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European Railway Deregulation: The Influence of Regulatory and Environmental Conditions on Efficiency

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Abstract

The objective of this paper is to analyze the impact of regulatory and environmental conditions on technical efficiency of European railways. Using a panel data set of 31 railway firms from 22 European countries from 1994 to 2005, a multi-output distance function model, including regulatory and environmental factors, is estimated using stochastic frontier analysis. The results obtained indicate positive and negative efficiency effects of different regulatory reforms. Furthermore, estimating models with and without regulatory and environmental factors clearly indicates that the omission of environmental factors, such as network density, substantially changes parameter estimates and, hence, leads to biased estimation results.

Keywords: European railways, technical efficiency, stochastic frontier analysis

JEL-Classification: L92, L51, L22

1 Introduction

Since the early 1990s, the European railway sector has undergone a major restructuring and deregulation process. Arguments for the reforms have included the high subsidy requirements and the falling market share of the sector compared to other modes of transportation and the need for an efficient integrated railway system throughout Europe to facilitate open cross-border freight traffic within the single European market. In order to promote competition and improve efficiency, the restructuring and deregulation process has focused on market liberalization by granting non-discriminatory access to the

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European railway network. The reforms have been concentrated primarily on separating infrastructure management from transport operations and defining and ensuring access rights to the national railway markets by third parties.

The majority of European countries have implemented some kind of reform in the railway sector, although these reforms differ broadly in terms of their dates of implementation and their degrees. For example, Sweden restructured its railways in the mid-1980s, whereas Italy did not open the sector until 1999. All European countries except Estonia have separated infrastructure and transport operations accounting, and some countries, like Germany and Italy, have implemented an organizational separation by establishing subsidiary companies for infrastructure and transport operations within a holding structure. The UK, Sweden and other countries went even further, creating a complete institutional separation, with one firm owning the infrastructure and providing network access to competitive transportation firms for transport operations. Finally, a few countries, including France and the Czech Republic, chose a mixed structure of organizational and institutional separation by establishing separate entities but with strong monetary and operational connections.

Considering regulation of access by third parties, the situation is even more complex. While some countries have implemented access rights strictly according to the European legislation, others have established separate national reforms, opening their rail freight and rail passenger markets further for domestic and international railway undertakings. For example, Sweden, the UK and Germany not only introduced open access arrangements years in advance of the European legislation, but they also defined more comprehensive access rights than those stipulated by the EC Directives.

In addition to these regulatory factors, European railway firms are also influenced by environmental factors such as population density, the economic situation and network density. For example, in Spain, gross domestic product per capita in 2005 (measured in year-2000 US dollars and using purchasing power parities) was nearly two times higher than that of Poland. Expecting that higher income per capita increases demands for freight as well as passenger transport, rail services in Spain should be positively influenced by this environmental factor.

Several studies on the efficiency of European railways have been performed (for example, Oum and Yu 1994, Cowie and Riddington 1996, Coelli and Perelman 2000, Cantos and Maudos 2000, Cantos et al. 2002), but to our knowledge, only three focused on the impact of European railway deregulation on rail efficiency since 1990.

In a 1999 paper Cantos et al. used a panel of 17 European state-owned railways covering the years 1970-95 to evaluate productivity changes in the European railway industry. The results, which were obtained by using a non-parametric approach (data envelopment analysis), indicated a significant increase in efficiency, mainly based on technical progress between 1985 and 1995. Further, when the study incorporated measures of autonomy and financial independence from the government, the analysis showed higher efficiency values and technical change for railway firms with a greater degree of governmental independence.

A study on European railways by Friebel et al. (2005) investigated the impact of policy reforms on 12 European national railway firms. Applying a production frontier model, they compared passenger traffic efficiency for the period 1980-2003, during which most of the European railway markets were reformed. The authors found that the gradual implementation of reforms improved efficiency, whereas multiple reforms implemented simultaneously had, at best, neutral effects. Controlling for the effect of separation, the results revealed no significant difference in efficiency between fully integrated companies and organizationally separated firms.

Driessen et al. (2006) used a comparable data set of 13 European national railway firms covering the years 1990-2001 to investigate the impact of competition on productive efficiency in European railways. The authors applied a two-stage data envelopment analysis (DEA) approach, wherein the first-stage DEA efficiency values were regressed upon several country-specific institutional factors, including separation of infrastructure from operations, third party access rights, competitive tendering and managerial independence from the government. The results showed a positive influence on efficiency of competitive tendering, a negative influence of third-party access rights and a negative influence of managerial independence. No unambiguous effect was found for the influence of separation on efficiency. Driessen et al.'s results for third-party access and managerial independence were in conflict with the findings of other studies (for example, Friebel et al. 2005, Gathon and Pestieau 1995); the authors suggested this difference may have been caused by differences in the data, varying variable definitions or the estimation methodology used.

Overall, extant research on the impact of regulatory reforms on European railway efficiency is rare and many of its findings remain ambiguous. Therefore, in order to investigate the influence of regulatory conditions on the efficiency of European railways, we apply stochastic frontier analysis (SFA) and estimate technical efficiency of a sample of railway companies from 22 European countries for the period 1994-2005. Specifying a multi-output distance function panel model, including regulatory and other country- and firm-specific variables, along with a time trend, we compare efficiency across countries and changes in efficiency over time.

The outline for the remainder of this paper is as follows. Section 2 provides an overview on the European railway deregulation and presents theoretical foundations of the relationship between efficiency and regulatory reforms. The methodology is discussed in Section 3. Section 4 introduces the modeling approach and describes the data. Estimation results are presented in Section 5. Section 6 summarizes, concludes and highlights directions for further research.

2 European Railway Deregulation and Efficiency

Since the beginning of railway transport in Europe in the first half of the 19th century, railways have been regarded as an important strategic resource for military actions and national economic development. Each European country established its own national railway system without considering inter-country connections. Hence, until the beginning of the European liberalization process in the early 1990s, the European railway sector was characterized by state-owned monopoly railway companies without an integrated cross-border railway system. Compared to other transportation modes, like road or inland waterways transport, this country-based system was not able to meet the increasing transportation needs of a single European market, much less the transportation needs of a world-wide trade system.

Table 1 shows the development of the modal split for passenger transport and freight transport in the EU-15 countries from 1970 to 2000. Within the passenger transport sector, passenger cars played by far the most important role. While from 1970 to 1995 the modal split for passenger cars increased by more than 8% from 73.4% to 79.5%, the modal split for rail declined by more than 40%, from 10.4% to 6.2%. For buses and coaches, as well as tram and metro, the modal split decreased by 32.8% and 42.1%, respectively. In contrast, air passenger transport increased 187.5% in modal split. In 2000, the 5.8% modal split for air passenger transport nearly reached the modal split for rail of 6.2%.

In the freight transport sector, the decrease in rail transport is even more significant than in the passenger transport sector. From 1970 to 1995, the modal split of rail transport decreased by almost 58%, from 20.1% to 8.2%. Within the same period, the modal split of the other two major players, road and sea transport, increased by 24.3% and 22.5%, respectively. By 2000, these two forms of transport already provided transport equalling more than 80% of the total freight transport.

