Standard costs of regional public rail passenger transport: evidence from Italy[1]

Alessandro Avenali[a], Andrea Boitani[b], Giuseppe Catalano[a],

Giorgio Matteucci[a], Andrea Monticini[b,*]

[a] Department of Computer, Control and Management Engineering, Sapienza Università di Roma, Via Ariosto 25, Roma
[b] Department of Economics and Finance, Università Cattolica del Sacro Cuore, Via Necchi, 5, Milano

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Abstract

The paper estimates the standard cost in Italian regional public rail passenger transport services (LPTR), depending on service characteristics. The results highlight the crucial role of: number of seats per ride, commercial speed, service size and length of rail tracks. The model also shows the positive link between investment in rolling stock and the unit cost of the service. Finally, based on the empirical evidence, we propose regulatory adjustments to accomplish policy targets regarding the fair allocation of public LPTR funds to Regions and Local Authorities and a more efficient use of (scarce) local and national public resources.

Keywords
rail passenger transport, standard costs, cost models, local public transport, fiscal federalism, bootstrap

[*] Corresponding author: Andrea Monticini

Tel: +39 0272343215 – E-mail address: andrea.monticini@unicatt.it

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1. Introduction

In the past two decades, many EU-member States (e.g., Sweden, Finland, Germany, France and the United Kingdom) have introduced competitive tendering procedures in the local public transport (LPT) industry, in order to boost efficiency in service provision, enhance productivity and reduce LPT firms losses and/or Local Authorities spending.

In this process - regulated by the European Directive 1370/07/EU - recent Italian legislative interventions have specified that standard cost models[2] has to be used to verify whether the maximum economic compensation (defined ex ante by a Local Authority) to acquire a specific LPT service through a competitive procedure is overestimated or not.

This paper develops a workable model for the (top-down) econometric estimation of the standard cost in local services (LPTR). The contribution of the paper to the literature and the policy debate is twofold. On the one hand, the proposed methodology can be suitably used by policy makers in defining new methods for the allocation of public funds to Local Authorities. On the other hand, it provides a benchmark for the definition of the economic compensation to be set as auction-base in LPTR tendering procedures. In such a way, LPTR firms will be encouraged to promote their efficiency on the principle of yardstick competition (Shleifer 1985, Mizutani 1997, Mizutani *et al.* 2009). In fact, through standard costs, local Authorities might acknowledge to LPTR service providers a compensation that matches the costs of a reasonably efficient operator and not the specific costs of the firm supplying the service.

In this paper the unit standard cost is defined as the economic cost per seat kilometre (net of out-of-service, non-revenue generating seat kilometres) and it is estimated from data collected from LPTR operators in Italy covering around 96% of the total amount of regional

[2] In summary, the standard cost should reflect the cost of a LPT service provided by an efficient operator and given a specified service quality, where the “efficiency levels” are defined on the basis of the activities and costs of several operators and/or of knowledge of the industrial process for the provision of LPT services.

train kilometres produced in 2012.[3] The approach adopted in this work aims at identifying the (quantitative/qualitative) features of the service which validate significant differences in the unit standard cost. In order to achieve this goal, the technological characteristics of the production process and the inputs have been studied by conducting interviews with engineers and managers of the LPTR operators included in our sample. Finally, we discuss how the model could be adjusted by means of suitable regulatory constraints to achieve policy targets regarding the fair distribution of public LPTR funds.

As for the empirical analysis, the crucial problem we face is that our sample size is quite small and thus the traditional statistical inference, based on the central limit theorem (asymptotic theory), could be inappropriate. For that reason, our statistical inference is based on the bootstrap (Efron 1979), that has been shown (Hall 1992) to deliver much more accurate inference in finite samples (while in large sample is at least as accurate as the approximation obtained from first-order asymptotic theory).[4] We perform several tests to check the robustness of our results.

The paper is organized as follows. Section 2 contains a review of the relevant literature. Section 3 identifies cost categories which define the standard cost model and the key aspects of the production process of local public rail transport services. Section 4 describes the data set and variables. Section 5 presents the model and the results, section 6 develops some test examples and policy implications, and section 7 concludes the paper.

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[3] In many Italian Regions rail services are exclusively provided by a regional division of Trenitalia, the incumbent state-owned rail company. In a few Regions there also exists one (or more than one) small network operated by independent region-owned operator. The regional divisions of Trenitalia serve markedly different networks as for size, service density and commercial speed. They also make use of different rolling stocks (while they share the same labour contract). Therefore the actual unit costs may vary widely among different regional divisions of Trenitalia as well as between Trenitalia and other companies.

[4] However, the idea to adopt bootstrap inference in transport research is not new; see for example Bilotkach *et al.* (2015), Maness and Cirillo (2016).

2. Literature Review

There exist a large body of literature on the topic of the present paper (for a critical review see Catalano *et al.* 2019). The pioneering works aimed at describing the LPTR industry estimated basic cost/output relations (Borts 1960, Griliches 1972). Further studies focused on scale and density economies and introduced in the cost function size variables - such as track miles, rolling stock size - and average service speed (Keeler 1974, Braeutigam *et al.* 1984) Braeutigan (1984) finds unexploited economies of traffic density for most railroads, but constant long-run returns to scale. Caves *et al*. (1980, 1981, 1985) makes use of multi output translog cost functions to estimate density and scale economies and productivity growth in US and Canadian Railways. Preston and Nash (1993) introduces traffic density in the translog cost function to analyse and compare density and scale economies in the European Railways. Although these studies employ different output measures (such as train-kilometres, car-kilometres, car-hours, ton-kilometres for freight), they all find substantial increasing returns to density and decreasing returns to scale. Kim (1987) uses passenger kilometres and ton-kilometres as output measures and finds that the US railroad industry suffered from diseconomies of scope associated with the joint production of freight and passenger services while detecting product-specific economies of scale with respect to the production of both freight and passenger services. De Borger (1991) provides an early application of the hedonic output aggregation method to the railroad industry and introduces operating characteristics (related to the length of the network and the load factor) in the cost function. Also Braeutigam *et al*. (1982) estimates an hybrid cost function where engineering process functions were used to provide observations on the speed of the service.

It is worth noting that many papers jointly analyse passenger and freight services and only more recently some papers have focused on passenger services only. Viton (1980) analyses rapid mass transit services in US and Canada and finds, differently from previous works, diseconomies of density related to services delivered in metropolitan congested areas. Filippini and Maggi (1992) discusses the efficiency of the Swiss Private Railways. They find that most of the Swiss private railway companies operate at an inappropriately low scale and density. Savage (1997) estimates the costs for US urban mass transit systems and finds large economies of density in operating costs. These economies become even more substantial when the rail infrastructure maintenance costs and capital costs are incorporated. Mizutani (2004) estimates the cost of privately owned passenger railways in Japan and finds that, on average, the costs of public railways are higher than those privately owned. Daniel *et al.* (2010) estimates costs for a single operating company in the Netherlands for a large number of years. They find that seats-kilometres is the output measure that yields the best statistical results when estimating costs of passengers services, as regards the presence of density economies the results are ambiguous (they cannot reject the hypotheses of constant return to density).

