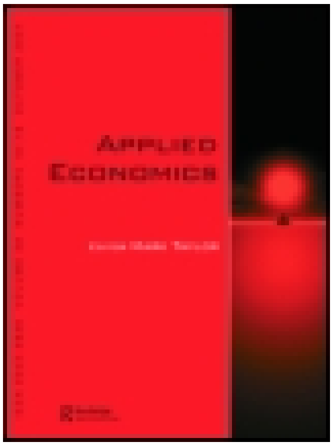

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Technical efficiency of European railways: a distance function approach

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This study has two principal objectives. The first objective is to measure and compare the performance of European railways. The second objective is to illustrate the usefulness of econometric distance functions in the analysis of production in multi-output industries, where behavioural assumptions such as cost minimization or profit maximization, are unlikely to be applicable. Using annual data on 17 railways companies during 1988–1993, multioutput distance functions are estimated using corrected ordinary least squares (COLS). The resulting technical efficiency estimates range from 0.980 for the Netherlands to 0.784 for Italy, with a mean of 0.863. The distance function results are also compared with those obtained from single-output production functions, where aggregate output measures are formed using either total revenue or a Tornqvist index. The results obtained indicate substantial differences in parameter estimates and technical efficiency rankings, casting significant doubt upon the reliability of these single-output models, particularly when a total revenue measure is used to proxy aggregate output.

I. INTRODUCTION

Substantial changes have occurred in many European railways companies during the 1970s and 1980s. These changes have been primarily driven by a general tightening in Government budgets across Europe and by the introduction of European Commission regulations which impose strict controls upon government subsidies. The effect of these changes upon the performance of European railways is yet to be determined. The intention of this study is to obtain reliable and up-to-date measures of performance in European Railways. In doing this a multioutput distance function methodology is utilized. The selection of this relatively new approach is motivated by a desire to avoid making unrealistic assumptions, such as cost-minimizing behaviour, while at the same time properly accounting for the multioutput nature of railways production.

There is a long tradition in the estimation of production characteristics and performances in railways. This literature extends from Klein's (1953) econometric study on US railways to the recent studies using frontier analysis techniques (Perelman and Pestieau, 1988; Deprins and Simar, 1988; Gathon and Perelman, 1992 and Cowie and Riddington, 1996). The majority of research on railways has been devoted to detailed partial productivity analysis (British Railways Board and University of Leeds, 1979; Nash, 1985) and to total factor productivity (TFP) comparisons based on the estimation of multioutput cost functions (Caves and Christensen 1980; Caves *et al.*, 1981).[1]

The analytical framework used in many of these studies is influenced by the three characteristics which are common to almost all railways companies. First, multioutput production: passenger and freight services are provided simultaneously and share a number of common inputs. Second, all railways companies benefit from some degree of (natural) monopoly, even if other transportation modes indirectly compete with them. Third, railroad passenger transportation, and to a lesser extent freight transportation,

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[1] For a survey of these studies, see Dodgson (1985).

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are public services, which are often submitted to high regulation.

The three characteristics described above are common to all 17 European railways companies considered in this study (see Table 2 for a list of these companies). All of the companies produce both passenger and freight services and are state-owned (during the sample period).[2] All companies hold a natural monopoly position in rail transportation, but in return, their activity is constrained to varying degrees by public authorities and, in most cases, by European Union regulations.

A multioutput dual cost function approach has been used by a number of authors in analyses of the North American railways industry (e.g., Caves and Christensen, 1980; Caves *et al.*, 1981). This method is unlikely to be an appropriate method of analysis in the state-owned European industry, where cost-minimization is an objective which rarely has a high priority. In fact, in terms of performance measurement, Pestieau and Tulkens (1993) argue forcefully that technical efficiency measurement is probably the only appropriate way to compare the performance of enterprises operating in such environments. They observe that the technical efficiency objective, that is, the maximization of physical outputs for a given combination of physical inputs[3] is, in fact, the only objective that is compatible with all other objectives fixed by various control authorities and, for this reason, appears to be an unavoidable goal. Hence, in this study, we focus upon the use of technical efficiency as our measure of performance in European railways.

This study, hence, has two principal objectives. The first is to measure the technical efficiency of European railways, while the second objective is to provide a detailed illustration and discussion of distance function methods, which is believed to have significant potential in applied econometric analyses of multioutput industries. The analysis includes a comparison of the distance function results with results obtained from a single-output production function, where the single-output measure is an aggregate measure of passenger and freight services. The results indicate that output aggregation can have a substantial influence upon both parameter estimates and technical efficiency measures. In addition to this, the results also identify a significant improvement in railways technical efficiency over the past decade. A phenomenon that can be interpreted as the result of a catching-up process, which is expected to be primarily due to the gradual introduction of European Commission regulations restricting the use of government subsidies.

