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The allocative efficiency measure by means of a distance function: The case of Spanish public railways

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Abstract

This paper is an empirical application of the distance function to study the allocative efficiency of a regulated railway Spanish firm, RENFE, where the cost minimising hypothesis may be questioned. Besides and in contrast with other studies, we include the possibility of the presence of persistent allocative inefficiency. To achieve these aims, we have estimated a system of equations for the inputs distance function and cost shares using annual data over the period 1955–95. Using this procedure we have checked the presence of persistent allocative inefficiency, in particular a systematic overutilisation of labour and underutilisation of capital. Moreover, we have found some empirical evidence that, since 1984, management contracts have improved the input allocation in Spanish railways.

Keywords: Economics; Allocative efficiency; Distance function; Bootstrap; Public firm

1. Introduction

The aim of this paper is to verify whether there exists allocative efficiency in the Spanish public railways: RENFE. To do this, we analyse whether the proportion of productive factors chosen by the firm, with specific technology and given prices, is the most appropriate in order to minimise costs. The neo-classical model in production theory starts from the hypothesis of minimum cost production for firms; see for example Friedlaender et al. (1993) and McGeehan (1993) for railway systems. However, nowadays there are more and more studies which are sceptical of this hypothesis of cost minimising behaviour and study the problems of the allocative efficiency in companies, especially in the regulated sector and the public sector (Toda, 1976; Atkinson and Halvorsen, 1986; Domenech, 1993; Grosskopf and Hayes, 1993; Grosskopf et al., 1995; Bosco, 1996).

In these latter three studies the allocative efficiency was investigated using a new methodology: a Shephard (1953) input distance function.

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In general terms, this function has some advantages over production and cost functions. With reference to the first, the distance function is valid for various outputs, which justifies its usage in the case of a multioutput firm such as RENFE. Compared with the cost function, although with this latter approach inefficiency can also be analysed, the distance function offers three advantages. Firstly, it does not imply cost minimisation. Secondly, to be estimated, the distance function requires neither information on input prices nor the assumption of these being exogenous. This is of great relevance in the context of the public sector where there are often distinct control mechanisms on input prices. The third advantage is that the distance function allows us to directly obtain a measure of allocative inefficiency independent of the degree of technical inefficiency. [1]

Due to this, an input distance function is used with the objective being to check, taking into account the productivity and the relative prices of the distinct factors of production, whether the input allocation has been efficient in RENFE or, if this is not the case, what inputs are being relatively under or overutilised. Besides, in contrast with other studies which have calculated allocative inefficiency using an input distance function (Grosskopf and Hayes, 1993; Atkinson et al., 1998), we assume that the employment of an input in a proportion different from that which would minimise cost could be systematic, and incorporate this possibility into our empirical model. By doing this we can obtain not only a measure of relative allocative inefficiency but also a measure of absolute allocative inefficiency.

The sample period studied covers the years 1955–1995. During this period, railway transport in Spain was operated and managed by a single company, RENFE, which operates goods and passenger transport services in a quasi-monopoly regime. [2] There are reasons to question the fact that, in RENFE, resources are allocated in an efficient way. In 1984, a Government Commission carried out a report which highlighted the lack of competitiveness of the firm. In this report the relatively minor share of inter-city transport accounted for by the railway is shown: the average shares accounted for by RENFE were 8.5% in passengers and 8% in goods, in contrast to European averages of 10% and 24%, respectively. These shares began to decline in the 1950s and this process continued until the late 1970s. Regulation made it practically impossible to reduce services and close lines and prevented the network size being adjusted to changes in the market (De Rus, 1989). On the other hand, transport service prices are fixed by the administration, with the criterion that fares evolve in accordance with production costs and service quality. Moreover, it had been established as a general rule that operating revenues shall cover costs. This type of regulation could result in a lack of incentives in managerial activities to minimise costs.

Since the 1980s a series of measures have been observed which have tended to reduce capacity excess problems and the inefficiency the company was experiencing (Carbajo and De Rus, 1991). Several management contracts were agreed in which the State established objectives to be achieved by the company as a condition for the granting of subsidies. In this way, RENFE began a policy of adjustment which included staff reduction and the closing of lines which showed a high level of deficit. For example, the management contract in 1984–1986 provided an agreement to close 882 km of lines and to reduce the workforce by 15 000 in the space of four years. Subsequently, the 1988–1991 management contract designed a new fare system with the aim of achieving a financial clean-up. Finally, in 1994 another man-

[1] Although the objective of our work is to study allocative efficiency, the methodology of the distance function also enables us to calculate technical efficiency (see for example Atkinson et al., 1998; Coelli and Perelman, 1999). There are many studies in the literature on the railway sector which analyse the technical efficiency using production frontiers (for example, Perelman and Pestieau, 1988; Gathon and Pestieau, 1992; Gathon and Pestieau, 1995).

[2] Although other railway companies exist in Spain, RENFE accounted for 92% and 96% of total travellers and goods traffic, respectively, during 1995.

agement contract was approved, which provided for cost-reduction, revenue increase and improvements in asset turnover. Furthermore, headway has been made towards the consolidation of business units as the basic instruments to manage the activity of RENFE, each being fixed with objectives and incentives. [3]

Our research provides empirical evidence on how these policies – reallocation of resources and management incentives – have affected company efficiency levels, favouring a better input allocation, given productivity and their relative price levels.

The structure of the paper is as follows. In Section 2 the theoretical model is presented. In Sections 3 and 4 there is an explanation of the methodology used for the estimation of the shadow prices by means of the Shephard distance function. Section 5 concerns itself with the econometric model. In Section 6 we describe the data set that we used. Section 7 reports the empirical results. Finally, in Section 8 we present a brief summary and conclusions.

2. The theoretical model

Neo-classical production theory starts from the hypothesis of minimum cost production by firms. According to this hypothesis, the existence of allocative efficiency implies that the firm hires inputs x_i and x_j in a combination such that their respective prices (w_i and w_j) equal their respective marginal revenue product (MRP_i and MRP_j). In relative terms

$$\frac{\mathrm{MRP}_i}{\mathrm{MPR}_j} = \frac{w_i}{w_j}. \tag{1}$$

However, this condition may not be satisfied if costs are not being minimised with respect to market prices, but with respect to others which are called *shadow prices*. Recently many empirical studies which question the above hypothesis have appeared: Eakin and Kniesner (1988), Grosskopf and Hayes (1993) or Grosskopf et al. (1995a), are some examples. In our theoretical set-up we try to explain the existence of these shadow prices in a public company like RENFE, and their relationship with market prices.

