European Railway Deregulation: Essays on Efficiency and Productivity of European Railways

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Contents

List of Figures

List of Tables

1 Introduction

In the late 1980s and early 1990s, in the context of the development of a competitive and trade-barrier-free single European market, the European Union and its member states began reforming several network industries, including telecommunications, energy, and transport. The importance of network industries for overall economic development is based on their role as essential input factors for almost all economic sectors; network industries provide the infrastructure for the exchange of information, energy, people, goods, and services, which is crucial for the economic development of the single European market. Therefore, the European reform policy focused on the deregulation and liberalization of the theretofore monopolistically structured network industries, with the aim of increasing the economic performance of these industries and of promoting overall economic development with significant spill-over effects.

One of the industries to be deregulated was the European railway system. Historically, each member state had had its own national monopoly railway company but, compared to other transportation modes like road or inland waterways, this country-based system could not meet the increasing transportation needs of a single European market. During the 1970s and 1980s, the intermodal market share of rail transport in both the passenger and freight sectors continually decreased while the amount of railway subsidies continually increased in most European countries. In order to bring a halt to this counter-productive development and to enhance the economic performance of European railways, the European Commission implemented the first railway directive in 1991 as the first step in the ongoing European railway deregulation process.

The objective of this thesis is to analyze the effectiveness of the European railway deregulation process in enhancing efficiency and productivity in the European railway industry. A series of benchmarking methods that compare the productive performance of an individual firm to a reference set of firms is used to evaluate the impact of different production technologies and country- and firm-specific environmental and regulatory conditions on efficiency and productivity.[1]

In general, benchmarking methods can be differentiated into non-parametric and parametric methods. Non-parametric methods, such as data envelopment analysis (DEA), use linear programming techniques to define a non-parametric best-practice frontier. The advantage of these methods is that they do not require the pre-specification of a specific functional form for the frontier, so they avoid any functional misspecification

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[1] The data are available on request from the author.

that might lead to distorted efficiency results. Chapter 2[2] discusses an innovative two-stage DEA super-efficiency model used to investigate whether there are economies of scope in vertical integrated railway firms that own the infrastructure and participate in the transport segment. Whether such economies of scope that militate against complete institutional vertical separation exist is one of the most controversial questions in the area of European railway deregulation. On the one hand, if no scope economies exist, institutional separation will not result in any cost disadvantages, the problem of third-party discrimination incentives of vertically integrated firms will be eliminated, and institutional separation will enhance competition and efficiency and promote economic welfare. On the other hand, if scope economies do exist, institutional separation will result in cost disadvantages which might exceed the gains in efficiency and economic welfare from more competition. In this case, an integrated sector structure would be more advantageous. The results obtained by applying the DEA super-efficiency model to a unique sample of 54 integrated and separated railway companies from 27 European countries indicate that, for a majority of integrated European railways, economies of scope exist. Furthermore, connecting these results to an IBM study on the opening of the rail markets in Europe in 2004 (IBM, 2004) reveals that all integrated firms located in countries that were assigned in the IBM study to the group with an ‘on schedule market opening’ show economies of scope. Conversely, integrated firms located in countries that were assigned to the group with a ‘pending departure or delayed status of market opening’ show diseconomies of scope or – in a broader context – low efficiency scores. This connection between the regulatory environment and economies or diseconomies of scope suggests a reinterpretation of the finding of diseconomies of scope as being a managerial inefficiency resulting from a lack of competition. Further, it suggests that integrated firms that are subject to competition do not significantly suffer from managerial inefficiency and are able to realize productivity advantages from economies of scope. Altogether, our analysis shows that economies of scope exist for a majority of integrated railway companies. Further deregulation policy should consider that issue and weigh the advantages and disadvantages of institutional separation carefully

Chapters 3 and 4 use different parametric stochastic frontier analysis (SFA) models to investigate the productivity development and the influence of regulatory and environmental conditions on the technical efficiency of European railways. Compared to non-parametric methods, parametric approaches have the advantage of accounting for

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[2] ‘Testing for Economies of Scope in European Railways: An Efficiency Analysis’ (with Christian Growitsch), forthcoming in *Journal of Transport Economics and Policy*; presented at the 9th European Workshop on Efficiency and Productivity Analysis (EWEPA, Brussels, Belgium, June 2005), the 1st Halle Efficiency and Productivity Analysis Workshop (HEPAW, Halle, Germany, June 2006), the Verein für Socialpolitik (Annual Meeting, Bayreuth, Germany, September 2006), the 4th Annual Conference on Railroad Industry Structure, Competition and Investment (Madrid, Spain, October 2006), the 5th Annual International Industrial Organization Conference (Savannah, USA, April 2007), the XII. Spring Meeting of Young Economists (Hamburg, Germany, May 2007).

statistical noise. SFA estimates the best-practice frontier with a 'composed error term' that includes a standard error component to account for measurement errors and other random factors, and a non-negative error component term to represent technical inefficiency. With this kind of estimation, firm-specific deviations from the frontier can be distinguished as to whether they are the result of inefficiency or random noise. Another advantage of parametric methods is that they allow the incorporation of firm- and country-specific heterogeneity into the analysis. However, since parametric methods require pre-specification of the frontier's function form and an assumption about the distribution of the inefficiency component, the estimation procedure must be carefully chosen based on economic theory and empirical facts.