Wheat and Smith (2014), analyses train operating companies in the UK and, in order to model the cost structure of that industry, employ an hedonic cost function with three outputs (route-kilometres, train-hours and the number of stations) and nine characteristics of train services including average speed and load factor. They discuss whether infrastructure inputs should be included in the cost analysis and argue that, while those inputs are difficult to measure, their inclusion would divert the focus from train operating companies to the rail industry as a whole. Thus, they choose to leave infrastructure inputs out of their analysis.

3. Cost categories and drivers

In this section we identify the cost categories to be included in our cost model (the sample data are summarized in Table 3): (i) operation and maintenance costs[5], (ii) administrative

[5] Due to missing data and non-homogeneity of the available data on the access charge to the rail network operator for passenger trains, our cost model does not take into account the access charge cost component.

costs and other overheads, and (iii) the cost of capital. The cost of capital is based on an estimation of the pre-tax Weighted Average Cost of Capital (WACC) of the LPTR sector, namely, the minimum return on the Net Invested Capital that has to be generated to fully reward all providers of financial resources, that is, debt and equity (Damodaran 2012). We follow Filippini and Maggi (1992, 1993) in considering the net book value of trains and maintenance facilities as a good proxy of the Net Invested Capital.[6]

In order to calculate the economic cost for the provision of a specific transport service, the value of the total number of employed vehicles is accounted for, including those owned by the train company (gross of non-repayable public funds), those rented/leased, and those given to LPTR firms free of charge by a Local Authority. Since operators may use different depreciation periods for their fixed assets, the depreciation rate has been normalized by considering a uniform depreciation period. Furthermore, possible extraordinary maintenance of the assets is usually capitalized and thus it is considered as an additional asset. Wrapping up, we estimated a depreciation period of 30 years as for trains and for the capitalized maintenance of trains and a slightly longer depreciation period for the depots, namely, 32.5 years[7].

Since most of the interviewed operators do not apply the international accounting standards, they are unable to determine the fair values of their assets. Depreciation reflects just a nominal amount of the assets value yearly consumed in the production process. Consequently, in order to assess the correct economic value of fixed assets, we deem

[6] A better proxy of the Net Invested Capital could be obtained by considering the net book value of trains and maintenance facilities in the last years (e.g. in the last three years), in such a way to reduce the risk of selecting a single year with too many or too few investments. However, our sample is characterized by data of just one year.

[7] We accept here the estimates of the average technical life of different well-maintained fixed assets for LPTR services as made by a working group jointly set up by the Italian Government, Regions and Local Authorities.

appropriate to apply the current cost accounting method. In this case, we estimate the current market value of the assets by multiplying the gross book value by a suitable deflation index (provided by the Italian National Institute of Statistics), depending on the age of the asset.

Finally, the overall economic cost of any observed service is divided by the number of seat kilometres to define an effective measure of the unit cost of the service. Indeed, the observed services presents a large variance in terms of the number of offered seats per ride.

3.1 Key aspects of the production process

In order to classify the main drivers of the unit cost and characterize the function to be estimated, it is necessary to analyse the technological features and the inputs involved in the production process. To this purpose, interviews have been conducted with engineers and managers of LPRT firms in our sample. The following observations emerged.

Observation 1. One of the main characteristics of local public transport services is the commercial speed, as for the specific LPTR services under scrutiny we measure commercial speed as the total number of train kilometres divided by the journey time (from the departure station to the final one). The commercial speed is perceived by passengers as an hedonic characteristic of the service, and, at the same time, it summarizes a plurality of elementary aspects of the service (such as, the average distance between consecutive stops, the average slope of the rail tracks, the average level of track maintenance, etc.).

Observation 2. In LPTR services, the economic cost of the rolling stock and of the maintenance facilities (depreciation and relative cost of capital, charges for rents and leases) are the main component of a service cost, averaging about 40% of total cost. Table 3 shows some features of the detected services and highlights that the most significant part of this cost component refers to the rolling stock. The annual productivity of trains depends, on the one hand, on the commercial speed at which the service is provided, and, on the other hand, by the ratio between the service size (that is, the amount of revenue train kilometres) and the extension of the rail network. In particular, although trains can be used by multiple drivers on the same day (a single daily machine shift can unfold along more than one driver shift), a reduction in commercial speed reduces the annual number of kilometres that each train can run. In addition, the more a railway network is interconnected and large, the more the machine shifts can be optimized through dedicated software. In such cases, it is possible to significantly raise the train kilometres supplied without increasing the number of trains. Thus, the cost of the rolling stock is shared across a larger number of train kilometres and the cost per train/seat kilometre of service decreases. Therefore, an intensive use of the rolling stock on the railway network may signal lower cost per train/seat kilometre, essentially due to economies of density.

Observation 3. On board personnel represents on average 25% of total costs in the Italian LPTR industry. The number of train-km per year each driver is able to produce depends significantly on the commercial speed and on the length of each journey. Therefore, an increase in commercial speed (for example by reducing the number of stops), or lengthening some routes may allow an increase in drivers productivity. In addition, the services provided on short routes are often characterized by short-distanced stops and thus lower commercial speed. Since on board personnel is an important driver of total cost and it is strongly influenced by commercial speed, one can expect that the marginal effect of commercial speed on the cost per train/seat kilometre is much more important in services with low commercial speed than in those with higher commercial speeds.

Observation 4. The energy consumption (in the case of electrified lines) or fuel (in the case of diesel powered trains) is more intense for services with close stops, because of the frequent restarts and accelerations that trains are subject to. However, regarding the electric power consumption, network operators typically impute an energy cost per kilometre travelled by trains, and therefore independent of the commercial speed. Furthermore, in most cases, the non-electrified lines represent a small part of the detected traffic. Therefore, we presume that a marginal increase in commercial speed can result in a limited reduction of energy consumption. However, for any commercial speed, the powertrain cost per train kilometre of a diesel-driven train results quite higher than that of an electric-driven one (with similar capacity).

Observation 5. Operators (or consortia of operators) above a certain size may be advantaged or disadvantaged in the acquisition of certain production inputs; thus, pecuniary economies or diseconomies of scale may arise. For example, by means of well-planned tenders for the procurement of several trains and/or train parts, it is possible to purchase goods/services at lower unit prices. On the other hand, when the train company is large, labour unions can obtain better contractual terms (thus determining a higher driving cost per hour) thanks to a stronger bargaining power in second tier negotiations.

4. Data and variables

The survey was carried out by means of a specific questionnaire containing detailed economic and transport information. The detection regards accounting and transport data relative to year 2012, resulting in 29 observations, corresponding to 34 service contracts, referred to as service bundles hereafter. A service bundle is a set of one or more service contracts for which the firm is able to measure only jointly its direct and indirect costs. The collected data represent approximately 220,000,000 train kilometres, which account for over 95% of the total supply of regional railway services in Italy in 2012.