2.1. Formalisation of the theoretical model

The theoretical model is based on the hypothesis of maximisation of management utility, as an alternative objective to the maximisation of profits (Williamson, 1963; Niskanen, 1968). Under this hypothesis, and following Atkinson and Halvorsen (1986), the company management utility function can be formalised as a function of two variables, profit and the quantity of inputs. The maximisation problem is

$$\max \quad U = U(P, x) \tag{2}$$

$$\text{s.t.} \quad P = R(x) - \sum_{i=1}^{n} w_i x_i, \tag{3}$$

where $U(\cdot)$ is a twice continuously differentiable quasi-concave utility function, P is the profits obtained by the fim, x is the vector of inputs, R is a firm revenue. It is assumed that revenue is a function of output, so $R = g(y)$, where y is the vector of outputs. Moreover, since $y = f(x)$, this can be written as $R = g\{f(x)\}$, w_i is the market price of i input and x_i is the quantity of i input $(i = 1, \ldots, n)$.

It is assumed that $\partial U/\partial P > 0$, and $\partial U/\partial \geqslant$ or <0 depending on the given input. That is to say, there will be inputs which yield a positive utility (i.e. "visible" inputs as staff, sophisticated machinery, etc.), others that yield negative utility (i.e. those which imply a bigger effort on the part of the manager) and others that are neutral.

The solution for the maximisation problem is expressed through the Lagrangian:

$$L(P,x,\lambda) = U(P,x) - \lambda \left[P - R(x) + \sum_{i=1}^{n} w_i x_i \right]. \tag{4}$$

From this, we find that marginal revenue value for the ith input is equal to

[3] The present management structure of RENFE comprises the following business units: Sub-urban, Regional, Long Distance and High Speed for passenger services, and Freight, Intermodal, Traction and Rolling Stock Maintenance for the remaining.

$$\frac{\partial R}{\partial x_i} = w_i - \frac{\partial U/\partial x_i}{\partial U/\partial P} = w_i^s, \quad (5)$$

where w_i^s is the shadow price of *input i*. Hence, w_i^s differs from w_i by the effects of the manager's behaviour.

Dividing the marginal revenue product of input i by that of input j, we get

$$\frac{\partial R/\partial x_i}{\partial R/\partial x_j} = \frac{\sum_{r=1}^{m} \partial R/\partial y_r \partial y_r/\partial x_i}{\sum_{r=1}^{m} \partial R/\partial y_r \partial y_r/\partial x_j} = \frac{\mathrm{MRP}_i}{\mathrm{MRP}_j} = \frac{w_i^s}{w_j^s}, \quad (6)$$

where y_r is the quantity of output r $(r = 1, \ldots, m)$.

Consequently

$$\frac{\mathrm{MRP}_i}{\mathrm{MRP}_j} = \frac{w_i^s}{w_j^s}. \quad (7)$$

In contrast to Eq. (1), the necessary condition for cost minimisation can be satisfied with regard to shadow prices (w^s) which may differ from market prices.

2.2. Theoretical model conclusions

Some interesting conclusions can be derived from the above analysis (see Eq. (5)):

1. The difference between w and w^s will inversely depend on the magnitude of the marginal utility of profit, $\partial U/\partial P$. When $\partial U/\partial P$ is high (low), that is, when more (less) incentives exist to maximise profit, it will tend to be more (less) cost efficient.
2. The difference between w and w^s will also depend on the magnitude of the relationship between managers' utility and inputs ($\partial U/\partial x_i$).
3. Moreover, relative comparisons of inputs can be obtained. For instance, if $w_i^s > w_i$ and $w_j^s < w_i$ then the i input will be underutilised relative to j input and vice versa.

The inconvenience of this model arises due to the fact that the shadow prices are not observable, and from Eq. (5) a difficult relationship between shadow prices and market prices is obtained, since the utility function is unknown. Therefore it is necessary to introduce a more simplified relationship between both. To achieve this objective a Shephard distance function is introduced (Färe and Grosskopf, 1990).

3. The distance function

Formally, given any two vectors x and y, the Shephard (1953) input distance function is defined as follows:

$$D_I(x, y) = \max_{\delta}(\delta \geqslant 1 : (x/\delta) \in L(y)), \quad (8)$$

where y $(y_1 \cdots y_m)$ is the vector of outputs, x $(x_1 \cdots x_n)$ is the vector of inputs and $L(y) = (x \in R_n^+ : x \text{ can produce } y \in R_m^+)$.

To explain the distance function graphically, we consider the case (Fig. 1) where a firm produces a single output (y) that uses two production factors (x_1 and x_2).

The ratio OR/OP is the Farrell (1957) radial measure of technical efficiency (TE) for the point P. It signifies the maximum proportional reduction that can be achieved in the utilised inputs which still allows production of the same amount of output. Formally

$$\mathrm{TE}(x, y) = \min_{\lambda}(\lambda \in (0, 1) : \lambda x \in L(y)). \quad (9)$$

The maximum value of this index is one, which means that the firm is operating on the isoquant and thus technically efficient. A value lower than one (as can be seen in Fig. 1) informs us about degree of the technical efficiency achieved by the firm. It can be seen that from reciprocal of the index we obtain the definition of the distance function, that is, OP/OR represents the largest scalar by which all factors can be divided proportionally and continue producing the same output level.

Evidently $x \in L(y)$, *if and only if* $D_1(x, y) \geqslant 1$. If D_I equals one, it means that production is technically efficient. A higher value than one informs us about the degree of efficiency achieved. [4]

The Shephard input distance function satisfies the following properties: [5]

[4] We could also define an output distance function as the maximum possible proportional expansion in the output vector, given the input vector and technology. Applications of this type of function can be found in English et al. (1993) and Grosskopf et al. (1995b).

[5] Proofs of these properties can be found in Cornes (1992).