Chapter 3 analyzes the productivity development of 22 European railway markets during the deregulation period of 1990-2005 using a stochastic frontier panel data model, the so-called 'true' fixed effects model proposed by Greene (2004a,b, 2005). Compared to basic fixed effects stochastic frontier models for panel data, this approach has the advantage of controlling for unobserved firm- and country-specific heterogeneity and of allowing the inefficiency to vary over time. The generalized Malmquist productivity index approach proposed by Orea (2002) is used as well in order to decompose total factor productivity change into three factors: technological progress, technical efficiency change, and scale effects. The aim is to determine the influence of regulatory changes on different sources of productivity growth. To our knowledge, this is the first productivity analysis of Eastern and Western European railway companies to include 16 of the last 18 years of deregulation and liberalization in the European railway sector and, more significantly, that accounts for unobserved heterogeneity. The results indicate that technology improvements have been by far the most important driver of productivity growth, followed by gains in technical efficiency and, to a lesser extent, scale effects. Altogether, average technical change estimates show an average productivity growth of 29 percent due to technological progress over the entire observed period. While the development of technological change is found to be positive in all periods, the development of average technical efficiency change from one year to the next is observed to be quite volatile. In the 1992-1997 period, right after the first railway deregulation directive, the average technical efficiency estimates indicate an increasingly positive contribution of technical efficiency change to average productivity growth. After that, this contribution declined and finally, from 2002, it increased again. Over the whole observed period, average technical efficiency estimates show an increase in technical efficiency of 7 percent. Furthermore, in terms of efficiency comparison, the results indicate a convergence of firm-specific technical efficiency levels over time; in particular, firms whose initial performance was sub-par realized significant catch-up effects in the early and mid-1990s. Considered as a whole, including an estimated 3 percent contribution of scale effects, we find an average productivity growth of 39 percent in the observed period of deregulation. This suggests that the aim of the deregulation policy has been met. Further deregulation policy should continue to enhance this development and in particular should promote further technology improvements as the main driver of productivity growth.

Chapter 4[3] investigates the impact of regulatory reforms, including vertical separation options and third-party access rules, as well as environmental conditions on the technical efficiency of 31 European railway firms from 22 European countries during the period 1994-2005. From a theoretical perspective, the positive or negative impact of individual reforms on railway efficiency is not clear-cut. For example, different third-party access rights, expected intrinsically to increase both competition and efficiency, may also cause a loss of traffic density economies and an increase in coordination costs that could negate the beneficial effect of increasing competition and might lead to a decrease in efficiency. Similar arguments apply to different kinds of vertical separation. The results obtained by using a time-varying inefficiency effects stochastic frontier model for panel data proposed by Battese and Coelli (1995), indicate both positive and negative effects on technical efficiency by individual regulatory reforms. While we find no significant influence on technical efficiency from accounting, organizational, or institutional separation, the estimated results for third-party access rights differ between passenger and freight transport, as well as between international and domestic services. In particular, access rights for domestic railway firms providing freight transport services are found to have a positive influence on technical efficiency, whereas access rights for domestic railway firms providing passenger transport services and those for international services according to Directive 91/440/EEC are observed to have a negative influence on technical efficiency. In the case of international services, these results indicate a continuing low degree of interoperability among the national railway systems, which results in higher network coordination and management costs for international transport services compared to those of domestic transport services. The different results for domestic passenger and freight transport services could be attributable to either higher network coordination and management costs of passenger transport services compared to freight transport services or to the very low development of competition within the passenger transport segment in most European countries. In the latter case, the estimated negative impact of third-party access for domestic railway firms providing passenger services could be a temporary effect that might disappear or even turn positive given the development of more competition over time. This interpretation is also confirmed by the analysis of the development of firm-specific technical efficiency levels over time. Our findings reveal that, although individual regulatory reforms have negative effects on technical efficiency, railway firms located in countries with an early and comprehensive reform program show only a slight decrease or even an increase in technical efficiency over time. Altogether, the results point to significant implementation and adjustment

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[3] 'European Railway Deregulation: The Influence of Regulatory and Environmental Conditions on Efficiency', invitation to resubmit to *Journal of Regulatory Economics*; presented at the 10th European Workshop on Efficiency and Productivity Analysis (EWEPA, Lille, France, June 2007), the 2nd Halle Efficiency and Productivity Analysis Workshop (HEPAW, Halle, Germany, May 2008), the 5th North American Productivity Workshop (NAPW, New York, USA, June 2008), the 35th Conference of the European Association for Research in Industrial Economics (EARIE, Toulouse, France, September 2008).

problems in many European countries probably caused by a still relatively low degree of interoperability among the national railway systems and the low levels of competition within the passenger transport sector. Further deregulation policy should consider these issues and focus particularly on the improvement of interoperability among the national railway systems and the enhancement of competition within the passenger transport sector.

Chapter 5 summarizes the results of the three empirical analyses. It contains overall conclusions, highlights implications for policy, and provides directions for further research.

2 Testing for Economies of Scope in European Railways: An Efficiency Analysis

2.1 Introduction

In the late 1980s and early 1990s, European national governments and the European Commission decided to introduce competitive elements into the European railway industry. The railway sector had been performing poorly because of high subsidy requirements and an increasingly falling market share compared to other modes of transportation. The predominant means of restructuring the industry had been to open markets and to separate infrastructure from operations (Nash and Rivera-Trujillo, 2004). The rationale for separation was that it would provide discriminatory-free access to the infrastructure for transport operators and enhance competition within the railway industry. More competition, in turn, would increase efficiency and demand for railway services and, hence, raise economic welfare (Commission of the European Communities, 1996).

However, in many European countries, vertically integrated firms still own the railway infrastructure and participate in the transport segment. Although these firms are obliged to grant infrastructure access to third parties and to organizationally separate the infrastructure from the transportation business, there is a potential for market foreclosure and third-party discrimination. An expanded institutional unbundling in the sense of complete ownership separation could eliminate this problem. Some European countries, like the United Kingdom and Sweden, have already implemented new institutional arrangements; in these countries a state-controlled firm owns the infrastructure and provides network access and services to numerous competitive transportation firms. In other countries, such as Germany or Austria, the railway sector is still dominated by integrated incumbents, who argue that an institutional separation would diminish the advantages of vertical integration and would, therefore, not be effective in raising economic welfare. Economies of scope provided by this kind of vertical integration could result either from technical advantages or from transactional advantages of joint production. The shared use of headquarters services such as management, marketing or communication services could lower production costs within an integrated structure compared with a separated organizational structure, for example. If such economies of scope exist, integrated organization would be efficient, whereas a separation with competition in transport operations would be advantageous if economies of scope do not exist.