Table 1. Number of train kilometres provided by firms included in the sample

Region	*Detected train revenue kilometres*	*Total train kilometres*	*% train kilometres detected over total*
Abruzzo	3,838,603.61	4,478,465.61	85.7%

Basilicata	2,566,122.21	2,566,122.21	100%
Calabria	6,586,791.06	7,832,110.46	84.1%
Campania	15,531,826.16	15,531,826.16	100%
Emilia Romagna	17,272,166.82	17,272,166.82	100%
Friuli V. Giulia	2,923,542.14	3,157,686.14	92.6%
Lazio	21,094,100.32	21,094,100.32	100%
Liguria	6,438,471.64	6,438,471.64	100%
Lombardia	38,232,145.00	38,232,145.00	100%
Marche	3,821,848.56	3,821,848.56	100%
Molise	1,934,544.75	1,934,544.75	100%
Piemonte	18,898,112.47	19,036,692.47	99.3%
Puglia	8,846,647.99	12,996,689.99	68.1%
Sardegna	4,431,175.97	4,431,175.97	100%
Sicilia	9,958,742.69	9,958,742.69	100%
Toscana	22,740,882.63	22,740,882.63	100%
Trento-Bolzano	8,179,427.80	8,179,427.80	100%
Umbria	3,672,025.40	5,922,965.40	62.0%
Valle d,Aosta	1,703,636.53	1,703,636.53	100%
Veneto	18,551,791.41	18,551,791.41	100%
TOTAL	217,222,605.16	225,881,492.56	96.2%

Table 1 highlights the relevance of the collected data showing the amount of train kilometres detected compared to the total amount of train kilometres offered in Italy in 2012.

Table 2 presents the descriptive statistics for some variables characterizing the service bundles included in the sample, showing a wide gap between minimum and maximum values of each variable under scrutiny, independently of the network size.

Table 2. Some descriptive statistics

	Mean	*Min*	*Max*	*Std. dev.*
Train kilometres (mln)	7.49	0.58	38.23	8.35
Seat kilometres (mln)	2,655.19	86.40	17,745.93	3,879.90
Commercial speed	51.82	30.80	71.65	10.79
Train productivity (train overall kilometres/used trains)*	97,056.14	20,224.80	163,772.91	35,300.53
Driving hours	654.79	359.03	1,077.31	155.68
Seats per ride	263.98	91.00	550.00	135.66

* Train overall kilometres includes those run out of the service necessary to bring trains from depots to the station which the service to the users starts from. The amount of trains includes the number of train used during peak hours plus redundancy for possible train breakdowns and programmed maintenance.

Table 3 shows the average incidence of different cost elements on the cost per seat kilometre as emerging from the survey.

Table 3. Cost per seat kilometre: components

Component (€/skm)	*Mean*	*Min*	*Max*	*Std. dev.*
Driving personnel	0.00897	0.00380	0.02360	0.00529
Non driving crew	0.00664	0.00220	0.01930	0.00471
Cost of fuel	0.00332	0.00009	0.01077	0.00335
Cost of electric power	0.00207	0.00048	0.01208	0.00284
Rolling stock (depreciation, rent/leasing, etc.)	0.01068	0.00510	0.04140	0.00739
Maintenance, general costs and other production costs	0.01828	0.00790	0.04360	0.00964
Cost of capital	0.01357	0.00090	0.04460	0.01029

Note that the maintenance cost includes the cost for outsourced maintenance, the cost of spare parts, the cost of personnel for in-house maintenance, depreciation of equipment, facilities and buildings used for in-house maintenance (net of capitalized extraordinary maintenance). The cost for rolling stock includes depreciation of capitalized maintenance work on the trains. Overhead costs include the cost of dedicated personnel. Other production costs including all those cost pertaining to the industrial production of the service, such as, for example, electronic ticketing systems and other ICT-related costs not considered elsewhere are included in the overhead costs.

5. Methodology and empirical analysis

In this section we present multiple regression models of the unit cost of LPTR services, by employing different sets of explanatory variables. These models are meant to be readily usable by Local Authorities in setting the maximum economic compensation in competitive tendering procedures and by policy makers in defining new methods for the allocation of public funds to Regions and Local Authorities. Following Avenali *et al.* (2014, 2016, 2018), we identified the variables which are expected to be the most significant in explaining the service costs (i) by taking into account the key aspects of the production process identified in Section 3.1 and (ii) by conducting several interviews with practitioners and policy makers of the LPTR sector. In particular, we detected the following variables:

- Ns: number of seats per ride. It reflects the different choices in organizing the services by means of differences in trains involved in the production process.
- $Sp(km/h)$: commercial speed. This is a qualitative (hedonic) characteristic of a service, which can be barely controlled by the operator. It reflects a plurality of technical crucial aspects of the service, such as, the average distance between consecutive stops, the average slope of the rail tracks, the average level of track maintenance.
- Skm: seat kilometres (in millions). It is a quantitative measure of the service size commonly used in the literature. Since the Italian LPRT services have a large variance in terms of number of seats per offered ride, Skm is more appropriate than train kilometres in measuring the size of the service.
- Rkm: kilometres of rail tracks used to produce the service. It represents the network extension and, to some extent, its complexity.
- T: rail turnover or network turnover. It is defined as the ratio between Skm and Rkm and measures the intensity in usage of rail tracks.
- St: density of stations. It the ratio between the number of stations and Rkm. A higher density reflects the urban characteristic of the rail service, such as, in particular, more complex operations and train maintenance and a higher frequency.
- $Askm(€/skm)$: degree of renewal of the fleet. It is defined as the ratio between the monetary value the rolling stock andSkm. If the operator owns all the rolling stock, the monetary value is the sum of all depreciations of the owned vehicles (assuming a 30 years depreciation life including the depreciation of the capitalized maintenance of the trains). This variable identifies a qualitative characteristic under the control of the LPT operator. To have an upper bound to the degree of renewal of the fleet for Italian

firms, we made use of consensus estimations of the standard market values (in 2012) of several newly equipped train types.

- Di: percentage of seat kilometres powered by diesel. It is the ratio between the diesel-powered seat kilometres and the overall seat kilometres.

We focus on modeling the main (quantitative/qualitative) services' characteristics which cause significant differences in the unit production cost, while we abstract from the unit input costs as they are not available. However, the modeling choice is justified by observing that a single train operator (i.e. Trenitalia, the Italian train incumbent) is running most of the contracts in our sample and unit input costs are then unlikely to explain significant variabilities of costs within the sample.

5.1 The econometric model

The Italian LPRT services have a large variance in terms of the number of seats available per offered ride. In order to determine statistically significant and robust cost models we deemed appropriate to estimate the economic cost of the service per seat kilometre. The proposed models were based on different sets of explanatory variables that proved to be highly statistically significant and consistent with the production process analysis.

We obtain the standard value of the cost per seat kilometre, denoted by *Cskm*, by using an OLS estimation and by taking into account for each model the relative subset of explanatory variables.

The first estimated model is the following:

$$Cskm_j = \alpha + \frac{\beta}{Sp - 28} + \gamma \times T + \delta \times Askm + \theta \times Di^2 + \varepsilon_j \qquad (1)$$

where $j = 1, \ldots, N$, N is the sample size, $\varepsilon_j \sim (0, \sigma_j^2)$ with possibly $\sigma_j^2 \neq \sigma_t^2$ for $j \neq t$.