Altogether, before liberalization began in the industry in the early 1990s, the modal split for rail significantly decreased for both the passenger and freight transport sector. From 1995 to 2000, the development stabilized with no change in modal split for rail in the passenger transport sector and only a slight decrease in modal split for rail (3.5%) in the freight transport sector.

As a result of rail's decreasing share of the transport market, the European Commission adopted Directive 91/440/EEC in 1991 to deal with the development of the Community's railways. This was the beginning of the ongoing, step-by-step liberalization process in European railways. Table 2 represents the regulatory framework and chronological sequence in detail. The primary elements of the reforms have been:

- separation of infrastructure management from transport operations,
- implementation of interoperability among the national railway systems,

Table 1: Passenger and freight transport - modal split for EU–15 (in %) [a]

	Passenger transport					Freight transport				
	Pass. cars	Rail	Buses & Coaches	Tram & Metro	Air	Road	Rail	Inland water-ways	Pipe-lines (Oil)	Sea (intra-EU)
1970	73.4	10.4	12.8	1.9	1.6	34.6	20.1	7.3	4.5	33.5
1980	75.9	8.4	11.8	1.4	2.5	36.3	14.6	5.3	4.3	39.4
1990	78.6	6.8	9.4	1.2	4.0	41.8	10.9	4.6	3.1	39.6
1995	79.5	6.2	8.6	1.1	4.6	43.0	8.5	4.4	3.1	41.0
2000	78.6	6.2	8.3	1.1	5.8	43.2	8.2	4.2	2.8	41.7
1970–1980	3.4	−19.2	−7.8	−26.3	56.3	4.9	−27.4	−27.4	−4.4	17.6
1980–1990	3.6	−19.0	−20.3	−14.3	60.0	15.2	−25.3	−13.2	−27.9	0.5
1990–1995	1.1	−8.8	−8.5	−8.3	15.0	2.9	−22.0	−4.3	0.0	3.5
1995–2000	−1.1	0.0	−3.5	0.0	26.1	0.2	−3.5	−4.5	−9.7	1.7
1970–1995	8.3	−40.4	−32.8	−42.1	187.5	24.3	−57.7	−39.7	−31.1	22.5

[a] Based on passenger-km for passenger transport and tonne-km for freight transport.
Source: European Commission, Directorate-General for Energy and Transport (2007, 2003).

- assurance of third party access to the infrastructure, and
- introduction of independent railway regulatory systems.

Overall, the intention of the reforms has been to provide transport operators non-discriminatory access to the infrastructure and to enhance competition. More competition is expected, in turn, to increase efficiency and demand for railway services.

However, the positive or negative impact of the individual reforms – particularly vertical separation and institutional separation – on efficiency is not clear-cut. On one hand, vertical separation promotes cost transparency, which prevents cross-subsidization and reduces information asymmetries between infrastructure and transport operations (Di Pietrantonio and Pelkmans 2004)), thereby reducing the potential for the infrastructure's management to discriminate against competitive transportation firms and enhancing competition and efficiency. On the other hand, a potential loss of economies of scope between infrastructure and transport operations could eliminate the beneficial effect of increasing competition and could lead to decreased efficiency.

Third party access rights, expected to increase both competition and efficiency, may also cause a loss of traffic density economies and an increase in coordination costs. This is particularly true for the passenger transport sector, where economies from traffic density are highly relevant and where detailed traffic coordination is needed for scheduled services. Moreover, the impact on efficiency of access rights for international services relies on the interoperability among the national railway systems; a low degree of interoperability increases coordination costs and reduces efficiency. Thus, whether third party access rights increase or decrease railway efficiency depends on the relationship of coordination costs to revenues from more competition (Di Pietrantonio and Pelkmans 2004).

Finally, the impact of regulatory reforms on efficiency relies on their enforcement. If deregulation has an overall positive impact on efficiency, and if there is an independent regulatory body to monitor the day-to-day implementation, the influence on efficiency should be positive.

Irrespective of the regulatory reforms' uncertain impact, efficiency may also be affected by environmental factors. The national railway systems in Europe vary broadly in size and key activities, so a specific reform's positive impact on efficiency in one country does not necessarily point to the same impact in another country. Firm-specific and country-specific influences on efficiency have to be considered.

For example, a primary factor characterizing railway networks is network density (network length in km per square area km). The impact of network density on efficiency is not necessarily clear. A higher network density could lead to a higher demand for railway services – particularly passenger services – because of better accessibility and more transport options, which would positively influence efficiency, but a higher network density could also increase coordination and maintenance costs of the network, leading to a negative impact on efficiency.

A second factor is the percentage of electrified lines in the total network length, which can be interpreted as a quality indicator. Compared to diesel traction, electric traction permits higher train speed, which reduces journey time and increases train frequency. The significant increase in passenger numbers that generally occurs after electrification – the so-called "sparks effect" – suggests that electric trains are valued more than diesel trains (e.g. Newman and Kenworthy 1999, Hensher et al. 1995). Thus, a greater percentage of electrified lines is likely to positively influence efficiency.

In order to control for varying income and population structures among the countries, a cross-country efficiency analysis should also incorporated gross domestic product per capita and population density. Since a higher income raises freight and passenger transportation needs, gross domestic product per capita can be expected to have a positive impact on efficiency. On first glance, a similar impact could be assumed for a higher population density, but considering the higher costs for passenger transport compared to freight transport and a presumably higher amount of public-service obligations within a populous country, population density might also have a negative impact on efficiency.

Finally, economic differences among Western and Eastern European countries and the relatively short duration of EU membership among Eastern European countries (since 2004) should be accounted for as well. Assuming that Eastern European countries have lower economic and technological development, they can be expected to have lower efficiency.

Table 2: European Railway Deregulation

Date	Description	Content
07/1991	Directive 91/440/EEC on the development of the Community's railways (transposition deadline 01/1993)	Management independence of railway undertakings; accounting separation between infrastructure management and transport operations; improvement of the financial situation of railway undertakings; access to the railway infrastructure for railway undertakings providing international combined goods transport and for international groupings providing international services between the states in which they are establish (Article 10)
06/1995	Directive 95/18/EC on the licensing of railway undertakings (transposition deadline 06/1997)	Criteria applicable to the issue, renewal or amendment of licences of railway undertakings when they provide the services referred to in Article 10 of Directive 91/440/EEC
	Directive 95/19/EC on the allocation of railway infrastructure capacity and the charging of infrastructure fees (transposition deadline 06/1997)	Principles and procedures to be applied with regard to the allocation of railway infrastructure capacity and the charging of infrastructure fees for railway undertakings when they provide the services referred to in Article 10 of Directive 91/440/EEC
07/1996	Directive 96/48/EC on the interoperability of the trans-European high-speed rail system (transposition deadline 04/1999)	Establishing the interoperability of the trans-European high-speed rail system in terms of its construction, design, service and operation
First Railway Package		
02/2001	Directive 2001/12/EC amending Directive 91/440/EEC (transposition deadline 03/2003)	Extension of access rights to international rail freight services on the Trans European Rail Freight Network (TERFN); independent organizational entities for transport operations and infrastructure management (organizational separation); assignment of essential functions such as rail path allocation, licensing and infrastructure charging to bodies or firms that do not themselves provide any rail transport services; accounting separation between passenger and freight transport services
	Directive 2001/13/EC amending Directive 95/18/EC (transposition deadline 03/2003)	Validity of licences throughout the whole EU; notification of the Commission of all issued licences; requirement of a safety certificate for the rolling stock and staff for operators as well as the attribution of train paths