Following this argument, a decision for or against institutional separation necessitates an analysis of potential economies of scope within the railway sector. Previous research (for example, Bitzan, 2003; Ivaldi and McCullough, 2004) addressed this issue without actually comparing different production technologies and based on only a single country. In this paper, we conduct a multi-country analysis to investigate the performance of European railways, with particular focus on economies of scope. Our unique dataset consists of 54 railway companies from 27 European countries, observed over the five-year period from 2000 to 2004. The companies represent a variety of firm sizes, input-output combinations and, most importantly, institutional settings, namely integrated railways and unbundled network and train operators. Unbundled infrastructure firms (so-called infrastructure managers) own a network and sell network capacity to transportation firms but do not offer any own transportation services. They coordinate the traffic on the network aiming at optimal capacity utilization. Unbundled passenger and freight operators offer passenger and freight services, respectively, and depend on network access provided by the infrastructure managers. Integrated firms, finally, offer all activities from a single source.

To test the hypothesis that integrated railways realize economies of scope, we analyze the technical efficiency of integrated railways compared to unbundled railways by applying a distance function model. In contrast to previous research, this allows us to refrain from determining any specific firm objectives, such as profit maximization, which is crucial for a sample of regulated companies.[1] In addition, distance functions do not require information on input and output prices, so international comparisons are facilitated.

Our analysis adopts a two-step approach, which is innovative in its application, not just for the railway sector, but for network industries in general. In the first step, we estimate the technical efficiency of integrated and non-integrated railways using the non-parametric data envelopment analysis (DEA), which allows us to avoid any specific assumptions about the underlying technology's functional form. In order to make a set of non-integrated railways comparable to the integrated railways, we follow a suggestion by Morita (2003) and construct virtually integrated firms from samples of different specialized firms. In the second step, we determine whether joint or separate production is more efficient by applying a DEA super-efficiency model, which relates the efficiency for the integrated production to a reference set consisting of the separate production technology. The major methodological advantage of this procedure is that it enables us to compare two different production technologies, rather than analyzing one production frontier derived from all firms, as was done in most previous research. While we provide general empirical results rather than a precise firm-level quantification of economies of scope, an application to the railway industry – as well as to other network sectors, such as electricity, gas, and telecommunications – aids understanding of industry structure and possible effects of governmental policies.

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[1] For discussion of distance functions in favor of cost or revenue functions, see Coelli and Perelman (2000) and section three of this paper.

This paper aims to fill a void in previous research and empirically analyzes the question of whether economies of scope in European railways exist. The outline for the remainder of this paper is as follows: The theoretical foundations and previous literature are presented in Section 2.2. Section 2.3 discusses methodology. Section 2.4 introduces the modeling approach and describes the data. Estimation results are presented in Section 2.5. Section 2.6 contains conclusions and highlights policy implications and directions for future research.

2.2 Economies of Scope in Railways – Theoretical Background and Previous Research

The primary argument against separation in the railway industry has been the potential existence of significant economies of scope (see, for example, Bureau of Transport and Regional Economics (BTRE), 2003). However, empirical evidence for such economies in the industry is scarce. This section provides a theoretical overview of the conditions of economies of scope and their possible sources in railway industries, followed by a review of previous research on efficiency and scope economies in railways and a presentation of the ability of non-parametric frontier techniques to measure economies of scope.

Economies of scope arise, in general, when cost savings can be realized as a result of a joint production of goods. Hence, it is more efficient for a single firm to produce a certain output vector than for two or more firms to produce the same output vector separately. Technically, economies of scope occur when the costs of producing a specific output vector Y jointly are lower than the costs of producing the same output vector separately under the restriction of orthogonal nonnegative output vectors Y_i (Baumol et al., 1988):

$$C\left(Y\right) < \sum_{i=1}^{m} C\left(Y_i\right), \quad for\, Y = \sum_{i=1}^{m} Y_i. \tag{2.1}$$

Diseconomies of scope occur when that inequality is reversed. In the case of railway production, the output vector may be divided into infrastructure management (Y_I), passenger transportation (Y_P), and freight transportation (Y_F). Economies of scope exist when the inequality

$$C\left(Y_I, Y_P, Y_F\right) < C\left(Y_I, 0, 0\right) + C\left(0, Y_P, 0\right) + C\left(0, 0, Y_F\right) \tag{2.2}$$

holds and the separate production of outputs comes at higher cost than joint production. If this applies to railway production, an integrated market solution with only one firm is favorable to an institutional arrangement wherein the infrastructure manager is institutionally separated from passenger and freight operators.

The primary argument in favor of economies of scope in the railway industry is that of potential transaction costs savings within an integrated organization: Railway services are characterized by a high level of technological and transactional interdependence between infrastructure and operations, including long-term capacity allocation, security management, timetable coordination, and investment planning, as well as everyday operational decisions on traffic coordination, like train length, train speed or emergency service. Technologically, all these activities can be organized within a hierarchical (integrated) structure as well as within a contractual market structure among separated firms; depending on the amount of transaction costs, one or the other has to be preferred.[2]