Equation (1) represents the relationship between $Cskm$, a constant α, the function of the commercial speed $1/(Sp-28)$, the network turnover T, the degree of renewal of the fleet $Askm$, and the function of the percentage of seat kilometres powered by diesel Di^2. According to the theoretical observations sketched out above, *ceteris paribus*: (i) the higher the commercial speed, the lower $Cskm$ ($\beta>0$); (ii) the higher the network turnover, the lower $Cskm$ ($\gamma<0$); (iii) the higher the degree of renewal of the fleet $Askm$, the higher $Cskm$ ($\delta>0$); (iv) the higher the percentage of seat kilometres powered by diesel, the higher $Cskm$ ($\theta>0$). Table 4 shows the results of equation (1).

To obtain robust empirical evidence the small sample size (that is, 29 observations) is an issue to be faced. We address that issue by using bootstrap methods. These were originally introduced by Efron (1979) and have become a quite standard approach to obtain robust inference when the sample size is small. Davidson and Mackinnon (2004, p. 171) for the regular bootstrap, and Davidson and Flachaire (2008) for the wild bootstrap, show very good performance of the bootstrap using a sample size of 10 observations.

Table 4. $Cskm$: regression results – model (1)

Regressor	*Coefficient*	*Estimates (std. err)*	Asy. p-value	Bootstrap p-value
Constant: 1	α	0.02716*** (0.009)	0.007	0.000
Commercial speed: $\frac{1}{Sp-28}$	β	0.24975** (0.060)	0.000	0.048
Network turnover: T	γ	-0.00349*** (0.001)	0.003	0.010
Degree of renewal of the fleet: $Askm$	δ	3.52342*** (0.804)	0.000	0.009
Percentage of diesel-powered seat kilometres: Di^2	θ	0.02816** (0.013)	0.053	0.047
n. obs. = 29; F = 42.81; Adj R^2 = 0.856			Breusch-Pagan test for heteroskedasticity: LM=9.05 p-value:0.059; Schwarz criterion (BIC): -141.419	

***=Significant at 1% level; **=Significant at 5% level; *=Significant at 10% level.
Based on HC2 standard errors and 9999 wild bootstrap replications.

After fitting a regression model, when the regression residuals are homoscedastic, the appropriate bootstrap is the regular bootstrap, while if the regression residuals display heteroscedasticity, the appropriate bootstrap method is the so-called wild bootstrap (see for details Davidson *et al.* 2007 and Davidson and Flachaire 2008). In our analysis, we estimate a regression model and we test for homoscedasticity (the Breusch-Pagan test for heteroskedasticity is reported in table 4 and 5), and if we reject the null hypothesis of No-homoschedasticity, we compute the robust standard errors (see Davidson and Mackinnon 2004) and the p-values by the wild bootstrap. In our empirical analysis we used 9999 (wild) bootstrap replications. For completeness, close to the bootstrap p-values, the standard p-values based on the asymptotic approximation (Gaussian distribution) have been reported.

Table 4 reports the estimated coefficients. As we can observe, all the coefficients are highly statistically significant.

As anticipated, other models including different sets of explanatory variables have been taken into account. For instance, models (2), (3), (4) and (5) are based on considering, respectively, the quantity of seat kilometres, the density of stations, the length of network and finally the average number of seats per ride in substitution of the network turnover.

$$Cskm_j = \alpha + \frac{\beta}{Sp-28} + \gamma \times Skm + \delta \times Askm + \theta \times Di^2 + \varepsilon_j \tag{2}$$

$$Cskm_j = \alpha + \frac{\beta}{Sp-28} + \gamma \times St + \delta \times Askm + \theta \times Di^2 + \varepsilon_j \tag{3}$$

$$Cskm_j = \alpha + \frac{\beta}{Sp-28} + \gamma \times Rkm + \delta \times Askm + \theta \times Di^2 + \varepsilon_j \tag{4}$$

$$Cskm_j = \alpha + \frac{\beta}{Sp-28} + \gamma \times Ns + \delta \times Askm + \theta \times Di^2 + \varepsilon_j \tag{5}$$

where $j=1,\ldots,N$, N is the sample size, $\varepsilon_j \sim \left(0,\sigma_j^2\right)$ with possibly $\sigma_j^2 \neq \sigma_t^2$ for $j \neq t$.

Compared to equation (1), equation (2) replaces network turnover T with the quantity of seat kilometres *Skm*. Clearly, the higher *Skm*, the lower *Cskm* (γ<0).

Equation (3) replaces the network turnover T used in equation (1) with the density of stations St. We expect the higher the density of stations, the higher $Cskm$ ($\gamma>0$).

Equation (4) replaces the network turnover T used in equation (1) with the kilometres of rail tracks (length of network) Rkm. In this case, the higher the kilometres of rail tracks used to produce the rail service, the lower $Cskm$ ($\gamma<0$).

Finally, equation (5) replaces the network turnover T in equation (1) with the average number of seats per ride. Obviously, the higher the number of seats per ride, the lower $Cskm$ ($\gamma<0$).

Tables **5, 6, 7 and 8** show the results of the estimated models **(2), (3), (4) and (5)**, respectively.[8]

Table 5. $Cskm$**: regression results – model (2)**

Regressor	*Coefficient*	*Estimates (std. err)*	Asy. p-value	Bootstrap p-value
Constant: 1	α	0.0195389** (0.007)	0.019	0.021
Commercial speed: $\frac{1}{Sp-28}$	β	0.2296122*** (0.579)	0.000	0.002
Seat kilometres: Skm	γ	-0.0000016** (0.000)	0.096	0.018
Degree of renewal of the fleet: $Askm$	δ	3.6486565*** (0.579)	0.000	0.000
Percentage of diesel-powered seat kilometres: Di^2	θ	0.0316654*** (0.012)	0.015	0.009
n. obs. = 29 F = 40.92 Adj R^2 = 0.85			Breusch-Pagan test for heteroskedasticity: LM=18.33 P-value:0.107 Schwarz criterion (BIC): -140.27	

***=Significant at 1% level; **=Significant at 5% level; *=Significant at 10% level.
Based on 9999 bootstrap replications.

Table 6. $Cskm$**: regression results – model (3)**

Regressor	*Coefficient*	*Estimates (std. err)*	Asy. p-value	Bootstrap p-value
Constant: 1	α	0.00449 (0.007)	0.578	0.564

[8] The density of stations is not available for one instance of the sample. Thus model (3) is estimated through a subsample of 28 observations.

Commercial speed: $\frac{1}{Sp-28}$	β	0.14711** (0.065)	0.034	0.023
Density of stations: St	γ	0.07238 (0.063)	0.263	0.324
Degree of renewal of the fleet: $Askm$	δ	3.55466*** (0.739)	0.000	0.006
Percentage of diesel-powered seat kilometres: Di^2	θ	0.03989*** (0.014)	0.011	0.003
n. obs. = 28 F = 44.66 Adj R^2 = 0.848			Breusch-Pagan test for heteroskedasticity: LM=15.57 p-value: 0.003 Schwarz criterion (BIC): -134.773	

***=Significant at 1% level; **=Significant at 5% level; *=Significant at 10% level.
Based on HC2 standard errors and 9999 wild bootstrap replications.

