some drawbacks typical of DEA assessment of production inefficiency in public transit systems and, more generally, in regulated network utilities. Because of the presence of different exogenous factors and random noise, which are not accounted for in standard deterministic DEA methodology, the latter may lead to imprecise and unreliable estimates of firms' inefficiency: some production units could benefit from a particularly favourable (unfavourable) external context, such as for instance high-powered (low-powered) incentive regulation or high (low) network speed, as well as from a lucky (unlucky) situation linked to unpredictable and often unobservable events. This firm-specific heterogeneity would therefore be mixed with good (bad) performances due to managerial skills, thus resulting in an excessively high (low) efficiency scores.

The approach we have adopted to overcome the above shortcomings is based on the three-stage methodology proposed by Fried *et al.* (2002). The latter allowed us to control for the impact of regulatory policy, environmental characteristics and statistical noise within a mixed DEA-SFA framework for firms' performance evaluation. In particular, stage two involved the estimation of stochastic frontier equations separately for each production factor, having the corresponding DEA input slacks calculated at stage one as dependent variable and non-discretionary regulatory and environmental factors as explicative variables. The aim was to purge slacks of external effects and statistical noise not accounted for in stage one, by letting the exogenous characteristics generating a different impact on each input excess. This feature of the empirical strategy represents a second important methodological aspect addressed in the study. In fact, the results from stage two, besides to permit the re-running of DEA using adjusted input quantities (third stage), provide also novel evidence on the impact of the three types of determinants of input-specific resource wastes: regulation and environmental characteristics, the so-called pure managerial inefficiency, and statistical noise.

The issues analyzed have also proved fruitful from the perspective of empirical regulatory economics and the policy implications the latter provides. To date a limited number of studies have analyzed how LPT systems actually respond to changes in regulatory incentives. Previous literature on this subject include the contributions by Dalen and Gomez-Lobo (1997; 2003), Gagnepain and Ivaldi (2002a, b), Kerstens (1996) and Piacenza (2006). Although all these studies concluded that incentive theory and modern regulatory economics are necessary components for the production analysis of LPT systems, none of them has tried to disentangle the role played by regulation and other firm-specific exogenous factors (e.g. network characteristics) from the one attributable to pure management skills in causing the arising of global production efficiency. Furthermore, Gagnepain and Ivaldi (2002a, b) and Dalen and Gomez-Lobo (1997) identified *a priori* a lack of productivity in labor factor (in particular in driver category) as the main source of inefficiency, due to the strong incidence of this input on total operating costs (70% on average in our sample) and to the presence of significant informational asymmetries between LPT operator and regulator as for the actual input needs in the production process. However, no attempt has been made by this group of studies to provide explicit evidence on the determinants of efficiency differentials among firms at single input level, in spite of the importance of this aspect to assess whether current regulatory policy is properly addressed towards a more rational and thrifty management of resources.

Our principal finding is that, after controlling for the subsidization scheme, environmental characteristics, and statistical noise, average production efficiency in the LPT industry increases and the dispersion among operators significantly reduces. From this result one can deduce that the main source for inefficiency has to be searched for in non-discretionary exogenous factors and random events under which LPT companies operate, while pure managerial skills only play a minor role. Secondly, the implementation of high-powered incentive contracts (fixed-price subsidies) as well as the presence of favourable network conditions (high commercial speed) reveal a marked ability of enhancing production efficiency already highlighted by previous empirical literature. As for Italy, this evidence confirms the policy indications by Piacenza (2006), which point out a scope for public transport policy to increase efficiency by acting on both subsidies and local traffic regulation. Finally, the reducing impact on input wastes exerted by incentive mechanisms is found to be particularly evident in the usage of "drivers" and "materials and services". Such a result sheds some light on the determinants of input-specific efficiency differentials in the industry, thus extending the existing evidence on mean overall inefficiency. Moreover, from a policy point of view, it provides useful insights on the effectiveness of the ongoing Italian regulatory reform, which seems to have well worked on the management of those production factors that are more sensitive to rationalisation.

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