Supporters of an integrated structure argue that, within a separated structure with several independent operators, the number of contract negotiations as well as technical and organizational interfaces will increase, increasing transaction costs. While this argument is less likely to hold for real-time traffic coordination, it may be a consideration in long-term capacity allocation; real-time traffic coordination costs do not depend on the number of operators on the network but on the number of train movements. As long as only one network firm – either integrated or separated – is responsible for this production stage, no significant transaction cost differences should be expected (Knieps, 2004). On the other hand, the process of identifying the most efficient institutional arrangement for long-term capacity allocation is rather sophisticated. Long-term investment decisions in particular may differ between one integrated and several separated firms since railway operations depend heavily on exact coordination between the infrastructure and operations section. Every decision on rolling stock or wheel design affects the track design and track maintenance requirements, and vice versa (Pittman, 2005). For example, a passenger operator investing in high-speed trains must be sure that the track system is capable of providing high-speed transportation, while the infrastructure provider has to know what kind of capacity is needed at what time and at what place. Such coordination is information-intensive, and whether this interaction can be provided at lower transaction costs within an integrated or separated structure cannot be easily determined. On first glance, the number of participating firms in a separated system gives reason to favor the integrated system. However, the flow of information in a widely branched firm bears significant risks of increasing amounts of information and, hence, transaction costs.

Related to this issue, another problem of long-term capacity allocation can arise as a result of different investment incentives within the two possible institutional arrangements. For example, an integrated infrastructure provider and transport operator has an incentive to invest in network infrastructure in order to prevent his rolling stock from wear and tear. In a separated system, with other firms owning the rolling stock, this incentive disappears (Mulder et al., 2005). Similarly, a separated transport operator has no incentive to invest in his rolling stock simply to reduce the wear and tear on the tracks. Thus, underinvestment may occur on either side, raising costs in the long-run. Therefore, incentives between the infrastructure provider and the transport operators have to be efficiently coordinated. For example, track access charges should consider

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[2] For a detailed description of transaction costs theory, see Williamson (1975, 1985).

cost-influencing investments on either side: An infrastructure owner has an incentive to invest in the network if he gets paid for it via higher access charges, while transport operators have an incentive to invest in rolling stock if they can thereby secure lower access charges. Such a system of long-term investment coordination within a separated structure certainly leads to more (cost-intensive) interactions and negotiations between the production stages; however, within an integrated organization the lack of competition and the direct monetary connection between performance and counter-performance may result in an inefficient and similarly cost-intensive resource allocation. The question of which effect is being dominant remains hard to answer.

These issues illustrate the complexity of the interdependencies between infrastructure and operations and the difficulty in judging for or against economies of scope. Thus, the optimal institutional arrangement in the railway sector becomes an empirical question.

Studies with specific focus on vertical separation and economies of scope are rare. In a 2003 paper Bitzan used a data set of 30 U.S. Class I freight railways covering the years 1983-1997 to evaluate the cost implications of competition in the U.S. rail freight industry (Bitzan, 2003). The results, which were obtained by estimating a translog quasi-cost function, indicated economies of vertical integration, suggesting that vertical separation leads to increased costs. However, considering different technological characteristics in other countries Bitzan restricted his findings to the U.S. freight railway industry. Bitzan pointed out that the European railway systems in particular, with their usually much smaller networks and higher proportion of passengers within the combined passenger and freight operations, may lead to other cost implications of competition and/or separation.

Ivaldi and McCullough (2004) used a comparable data set of 22 U.S. Class I freight railways covering the years 1978-2001 to evaluate the technological feasibility of separating vertically integrated firms into an infrastructure company and competing operating firms. The results, which were obtained by estimating a generalized McFadden cost function, indicated vertical as well as horizontal economies of scope in a technological sense. The authors stated that vertical separation may lead to a 20-40 percent cost disadvantage against a vertically integrated system and to even greater disadvantages if bulk and general freight operations are also separated. Observing only integrated firms in the sample, Ivaldi and McCullough restricted their findings to pure technological effects of separation; neither the effects of transaction costs in an integrated system compared to a separated system, nor the effects of competition were assessed. Like Bitzan, they considered rail system characteristics in other countries to be significantly different and, thus, restricted their findings to the U.S. rail freight system.

Cantos-Sanchez (2001) estimated a translog cost function from a panel of 12 European state-owned railways for the period 1973-1990. His findings reported cost substitutability between track infrastructure and passenger operations but cost complementarity between track infrastructure and freight operations; that is, higher track costs lead to lower passenger operation costs as well as higher freight operation costs. This result indicated diseconomies of scope between passenger and freight operations; however, considering the risk that separated firms do not account for these interdependencies, this finding also suggested that there are benefits to vertical integration, as Nash and Rivera-Trujillo (2004) stated.

A recent study on European railways by Friebel et al. (2005) investigated the impact of policy reforms on 12 European national railway firms. By applying a production frontier model they compared passenger traffic efficiency for the period 1980-2000, 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 Friebel et al. showed that there were no significant differences in efficiency between fully integrated firms and organizationally separated firms, but that full institutional separation had a positive effect on efficiency, when the United Kingdom is excluded from the dataset. The results also indicated that, in general, smaller railway firms (firm size being measured in terms of network length) improved efficiency more than larger firms did.

Overall, previous research on the economics of vertical integration in railways has shown that the impact of scope economies on the efficiency of railway systems remains ambiguous. What's more, several important issues, such as different production technologies in integrated and separated organizational arrangements and limitations resulting from specific behavioral assumptions, have not yet been addressed. Therefore, in order to estimate scope economies in a technological and, especially, transactional sense, we apply DEA. Our pan-European data set incorporates railway firms from 27 European countries for the period 2000-2004. In contrast to data in previous studies, the data includes not only integrated railway firms, but separated firms, differentiated between infrastructure managers, passenger operators and freight operators. To our knowledge, this is the first study using this kind of data in a European railway efficiency comparison. Furthermore, our estimation technique compares two different production frontiers of separated and integrated firms, rather than analyzing one frontier derived from all firms, as was done in most previous work, and thus, incorporates different production technologies. Variations of this technique can be found in Ferrier et al. (1993), Prior (1996), Fried et al. (1998), Prior and Sola (2000), Kittelsen and Magnussen (2003), and Cummins et al. (2003), which evaluated scope and diversification economies in the banking, hospital, health care, and insurance sectors.