Table 2: continued

Date	Description	Content
	Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification (replaced Directive 95/19/EC) (transposition deadline 03/2003)	Framework for the allocation and charging of capacity; publication of a network statement by infrastructure managers with information on the network, access conditions, capacity allocation and tariff structure; establishment of independent regulatory bodies
03/2001	Directive 2001/16/EC on the interoperability of the trans-European conventional rail system (transposition deadline 04/2003)	Establishing the interoperability of the trans-European conventional rail system in terms of its construction, design, operation etc.; closely linked to Directive 96/48 EC
	Second Railway Package	
04/2004	Regulation (EC) No 881/2004 establishing a European Railway Agency (Agency Regulation)	The agency´s primary task is to reinforce safety and interoperability of railways throughout Europe
	Directive 2004/49/EC on safety on the Community's railways and amending Directive 95/18/EC and Directive 2001/14/EC (transposition deadline 04/2005)	Common safety targets and common safety methods throughout the Member states; common principles for the management, regulation and supervision of railway safety; establishment of a safety authority and an accident and incident investigating body in every Member State (Railway Safety Directive)
	Directive 2004/50/EC amending Directive 96/48/EC and Directive 2001/16/EC (transposition deadline 04/2005)	Conditions for the interoperability of the trans-European high-speed rail system in terms of the design, construction, placing in service, upgrading, renewal, operation and maintenance, as well as qualifications, health and safety conditions of the staff who contribute to its operation
	Directive 2004/51/EC amending Directive 91/440/EEC (transposition deadline 12/2005)	Extension of access rights to international rail freight services on the whole network as from 01/2006; extension of access rights to all kinds of rail freight services as from 01/2007
	Third Railway Package	
10/2007	Regulation (EC) No 1371/2007 on rail passengers' rights and obligations	Minimum quality standards for rail passenger services
	Directive 2007/58/EC amending Directive 91/440/EEC and Directive 2001/14/EC (transposition deadline 06/2009)	Introduction of open access rights for international rail passenger services as from 01/2010
	Directive 2007/59/EC on the certification of train drivers operating locomotives and trains on the railway system in the Community (transposition deadline 12/2009)	Introduction of a European train driver license

Source: Holvard (2006), European Union (2007).

3 Methodology

To model the production technology of railway undertakings, we apply an input-oriented distance function. Compared to other representations of technologies, such as cost or revenue functions, the distance function approach has the advantage of permitting both multiple inputs and multiple outputs. Further, it requires no specific behavior assumption, such as cost minimization or profit maximization which, in the case of the mainly state-owned and highly regulated European railway industry, is likely to be violated (Coelli and Perelman 2000).

Distance functions can be differentiated into those that are input-oriented and those that are output-oriented. Depending on whether the input set or the output set is assumed to be determined by exogenous factors, the output or the input orientation is appropriate. In this study, the input-orientation is favored over an output-orientation because we assume that railway undertakings have a higher influence on the usage of inputs compared to the outputs. This assumption is supported by the substantial proportion of state-controlled public transport requirements within railway passenger transportation and by the decreasing market share of rail transportation within both the passenger and freight transport sector over the last decades (Coelli and Perelman 2000).[1]

By modeling a production technology as an input distance function, one can investigate how much the input vector can be proportionally reduced holding the output vector fixed. Assuming that the technology satisfies the standard properties of economic theory (see, e.g., Färe and Primont 1995) the distance function can be defined as:

$$D_I(x, y) = \max\{\theta : (x/\theta) \in L(y)\}, \quad (1)$$

where the input set $L(y)$ represents the set of all input vectors x that can produce the output vector y, and θ measures the proportional reduction of the input vector x . The function is non-decreasing, linearly homogeneous and concave in x, and non-increasing in y (Coelli et al. 2005). From $x \in L(y)$ follows $D_I(x, y) \geq 1$. A value equal to unity identifies the respective firm as being fully efficient and located on the frontier of the input set. Values greater than unity belong to input sets above the frontier indicating inefficient firms.

To estimate the input distance function we adopt a translog (transcendental-logarithmic) function form. Unlike a Cobb-Douglas form, which assumes the same production elasticities, the same scale elasticities, and a substitution elasticity equal to unity for all firms, the translog does not impose such restrictions and, hence, is more flexible (Coelli et al. 2005).

[1] Estimating both an input- and an output-oriented distance function for European railways, Coelli and Perelman (2000) found similar results for both orientations and concluded that the choice of orientation in this industry is not as important for efficiency measurement as it is in other industries.

Following Coelli and Perelman (1999, 2000) the translog input distance function may be defined as

$$
\begin{aligned}
ln\, D_{it}^{I} \;=\; & \alpha_0 + \sum_{m=1}^{M} \alpha_m \, ln\, y_{mit} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M} \alpha_{mn}\, ln\, y_{mit}\, ln\, y_{nit} + \sum_{k=1}^{K} \beta_k \, ln\, x_{kit} \\
& + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl}\, ln\, x_{kit}\, ln\, x_{lit} + \sum_{k=1}^{K}\sum_{m=1}^{M} \theta_{km}\, ln\, x_{kit}\, ln\, y_{mit} \qquad (2) \\
& + \phi_t\, t + \frac{1}{2}\phi_{tt}\, t^2 + \sum_{m=1}^{M} \psi_{mt}\, ln\, y_{mit}\, t + \sum_{k=1}^{K} \lambda_{kt}\, ln\, x_{kit}\, t,
\end{aligned}
$$

where D_{it}^{I} is the input distance term; $i = 1, 2, ..., I$ denotes firms; $t = 1, 2, ..., T$ is a time trend; x_{kit} and y_{mit} denote the k-th ($k = 1, 2, ..., K$) input quantity and m-th ($m = 1, 2, ..., M$) output quantity, respectively; and $\alpha, \beta, \theta, \phi$ and ψ are unknown parameters to be estimated.

In accordance with economic theory the input distance function must be symmetric and homogenous of degree +1 in inputs. Symmetry requires the restrictions

$$\alpha_{mn} = \alpha_{nm}, \quad (m, n = 1, 2, ..., M) \quad \text{and} \quad \beta_{kl} = \beta_{lk}, \quad (k, l = 1, 2, ..., K,), \qquad (3)$$

and homogeneity of degree +1 in inputs is given if

$$\sum_{k=1}^{K} \beta_k = 1, \quad \sum_{l=1}^{K} \beta_{kl} = 0, \quad \sum_{k=1}^{K} \theta_{km} = 0 \quad \text{and} \quad \sum_{k=1}^{K} \lambda_{kt} = 0. \qquad (4)$$

In order to estimate technical efficiency and the influence of regulatory and environmental conditions, we apply stochastic frontier analysis (SFA), a method simultaneously introduced by Aigner et al. (1977) and Meeusen and van den Broeck (1977). SFA is a parametric method which estimates a production function with a "composed error term" that includes a standard error term v_{it}, accounting for measurement errors and other random factors, as well as a non-negative random error term u_{it}, representing technical inefficiency. Contrarily to models, which incorporate only one error term and, hence, account firm-specific deviations from the best practice frontier to technical inefficiency only, SFA decomposes the deviations into two parts: firm-specific technical inefficiency and random noise.