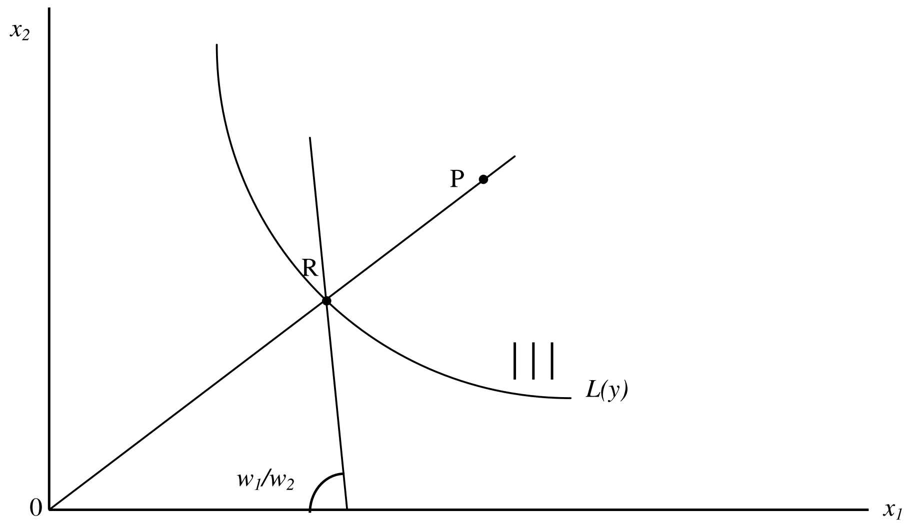

Fig. 1.

1. $D_I(x, y)$ is dual of the cost function;
2. $D_I(x, y)$ is decreasing in outputs;
3. $D_I(x, y)$ is increasing in inputs;
4. $D_I(x, y)$ is homogeneous of degree 1 in x;
5. $D_I(x, y)$ is concave in x.

4. Estimation of shadow prices by means of a Shephard distance function

Initially, studies using shadow prices to obtain a measure of allocative efficiency were based on the estimation of a system of equations formed by a shadow cost function and the set of cost share equations (Atkinson and Halvorsen, 1986; Eakin and Kniesner, 1988; Domenech, 1993). This equations system establishes an appropriate parametric correction in input prices to satisfy the cost minimisation condition.

Färe and Grosskopf (1990) study an alternative method to get shadow prices out of inputs using Shephard's distance function. They assume that the firm minimises costs with respect to certain shadow prices that may differ from market prices. Therefore, the cost function can be defined as

$$C(y, w^s) = \min_x (w^s x : x \in L(y)) = w^s x(y, w^s), \quad (10)$$

where w_i^s is the *shadow price* of factor i for which the cost minimisation condition would be satisfied.

Applying duality theory to the cost function and distance function, [6] Färe and Primont (1990) derive the dual Shephard's lemma

$$\frac{\partial D_I(x, y)}{\partial x} = \frac{w^s}{C(y, w^s)}. \quad (11)$$

That is, the derivative of the distance function with respect to an input is the normalised shadow price. From (11), with any two given inputs $i, j = 1, 2, \ldots, n$, the shadow price ratio is obtained

$$\frac{\partial D_I(x, y)/\partial x_i}{\partial D_I(x, y)/\partial x_j} = \frac{w_i^s(y, x)}{w_j^s(y, x)}. \quad (12)$$

Now, if the cost-minimisation assumption is satisfied, this normalised shadow price ratio should be the same as the input market price ratio. However, if inputs are not selected in the appropriate proportion, that is to say, if allocative in-

[6] The duality between the distance function and cost function is explained in Färe and Primont (1995).

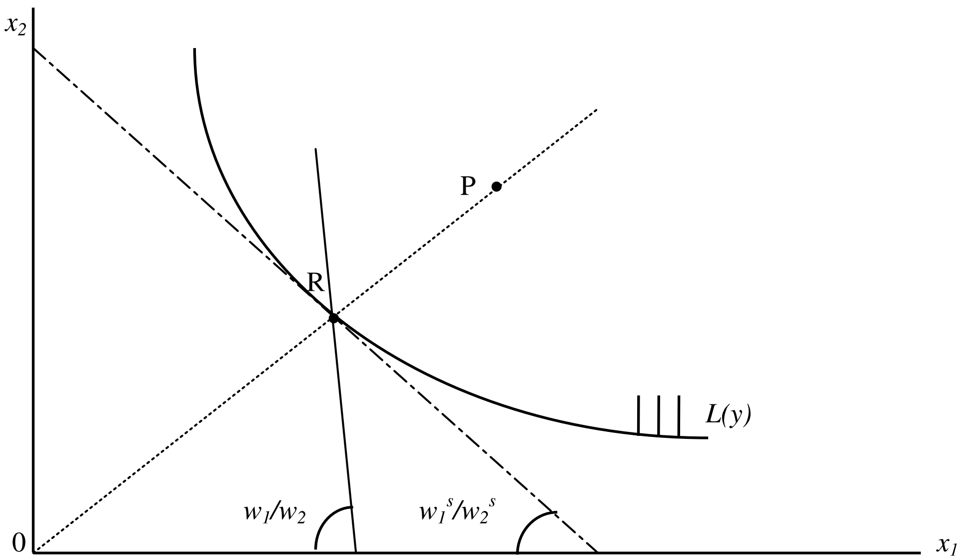

Fig. 2.

efficiency occurs, the aforementioned price ratios will differ.

To study the quantity and direction of such a deviation, a relationship between the normalised shadow prices obtained through the distance function and the input market prices is introduced by means of a parametric price correction (Eakin and Kniesner, 1988; Färe and Grosskopf, 1990)

$$w_i^s(x,y) = k_i w_i, \tag{13}$$

Dividing expression (13) by that corresponding to input j we obtain

$$\frac{w_i^s(x,y)}{w_j^s(x,y)} = k_{ij}\frac{w_i}{w_j}, \tag{14}$$

where

$$k_{ij} = \frac{k_i}{k_j}. \tag{15}$$

Thus, from (14) the degree to which the shadow prices differ from the market prices is calculated. Moreover, we can obtain the direction of such inefficiency as follows:

(a) If $k_{ij} = 1$, there is allocative efficiency in *relative terms*.

(b) If $k_{ij} > 1$, the factor i is being underutilised relative to the j factor.

(c) If $k_{ij} < 1$, the factor i is being overutilised relative to the j factor.