2.3 Methodology

To specify a multiple-output multiple-input production technology,we apply the distance function approach proposed by Shephard (1953, 1970). Compared to other representations of technologies, such as cost or revenue functions, this approach requires no specific behavioral objectives, such as cost minimization or profit maximization, which are likely to be violated in the case of partly state-owned and highly regulated industries such as European railways (Coelli and Perelman, 2000).

Distance functions can be differentiated into input-oriented and output-oriented. The input orientation assumes that the output set is determined by exogenous factors and, hence, that the influence of firms on output quantities is limited; the output orientation assumes exactly the same for the input set. For railways, both versions can be appropriate. In support of the input-oriented approach, one could argue that the demand for outputs is highly influenced by macro-economic factors (for example, customer density) as well as by state-controlled public transport requirements. This argument particularly applies to several incumbent railway firms which still provide almost 100 percent of the rail transport services in their respective country. On the other hand, a major argument in favor of an output-oriented approach is the existence of barely controllable input factors, for example, political influence on capital expenditures (Coelli and Perelman, 1999). However, since we apply a constant return-to-scale estimation approach, there is no need to decide on the orientation as the input-oriented distance measure equals the output-oriented distance measure in reciprocal terms.

By modeling a production technology as an input distance function[3] one can investigate how much the input vector can be proportionally reduced while holding the output vector fixed. Assuming that the technology satisfies the standard properties listed in Färe and Primont (1995), the input distance function can be defined as:

$$D_I\left(x, y\right) = \max\{\theta : (x/\theta) \in L\left(y\right)\}, \tag{2.3}$$

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, positively linearly homogeneous and concave in x, and non-increasing in y (Lovell et al., 1994). 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 within the frontier, indicating inefficient firms.

In order to estimate the distance functions and obtain information about technical efficiency and scope economies of European railways, we use DEA, a method introduced by Charnes et al. (1978). DEA is a non-parametric approach which constructs a piecewise linear production frontier that envelopes all observed data points. This production frontier can be estimated using either constant or variable returns to scale (CRS and VRS, respectively). The CRS approach assumes that the observed firms can alter their sizes and, thus, identifies firms departing from optimal scale as inefficient. In contrast, the VRS approach compares firms within similar scales, accounting for efficiency variation based on scale differences. Although the VRS approach allows an efficiency comparison corrected for scale influences, we follow the CRS approach because an efficiency comparison should consider the long-term perspective, including increasing European deregulation and competition. Country-specific regulation and political influence preventing scale optimization in the short-run will diminish in the long-run, so firms

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[3] The output-oriented model is defined in a similar way (see, for example, Coelli and Perelman, 1999).

departing from optimal scale should be identified as inefficient. Furthermore, using the VRS approach could result in the number of comparable firms within a specific range of size becoming very low; and, in the extreme, when no firm of comparable size exists, a VRS DEA approach always identifies the benchmarked firm as 100 percent efficient. Finally, from the technical perspective, the VRS assumption may lead to infeasibility of the super-efficiency model used in the second stage of our analysis.[4] Nevertheless, for reasons of comparison and consideration of the possible influence of scale efficiency on our estimation results, we also calculate the VRS efficiency scores in the first stage of our analysis.

Taking it as given that the firms use K inputs and M outputs the CRS input-oriented frontier is calculated by solving the linear optimization program for each of N firms:[5]

$$\begin{aligned} &\max \theta, \\ &\text{s.t.} \qquad -y_i + Y\lambda \geq 0, \\ &\qquad\quad x_i/\theta - X\lambda \geq 0, \\ &\qquad\qquad\qquad \lambda \geq 0, \end{aligned} \tag{2.4}$$

where X is the $K \times N$ matrix of inputs and Y is the $M \times N$ matrix of outputs; the i-th firm's input and output vectors are represented by x_i and y_i respectively; λ is a $N \times 1$ vector of constants; and θ is the input distance measure. As defined earlier in this section, this measure indicates a firm's technical efficiency or inefficiency.[6]

To analyze economies of scope in the railway sector, we calculate so-called super-efficiency scores in a second step. Super-efficiency measures can be obtained by calculating the efficiency of one group of observations relative to a production technology defined by another reference group of observations; that is, we compare the efficiency of integrated railway firms relative to the efficiency frontier of non-integrated railway firms. In order to obtain a comparable set of non-integrated firms, we follow a suggestion from Morita (2003) and construct virtually integrated firms from samples of different separated firms. Assume, for example, that there are two kinds of products, A and B, which could be produced separately in two firms or jointly in one firm. There are n^A firms producing only A, n^B firms producing only B and n^{AB} firms producing both A and B. These firms can be compared by combining the n^A firms with the n^B firms, giving a number of $n^A \times n^B$ virtual firms. These virtual firms use the same inputs to produce the same outputs as the n^{AB} firms, but producing them under an alternative production technology.

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[4] For a discussion of infeasibility of super-efficiency models under VRS, see Zhu (2003).

[5] In order to calculate the input-oriented frontier under VRS, the convexity constraint N1' = 1 must be added.

[6] Note that this is the Shepard measure of technical efficiency. The corresponding Farrell measure can be obtained by taking the reciprocal of the Shepard distance function (see, for example, Wilson, 2005).

For J integrated firms and S non-integrated firms, the input distance function for an integrated firm j relative to the non-integrated firms' frontier can be defined as:

$$D_S\left(x_j, y_j\right) = \max\left\{\theta : \left(x_j/\theta\right) \in L^S\left(y_j\right)\right\}, \quad j = 1, 2, \ldots, J, \tag{2.5}$$

where $L^S\left(y_j\right)$ represents the set of all input vectors x of the non-integrated firms that can produce the output vector y_j. In contrast to a firm's input distance function value calculated within its own group (which is greater than or equal to unity), the relative efficiency value calculated for a reference set of the other firms' group can take values between zero and infinity.