By imposing the restrictions above by normalizing the translog input distance function by one of the inputs (Lovell et al. 1994) one can write the stochastic frontier production model as

$$\begin{aligned} -\, ln\, x_{Kit} \;\; = \;\; & \alpha_0 + \sum_{m=1}^{M} \alpha_m \, ln\, y_{mit} + \frac{1}{2} \sum_{m=1}^{M} \sum_{n=1}^{M} \alpha_{mn} \, ln\, y_{mit} \, ln\, y_{nit} + \sum_{k=1}^{K-1} \beta_k \, ln\, x^*_{kit} \\ & + \frac{1}{2} \sum_{k=1}^{K-1} \sum_{l=1}^{K-1} \beta_{kl} \, ln\, x^*_{kit} \, ln\, x^*_{lit} + \sum_{k=1}^{K-1} \sum_{m=1}^{M} \theta_{km} \, ln\, x^*_{kit} \, ln\, y_{mit} \\ & + \phi_t \, t + \frac{1}{2} \phi_{tt} \, t^2 + \sum_{n=1}^{M} \psi_{mt} \, ln\, y_{mit} \, t + \sum_{k=1}^{K-1} \lambda_{kt} \, ln\, x^*_{kit} \, t - ln\, D^I_{it}, \end{aligned} \tag{5}$$

where $x^*_{kit} = (x_{kit}/x_{Kit})$. Replacing the distance term $-ln\, D^I_{it}$ with a composed error term $v_{it} - u_{it}$ yields a standard SFA distance function model. The standard random error term v_{it} is assumed to be distributed independent of u_{it} as $i.i.d.\ N(0, \sigma_v^2)$. For the non-negative technical inefficiency term u_{it}, we assume a truncated normal distribution $N^+(\mu, \sigma_u^2)$, as suggested by Stevenson (1980).

To investigate the influence of regulatory and environmental conditions on efficiency, we follow the model specification of Battese and Coelli (1995). This one-stage approach provides more reliable predictors of firm-specific efficiency than using a two-stage approach, which performs a second-stage regression of the first-stage efficiency scores upon certain environmental or other firm-specific factors. As noted by Kumbhakar et al. (1991) and Reifschneider and Stevenson (1991), the two-stage approach assumes the efficiency scores to be distributed independently and identically in the first-stage production frontier estimation, while in the second-stage they are assumed to be a function of the environmental factors, suggesting they are not identically distributed. As a result, biased efficiency predictors are obtained. The Battese and Coelli (1995) time-varying inefficiency effects model for panel data solves this problem by estimating both the frontier and the inefficiency effects in one stage.

Assuming that the environmental factors directly affect technical efficiency, the inefficiency effect model is specified as

$$\mu_{it} = \delta_0 + \sum_{s=1}^{S} \delta_s \, z_{sit}, \tag{6}$$

where μ_{it} is the mean of the truncated normal distributed inefficiency term; z_{sit} denotes the s-th ($s = 1, 2, ..., S$) environmental or regulatory factor of the i-th firm in the t-th time period expected to influence technical efficiency; and δ are unknown parameters to be estimated.

Since only $\epsilon_{it} = v_{it} - u_{it}$ is observed, the technical efficiency of the i-th firm in the t-th time period is predicted by the conditional expectation of $exp\,(-u_{it})$, given the random variable ϵ_{it} (Coelli and Perelman 1999):

$$\begin{aligned} TE_{it} &= E\,[\,exp\,(-u_{it}|\,\epsilon_{it}\,] \\ &= \left\{ exp\left[-\mu_{it} + \frac{1}{2}\,, \sigma_*^2 \right] \right\} \cdot \left\{ \Phi\left[\frac{\mu_{it}}{\sigma_*} - \sigma_* \right] \Big/ \Phi\left[\frac{\mu_{it}}{\sigma_*} \right] \right\}, \end{aligned} \tag{7}$$

where $\Phi(\cdot)$ represents the distribution function of the standard normal random variable,

$$\mu_{it} = (1-\gamma)\left[\delta_0 + \sum_{s=1}^{S} \delta_s\, z_{sit}\right] - \gamma\,\epsilon_{it}\,, \qquad \sigma_*^2 = \gamma\,(1-\gamma)\,\sigma^2, \qquad \textit{and} \quad \gamma = \frac{\sigma_u^2}{\sigma_v^2 + \sigma_u^2}\,.$$

The predicted efficiency scores range between zero and one. A score of one defines an efficient firm operating on the best-practice frontier, while a score lower than one represents the degree of a firm's inefficiency. The γ-parameter corresponds to the estimated contribution of the inefficiency term to the variance of the total error term. A value of one indicates that all deviations from the best-practice frontier are due to inefficiency, whereas a value of zero indicates that all deviations from the best-practice frontier are due to noise. In the latter case using a standard estimation model (e.g. ordinary least squared) would be appropriate.

4 The data and empirical model

The data set, presented in Table 3, consists of 31 railway firms from 22 European countries observed over the period from 1994 to 2005 and was primarily taken from the railway statistics published by the Union Internationale des Chemins de Fer (UIC) (2004, 2005, 2006, 2007). In addition, since the UIC data reveal inconsistent and incomplete time-series for several countries, we also used other data sources, like companies' annual reports and in particular a data collection provided by NERA Economic Consulting. Within this data collection, great effort was made to fill the gaps of the UIC data and secure consistent and comparable time-series over time (National Economic Research Associates (NERA) 2004).

The sample includes the incumbent railway firms or their legal successors only. Some countries separated the infrastructure from transport operations; thus, more than one firm may be listed for these countries in Table 3. For example, in the Netherlands, the infrastructure is managed by Prorail while freight and passenger transport is provided

Table 3: Sample descriptive statistics: Average values during the period 1994 – 2005

Country	Railway firms	Inputs			Outputs	
		No. of Employees (10^3)	No. of Rolling stock (10^3)	Network length (km)	Passenger-km (10^6)	Freight tonne-km (10^6)
Austria	ÖBB/SCHIG	53.0	29.8	5648	8233	15218
Belgium	SNCB	40.9	24.2	3463	7606	7520
Czech Rep.	SZDC/CD	88.3	68.8	9443	7249	18106
Denmark	BD/DSB	15.1	5.4	2273	4979	1920
Finland	RHK/VR	13.3	14.7	5839	3318	9708
France	RFF/SNCF	176.2	137.3	30384	66807	48989
Germany	DB	261.5	229.1	37579	71104	75820
Greece	CH (OSE)	10.3	6.8	2426	1709	387
Hungary	MAV	52.4	26.5	7720	7047	6936
Ireland	CIE	5.4	2.3	1928	1467	482
Italy	FS	114.7	86.0	16027	44766	22571
Latvia	LDZ	17.2	10.9	2350	1012	13815
Lithuania	LG	15.2	14.6	1882	749	9169
Luxembourg	CFL	3.1	3.0	274	293	560
Netherlands	Prorail/NS	26.6	9.5	2776	14524	3297
Poland	PKP	188.0	139.2	21921	19564	55930
Portugal	Refer/CP	11.7	5.9	2829	4091	2107
Slovenia	SZ	9.1	7.2	1213	681	2731
Slovakia	ZSSK/ZSR	47.7	34.4	3663	3145	11299
Spain	Renfe	34.4	32.5	12460	17778	10907
Sweden	BV/SJ	19.3	21.3	9811	6513	16193
Switzerland	CFF	29.7	26.0	2981	12514	9134

Source: Union Internationale des Chemins de Fer (UIC) (2004, 2005, 2006), annual reports, company statistics.

by Nederlandse Spoorwegen (NS).[2] For the purpose of comparison, observations for these countries are generated by combining the data of the separated firms. Unfortunately, we had to exclude the United Kingdom and Estonia from our analysis due to poor data. Consequently, our sample altogether covers 21 of the EU-25 member states plus Switzerland. This creates an unbalanced panel, with the difference between 264 observations having full data coverage and the lower number of 243 de facto observations resulting from missing data.