Table 7. $Cskm$**: regression results – model (4)**

Regressor	*Coefficient*	*Estimates (std. err)*	Asy. p-value	Bootstrap p-value
Constant: 1	α	0.0173449* (0.010)	0.099	0.094
Commercial speed: $\frac{1}{Sp-28}$	β	0.2322331*** (0.055)	0.000	0.005
Length of network: Rkm	γ	-0.0000051 (0.000)	0.468	0.46
Degree of renewal of the fleet: $Askm$	δ	3.7090585*** (0.608)	0.000	0.000
Percentage of diesel-powered seat kilometres: Di^2	θ	0.0337123*** (0.012)	0.015	0.010
n. obs. = 29 F = 36.67 Adj R^2 = 0.835			Breusch-Pagan test for heteroskedasticity: LM=5.926 p-value: 0.204 Schwarz criterion (BIC): -137.519	

***=Significant at 1% level; **=Significant at 5% level; *=Significant at 10% level.
Based on 9999 wild bootstrap replications.

Table 8. $Cskm$**: regression results – model (5)**

Regressor	*Coefficient*	*Estimates (std. err)*	Asy. p-value	Bootstrap p-value
Constant: 1	α	0.045*** (0.014)	0.004	0.000
Commercial speed: $\frac{1}{Sp-28}$	β	0.195*** (0.046)	0.000	0.001
Number of seats per ride: Ns	γ	-0.0000051*** (0.000)	0.002	0.003
Degree of renewal of the fleet: $Askm$	δ	3.391** (0.918)	0.001	0.032
Percentage of diesel-powered seat kilometres: Di^2	θ	0.022* (0.013)	0.107	0.098
n. obs. = 29 F = 34.45 Adj R^2 = 0.880			Breusch-Pagan test for heteroskedasticity: LM=9.617 p-value: 0.047 Schwarz criterion (BIC): -146.585	

***=Significant at 1% level; **=Significant at 5% level; *=Significant at 10% level.

Based on HC2 standard errors and 9999 wild bootstrap replications.

It is interesting to note that from equations (1), (2), (3). (4) and (5) we can easily obtain the expression of the standard cost per train kilometre ($Ctkm$) by considering the number of seats per ride (Ns):

$$Ctkm = Cskm \times Ns \qquad (6)$$

Although according to the Schwarz criterion (BIC) the best empirical specification is provided by model (5)[9], we use model (1) in the next sections because it is theoretically closer to the production process analysis provided in Section 3.1. Of course, our policy analysis can be easily extended to model (5) and to the other estimated models.

5.2 Causes of variability in unit standard costs

Let us discuss in this section the impact of each explanatory variable identified in equation (1) on the unit standard cost.

5.2.1 Commercial speed

The first effect is related to the commercial speed, that, by increasing, produces a decrease of the unit standard cost (mainly as it raises the productivity of trains and driving personnel). More in detail, the functional form that the estimated unit cost tends to assume, with respect to this variable, is L-shaped (namely, a hyperbolic function). In other words, a marginal increase in commercial speed is much more effective in reducing the unit cost of services characterized by lower commercial speed.

Note that the asymptote of the regressor $1/(Sp-28)$ has been selected in order to maximize the fitness of the regression and the significance of the parameters. Obviously, each of the

[9]The smaller the BIC, the better is the estimated model.

detected services has a commercial speed exceeding 28 km/h and thus the term $Sp-28$ is always positive for these services. For predictive purpose the model should not be applied to trains that do not reach the 28 km/h threshold. However, to the best of our knowledge, no rail service in Italy presents average commercial speed below such a threshold.

5.2.2 Network turnover

A second effect is due to the rail turnover T The higher this variable, the higher the use of that rail infrastructure by each rail operator. The shape of the function is downward sloping as the rail turnover raises; therefore, increasing the scale of the service on the same railway lines implies a decrement in $Cskm$; therefore, increasing returns to density occur.

As observed in Section 3.1, the impact of the rail turnover on $Cskm$ could depend on a raise of train productivity as the network turnover increases. To support such an assumption, we performed a regression analysis that links the average number of revenue kilometres produced yearly by a train with commercial speed and the network turnover. We observed that the productivity of trains raises with the commercial speed of the service and with the logarithmic of the rail turnover (see the Appendix). Therefore, as the rail turnover increases, the yearly train productivity raises but at decreasing marginal rates. For instance, a 70 km/h commercial speed service and with a rail turnover of about 5 million of seat kilometres per track kilometre presents a yearly average productivity per train equal to 146,362.62 km, while a service provided at 45 km/h commercial speed and with a rail turnover of about 1 million of seat kilometres per track kilometre has a yearly train productivity equal to 61,049.27 km.

5.2.3 Renewal of the rolling stock

The variable $Askm$ is a proxy of the quality perceived by the users of the service. Depreciation and rent/leasing of the fleet reflects, in fact, one of the most important and expensive components of the quality of service provided to the users. In particular, the functional form that estimates the unit standard cost tends to assume, with respect to the degree of renewal, an increasing linear shape.

5.2.4 The diesel-powered rolling stock

Variable Di takes into account the impact on the unit standard cost of the share of diesel powered trains. Indeed, the powertrain cost per train kilometre is larger in the case that the train is powered by diesel than by electric energy. Moreover, the maintenance cost per seat of a diesel-powered train is usually higher than of an electric-driven train.

In particular, $Cskm$ tends to increase less than linearly as Di raises. Thus, where tDi is small, the marginal increment of the unit standard cost is low as the cost for diesel-train maintenance and fuel have a little impact on the overall cost. Where Di is close to one, the marginal increase of $Cskm$ becomes high since the impact of the cost for diesel-train maintenance and fuel is large.

6. Test examples and policy implications

A simple numerical example can help in understanding the features and the policy implications of the proposed model (from now on, Example A). Let us take a train company producing 25 million electric-powered train kilometres per year over a network 1,600 km long, where the rolling stock offers on average 435 seats per ride (i.e. 10,875 million seat kilometres are offered to the users in one year). Let the commercial speed be 50 km/h, and the degree of renewal of trains equal to 0.00577 €/skm. Thus, making use of equation (1) and plugging in the estimated parameters from Table 4, the standard cost of this service per seat kilometre turns out to be equal to:

$$Cskm = 0.02716 \underbrace{\frac{+0.24975}{50-28}}_{\substack{commecial\ speed \\ effect}} \underbrace{-0.00349 \times \frac{10'875}{1'600}}_{\substack{network\ turnover \\ effect}} \underbrace{+3.52342 \times 0.00577}_{\substack{degree\ of\ renewal \\ effect}} + 0 \times 0.02816 = 0.03512\ €/skm$$

From equation (**6**) the unit cost can be easily converted into the cost per train kilometre:

$$Ctkm = 435 \times Cskm = 15.28\ €/tkm$$

Starting from Example A, the ensuing figures show the effect on the standard cost per train kilometre of the commercial speed, of the rail turnover and of the size of the offered service. Figure 1 plots the (ceteris *paribus*) relation between the standard cost per train kilometre and commercial speed (in a range of values between 35 km/h and 70 km/h). Figure 2 plots shows the (ceteris paribus) relation between the standard cost per train kilometre and the rail turnover (in a range of values between 6.5 and 10.5). Finally, Figure 3 plots the relation between the standard cost per train kilometre and the service size (in a range of values between 23 and 35 million of train kilometres).