As can be observed in Fig. 2, the normalised shadow price ratio would indicate the isocost slope if costs were actually minimised with the chosen input proportion. That is to say, the isocost with slope $w_1^s(x,y)/w_2^s(x,y)$ tells us what prices (shadow prices) would minimise the cost of producing output y, with the observed input bundle and given technology.

Starting with Färe and Grosskopf (1990), there have been numerous studies in which distance functions are used to check allocative efficiency in production: Grosskopf and Hayes (1993) and Grosskopf et al. (1995a) are some examples.

Next, we turn to applying this methodology to RENFE. We begin by proposing the econometric model.

5. The econometric model

To obtain the shadow factor prices, we estimate a translog input distance function. Since we also want to provide a measure of *absolute allocative* *inefficiency*, we propose that the input distance function should be estimated jointly with the cost share equations, which we can obtain by differentiating the translog distance function with respect to $\ln x_i$. [7] This procedure is expected to improve the precision of the parameter estimates. However, as Schmidt (1985–86, p. 310) pointed out, "a disadvantage of doing so is that consistency then hinges on the correct specification of the entire system".

One of the difficulties in estimating this model is that the distance function value $D_I(x,y)$ is not known. To solve this problem, we assume that its value is, for instance, equal to one which implies the assumption of technical efficiency. Of course, this is not necessary, since the distance function is homogeneous of degree one in inputs and the cost share equations are homogeneous of degree zero in productive factors. That is, the measure of allocative inefficiency that it is obtained by means of a translog input distance function is independent of the degree of technical inefficiency. [8]

So, we propose the following system of equations:

$$\ln 1 = \ln D_I(x,y), \tag{16}$$

$$\frac{\partial \ln D_I(x,y)}{\partial \ln x_i} = \frac{\partial D_I(x,y)}{\partial x_i}\frac{x_i}{D_I(x,y)} = \frac{w^s}{C(y,w^s)}x_i = W_i^s x_i \quad (i = 1,\ldots,n). \tag{17}$$

To estimate the distance function it is necessary to select a specific functional form. In doing so, a series of characteristics are being imposed on the technology without exact knowledge as to whether or not such properties are true or false. For this reason it is especially advantageous to use flexible functional forms that impose the least possible restrictions on the technology that one is trying to describe. Due to this we have used a Translog multiproduct function.

In short, the Shephard input distance function is defined as

$$\begin{aligned}\ln 1 = {} & \alpha_0 + \sum_{r=1}^{m}\alpha_r \ln y_r + \frac{1}{2}\sum_{r=1}^{m}\sum_{s=1}^{m}\alpha_{rs}\ln y_r \ln y_s \\ & + \sum_{i=1}^{n}\beta_i \ln x_i + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\beta_{ij}\ln x_i \ln x_j \\ & + \sum_{r=1}^{m}\sum_{i=1}^{n}\rho_{ri}\ln y_r \ln x_i + \varepsilon.\end{aligned} \tag{18}$$

The cost share equations are

$$\frac{x_i w_i}{C} = \beta_i + \sum_{j=1}^{n}\beta_{ij}\ln x_j + \sum_{r=1}^{m}\rho_{ri}\ln y_r + \mu_i \tag{19}$$

for $r,s = 1,\ldots,m$ outputs; $i,j = 1,\ldots,n$ inputs, and where C represents total cost.

We assume the error of (18) is a composed error term: $\varepsilon = u + v$. The first term, u $(u \geqslant 0)$ captures technical inefficiency and it is assumed to be the absolute value of a normal random variable with zero mean and variance σ_u^2. The second term, v, captures the effect of random noise on input distance function. This noise component is symmetrically distributed with zero mean and variance σ_v^2. Both terms are independently distributed.

On the other hand, the theoretical model captures the idea that allocative inefficiency can be systematic and continuous in time. In contrast to Grosskopf and Hayes (1993) this fact is taken into account in our estimation. For this reason, we consider, as Ferrier and Lovell (1990) and Rodríguez (2000), that the difference between observed and efficient input shares, the error term μ_i of Eq. (19), has an additive structure of the form

$$\mu_i = \eta_i + A_i, \quad i = 1,\ldots,n.$$

The terms η_i capture the effects of random noise on efficient input shares, being random disturbance terms with the usual characteristics (iid, $N(0,\sigma_\eta^2)$). The terms A_i (positive or negative) capture persistent allocative inefficiency in the use of

[7] Although the distance function does not need information about input prices, as we have noted below, these price data are used (indirectly) in constructing the cost share equations as well as in the construction of the efficiency (k) ratio.

[8] Technical efficiency affects only the intercept of the translog distance function. Consequently, the derivatives of the distance function with respect to inputs are independent of the degree of technical inefficiency.

inputs. That is, A_i represent a measure of *absolute allocative inefficiency*. These systematic allocative errors vary by input but not by observation. Thus, Eq. (19) can be rewritten as

$$\frac{x_i w_i}{C} = (\beta_i + A_i) + \sum_{j=1}^{n} \beta_{ij} \ln x_j + \sum_{r=1}^{m} \rho_{ri} \ln y_r + \eta_i, \tag{19'}$$

where the identification of the parameters A_i is achieved from the constant estimated in (19′).

Note that the disturbance terms of Eqs. (18) and (19′), ϵ and η, respectively, may be contemporaneously correlated, but this is consistent with the assumption that technical and allocative inefficiency are independently distributed.

Given that the dependent variable in the distance function equation is $\ln 1 = 0$, estimation can be carried out if a nonzero linearity of the parameters is imposed. Therefore, the conditions required by the theory (see Section 3) have been imposed:

(a) homogeneity of degree one

$$\sum_{i=1}^{n} \beta_i = 1, \quad \sum_{j=1}^{n} \beta_{ij} = 0, \quad \sum_{r=1}^{m} \rho_{ri} = 0,$$

(b) and symmetry

$$\beta_{ij} = \beta_{ji}.$$

According to our model, the proportionality factors (k_{ij}) can be derived from Eqs. (14) and (12):

$$k_{ij} = \frac{w_i^s(x,y)/w_j^s(x,y)}{w_i/w_j} = \frac{\left((\partial D_I(x,y)/\partial x_i)/\left(\partial D_I(x,y)/\partial x_j\right)\right)}{w_i/w_j}. \tag{20}$$