[2] In 2000, NS passenger and freight service were split into two entities, with Railion NL (a subsidiary company of DB) taking over the freight service section. Due to missing data from Railion NL, our data set does not include observations for the Netherlands since 2000. The same applies for Denmark and Sweden since 2001, where the freight section was taken over by Railion DK (another subsidiary company of DB) and GreenCargo, respectively.

To estimate the multiple input and multiple output technology, we use three input variables and two output variables. The *number of employees* (emp) (annual mean), *number of rolling stock* (roll), and *network length* (net) (in km) are used as physical measures for labor and capital input.[3] Since revenues for passenger transport depend on the number of passengers and the distance traveled, we measure the passenger service output using the variable *passenger-km (pkm).* Accordingly, freight transport revenues depend on the amount and distance of tonnes transported. Hence, we measure freight transport services output by the variable *freight tonne-km (tkm).* As noted by Oum and Yu (1994) these output measures, compared to other measures like passenger train-km and freight train-km, also take the potential influence of government restrictions on allocation into account.

The descriptive statistics in Table 3 show that our sample covers a wide range of different firm sizes as well as different key aspects of activity. For example, the scale of operations (measured in network length) of the biggest railway company in Europe, DB in Germany, is more than 130 times as large as the scale of operations of the smallest railway company, CFL in Luxembourg. Furthermore, especially railway firms operating in Eastern Europe, such as LDZ in Latvia or LG in Lithuania, mainly provide freight transport services while the relation between freight and passenger services in other countries - for example, SNCB in Belgium - is close to equal. On the other hand, in Italy FS provides almost twice as many passenger services as freight services.

We account for these differences by incorporating firm-specific and country-specific environmental factors into our estimations. The variables *network density* (network length in km per square area km) and *electrified* (percentage of electrified lines of the total network length) characterize firm-specific differences that are considered to be outside the control of the firm – at least in the short run. Similarly, the variables *gross domestic product per capita* (measured in US-dollars of 2000 and purchasing power parities) and *population density* (population per square area km) represent exogenous country-specific conditions. Finally, the dummy variable *East Europe* accounts for differences among Western and Eastern European countries.

Table 4 provides descriptive statistics for the environmental variables as well as an overview of the regulatory variables used to measure the impact of regulatory conditions on efficiency. As shown, we focus on three primary aspects of European railway deregulation: vertical separation of infrastructure and operations, third party access rights and

[3] Data on energy, another primary input of railway services, were not available. However, as stated by Coelli and Perelman (1999), this should not be a serious problem for our estimation results as it can be assumed that energy is closely related to rolling stock .

independent regulation.[4] Table 5 displays the year of regulatory change for each variable and each country between 1994-2005.

Table 4: Definition of regulatory and environmental variables and descriptive statistics

Environmental variables	Description	Mean	Std. Dev.	Min	Max
NetDen	Network density (10^{-1}) (network length in km/area km^2)	0.6	0.3	0.2	1.2
Electrified	Percentage of electrified lines (electrified lines in km/network length in km)	46.8	27.9	0.0	100
GDP	Gross domestic product per capita (10^3) (US-$ of 2000 and purchasing power parities)	21.3	8.9	5.7	53.6
PopDen	Population density (Population/area km^2)	125.4	82.7	15.0	380.8
East	East Europe ($yes = 1$)				
Regulatory variables	**Description**				
SepAcc	Accounting Separation between infrastructure and transport operations ($yes = 1$)				
SepOrg	Organizational Separation between infrastructure and transport operations ($yes = 1$)				
SepFull	Institutional Separation between infrastructure and transport operations ($yes = 1$)				
IntAccess	Access rights for railway undertakings providing international combined goods transport and for international groupings providing international services between the states in which they are established (Directive 91/440/EEC) ($yes = 1$)				
DomFreight	Access rights for domestic railway undertakings providing rail freight services ($yes = 1$)				
DomPass	Access rights for domestic railway undertakings providing rail passenger services ($yes = 1$)				
RegBody	Independent regulatory body ($yes = 1$)				

Source: Union Internationale des Chemins de Fer (UIC) (2004, 2005, 2006), annual reports, Heston et al. (2006).

Referring to vertical separation, we distinguish between *accounting separation*, *organizational separation* and *institutional separation*. As mentioned in the introduction, several countries chose a mixed structure of organizational and institutional separation. For example, in France two different entities were created in 1997, with RFF owning the infrastructure and SNCF providing the transport services. However, infrastructure maintenance and some infrastructure enhancement are still managed by SNCF based on a contract with RFF (National Economic Research Associates (NERA) 2004). Therefore we do not consider an institutional (full) separation for France. In fact, such a mixed or

[4] Other factors such as public versus private ownership, competitive tendering for regional passenger services, or horizontal separation of freight and passenger services are not considered because of too low cross-country and time variation in our sample.

Table 5: Regulatory variables (1994–2005)

Country	Separation			Third party access			
	Accounting	Organizational	Institutional	Intern. access	Domestic freight	Domestic pass.	Reg. body
Austria	1992	1997		1993	1998	1998	2000
Belgium	1991	2005		1998			
Czech Rep.	1994	2003		1995	2000	2000	1995
Denmark[a]	1997		1997	1995	1999	1999	
Finland	1995		1995	1998			
France	1997	1997		1999			
Germany	1994	1999		1994	1994	1994	1994
Greece	1999			1997			
Hungary[a]	2003			1998[b]	2005		
Ireland	1996			1997			
Italy	1998	2000		1999	2000	2000	
Latvia	1997	2005		1999	1998	1998	2002
Lithuania	2001			1997	1996	1996	
Luxembourg	1995			1996			
Netherlands[a]	1996	1996	2002	1998	1998		2004
Poland	1998	2001		1998	2004	2004	2004
Portugal	1997		1997	1996	2004		1998
Slovenia	1999	2004			2003	2003	
Slovakia[a]	1994		2002	1997	1994	1994	
Spain	1994		2005	1998	2005		
Sweden[a]	1988		1988	1995	1996		2004
Switzerland	1997			2000	2000	2000	2005

Source: Commission of the European Communities (2006), IBM (2004, 2006), Conway and Nicoletti (2006), NEA (2005), Steer Davies Gleave (2004, 2005), National Economic Research Associates (NERA) (2004), European Conference of Ministers of Transport (ECMT) (1998), European Commission, Directorate-General for Energy and Transport (http://ec.europa.eu/transport/rail/countries/es/admin_en.htm), various company websites, annual reports.
[a] incomplete time-series, [b] or earlier.