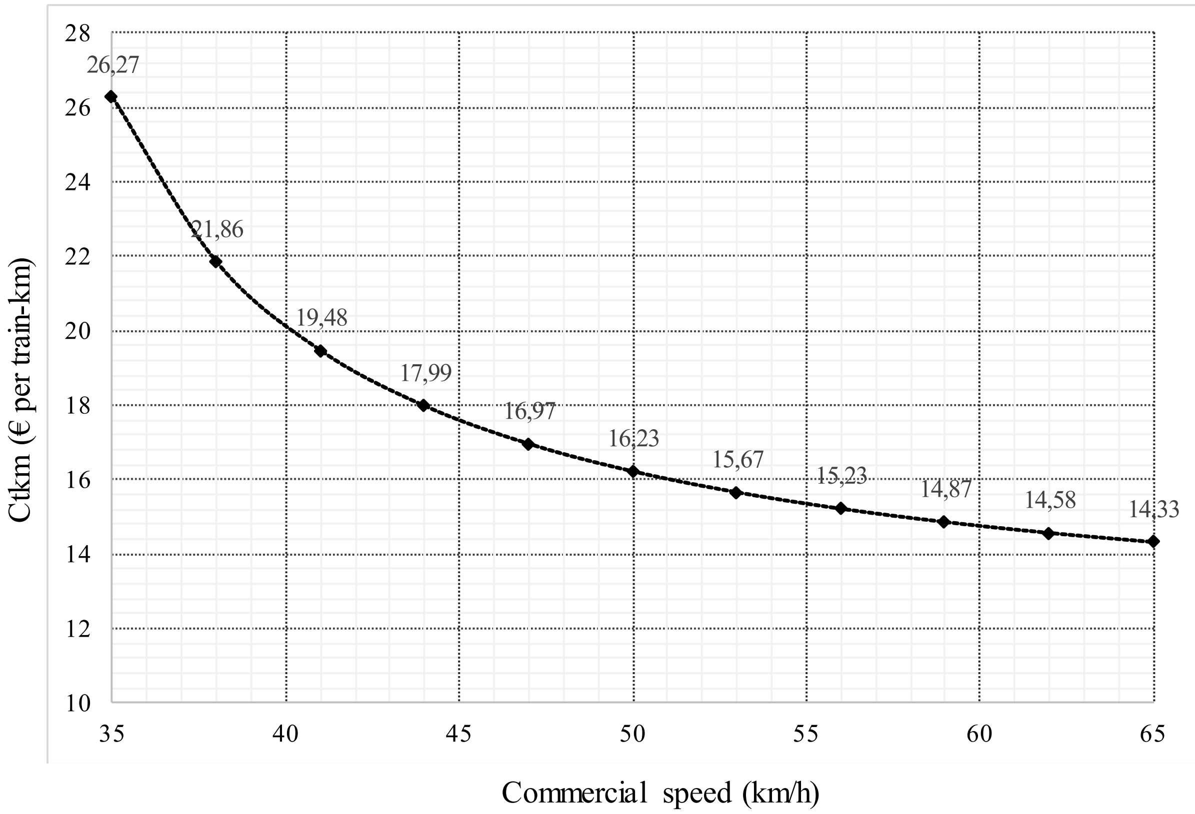

Figure 1. Example A: simulating the effect on *Ctkm* of an increase in commercial speed

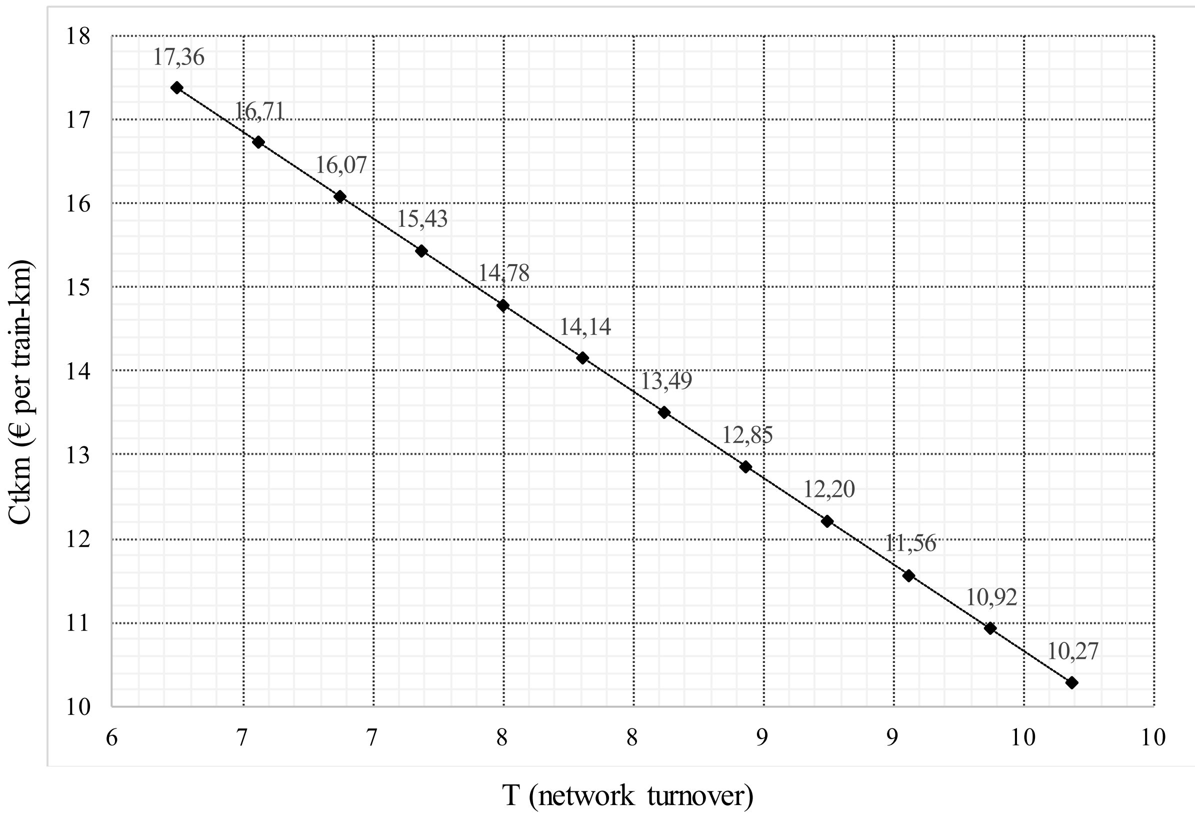

Figure 2. Example A: simulating the effect on *Ctkm* of an increase in the network turnover (T)