This paper is organized into sections. The following section provides a discussion of methods that may be used to model multioutput technologies, including a detailed description of the distance functions methods that are used in the empirical analysis. In Section III, technical efficiency in European railways is investigated using a variety of estimated distance functions, and in the final section some concluding comments are made.

II. MULTIOUTPUT PRODUCTION AND DISTANCE FUNCTIONS

The majority of econometric studies that have attempted to model a multiple-output technology have either: (a) aggregated the multiple outputs into a single index of output (this index may be simply aggregate revenue or perhaps a multi-lateral superlative index such as a Tornqvist[4] or Fisher index); or (b) modelled the technology using a dual cost function.[5] These approaches, however, require certain assumptions to be made. The first of these methods require that output prices be observable (and reflect revenue maximizing behaviour), while the latter approach requires an assumption of cost-minimizing behaviour. There are a number of instances, however, when neither of these requirements are met. The public sector contains many examples. One example being the case of European Railways, where the vast majority of organizations are both government-owned and highly regulated.

Some recent parametric frontier papers have also attempted to solve the multiple output problem by estimating the production technology using either: (a) an input requirements function (e.g., Gathon and Perelman, 1992) in which a single (possibly aggregate) input is expressed as a function of a number of outputs; or (b) an output- or input-orientated distance function (e.g., Lovell *et al.*, 1994; Grosskopf *et al.*, 1997) which can accommodate both multiple inputs and multiple outputs. The input requirements function approach has the advantage of permitting multiple outputs but at the cost of restricting the production technology to a single input. The distance function approach, however, requires no such restriction. We now discuss the distance function approach in some detail.

Distance functions

We begin by defining the production technology of the firm using the output set, $P(x)$, which represents the set of all

[2] The privatization process of some British Railways activities started in April 1994. For a description of this process see Dodgson (1994).
[3] Or alternatively minimizing the inputs required to produce given outputs.
[4] See Caves *et al.* (1982).
[5] For example, see Ferrier and Lovell (1990). Also note that a dual profit or revenue function could alternatively be considered.

output vectors, $y \in R_+^M$, which can be produced using the input vector, $x \in R_+^K$. That is,

$$P(x) = \{y \in R_+^M : x \text{ can produce } y\} \tag{1}$$

We assume that the technology satisfies the axioms listed in Fare *et al.* (1994).

The output distance function, introduced by Shephard (1970) is defined on the output set, $P(x)$, as:

$$D_O(x, y) = \min\{\theta : (y/\theta) \in P(x)\} \tag{2}$$

As noted in Lovell *et al.* (1994), $D_O(x,y)$ is nondecreasing, positively linearly homogeneous and convex in y, and decreasing in x. The distance function, $D_O(x,y)$, will take a value which is less than or equal to one if the output vector, y, is an element of the feasible production set, $P(x)$. That is, $D_O(x,y) \leq 1$ if $y \in P(x)$. Furthermore, the distance function will take a value of unity if y is located on the outer boundary of the production possibility set. That is, $D_O(x,y) = 1$ if $y \in \text{Isoq}\, P(x) = \{y : y \in P(x), \omega y \notin P(x), \omega > 1\}$, using similar notation to that used by Lovell *et al.* (1994).

Note that a distance function may be specified with either an input orientation or an output orientation. This study begins by focusing upon an output distance function, primarily because there is a wish to make comparisons between technical efficiency measures made relative to a single-output production frontier and those obtained relative to a multioutput distance function.

Distance functions have been estimated using a variety of methods in recent years. These include: data envelopment analysis (DEA); parametric deterministic linear programming (PLP); corrected ordinary least squares (COLS); and stochastic frontier analysis (SFA). These methods are discussed and compared in Coelli and Perelman (1996, 1999). This study uses the corrected ordinary least squares (COLS) method. The COLS method has the advantages of being easy to estimate and also permits the conduct of traditional hypothesis tests. Furthermore, a recent study by Coelli and Perelman (1999) found that COLS, parametric linear programming and DEA gave quite consistent technical efficiency rankings when applied to a single data set.