"hybrid" structure is more similar to an organizational separation with separated divisions for infrastructure management and transport operations within a holding company, as that which is in place in Germany or Italy. Similar arguments apply to Austria since 1997, the Czech Republic since 2003, and the Netherlands between 1996 and 2002. Hence, despite the existence of separated entities we consider the railway sector in these countries for these years as being organizational rather than institutional (fully) separated.

Third party access conditions are accounted for using three variables. The first – *international access* – refers to access rights for international railway undertakings according to Directive 91/440/EEC. Contrarily, the second and third access variables – *domestic freight* and *domestic passenger* – refer to national legislation defining access rights for domestic railway undertakings providing rail freight services and rail passenger services, respectively.[5]

The last regulatory variable – *regulatory body* – points to the existence of independent regulation within a country. The primary information source for this variable was an IBM (2006) study, in which the authors identified three different models of regulatory bodies: the ministry model, the special regulatory model and the railway authority model.

In the ministry model, railway regulation responsibility lies within the Ministry of Transport; no other standing organization deals with regulatory issues. We do not consider this model as an independent regulatory body since the infrastructure – and, in most countries, the main rail transport operator as well – is completely state-owned. In contrast, within the special regulatory and railway authority models, either a traditional railway authority or an independent regulatory authority is responsible for railway regulation matters; thus, both models are regarded as independent regulatory bodies.

Inclusion of all described regulatory and firm- and country-specific environmental variables leads to the following inefficiency frontier model (Model I):[6]

$$\begin{aligned}
-\,ln\,net_{it} \;=\;& \alpha_0 + \alpha_1\,ln\,pkm_{it} + \alpha_2\,ln\,tkm_{it} + \frac{1}{2}\,\alpha_{11}\;(ln\,pkm_{it})^2 + \frac{1}{2}\,\alpha_{22}\;(ln\,tkm_{it})^2 \\
& + \alpha_{12}\,ln\,pkm_{it}\,ln\,tkm_{it} + \beta_1\,ln\,(emp_{it}/net_{it}) + \beta_2\,ln\,(roll_{it}/net_{it}) \\
& + \frac{1}{2}\,\beta_{11}\;(ln\,(emp_{it}/net_{it}))^2 + \frac{1}{2}\beta_{22}\;(ln\,(roll_{it}/net_{it}))^2 \\
& + \beta_{12}\,ln\,(emp_{it}/net_{it})\;ln\,(roll_{it}/net_{it}) \qquad (8)\\
& + \theta_{11}\,ln\,(emp_{it}/net_{it})\;ln\,pkm_{it} + \theta_{12}\,ln\,(emp_{it}/net_{it})\;ln\,tkm_{it} \\
& + \theta_{21}\,ln\,(roll_{it}/net_{it})\;ln\,pkm_{it} + \theta_{22}\,ln\,(roll_{it}/net_{it})\;ln\,tkm_{it} \\
& + \phi_t\,t + \frac{1}{2}\,\phi_{tt}\,t^2 + \psi_{1t}\,ln\,pkm\,t + \psi_{2t}\,ln\,tkm\,t \\
& + \lambda_{1t}\,ln\,(emp_{it}/net_{it})\;t + \lambda_{2t}\,ln\,(roll_{it}/net_{it})\;t + v_{it} - u_{it}
\end{aligned}$$

and,

$$\begin{aligned}
\mu_{it} \;=\;& \delta_0 + \delta_1\,NetDen_{it} + \delta_2\,Electrified_{it} \\
& + \delta_3\,ln\,GDP_{it} + \delta_4\,ln\,PopDen_{it} + \delta_5\,East_{it} \\
& + \delta_6\,SepAcc_{it} + \delta_7\,SepOrg_{it} + \delta_8\,SepFull_{it} \qquad (9)\\
& + \delta_9\,IntAccess_{it} + \delta_{10}\,DomFreight_{it} + \delta_{11}\,DomPass_{it} \\
& + \delta_{12}\,RegBody_{it} + \delta_{13}Time.
\end{aligned}$$

[5] Note that the year specifications of these variables listed in Table 5 refer to the first complete year in which the law was valid rather than the exact enactment date.

[6] Note that the *time* variable is included in both the stochastic frontier and the inefficiency effect model: within the stochastic frontier it accounts for technological change while within the inefficiency effect model it accounts for changes in technical efficiency.

5 Results

As described in the methodology section (see Section 3), firm-specific technical inefficiency represents the deviation of a firm from the best practice production frontier. Therefore, in order to obtain accurate technical efficiency scores, it is crucial to estimate an appropriate functional form of the production function underlying the frontier. Using the generalized likelihood-ratio test, we evaluate several alternative specifications of our model. The test statistic, λ, is defined by

$$\lambda = -2\left[lnL(H_0) - lnL(H_1)\right], \tag{10}$$

where $L(H_0)$ and $L(H_1)$ are the log-likelihood value of the restricted model under the null hypothesis and the unrestricted model under the alternative hypothesis, respectively. If the null hypothesis is true, then λ is approximately chi-squared distributed with degrees of freedom equal to the number of parameters assumed to be zero in the null hypothesis.

The generalized likelihood-ratio tests for Model I are reported in Table 6.[7] The first three null hypotheses refer to the parameters of the stochastic production frontier. All three hypotheses – that the Cobb-Douglas functional form is an adequate representation of the input distance function, that no technical change occurs, and that a Hicks neutral technical change occurs – are strongly rejected by the data. Hence, the translog stochastic production frontier with non-neutral technical change defined by equation 8 is an adequate representation of the data.

Null hypotheses four and five refer to the parameters of the technical inefficiency model defined by equation 9. Hypothesis four – that technical inefficiency effects are absent from the model – is strongly rejected by the data. Hence, a traditional regression model (ordinary least squares), which accounts all deviations from the best-practice frontier to random noise, is not a an adequate representation of the data. This is also confirmed by the estimated value of the variance parameter γ for Model I (see Table 7). The γ-value is close to one, indicating that most of the deviations from the best-practice frontier are due to technical inefficiencies rather than random noise. Since the estimated coefficients δ_3 , δ_6, δ_7 and δ_8 are statistically insignificant in Model I, we test the fifth null hypothesis: that no joint effect of the corresponding variables exists on inefficiency. Accepting this null hypothesis confirms that these variables do not significantly affect technical inefficiency in Model I.

Altogether, the tests results demonstrate, that our model specification of a translog inefficiency frontier model with non-neutral technical change is an adequate representation of the data. However, the preferred form is given by omitting the variables *gross domestic product per capita*, *accounting separation*, *organizational separation*, and *institutional separation.* This model is denoted as Model II in Table 7.