The corresponding CRS super-efficiency model is calculated by solving the linear optimization program J times for each of the integrated firms:

$$\begin{array}{lrl} \max\theta_j, & & \\ \text{s.t.} & -y_j + Y_s\lambda_s \geq 0, & j = 1, 2, \ldots, J, \\ & x_j/\theta_j - X_s\lambda_s \geq 0, & s = 1, 2, \ldots, S, \\ & \lambda_s \geq 0, & \end{array} \tag{2.6}$$

where X_s is the $K \times N$ input matrix and Y_s the $M \times N$ output matrix of all non-integrated firms; x_j is the input vector and y_j the output vector of the evaluated integrated firm; and λ_s is a $N \times 1$ vector of constants of the separated firms. If the input distance function value, that is, the super-efficiency score, for the evaluated firm θ_j is lower than unity, the integrated firm is dominant over (more efficient than) the non-integrated frontier, whereas a value greater than unity indicates a dominance of the non-integrated firms' frontier over the evaluated firm. However, if for the integrated firm the input distance function value relative to its own group θ is also greater than unity, the firm is also dominated by its own group's frontier. Hence, considering only the super-efficiency scores is not sufficient to identify the favorable technology or the existence of economies or diseconomies of scope. Consequently, as suggested by Cummins et al. (2003) we measure the distance between the two production frontiers by calculating the ratio of the efficiency and super-efficiency scores.

To illustrate this, consider non-integrated and integrated firms producing a single output with two inputs. The two input production frontiers are shown in Figure 2.1, where the production frontier for the integrated firms is labeled $L_j(y)$, and the production frontier for non-integrated firms is labeled $L_s(y)$.[7] Fully efficient firms operate on their respective frontier and show distance function (efficiency) values relative to their own group equalling unity. Economies (diseconomies) of scope for all observations can be identified if the production frontiers do not intersect and the integrated (non-integrated) frontier is placed closer to the origin. If the two production frontiers exhibit an intersection point as shown in Figure 2.1, economies of scope for some observations and diseconomies of scope for other observations can be identified.

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[7] Figure 2.1 and its description follow Cummins et al. (2003).

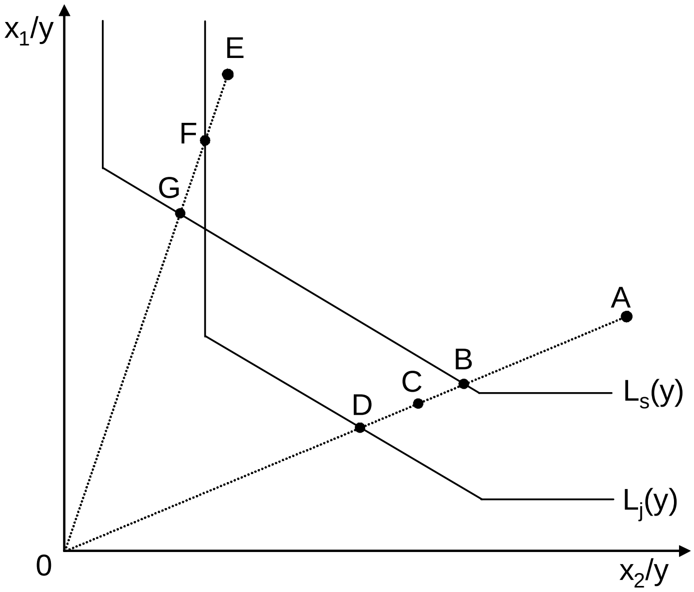

Figure 2.1: Economies and Diseconomies of Scope

For example, assume an integrated firm operating at point A in Figure 2.1. The distance function value relative to the integrated frontier is $\theta = 0A/0D > 1$, and the distance function value relative to the separated frontier, which is $\theta_j = 0A/0B > 1$, indicate this firm is dominated by its own and the other group's frontier. In order to measure which frontier is placed closer to the origin and to test if economies or diseconomies of scope occur for firm A, we calculate the ratio of the two distance function (efficiency) values:

$$\hat{\theta} = \frac{\theta}{\theta_j} = \frac{0A/0D}{0A/0B} = \frac{0B}{0D}. \tag{2.7}$$

Since the distance function value of point A relative to the integrated frontier is greater than its distance function value calculated with respect to the separated frontier, the ratio from Equation 2.7 is greater than unity, indicating that the integrated ('own') frontier is placed closer to the origin. Hence, for this firm, economies of scope can be identified. The opposite case – diseconomies of scope – can be shown for an integrated firm operating at point E. While both distance function values – that relative to its own frontier $\theta = 0E/0F$ and that relative to the other group's frontier $\theta_j = 0E/0G$ – are greater than unity, the ratio $\hat{\theta} = \theta/\theta_j = 0G/0F$ is smaller than unity, since the separated frontier is placed closer to the origin than is the integrated frontier. In summary, if the ratio is greater (lower) than unity, a firm's own frontier dominates (is dominated by) the other group's frontier for the observed production point. Hence, for integrated firms, a ratio greater than unity indicates economies of scope, and a ratio lower than unity indicates diseconomies of scope.