A translog functional form is specified for the distance functions in this study. The functional form for the distance function would ideally be: (i) flexible; (ii) easy to calculate; and (iii) permit the imposition of homogeneity. The translog form has been used in other distance function studies (e.g. Lovell *et al.*, 1994; Grosskopf *et al.*, 1997) since it is able to satisfy these three requirements. The Cobb–Douglas form does satisfy points 2 and 3 but falls down under point 1 because of its restrictive elasticity of substitution and scale properties. Furthermore, as noted by Klein (1953, p. 227), the Cobb–Douglas transformation function is not an acceptable model of a firm in a purely competitive industry because it is not concave in the output dimensions.[6]

The translog distance function for the case of M outputs and K inputs is specified as[7]

$$\begin{aligned} \ln D_{Oi} = \alpha_0 &+ \sum_{m=1}^{M} \alpha_m \ln y_{mi} + \tfrac{1}{2} \sum_{m=1}^{M} \sum_{n=1}^{M} \alpha_{mn} \ln y_{mi} \ln y_{ni} \\ &+ \sum_{k=1}^{K} \beta_k \ln x_{ki} + \tfrac{1}{2} \sum_{k=1}^{K} \sum_{l=1}^{K} \beta_{kl} \ln x_{ki} \ln x_{li} \\ &+ \sum_{k=1}^{K} \sum_{m=1}^{M} \delta_{km} \ln x_{ki} \ln y_{mi} \qquad i = 1, 2, \ldots, N \end{aligned} \tag{5}$$

where i denotes the ith firm in the sample. Note that to obtain the frontier surface (i.e., the transformation function) one would set $D_{Oi} = 1$, which implies the left hand side of Equation 5 is equal to zero.

The restrictions required for homogeneity of degree + 1 in outputs are

$$\sum_{m=1}^{M} \alpha_m = 1 \tag{6a}$$

and

$$\sum_{n=1}^{M} \alpha_{mn} = 0 \qquad m = 1, 2, \ldots, M$$

and (6b)

$$\sum_{m=1}^{M} \delta_{km} = 0 \qquad k = 1, 2, \ldots, K$$

and those required for symmetry are

$$\alpha_{mn} = \alpha_{nm} \qquad m, n = 1, 2, \ldots, M$$

and (7)

$$\beta_{kl} = \beta_{lk} \qquad k, l = 1, 2, \ldots, K$$

It is also noted in passing that the restrictions required for separability between inputs and outputs are

$$\delta_{km} = 0 \qquad k = 1, 2, \ldots, K, m = 1, 2, \ldots, M \tag{8}$$

These last restrictions will be used when separability is tested for in the following section.

A convenient method of imposing the homogeneity constraint upon Equation 5 is to follow Lovell *et al.* (1994) and observe that homogeneity implies that

$$D_O(x, \omega y) = \omega D_O(x, y) \qquad \text{for any } \omega > 0 \tag{9}$$

[6] This is not such a serious problem, however, when optimizing behaviour is not an issue. For example, when the primary interest is in obtaining technical measures.
[7] Note that ln represents the natural logarithm.

Hence, following Lovell *et al.* (1994) one of the outputs is arbitraily chosen, such as the Mth output, and set $\omega = 1/y_M$ one obtains

$$D_O(x, y/y_M) = D_O(x, y)/y_M \quad (10)$$

For the translog form this provides:

$$\begin{aligned}\ln(D_{Oi}/y_{Mi}) = \alpha_0 &+ \sum_{m=1}^{M-1} \alpha_m \ln y^*_{mi} \\ &+ \tfrac{1}{2}\sum_{m=1}^{M-1}\sum_{n=1}^{M-1} \alpha_{mn} \ln y^*_{mi} \ln y^*_{ni} \\ &+ \sum_{k=1}^{K} \beta_k \ln x_{ki} + \tfrac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_{ki} \ln x_{li} \\ &+ \sum_{k=1}^{K}\sum_{m=1}^{M-1} \delta_{km} \ln x_{ki} \ln y^*_{mi} \\ & \qquad i = 1,2,\ldots,N \quad (11)\end{aligned}$$

where $y^*_{mi} = y_{mi}/y_{Mi}$.

To facilitate COLS estimation, Equation 11 is rewritten as

$$\ln(D_{Oi}/y_{Mi}) = \mathrm{TL}(x_i, y_i/y_{Mi}, \alpha, \beta\delta) \quad i = 1,2,\ldots,N \quad (12)$$

or

$$\ln(D_{Oi}) - \ln(y_{Mi}) = \mathrm{TL}(x_i, y_i/y_{Mi}, \alpha, \beta\delta) \quad i = 1,2,\ldots,N \quad (13)$$

and hence

$$-\ln(y_{Mi}) = \mathrm{TL}(x_i, y_i/y_{Mi}, \alpha, \beta\delta) - \ln(D_{Oi}) \quad i = 1,2,\ldots,N \quad (14)$$

The purpose is to obtain values of the parameters of the translog function which ensure that the function fits the observed data 'as closely as possible', while maintaining the requirement that $0 < D_{Oi} \leq 1$, which implies that $-\infty < \ln(D_{Oi}) \leq 0$.