[7] All maximum likelihood estimates of the models are obtained by using the software package Frontier 4.1 (Coelli 1996)

Table 6: Tests of Hypotheses

Null Hypothesis	Log-likelihood	λ	Critical value $\chi^2_{0.99}$	Decision
Model 1	225.71			
$H_0 : \alpha_{mn} = \beta_{kl} = \theta_{km} = \phi_{tt} = \psi_{mt} = \lambda_{kt} = 0$	90.31	270.80	30.58	Reject H_0
$H_0 : \psi_t = \phi_{tt} = \psi_{mt} = \lambda_{kt} = 0$	126.31	199.16	16.81	Reject H_0
$H_0 : \psi_{mt} = \lambda_{kt} = 0$	211.43	28.56	13.28	Reject H_0
$H_0 : \gamma = \delta_0 = ... = \delta_{12} = 0$	84.00	283.42	28.46*	Reject H_0
$H_0 : \delta_3 = \delta_6 = \delta_7 = \delta_8 = 0$	222.13	7.16	13.28	Accept H_0

* The test statistic λ has a mixed chi-squared distribution for the hypothesis involving $\gamma = 0$. The critical value is obtained from Table 1 in Kodde and Palm (1986).

The estimated coefficients of the first order terms and the time variable of the stochastic frontier production function are reported in the upper part of Table 7.[8] As all variables are normalized by their sample means, the first order coefficients can be interpreted as production elasticities for the sample average firm. Furthermore, the sum of the first order output elasticities equals scale elasticity, with an absolute value less than one indicating increasing returns to scale and an absolute value higher than one indicating decreasing returns to scale (Färe and Primont 1995).

All first order coefficients of the preferred Model II are statistically significant and show the expected signs. In other words, the estimated input distance function is decreasing in outputs and increasing in inputs. The sum of the first order output coefficients (-0.930) is less than one in absolute value, indicating increasing returns to scale at the average sample firm, as observed in the majority of railway studies. Finally, the statistically significant and positive coefficient of *time* (0.039) implies technological progress at a rate of 3.9% per annum for the average sample firm.

The coefficients of the inefficiency model are reported in the lower part of Table 7. For Model II, all coefficients except the coefficient of the constant are significantly different from zero at the 5% level. Among the estimates for the environmental variables, the positive coefficients δ_1 and δ_4 indicate that a higher *network density* as well as a higher *population density* leads to lower technical efficiency. Moreover, the positive coefficient δ_5 suggests a significantly lower technical efficiency of railways in Eastern Europe than in Western Europe. In contrast, the coefficient δ_2 is negative, which indicates that a higher *percentage of electrified lines* leads to greater technical efficiency.

Among the estimates for the regulatory variables the positive coefficients δ_9 and δ_{11} imply lower technical efficiency of railways in countries that established *access rights for international services according to Directive 91/440/EEC* or *access rights for domestic*

[8] Altogether, 15 out of the 21 coefficients of Model I are statistically different from zero at the 5% level. As no straightforward interpretation of the distance function coefficients exists and we are primarily interested in the inefficiency effects, we do not report all coefficients to conserve space.

Table 7: Parameter estimates

Variable	Parameter	Model I Coef.	Model I T-ratio	Model II Coef.	Model II T-ratio	Model III Coef.	Model III T-ratio	Model IV Coef.	Model IV T-ratio
Production frontier									
Constant	α_0	0.204	8.68	0.216	8.74	0.237	10.76	0.128	3.67
$ln\, pkm$	α_1	-0.326	-12.53	-0.344	-13.88	-0.370	-16.03	-0.227	-8.17
$ln\, tkm$	α_2	-0.606	-25.27	-0.586	-24.48	-0.571	-27.05	-0.642	-25.56
$ln\,(emp/net)$	β_1	0.352	4.33	0.352	4.11	0.157	1.84	0.490	5.83
$ln\,(roll/net)$	β_2	0.450	7.01	0.425	5.45	0.540	7.70	-0.009	-0.10
$time$	ϕ_t	0.040	8.85	0.039	8.04	0.038	9.99	0.064	7.24
Inefficiency model[a]									
$Constant$	δ_0	0.256	2.60	0.198	1.76	0.583	7.48	-1.031	-1.481
$NetDen$	δ_1	2.736	2.53	3.448	3.18	0.831	0.97		
$Electrified$	δ_2	-0.817	-6.28	-0.920	-6.89	-1.260	-11.11		
$ln\, GDP$	δ_3	0.099	0.88						
$ln\, PopDen$	δ_4	0.314	5.94	0.324	5.94	0.440	9.96		
$East$	δ_5	0.409	4.07	0.364	6.12	0.407	7.47		
$SepAcc$	δ_6	-0.054	-0.97						
$SepOrg$	δ_7	-0.080	-1.42						
$SepFull$	δ_8	-0.074	-1.08						
$IntAccess$	δ_9	0.201	3.89	0.204	3.71			1.205	1.91
$DomFreight$	δ_{10}	-0.258	-4.50	-0.253	-2.33			-0.024	-0.21
$DomPass$	δ_{11}	0.282	3.85	0.257	2.23			-0.201	-1.55
$RegBody$	δ_{12}	-0.231	-3.56	-0.255	-4.76			-0.052	-0.76
$Time$	δ_{13}	0.029	3.09	0.026	2.53	0.038	5.61	0.098	5.46
Sigma-squared	σ^2	0.021	6.42	0.021	6.67	0.029	7.98	0.055	4.35
Gamma	γ	0.955	49.83	0.946	44.23	0.952	71.32	0.865	18.18
Log-likelihood	LLF	225.71		222.13		194.80		120.73	
Mean efficiency	TE	0.794		0.797		0.786		0.819	

[a] Note that a negative sign represents a negative effect on inefficiency and, thus, a positive effect on efficiency.

railways providing passenger services. In contrast, the negative coefficients δ_{10} and δ_{12} indicate greater technical efficiency of railways in countries where *access rights for domestic railways providing freight services* are existent or where an independent regulatory body is in place. Finally, the positive coefficient δ_{13} points to a decrease in technical efficiency over time.

Two alternative models are also reported in Table 7. Model III omits the regulatory variables, whereas Model IV omits the firm- and country-specific environmental variables. Compared to Model II, both models are rejected based on likelihood-ratio tests.[9] Within

[9] The test statistic λ equals 54.66 for Model III and 202.80 for Model IV. Both values are greater than the critical value 13.28 ($\alpha = 0.01$, degrees of freedom = 4).

the production frontier estimates, the first order coefficient β_1 of Model II is statistically significant at the 10 % level only. In Model IV the first order coefficient β_2 is negative and statistically insignificant. All other first order coefficients of the alternative models are significant and show the expected signs. Considering the coefficients of the inefficiency model, the alternative models lead to substantially different results. Model III supports the results of Model II. The omission of all regulatory variables only changes the statistical significance of the coefficient δ_1 from significant at the 1% level in Model II to insignificant in Model III. In contrast, in Model IV, all coefficients of the regulatory variables except δ_9 are statistically insignificant. Furthermore, coefficient δ_{11} shows a negative sign compared to a positive sign in Model II. Altogether, these results support the assumption that an analysis of the impact of regulatory reforms on rail efficiency without considering firm- and country-specific environmental factors leads to biased estimation results.

Table 8 reports the average technical efficiency scores of Model II per country for the period of 1994 to 2005 as well as for three sub-periods. Over the whole 12-year period, the best results are achieved by BV/SJ in Sweden (98.3), RHK/VR in Finland (97.3), and Renfe in Spain (96.4). Meanwhile, MAV in Hungary (46.4), SZDC/CD in the Czech Republic (49.5), and ZSSK/ZSR in Slovakia (55.7) exhibit the worst results. Considering the sub-periods, this ranking is quite stable – except for CFF in Switzerland and CH in Greece taking over first place and the third worst place in the 1998-2001 sub-period, respectively.