Taking into account that we specified the distance function in terms of logarithms, from (17) we get

$$\frac{\partial \ln D_I(x,y)}{\partial x_i} = \frac{\partial \ln D_I(x,y)}{\partial \ln x_i} \frac{D_I(x,y)}{x_i} = [\text{as } D_I(x,y) = 1] = \frac{\partial \ln D_I(x,y)}{\partial \ln x_i} \frac{1}{x_i}. \tag{21}$$

Substituting (21) into (20) and using (19) we get that

$$k_{ij} = \left(\frac{\frac{\partial \ln D_I(x,y)}{\partial \ln x_i} \frac{1}{x_i}}{\frac{\partial \ln D_I(x,y)}{\partial \ln x_j} \frac{1}{x_j}} \right) \Bigg/ \frac{w_i}{w_j} = \frac{w_j x_j \left[\widehat{\beta_i} + \sum_{j=1}^{n} \widehat{\beta_{ij}} \ln x_j + \sum_{r=1}^{m} \widehat{\rho_{ri}} \ln y_r \right]}{w_i x_i \left[\widehat{\beta_j} + \sum_{i=1}^{n} \widehat{\beta_{ij}} \ln x_i + \sum_{r=1}^{m} \widehat{\rho_{ri}} \ln y_r \right]}. \tag{22}$$

6. Data

The railway activity is a multiproduct one, since not only can we distinguish between passenger and freight transport, but also such other products as origins–destinations which exist in the railroad network. However, the lack of data has led us to consider only two outputs: kilometres covered by travellers (millions of travellers-km transported) and kilometres covered by goods. With respect to the latter, only the pure traffic which includes tons (in millions) of commercial goods per kilometre has been considered. [9] Thus, our variables Fkm and Pkm measure the outputs freight-tonnage per kilometre and passengers per kilometre, respectively. Undoubtedly, using a highly aggregated series can provoke some biases. For instance, we are assuming implicitly that all passenger-kilometre are alike. In this sense, if we were able to distinguish between regional and long distance in passenger services, our model would be more accurate.

Three inputs have been considered: Labour (L), Capital (K), and Energy (E). Labour is the number of employees in full time equivalent units, and includes both permanent and temporary personnel. The labour cost is the personnel expense in millions of current pesetas. For the energy variable, motor equipment energy consumption has

[9] The post is included while the suppliers traffic and the interior service are excluded.

been used, in thousand million kilocalories. [10] The energy cost is the energy and fuels expenditure in millions of current pesetas each year.

As for the capital series, we have considered physical units of motor equipment which include, during the sample period, electric, diesel, and steam locomotives, as well as electric and diesel trains. Starting from the data provided in Muñoz Rubio (1995) and from RENFE reports, we have constructed, firstly, the age structure of each type of haulage unit which was in service in each year. Then, this has been depreciated according to their years of service, using a method of constant shares and allowing for an average serviceable lifetime of 30 years. Finally, due to diversity of haulage equipment, we have homogenised it based on energy performance, average traction power and productive routes. Thus, each unit of capital would represent a machine with the same energy performance, average traction power and productive routes as an electric locomotive in 1980. In doing this, the intention is to capture the modernisation process experienced by motor equipment over the period studied.

With regard to the total capital cost, we have used investments made by RENFE in mobile equipment, divided by the average number of years of serviceable life of equipment material, plus the expenses in repayments, all in millions of current pesetas.

As it would also be desirable to incorporate a variable which could capture the modernisation process on the railway network structure, we have taken traffic density (MODER) as a proxy of efforts made to improve the quality of the network. However, given the complexity of railway transport technology, it would be naive to think that in a distance function estimation we could encompass all the elements that could affect it.

Finally, we have incorporated a trend variable (PROGC) from 1984 with the idea of capturing the influence of management contract established in RENFE from this date.

The series of annual data used comes from the Communications and Transport Annual Report, compiled by the Institute of Transport and Communications Studies, RENFE Reports, Spain's National Accounts (INE, several issues) and Muñoz Rubio (1995). Table 1 displays the descriptive statistics of the data series used in our empirical procedure and also the relevant input ratios. The input data exhibit a serious decrease in terms of labour and energy.

[10] In energy-equivalent terms.

7. Empirical results

We jointly estimate the system of equations for the input distance function and the share equations given by expressions Eqs. (18) and (19), imposing homogeneity and symmetry restrictions, for the period 1955–1995.

In accordance with the theoretical model presented in Section 2, the outputs (Fkm and Pkm) would be exogenous and the inputs (E, L and K) endogenous. As a result of this, in Eqs. (18) and (19), we have the problem that the inputs and the errors are correlated. [11] To solve this, the system has been estimated using instrumental variables. The instruments used are the following Spanish macro series: fixed capital, number of employees in the agricultural sector and consumption of automobile gasoline.

The *relative allocative inefficiency* is given by the expression k_{ij} (see Eq. (22)) and is obtained from the parameters estimated from the system of equations. It is important to point out that if we did not take into account the correction of the error term proposed in Eq. (19′) and the A_i parameters were significantly different from zero, the k_{ij} coefficients would be biased; moreover, at the sample mean the k_{ij} values would not be significantly different from one.

The system (18), (19) and (19′) has estimated by means of iterative seemingly unrelated regressions (ITSUR), which is equivalent to maximum likelihood estimation and invariant to the omitted share equation.

[11] For a discussion on this point, see Coelli and Perelman (1999) and Atkinson et al. (1998).