Following Lovell *et al.* (1994) the corrected ordinary least squares (COLS) method can be used[8] to estimate an output distance function. The function is fitted in two steps. The first step involves interpreting the unobservable term '$-\ln(D_{Oi})$' in Equation 14 as a random error term and estimating the translog distance function using OLS. In the second step the OLS estimate of the intercept parameter, α_0, is adjusted (by adding the largest negative OLS residual to it) so that the function no longer passes through the centre of the observed points but bounds them from above. The distance measure for the ith firm is then calculated as the exponent of the (corrected) OLS residual.

Input distance functions

The above discussion considers various methods of fitting a curve in one or more output dimensions. It is important to note that the transformation function can also be fitted from an input perspective. The input distance function may be defined on the input set, $L(y)$, as:

$$D_I(x, y) = \max\{\rho : (x/\rho) \in L(y)\} \quad (19)$$

where the input set $L(y)$ represents the set of all input vectors, $x \in R^K_+$, which can produce the output vector, $y \in R^M_+$. That is,

$$L(y) = \{x \in R^K_+ : x \text{ can produce } y\} \quad (20)$$

$D_I(x, y)$ is nondecreasing, positively linearly homogeneous and concave in x, and increasing in y. The distance function, $D_I(x, y)$, will take a value which is greater than or equal to one if the input vector, x, is an element of the feasible input set, $L(y)$. That is, $D_I(x, y) \geq 1$ if $x \in L(y)$. Furthermore, the distance function will take a value of unity if x is located on the inner boundary of the input set.

A translog *input* distance function is obtained by imposing homogeneity of degree + 1 in inputs (instead of in outputs) upon the transformation function in Equation 5. Thus

$$\begin{aligned}\ln(D_{Ii}/x_{Ki}) = \alpha_0 &+ \sum_{m=1}^{M} \alpha_m \ln y_{mi} \\ &+ \tfrac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M} \alpha_{mn} \ln y_{mi} \ln y_{ni} + \sum_{k=1}^{K-1} \beta_k \ln x^*_{ki} \\ &+ \tfrac{1}{2}\sum_{k=1}^{K-1}\sum_{l-1}^{K-1} \beta_{kl} \ln x^*_{ki} \ln x^*_{li} \\ &+ \sum_{k=1}^{K-1}\sum_{m=1}^{M} \delta_{km} \ln x^*_{ki} \ln y_{mi} \\ & \qquad i = 1,2,\ldots,N \quad (21)\end{aligned}$$

is obtained where $x^*_{ki} = x_{ki}/x_{Ki}$ and D_{Ii} denotes the input-orientated distance measure. Estimation of a translog input distance function by COLS closely follows the approach used for output distance functions. The two main differences are that homogeneity is imposed in the inputs instead of the outputs (as discussed above) and, after OLS estimates are obtained, the OLS estimate of the intercept is adjusted by adding the largest positive residual (instead of the largest negative residual).

[8] This method is described in Greene (1980) for the case of production and cost functions.

III. APPLICATION TO EUROPEAN RAILWAYS

Data

The multioutput/multiinput technology of European railways is estimated using annual data on 17 companies observed over the six-year period from 1988 to 1993. The data are derived from data published by the International Union of Railways (UIC, 1988–1993). The model is defined with two output variables (passengers and freight) and three input variables (labour, rolling stock and lines).[9] The passenger service output and freight service output variables are measured using the sum of distances travelled by each passenger and the sum of distances travelled by each tonne of freight, respectively.

The labour input variable is measured by the annual mean of monthly data on staff levels. These staff measures consider only those staff involved in train services and station services. Staff involved in the maintenance of rolling stock and lines are not included given that some companies subcontract these activities.[10] Rolling stock is measured by the sum of available freight wagons and coach transport capacities in tonnes and seats, respectively. The third input used is the total length of lines.[11] For further detail on the construction of these data refer to Coelli and Perelman (1996).

One of the aims of this study is to assess the impact of measuring technical efficiency relative to a production frontier involving a single aggregate output measure versus using a multiple-output distance function. To this end, two commonly used aggregate output measures are defined. The first is the total revenue of railways transportation obtained by adding the revenues from passenger and freight services together.[12] The second aggregate output measure calculated is a multilateral Tornqvist output index (also known as the CCD index after Caves *et al.*, 1982) which uses revenue shares to weight passenger and freight activities.

Results and discussion

The COLS parameter estimates are presented in Table 1. Results for five different model formulations are presented: (i) a production function with total revenue used as a measure of aggregate output; (ii) a production function with aggregate output constructed using a multilateral Tornqvist index; (iii) an output distance function with separability between inputs and outputs imposed; (iv) an (unrestricted) output distance function; and (v) an input distance function.