Comparing the first and last sub-periods indicates that technical efficiency decreases for most of the firms. Only SZ in Slovenia (12.5%), ÖBB in Austria (6.2%), and Refer/CP in Portugal (0.8%) exhibit a positive development over time. Among the Eastern European firms, LG in Lithuania, PKP in Poland, and SZDC/CD in the Czech Republic are the worst hit, with a technical efficiency decline of 27.2%, 25.7%, and 24.7%, respectively. Among the Western European firms, CFL in Luxembourg shows a 25.7%, CIE in Ireland a 22.7%, and CH in Greece a 22.2% decline.

Table 8: Model II: Technical efficiency scores

Country	Railway firms	Average efficiency by period (in %)				Efficiency change (in %)
		1994-97	1998-01[a]	2002-05[b]	All	1994-97 to 2002-05
Austria	ÖBB/SCHIG	88.7	92.7	94.3	91.9	6.2
Belgium	SNCB	79.1	69.1	65.0	71.1	-17.8
Czech Rep.	SZDC/CD	58.4	46.1	44.0	49.5	-24.7
Denmark	BD/DSB	78.8	85.2		81.6	
Finland	RHK/VR	98.0	96.7	97.3	97.3	-0.7
France	RFF/SNCF	95.4	92.9	77.8	88.7	-18.4
Germany	DB	83.9	84.6	83.5	84.0	-0.5
Greece	CH (OSE)	89.0	52.3	69.2	70.2	-22.2
Hungary	MAV		45.7	47.2	46.4	
Ireland	CIE	91.9	89.4	71.0	84.1	-22.7
Italy	FS	84.7	73.5	70.2	76.1	-17.1
Latvia	LDZ	89.5	73.2	79.4	80.7	-11.3
Lithuania	LG	76.5	58.6	55.7	63.6	-27.2
Luxembourg	CFL	97.2	93.7	72.2	87.7	-25.7
Netherlands	Prorail/NS	96.3	94.3		95.7	
Poland	PKP	89.1	72.7	66.2	76.0	-25.7
Portugal	Refer/CP	94.3	88.3	95.1	92.6	0.8
Slovakia	ZSSK/ZSR	62.7	53.1	49.9	55.7	-20.4
Slovenia	SZ	70.2	71.6	79.0	73.6	12.5
Spain	Renfe	97.7	97.1	94.3	96.4	-3.5
Sweden	BV/SJ	98.4	98.2		98.3	
Switzerland	CFF	94.9	98.4	92.9	95.4	-2.1

[a] Denmark 1998-00, Netherlands 1998-99, and Sweden 1998-00; [b] Slovakia 2002-04.

6 Summary and Conclusions

Based on a multiple-output distance function panel model, including inefficiency effects, we analyzed the impact of regulatory and other environmental factors on the technical efficiency of 31 European railway firms from 22 European countries from 1994 to 2005. Our results indicate positive and negative effects of regulatory reforms as well as the significant influence of firm- and country-specific environmental factors.

Considering the analyzed environmental factors, we find that the percentage of electrified lines positively affects railways' technical efficiency. A higher proportion of electrified lines can be seen as a quality factor suggesting a technically updated railway network, with high-speed lines and a more efficient coordination system than a non-electrified railway network. The estimated negative influence of population density and network density can be explained by higher costs for passenger transport than for freight transport and higher coordination and maintenance costs of a widely branched dense network compared to a less dense network. Hence, railway firms that concentrate on passenger transport and those that operate a widely branched dense network exhibit lower technical efficiency than railway firms that concentrate on freight transport or operate a less dense network. Finally, we determined that firm location in Eastern Europe negatively influences technical efficiency, which can be due to a still lower economic and technological development in these former communist countries.

Referring to regulatory reforms, the estimated results for third party access rights differ between passenger and freight transport as well as international and domestic services. Access rights for international services according to Directive 91/440/EEC and those for domestic railways providing passenger transport are found to negatively influence technical efficiency whereas access rights for domestic railways providing freight services are found to positively influence technical efficiency. As our analysis is based on incumbent railway firms only and every country observation includes the network, these results provide an indication for different network coordination and management costs depending on the kind of third party activity on the network. It can be assumed that the coordination of international cross-border traffic is costlier than the coordination of domestic transport due to different network or train technologies, different languages, or different operational procedures among the countries. Thus, the negative impact on efficiency of access rights for international services suggest a low degree of interoperability among the national railway systems. Furthermore, regarding domestic transport, the results also point to cost differences between freight and passenger traffic coordination. Passenger transport provided by different parties requires a ticket clearing system as well as an adjusted train schedule, which probably allows for less flexibility than train scheduling for freight transport.

However, another reason for the different results could be the development of competition. Although in many countries competition in the freight transport sector has already been taking place for several years, competition in the passenger transport sector remains quite low in many countries. Hence, assuming that competition increases efficiency, the estimated negative influence of access rights for railways providing passenger transport on the technical efficiency of the incumbent firm could be a temporarily effect, disappearing, or even turning in the other direction, with more competition developing over time.

Finally, as the main function of an independent regulator body is to enforce regulatory reforms and to secure competition, the estimated positive effect on technical efficiency – if an independent regulatory body is establish – meets our expectations.

Since none of the separation variables within our estimations reveal a statistically significant influence on technical efficiency, we cannot derive any conclusions on the efficiency impact of different degrees of separation. This result confirms the study by Friebel et al. (2005), who noted that the estimation results on the efficiency impact of separation highly depend on how the countries are categorized. In addition, the statistically insignificant influence of GDP per capita was initially surprising. Normally, one would expect higher income to increase passenger as well as freight transportation needs and, hence, to positively influence technical efficiency. However, estimating a model without the regional dummy for Eastern and Western Europe showed a statistically significant positive influence of GDP as well as of institutional separation on technical efficiency; all other results remained unchanged. Therefore, we attribute both effects to differences between Eastern and Western Europe rather than to overall income or separation effects.

Comparing the development of technical efficiency change (Table 8) with the regulatory variables (Table 5) reveals another interesting result. The three Western European firms with the worst technical efficiency decreases over time (CFL, CIE, and CH) are the only ones located in countries that implemented only two of the listed regulatory reforms – namely, accounting separation and international access. This pattern indicates that, despite single negative effects of specific regulatory reforms on technical efficiency, none or just one or two small reforms are even worse.

Overall, our estimation results from Model II together with the two alternative Models III and IV, omitting either the regulatory variables or the firm- and country-specific environmental variables, show that an analysis of regulatory factors within the European railway industry should incorporate environmental factors as well. Otherwise, inadequate results may be obtained.

Finally, some limitations of our study and aspects for further research should be noted as well. Due to data problems, we were not able to include the United Kingdom or the last years of Denmark, the Netherlands, and Sweden in our estimations. Since railway deregulation in these countries is far advanced in several areas, it would be of great interest to examine the development of these railway sectors compared to others. In addition, the information on regulatory reforms used in this study rely primarily on the “law on the books” rather than “law in action”. More detailed data are needed to account for country-specific law implementation differences, especially for differences in the real day-to-day practice. Finally, we incorporated only quantitative input and output data. Aspects of railway safety, quality, and financing are important issues to consider in future research.

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