Table 1
Sample descriptive statistics

	Period 1955–1984				Period 1984–1995				Period 1955–1995			
	Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.	Min.	Max.
Physical outputs												
Tonnes-km of freight (in millions)	8572	1525	6330	11 239	10 224	1260	7617	11 318	8990	1608	6330	11 318
Passenger-km (in millions)	11 387	2381	7340	15 574	15 441	456.7	14 715	16 302	12 471	2730	7340	16 302
Physical inputs												
Labour	96 399	25 412	69 394	135 321	51 716	10 261	38 121	69 394	83 980	303 27	38 121	135 321
Capital	624.7	116.3	422.3	847.1	863.2	57.8	765.8	959.8	689.1	149.4	422.3	959.8
Energy (10^9 kcal)	10 284	8538	2625	24 122	2696	108.1	2456	2793	8247	8028	2456	24 122
Traffic density	1.515	0.279	1.030	2.005	2.045	0.115	1.828	2.186	1.658	0.342	1.030	2.186
Input shares												
Labour share	0.697	0.096	0.473	0.820	0.701	0.052	0.617	0.707	0.696	0.085	0.473	0.820
Capital share	0.116	0.036	0.062	0.182	0.193	0.061	0.112	0.291	0.139	0.056	0.062	0.291
Energy share	0.187	0.119	0.061	0.445	0.106	0.010	0.088	0.117	0.165	0.108	0.061	0.445
Ratio of inputs												
Labour/capital	470.3	445.9	138.3	2116.1	98.5	22.96	58.8	138.3	376.4	418.5	58.8	2116.2
Energy/capital	63.5	87.8	5.40	367.2	5.01	0.62	3.59	5.74	48.9	79.9	3.59	367.2

Before commenting on the results, two final considerations should be made. Firstly, we take into account that the errors of the system (18), (19) and (19′) display first-order autocorrelation. A first-order autoregressive parameter has therefore been introduced into the distance function and the cost share equations. Following Friedlaender et al. (1993) and Berndt et al. (1993), the coefficient of the autoregressive term has been fixed at the same value across the different share equations in order to maintain the property that the model be invariant to the elimination of any share equation. Secondly, attention should be drawn to the fact that the variables are in the form of deviations with respect to their geometric means. That is, the first-order coefficients of the distance function can be interpreted as elasticities at the sample mean. [12]

The estimated parameters are presented in Table 2. It is verified that the distance function, at the sample mean, fulfils the properties of being increasing and concave in inputs and decreasing in outputs (see Section 3), [13] and is also homothetic. [14] Moreover, from the first-order input and output coefficients in the distance function, it can be seen that, at the point-of-means, the passenger output elasticity is bigger than the freight one, and the same can be said about labour input in relation with the other inputs. Also, the trend variable (PROGC) coefficient is negative and statistically significant. Since 1984 management contracts have improved the input allocation in RENFE. On the other hand, the coefficient of the variable which measures the process of modernisation of the network is positive and significant. This positive sign indicates that if in the presence of technological progress the firm maintains the same combination of inputs to produce a given quantity of output, the distance value will increase. [15]

The estimated parameters A_L, A_K and A_E show, as we have mentioned, the average cost of absolute allocative inefficiency of the factors labour, capital and energy, respectively. The results show that A_L and A_K are significantly different from zero which implies that, at the sample mean, labour and capital have been employed inefficiently. In absolute terms, labour has been used in a quantity greater than the optimum while capital has been underutilised. The parameter A_E has been restricted to zero because in a earlier estimation its value was found not to be significantly different from zero. [16]

From the system (18), (19) and (19′) we have calculate the mean values and evolution over time of the allocative inefficiency, *in relative terms*, in accordance with what has been set out in Section 4. Moreover, from the estimated parameters we could only obtain a single value of k_{ij} for each observation. In order to get a distribution for these k_{ij}, we have used a standard bootstrap technique, consisting of selecting a random sample of residuals from the estimation of the system (18), (19) and (19′). Subsequently, "new" dependent variables were generated for each of the equations of the system, equal to the residuals selected randomly plus the value of the prediction of the corresponding equations. The reestimation of the system (18), (19) and (19′) with the pseudodata generated in this manner was repeated 100 times. [17] To obtain the confidence intervals for the k_{ij} we used the percentile method (Efron and Tibshirani, 1986).

Table 3 shows the results for the proportionality factors evaluated at the sample mean, together with their confidence intervals. Values of k_{ij} less than one indicate, given the factor prices, that

[12] Except for the trend variable which is not expressed in logs.

[13] Tests of monotonicity and concavity conditions suggest that the translog input distance function estimated was well behaved. In fact, the property of being increasing in inputs is satisfied at all observations. Similarly, the concavity conditions (the hessian matrix is negative semidefinite) were satisfied at all observations. However, the monotonicity condition in outputs was violated at 9 of 41 observations (7 in the case of Pkm and 2 in the case of Fkm).

[14] Homotheticity requires that $\rho_{ri} = 0\ \forall r, i$. The test statistic has a value of 4.69 and given that it has a $\chi 2$ with 4 degrees of freedom, we cannot reject the hypothesis of homotheticity.

[15] Graphically, in Fig. 1, taking P as our point of reference a technological improvement will lead to a shift of the isoquant to the left. See Färe and Grosskopf (1995) to construct a test of technical change.

[16] The estimated A_E was 0.01 with a t-statistic of 0.24.

[17] Taking into account in each case the correction for autocorrelation.

Table 2
Distance function estimated (sample 1955–1995)

Variable	Coefficient	t-statistic	
Constant	1.9324	1.1134	
Log(Fkm)	−0.4001	−6.8821	
Log(Pkm)	−0.9624	−9.3511	
Log(L)	0.6262	18.9441	
Log(E)	0.0950	5.2396	
Log(K)	0.2786	8.4083	
Log(Fkm) · Log(Fkm)	−4.0454	−1.9820	
Log(Pkm) · Log(Pkm)	5.3174	3.0681	
Log(Fkm) · Log(Pkm)	−0.9593	−0.7645	
Log(L) · Log(L)	0.0141	0.3619	
Log(L) · Log(K)	0.0198	0.7413	
Log(L) · Log(E)	−0.0339	−1.6192	
Log(E) · Log(K)	−0.0111	−0.7286	
Log(E) · Log(E)	0.0451	2.6332	
Log(K) · Log(K)	−0.0086	−0.3527	
Log(Fkm) · Log(L)	0.0676	1.2265	
Log(Fkm) · Log(K)	0.0178	0.4183	
Log(Fkm) · Log(E)	−0.0855	−1.9253	
Log(Pkm) · Log(L)	−0.0075	−0.1274	
Log(Pkm) · Log(E)	−0.0410	−0.8223	
Log(Pkm) · Log(K)	0.0485	1.0462	
Log(Pkm) · PROGC	0.0158	0.6840	
Log(Fkm) · PROGC	−0.0087	−0.2344	
PROGC · PROGC	−0.0001	−0.1484	
PROGC	−0.0229	−2.9255	
Log(E) · PROGC	−0.0018	−0.6578	
Log(L) · PROGC	−0.0135	−3.4299	
Log(K) · PROGC	0.0154	5.0068	
PROGC · MODER	−0.0123	−0.3957	
MODER	0.9065	9.1480	
MODER · MODER	0.2542	0.1318	
MODER · Log(Pkm)	−2.5724	−1.5142	
MODER · Log(Fkm)	1.6300	0.8752	
MODER · Log(L)	−0.0667	−1.0293	
MODER · Log(K)	−0.0383	−0.7593	
MODER · Log(E)	0.1051	1.9283	
A_L	0.1371	3.4059	
A_K	−0.1371	−3.4059	
Equation	R-squared	DW	S.E. regression
Statistics of model			
Distance function	–	1.98	0.016
Labour cost share	0.97	2.09	0.017
Capital cost share	0.96	1.70	0.013
Energy cost share	0.99	2.15	0.015