First it is observed that the *R*-squared measures[13] and *t*-ratios indicate these estimated models appear to be a reasonable fit to the observed data. All *R*-squared values are in excess of 94% and the *t*-ratios on almost all first-order coefficients and the majority of second-order coefficients exceed 1.96 in absolute value.[14] All first-order terms are also observed to have correct signs, with the exception of the coefficient of *rolling stock* in the first three (restricted) models.[15] It is noted, however, that the *t*-ratios associated with these incorrectly signed coefficients indicate that these coefficients are not significantly different from zero in models 2 and 3, but is significant in model 1 (the revenue model). In fact, the results for the revenue model are noticeably different to the other four sets of results, which as a group appear fairly similar, at least in the first-order terms.

The disparity between the revenue function results and the results obtained from the other specifications is also reflected in the technical efficiency predictions obtained from the various models. The means of these predictions for each rail company for each model and the correlations between the various sets of technical efficiency predictions are presented in Table 2. The most striking result is seen at the bottom of Table 2, where the correlations between the technical efficiency predictions of the revenue model and the other four sets of results range from 0.200 to 0.455, while the correlations among the remaining four sets of results range from 0.636 to 0.961. It is also observed that the mean technical efficiency for the revenue model is 0.595 while the means obtained from the other five models range from 0.783 to 0.878. Thus it is concluded that, assuming that the distance function estimates are closest to the true parameter values, the use of total revenue as a measure of aggregate output in this empirical analysis appears less than satisfactory. This is not a big surprise given that few publicly owned rail organizations set output prices with market conditions or cost recovery notions in mind. Furthermore, issues are further complicated by a variety of government subsidies that are paid to many of these companies.

[9] Information on energy use was not available. It is expected that energy use would be closely correlated with rolling stock and hence its omission is unlikely to introduce serious bias.

[10] For instance, the Swedish railways infrastructure is an independent company (BV).

[11] For a discussion of alternative railways technology specifications, see Cowie and Riddington (1996).

[12] These revenues are obtained by converting the nominal revenue figures to 1980 values using the relevant GDP deflator in each country. These figures are then deflated using OECD PPP GDP deflators to obtain the final revenue values expressed in 1980 ECUs.

[13] The *R*-squared measures are defined as the proportion of the variation in the logs of the radial distances explained by the estimated regression model. See Coelli and Perelman (1996) for details.

[14] All hypothesis tests in this paper are conducted at a 5% level of significance unless otherwise stated.

[15] The first order parameters are interpreted as elasticities because the data have been sealed by the sample means prior to estimation.

Table 1. *Estimated parameters for alternative models* [a,b,c]

			Distance functions		
			Output oriented		
Parameters	Total revenue (1)	Tornqvist output aggregation (2)	Separable (3)	Unrestricted (4)	Input oriented (5)
α_0	−0.360 (3.3)	−0.306 (6.8)	0.210 (5.1)	0.006 (0.2)	−0.061 (1.6)
α_1	–	–	−0.428 (16.2)	−0.528 (25.5)	−0.472 (18.1)
α_2	–	–	*−0.572*	*−0.472*	−0.390 (16.1)
α_{11}	–	–	−0.025 (0.4)	−0.378 (6.3)	−0.279 (4.5)
α_{22}	–	–	*−0.025*	*−0.378*	−0.311 (3.8)
α_{12}	–	–	*0.025*	*0.378*	0.293 (4.0)
β_1	1.225 (11.3)	0.934 (21.1)	0.872 (19.7)	0.592 (14.6)	0.543 (13.5)
β_2	−0.442 (4.0)	−0.088 (1.9)	−0.037 (0.8)	0.180 (4.9)	0.145 (3.5)
β_3	0.502 (6.0)	0.408 (12.1)	0.408 (13.6)	0.358 (14.3)	*0.312*
β_{11}	0.425 (0.5)	2.084 (6.2)	1.425 (3.9)	−0.708 (2.2)	0.216 (0.6)
β_{22}	0.689 (1.1)	0.885 (3.4)	0.470 (1.8)	−1.030 (3.8)	−0.558 (1.7)
β_{33}	1.819 (5.8)	1.367 (10.8)	1.226 (9.0)	0.738 (6.5)	*0.614*
β_{12}	−0.042 (0.1)	−1.136 (4.3)	−0.649 (2.3)	0.981 (3.6)	0.478 (1.5)
β_{13}	−0.886 (3.0)	−1.267 (10.4)	−1.155 (9.9)	−0.617 (4.9)	*−0.694*
β_{23}	0.499 (2.1)	0.251 (2.5)	0.239 (2.5)	0.135 (1.6)	*0.080*
δ_{11}	–	–	–	−0.693 (9.7)	−0.619 (6.4)
δ_{12}	–	–	–	*0.693*	0.409 (4.2)
δ_{21}	–	–	–	0.542 (6.2)	0.444 (4.1)
δ_{22}	–	–	–	*−0.542*	−0.414 (4.1)
δ_{31}	–	–	–	0.184 (3.1)	*0.175*
δ_{32}	–	–	–	*−0.184*	*0.005*
LLF	23.8	67.8	85.5	127.0	120.9
R^2	0.949	0.991	0.973	0.990	0.990
$\max(\varepsilon)$	0.980	0.335	0.298	0.234	0.298
σ^2	0.104	0.012	0.012	0.006	0.006