Since DEA efficiency measures are only point estimators calculated within a finite sample, they are highly sensitive to sampling variations and errors in the data and lack common statistical properties. In order to overcome this shortcoming, we apply a bootstrap procedure. Introduced by Efron (1979), bootstrapping is based on the idea that, when the original observed sample mimics the underlying population, every random draw from this sample with replacement can be treated as a sample from the underlying population itself. Bootstrapping is used when the original sampling distribution of the estimator of interest, for example, of the efficiency measures, is unknown. In general, the bootstrapping of our efficiency estimates can be described as follows: We first compute the efficiency measure $\hat{\theta}_i$ for each firm by DEA from the observed sample. Next, we generate a b-th $(b = 1, 2, \ldots, B)$ bootstrap sample θ_b^* of size n with replacement from $\hat{\theta}_i$, $i = 1, \ldots, n$, and calculate the bootstrap estimate $\hat{\theta}_b^*$ by using DEA. This procedure is repeated B times to obtain a set of estimates $\hat{\theta}_b^*$, $b = 1, 2 \ldots, B$. Based on this sampling distribution, the statistical properties of the estimated efficiency measures can be inferred.[8]

One major drawback of the outlined procedure is that it assumes a continuous true distribution F. However, especially in small samples with a large number of units identified as being fully efficient, the empirical distribution $\hat{F}$ of the efficiency scores is discontinuous with a positive probability mass at $\theta = 1$. Hence, $\hat{F}$ provides an inconsistent estimator of F (Cummins et al., 2003). This problem can be solved with a smoothed bootstrap procedure, developed and extended by Simar and Wilson (1998, 2000), where the empirical distribution $\hat{F}$ is smoothed using a Gaussian kernel density estimator. In our analysis we use this bootstrap procedure to estimate the bias and variance of the DEA efficiency estimates and to construct confidence intervals. As recommended by Hall (1986) we choose B=1,000 bootstrap replications. [9]

2.4 Modeling Approach and Data Description

The data set consists of 54 railway firms from 27 European countries and the period 2000-2004. Considering every year as an independent observation, we receive a sample of 152 observations in total.[10] The data was taken primarily from the railway statistics published by Union Internationale des Chemins de Fer (UIC) (2004, 2005) and combined with information from the companies' annual reports and companies' statistics.

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[8] For more details on the bootstrap, see Efron (1979) or Efron and Tibshirani (1993).

[9] For details of the procedure, please refer to Simar and Wilson (1998, 2000).

[10] The difference between 270 observations having full data coverage and the lower number of 152 de facto observations results from market entries that occurred later than 2000 and missing data, mainly in 2004. Assuming every year as an independent observation includes effects of technical progress and catching-up in the efficiency scores. However, long asset life in relation to the rather short observed time period of five years suggests these effects are negligible (Affuso et al., 2002).

The firms are divided into four different groups: Integrated firms, infrastructure managers, passenger operators, and freight operators. Every group sells a different type of product, with the integrated firms offering all activities from a single source. The essential activity in railway operations is the infrastructure management, which forms an indispensable requirement for transportation services. Infrastructure management is offered by either an infrastructure manager or an integrated firm and includes maintaining tracks, railway stations or signal facilities as well as schedule monitoring and system control. The infrastructure manager coordinates train movements, provides emergency service for defective transport devices and develops timetables. In short, the infrastructure manager provides and sells network access and services to the transportation firms, subject to the condition of optimal capacity utilization. Therefore, we use the variable *train-km driven on the network* as an output measure for infrastructure managers.[11] The second activity in railway operations is transportation, which can be distinguished between passenger and freight transportation. Transportation is provided by passenger operators, freight operators, or integrated firms. Since revenues for passenger operators depend on the number of passengers and the distance traveled, we use the variable *passenger-km* as an output measure. The freight operators' revenues depend on the amount and distance of tonnes transported. Hence, the corresponding output variable *freight tonne-km* is used.

We specify two different models for input variables. While the first model, Model I, is based only on physical measures for the input factors, the second model, Model II, also takes a monetary figure into account. In Model I, *number of employees*, *number of rolling stock*, and *network length* are used as physical measures for labor and capital input. In Model II, the 'physical' variables *number of employees* and *number of rolling stock* are replaced by the monetary variable *operating expenditure (OPEX)*. This variable represents the total operating expenses, including the costs of staff, materials, external charges, taxes, depreciation, value adjustments, and provisions for contingencies. Although this variable already includes capital costs, we still use the variable *network length* as a proxy for capital stock. We consider network length, since it is a long-lived asset, as a quasi-fixed input mainly built in the past and financed by capital grants from the government.[12] Furthermore, it reflects the cost impact of differences in network structure and density (Smith, 2006).

Both models have advantages and disadvantages. The use of physical measures for international comparison neglects the differences in relative factor prices among the countries, while using monetary values raises the problem of differences in price levels, accounting rules, and currency conversion. To limit this problem, we convert the finan-

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[11] The data on train-kms driven on the network was published first for the year 2003 by the Union Internationale des Chemins de Fer (UIC). If available, the data for preceding years was taken from the annual reports. If not available, the train-km values of the biggest passenger and freight operators in the specific country where used to approximate the value.

[12] This approach has been used frequently in previous literature. See Cantos et al. (2002) for a short review.

cial data of operating costs into an artificial common currency, the purchasing power standard (PPS). By applying purchasing power parities provided by Eurostat (2005) instead of conventional exchange rates, we account not only for currency conversion but also for differences in price levels and purchasing power among the countries. Nevertheless, the problem of varying accounting standards among the countries remains. Therefore, we estimate both models and check for differences by comparing the results.

While all described input and output variables for integrated firms are part of their corresponding production technology, the variable set for the non-integrated firms – passenger operators, freight operators, and infrastructure managers – differ by their type of activity. In order to estimate economies of scope, we use the parameter values of non-integrated firms to construct 'virtually' integrated firms, which are comparable to the actually integrated firms; every infrastructure manager is combined with every passenger operator and every freight operator by accumulating their individual parameter values. A new group of 'virtually' integrated firms is generated using a comparable production technology, since those 'virtually' integrated firms share the same inputs and produce the same outputs as the actually integrated firms. Furthermore, combining separated firms from different countries allows representations of the best possible combinations from a technological perspective. It limits the influence of country-specific conditions within the 'virtually' integrated firms, additionally. An example of how the 'virtually' integrated firms are constructed from the data is given in Table 2.1.