input i is being overutilised with respect to input j and vice versa. The results show that the capital and energy inputs are being relatively underutilised with respect to labour ($k_{\text{LABOUR, ENERGY}}) = 0.82$ and $k_{\text{LABOUR, CAPITAL}} = 0.39$). Moreover, energy is overutilised with respect to capital ($k_{\text{ENERGY,CAPITAL}} = 0.71$).

Fig. 3 illustrates the evolution over time of these coefficients. It can be observed that the values of $k_{\text{LABOUR, CAPITAL}}$ are below one during the

Table 3
Proportionality factors k_{ij} values

	Average value[a]
$k_{\text{ENERGY, CAPITAL}}$	0.7142
	(0.61, 0.81)
$k_{\text{LABOUR, CAPITAL}}$	0.3877
	(0.32, 0.47)
$k_{\text{LABOUR, ENERGY}}$	0.8242
	(0.75, 0.88)

[a] Evaluated at the means of the data using parameter estimates of (18), (19) and (19′). *Note*: confidence intervals at 95% of k_{ij} are in parentheses.

period analysed, implying that the relative overutilisation of labour with respect to capital has been maintained over the 41 years studied. Some similarities are also revealed in the behaviour of $k_{\text{LABOUR, CAPITAL}}$ and $k_{\text{ENERGY, CAPITAL}}$: allocative inefficiency has tended to be corrected over the period 1963–73. In this period RENFE experienced the highest levels of capital investment in its history due to the *Plan Decenal de Modernización* (Ten-Year Modernisation Plan). An improvement can also be appreciated as a consequence of the introduction of the management contracts in 1984.

With regard to the evolution over time of the coefficient $k_{\text{LABOUR, ENERGY}}$, we can see that over the earlier years of the period studied there was an overutilisation of energy, with the opposite occurring from 1966 on, i.e. the overutilisation of labour with respect to energy, a situation gradually accentuated over the remainder of the period.

Moreover, as a by-product of the analysis, we have measured returns to scale in RENFE. Its mean value turns out to be 1.37, which is consistent with the majority of the values presented in the literature on rail transport. [18] Finally, we have also measured the technical efficiency on RENFE and the total factor productivity (TFP) growth rate. In our case, the index of technical efficiency would simply measure the degree of technical inefficiency in a given year relative to the most efficient year and, at the sample mean, its value is 0.96. On the other hand, the average TFP growth rate, measured by a Mal-

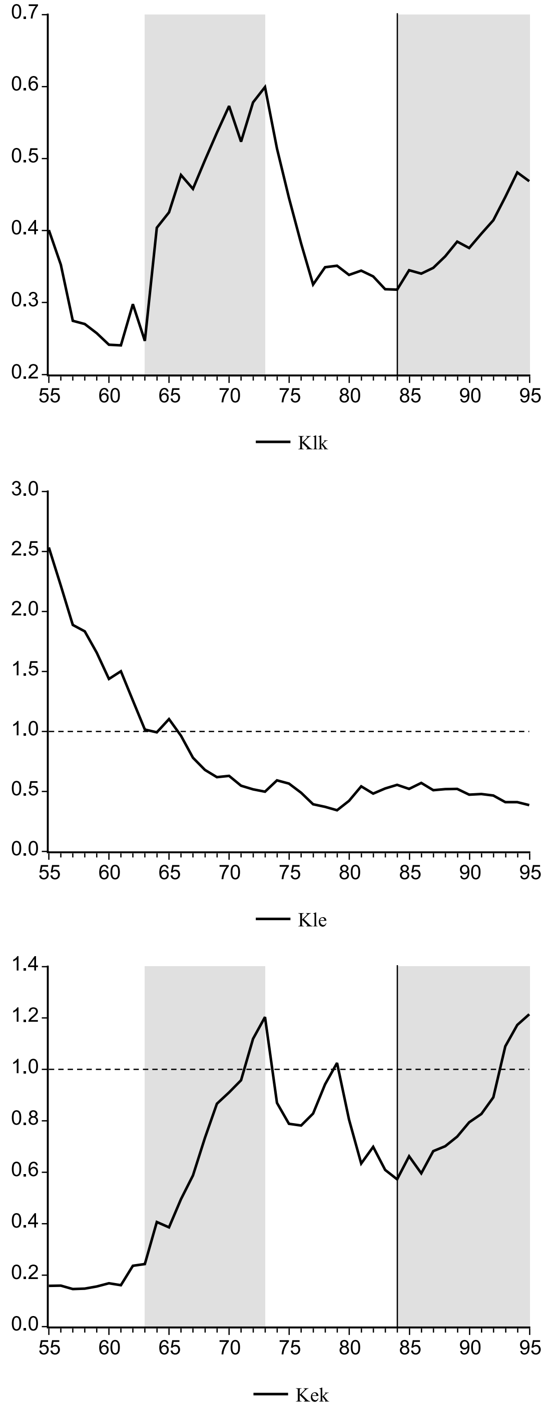

Fig. 3. Time path of the coefficients k_{ij}.

[18] The returns to scale associated with an increase in outputs is defined as: $RTS = -1/(\partial DI/\partial y)$.

quist productivity index, is close to zero (0.01%). This index can be decomposed in a positive rate of technical change, about 0.03% per year, compensated by a negative rate of efficiency change (−0.03%).

8. Summary and conclusions

This paper is an empirical application of the distance function to study the allocative efficiency of a regulated railway firm, RENFE, where the cost minimising hypothesis may be questioned. The distance function, which is the dual of the cost function, completely describes the technology and, like the cost function, it allows a multiproduct analysis. However, unlike the cost function, the input prices are not needed for its calculation and it does not imply cost minimisation.