Notes: [a] T-tests are presented in parentheses. [b] All output distance functions parameters have been multiplied by −1 in order to be comparable with the other results. [c] Italic parameters are calculated by homogeneity conditions.

The production function results obtained using the multilateral Tornqvist index appear to be better than the revenue model results. The parameter estimates have the expected signs (or are insignificant) and are much closer to the distance function estimates and the correlations between the technical efficiency predictions are positive and mostly of the order of 0.6 or more. The improved performance is probably due to a number of factors. First, the Tornqvist index relies upon revenue shares rather than actual price levels and hence will be less susceptible to intercountry price differentials as long as any differentials or subsidies are fairly evenly distributed across the two output groups. A second possible reason for a better performance is that the (deflated) revenue measure may be interpreted as an implicit quantity index and hence that if the price index used in deflation is a Laspeyres or Paasche index then the implicit technology is a linear technology. The Tornqvist index, on the other hand, is a superlative index because it is exact for the translog form which is a flexible functional form (i.e., a second order approximation to an arbitrary functional form) and hence is likely to provide a better measure of aggregate output.

The output distance function results presented in column 4 of Table 1 appear well behaved and well estimated. The second-order output cross-product term, α_{12}, has the correct sign so as to *encourage* the transformation curve to have a concave shape (rather than the convex Cobb–Douglas shape that would result if this term was zero). It is also observed that the first-order input coefficients sum to a value greater than one indicating the presence of increasing returns to scale at the mean. This observation conforms with results obtained in the majority of empirical railways analyses.

Separability restricted output distance function results are also presented in column 3 of Table 1 for comparative purposes. This model is included because it was noted that the Tornqvist production function differs from the output distance function in two respects: (i) it is separable and (ii) output aggregation is achieved using revenue share information rather than by estimated coefficients. The separability restricted function is estimated in an attempt to shed some light on the relative importance of these two factors. It is observed that the separability restricted distance function results appear to be more similar to the Tornqvist

Table 2. *Technical efficiency for alternative models (average scores for the period 1988–1993[a])*

Railways	Country	Total revenue (1)	Tornqvist output aggregation (2)	Distance functions: Output oriented: Separable (3)	Distance functions: Output oriented: Unrestricted (4)	Distance functions: Input oriented (5)
BR	United Kingdom	0.899 [1]	0.798 [6]	0.841 [5]	0.916 [2]	0.879 [5]
CFF	Switzerland	0.589 [8]	0.734 [14]	0.781 [12]	0.879 [9]	0.895 [2]
CFL	Luxembourg	0.565 [9]	0.789 [8]	0.804 [8]	0.876 [10]	0.861 [10]
CH	Greece	0.530 [11]	0.653 [17]	0.719 [15]	0.862 [12]	0.855 [11]
CIE	Ireland	0.800 [2]	0.749 [2]	0.769 [13]	0.900 [4]	0.881 [4]
CP	Portugal	0.271 [17]	0.776 [10]	0.786 [11]	0.831 [16]	0.802 [16]
DB	Germany	0.629 [7]	0.800 [5]	0.824 [6]	0.880 [8]	0.868 [8]
DSB	Denmark	0.670 [6]	0.751 [11]	0.796 [9]	0.821 [17]	0.826 [15]
FS	Italy	0.414 [16]	0.790 [7]	0.791 [10]	0.839 [15]	0.784 [17]
NS	Netherlands	0.672 [5]	0.942 [1]	0.943 [1]	0.976 [1]	0.980 [1]
NSB	Norway	0.430 [15]	0.877 [3]	0.897 [2]	0.885 [7]	0.879 [5]
OBB	Austria	0.794 [3]	0.723 [15]	0.718 [16]	0.904 [3]	0.864 [9]
RENFE	Spain	0.504 [14]	0.738 [13]	0.753 [14]	0.861 [13]	0.843 [13]
SJ	Sweden	0.546 [10]	0.682 [16]	0.728 [17]	0.843 [14]	0.834 [14]
SNCB	Belgium	0.512 [12]	0.807 [4]	0.843 [4]	0.865 [11]	0.850 [12]
SNCF	France	0.505 [13]	0.777 [9]	0.814 [7]	0.890 [6]	0.893 [3]
VR	Finland	0.789 [4]	0.926 [2]	0.882 [3]	0.900 [4]	0.877 [7]
	Mean	0.595	0.783	0.805	0.878	0.863
		Correlation table				
(1) Total revenue		1.000	0.215	0.200	0.455	0.421
(2) Tornqvist output aggregation			1.000	0.961	0.636	0.646
Distance functions						
(3) Output oriented − Separable				1.000	0.669	0.694
(4) Output oriented − Unrestricted					1.000	0.921
(5) Input oriented						1.000