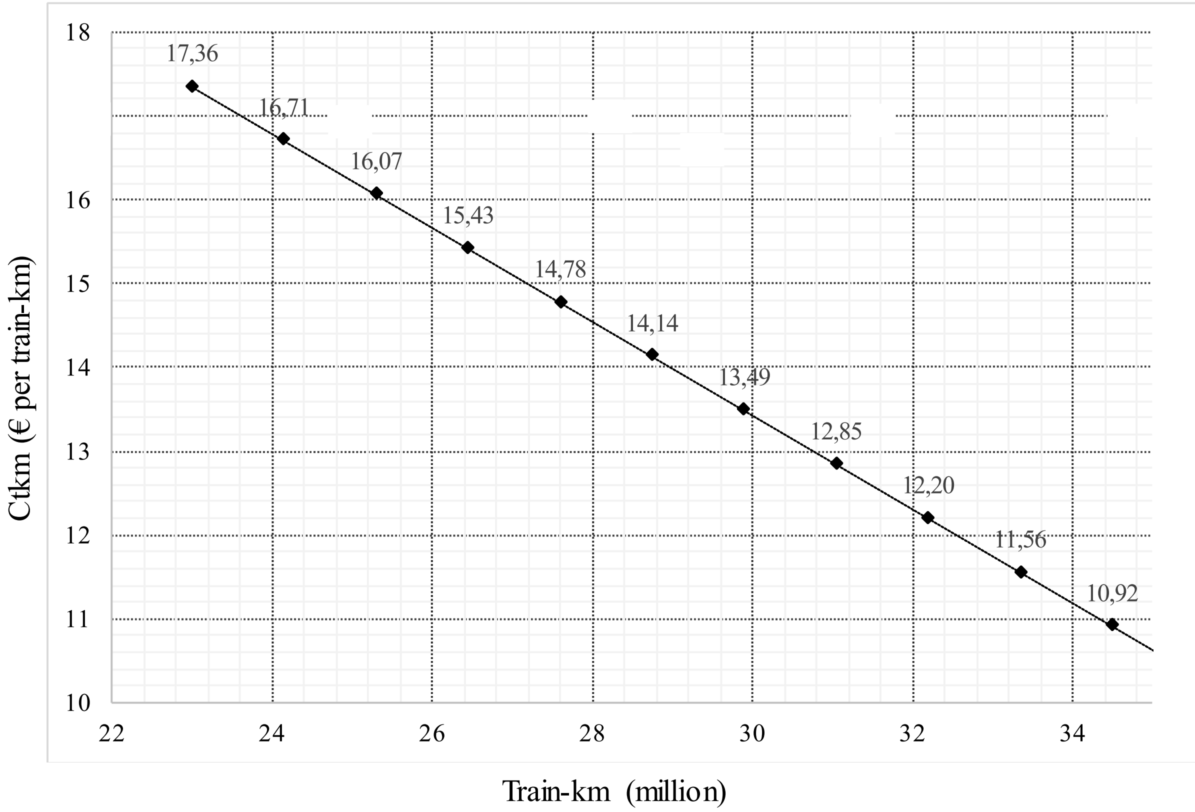

Figure 3. Example A: simulating the effect on *Ctkm* of an increase in the size of the service (train-km)

Note that, although the model does not explicitly define a link between the standard cost and variables that are under direct control of the train companies (such as, for example, the driving hours or the number of drivers), LPRT operators are still encouraged to increase their efficiency through the mechanism of *yardstick competition*. In fact, those operators who can provide the service at a unit costs lower than the economic compensation agreed in the service contract on the basis of standard cost will gain profit margins. Furthermore, we remark that the model is based on variables which cannot be easily manipulated by LPRT firms and thus the model is quite robust with respect to possible opportunistic behaviour.

Moreover, the model outcome provides Regions and the lower level Local Authorities with information about the impact of some policy decisions on the costs of the offered regional public rail transport services. For instance, a Local Authority that decides to increase the number of stations to improve the capillarity of the service is able to estimate the unit cost increment due to the resulting lower commercial speed of the service. Similarly, a Local Authority that reduces the scale of a service may anticipate how the unit cost of the service will rise.

Finally, to make it workable for regulatory purposes and pursue the efficiency goal in allotting public funds, the estimates provided by the econometric model could be modified by appropriate regulatory constraints. By doing so, we hybridize the proposed top down model by taking into account some aspects of process re-engineering.

For instance, the regulatory agency could link the maximum number of seats offered on average in each ride to the load factor detected during peak hours. In fact, the main driver in fleet sizing is the load factor at peak-time. Thus, should such a load factor be lower than a minimum acceptable threshold level (for example lower than 50%), then the regulatory agency could assign to the train company a unit standard cost corresponding to a downsized amount of seat kilometres in order to comply with a feasible load factor level. By doing so, the operator has an incentive to tailor the fleet to the existing demand level

7. Concluding remarks

In this paper we proposed a workable top down econometric model to compute the economic standard cost of a regional public rail passenger transport service. The model has been defined assuming an efficiency framework that reflects the average performance of the observed LPTR operators. Because of the small number of observations and the heteroscedasticity of the sample, we employed wild bootstrap techniques to safeguard consistency of the estimated model.

The economic standard unit cost of a regional public rail passenger transport service have been estimated by a multivariate regression model based on specific features of the produced service, namely, the commercial speed, the intensity of usage of the railway and the rolling stock renewal. In particular, this unit cost decreases as both the commercial speed and the intensity of usage raise, while it increases when the monetary value of the rolling stock grows.

The model can be empowered by introducing some regulatory constraint to mitigate the impact of particularly expensive and customized local services on the sharing the public financial resources among the Local Authorities. For instance, the model can apply minimum/ maximum thresholds for some basic characteristics of the services at issue (e.g. an upper bound on the fleet renewal degree, a lower bound for the on-peak load factor).

This paper responds to the changes occurring in the Italian transport policy in two ways. First, the proposed model represents a useful and extremely simple tool for the policy makers in the allocation of public funds among Local Authorities. Second, the proposed unit standard cost model works as an effective reference in determining the maximum economic compensation allowed to rail operators when services are tendered out.

References

Avenali A., Boitani A., Catalano G., D'Alfonso T., Matteucci G.2018, Assessing standard costs in local public bus transport: A hybrid cost model, Transport Policy, (62): 48-57.

Avenali A., Boitani A., Catalano G., D'Alfonso T., Matteucci G.2016, Assessing standard costs in local public bus transport: evidence from Italy, Transport Policy, (52): 164-174.

Avenali A., Boitani A., Catalano G., D'Alfonso T., Matteucci G.2014, Un modello per la determinazione del costo standard nei servizi di trasporto pubblico locale su autobus in Italia, Economia e Politica Industriale - Journal of Industrial and Business Economics 2014a, 4: 181-213.

Bilotkach V., Gitto S., Jovanović R., Mueller J., Pels E. 2015, Cost-efficiency benchmarking of European air navigation service providers, Transportation Research Part A: Policy and Practice, 77: 50-60.

Boitani A., Cambini C.2006. To bid or not to bid, this is the question: the Italian experience in competitive tendering for local bus services, European Transport, 33: 41-53.