We have obtained the shadow prices of the productive factors, which satisfy the condition of minimum cost. These shadow prices are used to calculate the degree of allocative inefficiency of the firm and the origin of this inefficiency by using a parametric correction of prices (k_{ij}). The procedure followed has consisted of estimating a system of equations for the input distance function and cost share equations, employing the iterative seemingly unrelated regressions method (ITSUR). Moreover, in contrast with other studies which have used this method, we assume that the employment of an input in a proportion different from that which would minimise cost could be systematic, and incorporate this possibility into our empirical model. The model was estimated using annual data over the period 1955–95. In order to achieve a distribution and the confidence intervals of the proportionality terms estimated, k_{ij}, we have used a standard bootstrap technique.

The results indicate that there is no allocative efficiency, since the calculated shadow prices are different from market prices. In particular, there is overutilisation of labour relative to capital and energy.

This overutilisation could be due in a some way to the difficulty of adjusting the optimal labour quantity in a regulated environment such as that in which RENFE operates. Moreover, and in accordance with our theoretical model, the overutilisation of labour could also be due in part to the lack of incentives for managers to achieve cost minimisation.

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References

Atkinson, S., Halvorsen, R., 1986. The relative efficiency of public and private firms in a regulated environment: The case of US electric utilities. Journal of Public Economics 29, 281–294.

Atkinson, S., Färe, R., Primont, D., 1998. Stochastic estimation of firm inefficiency using distance functions. Mimeo, Department of Economics, University of Georgia.

Berndt, E., Friedlaender, A., Chiang, J., Showalter, M., Vellturo, C., 1993. Mergers, deregulation and cost savings in the US rail industry. Journal of Productivity Analysis 4 (1–2), 127–144.

Bosco, B., 1996. Excess-input expenditure estimated by means of an input-distance function: The case of public railways. Applied Economics 28, 491–497.

Carbajo, J.C., De Rus, G., 1991. Railway transport policy in Spain. Journal of Transport Economics and Policy XXV (2), 209–215.

Coelli, T., Perelman, S., 1999. A comparision of parametric and non-parametric distance functions: With application to European railways. European Journal of Operational Research 117, 326–339.

Cornes, R., 1992. Duality and Modern Economics. Cambridge University Press, Cambridge.

De Rus, G., 1989. Las empresas públicas de transporte en España. Papeles de Economía Española 38, 349–382.

Domenech, R., 1993. Funciones de costes para la banca española: un análisis con datos de panel. Investigaciones Económicas XVII, 263–284.

Eakin, B.K., Kniesner, T.J., 1988. Estimating a non-minimum cost function for hospitals. Southern Economic Journal 54, 583–597.

Efron, B., Tibshirani, R., 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. Statistical Science 1, 54–77.

English, M., Grosskopf, S., Hayes, K., Yaisawarng, S., 1993. Output allocative and technical efficiency of banks. Journal of Banking and Finance 17, 349–366.

Färe, R., Grosskopf, S., 1990. A distance function approach to price efficiency. Journal of Public Economics 43, 123–126.

Färe, R., Grosskopf, S., 1995. Nonparametric tests of regularity, Farrell efficiency, and goodness-of-fit. Journal of Econometrics 69, 415–425.

Färe, R., Primont, D., 1995. Multi-output production and duality: theory and applications. Kluwer Academic Publishers, Norwell.

Farrell, M.J., 1957. The measurement of productive efficiency. Journal of The Royal Statistical Society, Series A 120, 253–281.

Ferrier, G.D., Lovell, C.A.K., 1990. Measuring cost efficiency in banking. Journal of Econometrics 46, 229–245.

Friedlaender, A.F., Berndt, E.R., Shaw-Er Wang Chiang, J., Showlater, M., Vellturo, C.A., 1993. Rail cost and capital adjustments in a quasi-regulated environment. Journal of Transport Economics and Policy XXVII (1), 131–152.

Gathon, H.-J., Pestieau, P., 1992. Measuring technical efficiency in European railways: A panel data approach. The Journal of Productivity Analysis 3, 131–151.

Gathon, H.-J., Pestieau, P., 1995. Decomposing efficiency into its managerial and its regulatory components: The case of European railways. European Journal of Operational Research 80, 500–507.

Grosskopf, S., Hayes, K., 1993. Local public sector bureaucrats and their input choices. Journal of Urban Economics 33, 151–166.

Grosskopf, S., Hayes, K., Hirschberg, J., 1995a. Fiscal stress and the production of public safety: A distance function approach. Journal of Public Economics 57, 277–296.

Grosskopf, S., Margaritis, D., Valdmanis, V., 1995b. Estimating output substitutability of hospital services: A distance function approach. European Journal of Operational Research 80, 575–586.

INE, Contabilidad Nacional de España (Spain National Accounts). Several issues.

Institute of Transport and Communications Studies. Ministerio de Transportes. Informes anuales. Various issues.

McGeehan, H., 1993. Railway costs and productivity growth. Journal of Transport Economics and Policy XXVII (2), 19–32.

Muñoz Rubio, M., 1995. Renfe (1941–1991). Medio Siglo de Ferrocarril Público, Ediciones Luna, Madrid.

Niskanen, W.A., 1968. The peculiar economics of bureaucracy. American Economic Review 58, 293–305.

Perelman, S., Pestieau, P., 1988. Technical performance in public enterprises: A comparative study of railways and postal services. European Economic Review 32, 432–441.

RENFE Reports (Memorias de RENFE). Various issues.

Rodríguez-Alvarez, A., 2000. Measuring allocative efficiency in a bureaucracy: the Spanish public hospitals. Unpublished Ph.D. dissertation, University of Oviedo, Oviedo.

Schmidt, P., 1985–86. Frontier production functions. Econometric Reviews 4 (2), 289–328.

Shephard, R.W., 1953. Cost and Production Functions. Princeton University Press, Princenton.

Toda, Y., 1976. Estimation of a cost function when the cost is not minimum: The case of Soviet manufacturing industries, 1958–1971. The Review of Economics and Statistics 58, 259–268.

Williamson, O., 1963. Managerial discretion and business behaviour. American Economic Review 5, 1032–1057.