Note: [a] Ranks appear in brackets.

production function than they are to the unrestricted output distance function. This is apparent in the estimated parameters, the mean technical efficiency levels and in the correlations between the technical efficiencies. Thus, it appears that, in this instance, the separability assumption is the principle factor that is driving the differences between the Tornqvist model and the output distance function. This conclusion is supported by the observation that the null hypothesis of separability is rejected by a generalized likelihood-ratio test at a 1% level of significance.

This conclusion has important implications for the use of the Tornqvist index in constructing an aggregate output measure for use in a single-output production function when modelling multioutput production technologies. It suggests that even if one is able to obtain accurate measures of revenue shares, and even if these shares provide a good indication of the shape of the production possibility curve, the single-output production function may still fall down because of the implicit assumption of separability (between the input and output functions). The application in this paper indicates quite clearly that this separability assumption can have a significant influence upon both parameter estimates and technical efficiency scores.

The final set of parameter estimates presented in Table 1 are for an input distance function (column 5). The input distance function results are included partly for comparative purposes but also because one could argue that an input orientation may be more appropriate in railways because the managers are likely to have more discretionary control over inputs rather than outputs.[16] This argument for endogenous input quantities and exogenous output quantities has been presented by a number of authors to justify the use of dual cost functions in investigating multi-output railways industries.

The input distance function results are reassuringly similar to the output distance function results. The first-order

[16] Recall that the main reason the study began with the output orientation was because it was a natural progression from a single output production function.

Table 3. *Productivity change in European railways from 1978–1983 to 1988–1993*

Railways	Country[a]	Index numbers: Efficiency change	Technical change	TFP change	Input changes (%): Staff	Rolling stock	Lines
BR	United Kingdom (1973)	1.458	0.954	1.392	−32.4	−50.4	−5.2
CFF	Switzerland	1.300	0.991	1.289	−3.7	−2.2	2.6
CFL	Luxembourg (1952)	1.268	1.048	1.329	−17.2	−12.5	1.0
CH	Greece (1981)	1.257	0.660	0.830	17.8	11.6	0.9
CIE	Ireland (1973)	1.329	0.936	1.245	−15.6	−29.8	−1.5
CP	Portugal (1986)	1.273	0.927	1.180	7.9	2.3	−12.3
DB	Germany (1952)	1.252	0.942	1.179	−26.1	−14.9	−5.1
DSB	Denmark (1973)	1.391	0.998	1.388	−6.6	−23.1	12.9
FS	Italy (1952)	1.238	0.975	1.207	−18.0	5.4	−2.5
NS	Netherlands (1952)	1.069	1.047	1.120	8.0	−15.7	−3.2
NSB	Norway	1.246	0.843	1.051	−33.9	−7.4	−4.4
OBB	Austria (1995)	1.312	0.924	1.212	−10.4	8.6	−2.7
RENFE	Spain (1986)	1.314	0.821	1.078	−18.6	−0.1	−5.9
SJ	Sweden (1995)	1.281	0.797	1.021	−26.7	−35.5	−6.6
SNCB	Belgium (1952)	1.326	0.984	1.304	−22.2	−16.1	−18.5
SNCF	France (1952)	1.255	0.813	1.021	−18.9	−28.1	−2.6
VR	Finland (1995)	1.336	0.863	1.154	−44.4	−12.6	−3.2
	Mean	1.286	0.907	1.167	−15.3	−13.0	−3.3

Note: [a] The year that the country joined the European Union is indicated in parentheses.

parameters do not differ greatly, other than by the expected degree due to the imposition of the homogeneity constraint upon the inputs instead of the outputs. The sum of the first-order output coefficients is less than one in absolute value, indicating the presence of increasing returns to scale. The mean technical efficiency, reported in Table 2, is 0.863. This is only marginally smaller than the output-orientated mean (0.878).[17] Finally a value of 0.921 is reported in Table 2 for the correlation between the technical efficiency predictions from the two models. Thus, all indicators suggest that the choice of orientation is not terribly crucial in this particular industry, especially if one's primary interest is in performance measurement.