Borts, G. H. 1960. The Estimation of Rail Cost Functions, Econometrica 28: 108-131.

Braeutigam, R. R., A. F. Daughety, and M. A. Turnquist. 1982, The Estimation of a Hybrid Cost Function for a Railroad Firm, Review of Economics and Statistics 64: 394-404.

Braeutigam, R. R., A. F. Daughety, and M. A. Turnquist. 1984, A Firm Specific Analysis of Economies of Density in the U.S. Railroad Industry, Journal of Industrial Economics 33: 3-20.

Cantos Sánchez P. 2001 Vertical relationships for the European railway industry, Transport Policy 8(2): 77-83.

Cantos P., Maudos J. 2001 Regulation and efficiency: The case of European railways, Transportation Research-A 35(5): 459-472.

Catalano, G., Daraio, C., Diana, M., Gregori, M., & Matteucci, G., 2019, Efficiency, effectiveness, and impacts assessment in the rail transport sector: a state-of-the-art critical analysis of current research, International Transactions in Operational Research 26 (1): 5-40.

Caves, D. W., and L. R. Christensen. 1980 ,The Relative Efficiency of Public and Private Firms in a Competitive Environment: The Case of Canadian Railroads, Journal of Political Economy 88: 958-976.

Caves, D. W., L. R. Christensen, and J. A. Swanson. 1981,Productivity Growth, Scale Economies, and Capacity Utilization in U.S. Railroads, 1955–74, American Economic Review 71: 994-1002.

Caves, D. W., L. R. Christensen, M. W. Tretheway, and R. J. Windle. 1985 ,Network Effects and the Measurement of Returns to Scale and Density for U.S. Railroads., In Analytical Studies in Transport Economics, edited by A. F. Daughety. New York, Cambridge University Press: 97-120.

Damodaran, A., 2012, Investment Valuation: Tools and Techniques for Determining the Value of Any Asset, John Wiley & Sons, Hoboken.

Daniel V. E., Pels E., Rietveld P. 2010, Returns to density in operations of the Netherlands railways, International Journal of Transport Economics 37(2): 169-191.

Davidson, J., Monticini, A., Peel, D., September 2007, Implementing the wild bootstrap using a two-point distribution, Economics Letters 96 (3), 309–315.

Davidson, R., Flachaire, E., 2008. The wild bootstrap, tamed at last, Journal of Econometrics 146 (1), 162 – 169.

Davidson, R., Mackinnon, J., 2004. Econometric Theory and Methods, Oxford University Press.

De Borger B. 1991, Hedonic Versus Homogeneous Output Specifications of Railroad Technology: Belgian Railroads 1950–1986, Transportation Research A:25 (4) 227-238.

De Borger B. 1992, Estimating a Multiple-output Generalized Box-Cox Cost Function: Cost Structure and Productivity Growth in Belgian Railroad Operations, 1950–1986, European Economic Review 36: 1379-1398.

Efron, B., 1979, Bootstrap Methods: Another Look at the Jackknife, The Annals of Statistics 7 (1), 1–26.

Filippini, M., R. Maggi. 1992, The Cost Structure of the Swiss Private Railways., International Journal of Transport Economics 19: 307-327.

Filippini, M., R. Maggi. 1993, Efficiency and Regulation in the Case of the Swiss Private Railways, Journal of Regulatory Economics 5: 199-216.

Griliches, Z. 1972, Cost Allocation in Railroad Regulation, Bell Journal of Economics and Management Science 3: 26-41.

Hall, P., 1992. The Bootstrap and Edgeworth Expansion. Springer Series in Statistics, Springer, New York.

Hensher, D. A., Wallis, I. P., 2005, Competitive tendering as a contracting mechanism for subsidising transport: the bus experience, Journal of Transport Economics and Policy, 39(3): 295-322.

Keeler, T. E. 1974,Railroad Costs, Returns to Scale, and Excess Capacity, Review of Economics and Statistics 56: 201-208.

Kim, H. Y. 1987,Economies of Scale and Scope in Multiproduct Firms: Evidence from U.S. Railroads, Applied Economics 19: 733-741.

Loizides J., Tsionas E. G. 2002, Productivity growth in European railways: A new approach, Transportation Research-A 36(7): 633-644.

Maness M., Cirillo C. 2016, An indirect latent informational conformity social influence choice model: Formulation and case study, Transportation Research Part B: Methodological, 93, Part A: 75-101.

Mizutani, F. 1997,Empirical Analysis of Yardstick Competition in the Japanese Railway Industry, International Journal of Transport Economics 24: 367-392.

Mizutani F. 2004, Privately owned railways, cost function, organization size and ownership, Journal of Regulatory Economics 25(3): 297-322.

Mizutani F., Kozumi H., Matsushima N. 2009, Does Yardstick regulation really work? Empirical evidence from Japan,s rail industry, Journal of Regulatory Economics 36(3): 308-323.

Preston, J., and C. Nash. 1993 , European Railway Comparisons: Lessons for Policy, Proceedings of the Third International Conference on Competition and Ownership in Surface Passenger Transport, September 26–29, Toronto, Canada: 439-452.

Savage, I. 1997, Scale Economies in United States Rail Transit Systems, Transport Research 31A: 459-473.

Shleifer A. 1985, A theory of yardstick competition, The RAND Journal of Economics, 16 (3): 319-327.

Viton, P. A. 1980, On the Economics of Rapid-Transit Operation, Transportation Research 14A: 247-253.

Wheat, P.E. and Smith, A.S.J. 2015, Do the usual results of railway economies of scale and density hold in the case of heterogeneity in outputs: A hedonic cost function approach, Journal of Transport Economics and Policy 49 (1): 35-57.

Appendix

In this Appendix we show how the average number of overall kilometres produced yearly by any train used for the rail service can be assessed in terms of commercial speed and rail turnover by using an OLS estimation. In particular, the proposed model to estimate the yearly train productivity *TPy* is as follows:

$$TPy=\alpha 2+\beta 2\times(Sp-30)+\gamma 2\times \ln(0.5+T)$$

The model indicates that the impact of the commercial speed on the yearly train productivity is modelled through a linear shape, while a logarithmic function describes the rail turnover effect. Moreover, the constants of the regressors $(Sp-30)$ and $\ln(0.5+T)$ have been selected in order to maximize the fitness of the regression and the significance of the parameters.

Table 9 shows the results of the estimated model.

Table 9. Yearly train productivity: regression results

Regressor	*Coefficient*	*Estimates (std. err)*	p-value	Bootstrap p-value
Constant: 1	$\alpha 2$	22,675.78** (10,476.62)	0.039	0.046
Commercial speed: $Sp-30$	$\beta 2$	1,632.32*** (353.08)	0.000	0.000
Network turnover: $\ln(0.5+T)$	$\gamma 2$	34,253.84*** (6,340.66)	0.000	0.000
n. obs. = 29 F = 29.30 Adj R^2 = 0.668			Breusch-Pagan test for heteroskedasticity: LM=2.051 p-value:0.358 Schwarz criterion (BIC): 664.5262	

***=Significant at 1% level; **=Significant at 5% level; *=Significant at 10% level, based on 9999 bootstrap replications.