Preferred results

Finally, we must address the question of which of our various sets of results do we wish to identify as our preferred results for the purpose of discussing the relative performance of European railways. The (unrestricted) input distance function is selected as the preferred estimates following a process of elimination. The production function estimates are rejected because they involve output aggregation. The separability-restricted model is rejected on the basis of the likelihood ratio test. Finally the input distance function is selected over the output distance function because it is believed that, over recent decades, it would have been easier for a railway to change the usage of input factors than to alter their market share.[18]

The technical efficiency predictions for the input distance function are tabulated in column 5 of Table 2. A mean technical efficiency level of 0.863 and mean values for individual companies that range from 0.784 for Italy to 0.980 for The Netherlands are observed. When these results are compared with past studies (e.g., Perelman and Pestieau, 1988), similar efficiency rankings are noted amongst the firms, but it is also observed that there has been a substantial increase in average technical efficiency, relative to these past studies. However, given that past studies have used a variety of data definitions and estimation techniques, it cannot be confidently concluded that a large amount of catch-up has actually occurred. Hence, it was decided to repeat the analysis using data from an earlier period.

Productivity change

An input-oriented distance function was estimated for the six-year period 1978–1983, using exactly the same variable definitions and companies as for the period 1988–1993. Then the methods described in Chapter 10 of Coelli *et al.* (1998) were applied to calculate (average) efficiency change, technical change and total factor productivity (TFP) change between these two periods. The results presented in Table 3 confirm the existence of significant catching-up

[17] One would expect input-orientated technical efficiencies to be smaller when the technology exhibits increasing returns to scale.
[18] From 1980 to 1994 the market share of rail transportation decreased from 24.9% to 15.9% in the European Union.

and productivity growth in European railways. Average TFP growth was 16.7% over this period. Results ranged from a 17% decline in Greece (the only country to experience a TFP decline) to an impressive 39.2% rise in TFP in the UK.

Most of this TFP growth appears to be due to cuts in input usage (as opposed to output growth or technological advance). The last three columns of Table 3 list the cuts instituted by almost all companies in staff, rolling stock and lines during the 1980s. These reductions have been primarily driven by the tighter budgetary constraints imposed upon European public enterprises over the last two decades.

As public enterprises, European railways have been required to pursue objectives other than profit maximization and cost minimization. Traditionally, these social objectives were used to justify government subsidies. However, in the 1970s this policy began to be strongly questioned, both by the national authorities themselves (because of budgetary constraints) and also by the European Union, because of concerns that the subsidies may distort market competition with other transportation modes. Hence, successive European Commission regulations, which have regulated government financial support to national railways companies, have played a major role in improving the performance of European railways.[19]

4. CONCLUSIONS

A key conclusion of this paper is that the use of total revenue as a measure of aggregate output in an empirical analysis of European railways, even after careful deflation, appears fraught with danger. This is not a terribly surprising result given that few publicly owned rail organizations set output prices with market conditions or cost recovery notions in mind. The analysis does suggest that the multilateral Tornqvist index may be a more suitable method of aggregating output. However, having said this, it is apparent that there are still substantial differences between the Tornqvist results and the output distance function results. It was hypothesized that these differences are most likely due to the combined effects of (i) the separability restriction, and (ii) the fact that output aggregation is achieved using revenue share information rather than by estimated coefficients. A separability restricted output distance function is used to attempt to shed some light on the relative importance of these two factors. The results obtained clearly indicate that (in this instance) the separability assumption is the principal contributing factor. This conclusion has important implications. It suggests that even if one is able to obtain accurate measures of revenue shares, and even if these shares provide a good indication of the shape of the production possibility curve, the single-output production function (involving an aggregate Tornqvist output measure) may still be suboptimal because of the implicit separability assumption.

Finally, the results indicate that, the technical efficiencies of European railways differ substantially from country to country. The technical efficiency levels range from 0.784 for Italy to 0.980 for the Netherlands, with a mean technical efficiency level of 0.863 across the sample. Furthermore, it is noted that a significant improvement has occurred in the performance of European railways during the 1980s. All 17 countries (with the exception of Greece) experienced TFP growth. Average TFP growth was 16.7% over this period, with the UK recording the strongest TFP growth of 39.2%. This improved performance in European railways was primarily driven by substantial cuts in labour usage and rolling stock, which were most likely a consequence of stricter government budgetary restrictions, combined with the influence of European Commission regulations placing constraints upon the level of government subsidies.

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[19] See for instance the European Communities Council decision of 20 May 1975 (75/327/CEE) 'on the improvement of the situation of railways undertakings and the harmonization of rules governing financial relations between such undertakings and States' (Official Journal of the European Communities, No. L 152/3).

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