Table 2.1: Construction of a 'Virtually' Integrated Firm from Separated Firms

	Input variables				Output variables		
Type of activity	Number of employees	Number of rolling stock	OPEX	Network length	Train-km	Pass.-km	Tonne-km
Infrastructure manager	10	–	60	100	600	–	–
Passenger operator	40	20	50	–	–	300	–
Freight operator	30	30	40	–	–	–	200
'Virtually' integrated	80	50	150	100	600	300	200

Tables 2.2 and 2.3 show the summary statistics of the data used in each model, classified for integrated firms and 'virtually' integrated firms. The descriptive statistics between the integrated and 'virtually' integrated firms are significantly different because of some very large integrated firms within the data set. We will control for this scale differences and their potential influence on efficiency results in Section 2.5. The number of observations of integrated firms differs slightly between the estimated models – 75 observations for Model I and 73 observations for Model II – because of missing data. The observations of 'virtually' integrated firms in Model I are generated by combining 33 observations of infrastructure managers with 16 observations of passenger operators and 11 observations of freight operators. On the country level, we combine infrastructure managers from 10 countries with passenger operators from 4 countries and freight

operators from 5 countries. In total, we obtain a number of 5,808 'virtually' integrated firms for Model I.

Table 2.2: Model I – Summary Statistics

	Integrated firms			'Virtually' integrated firms		
	Mean	Max	Min	Mean	Max	Min
Number of employees	50,517	249,251	952	12,870	36,192	3,465
Number of rolling stock	40,351	219,574	223	4,981	11,893	747
Network length (in km)	7,331	36,588	180	4,665	9,882	2,047
Passenger-km (in millions)	11,494	74,459	126	4,653	6,621	2,204
Tonne-km (in millions)	14,258	76,815	14	4,952	13,120	107
Train-km (in thousands)	134,764	988,200	2,382	63,158	128,000	22,667
Number of observations	75			3,300		

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

For Model II, 23 observations of infrastructure managers from 10 countries, 27 observations of passenger operators from 5 countries, and 8 observations of freight operators from 4 countries are combined for a total number of 4,968 'virtually' integrated firms. Again, the difference in the numbers is due to missing data. To eliminate extreme virtual input-output combinations, we adjust the sub-sample of 'virtually' integrated firms for outliers by applying the method suggested by Hadi (1992, 1994), which identifies multiple outliers in multivariate data. For Model I, 2,508 observations were dropped, leaving 3330 observations of 'virtually' integrated firms. Data for Model II is adjusted for 2,160 outliers, leaving a total of 2808 observations of 'virtually' integrated firms.[13]

Table 2.3: Model II – Summary Statistics

	Integrated firms			'Virtually' integrated firms		
	Mean	Max	Min	Mean	Max	Min
OPEX (in millions of PPS)	3,281	29,669	79	1,439	3,927	329
Network length (in km)	7,474	36,588	180	4,055	5,854	2,273
Passenger-km (in millions)	11,779	74,459	126	4,795	14,666	7
Tonne-km (in millions)	14,400	76,815	14	5,854	13,120	456
Train-km (in thousands)	137,999	988,200	2,382	45,151	64,341	36,442
Number of observations	73			2,808		

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

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[13] This large number of identified outliers results from a high fraction of unrealistic virtual input-output combinations, such as combinations of very large infrastructure managers with small passenger operators.

2.5 Results

Analysis of the DEA bootstrap estimations (Table 2.4) allows several conclusions to be drawn. For both models, the bias-corrected distance function values are, on average, greater than the original distance function values, indicating that a standard DEA approach without a bootstrap procedure tends to overestimate efficiency in our sample.[14] For Model I (Model II), the average distance function value for the integrated firms is corrected by about 15 percent (7 percent) and the average distance function value for the 'virtually' integrated firms is corrected by about 2 percent (1 percent), suggesting that bias-correction especially in small, data-sensitive samples is essential for correct efficiency results.

Table 2.4: Summary Statistics of Original and Bias-corrected Distance Function (Efficiency) Results[a]

	Integrated firms		'Virtually' integrated firms	
	Original	Bias-corrected	Original	Bias-corrected
Model I				
Weighted mean	1.8259	2.0934	1.3786	1.4008
Maximum (min. efficiency)	3.9459	4.5140	2.5344	2.6080
Minimum (max. efficiency)	1.0000	1.1597	1.0000	1.0024
Model II				
Weighted mean	1.3396	1.4289	1.5202	1.5401
Maximum (min. efficiency)	3.3012	3.4616	3.3123	3.4603
Minimum (max. efficiency)	1.0000	1.0728	1.0000	1.0017

[a] All estimates are made with FEAR, a package for frontier efficiency analysis with R (Wilson, 2005).

For Model I, the estimated bias-corrected distance function value of 2.0934 for the integrated firms implies that, on average, the same output quantity could have been produced despite reducing the input usage by more than 52 percent.[15] Model II, where the monetary variable *OPEX* is used instead of the physical variables *number of employees* and *number of rolling stock*, shows a much lower bias-corrected distance function value (1.4289), indicating a possible input reduction of about 30 percent on average. Given the problem of physical measures – neglecting differences in relative factor prices among countries – we consider the estimated function of Model II as a better approximation of the real production technology.[16]

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[14] Since full data coverage over the observation period is not given for all integrated firms, all average distance function values of the integrated firms are weighted by the number of observations per firm.

[15] The possible input reduction is calculated by 1 – (1/distance value).

[16] To control for structural differences among the countries, we estimated a truncated regression and regressed the efficiency scores of the integrated firms upon GDP per capita, network density, and

Table 2.5 shows the bias-corrected distance function results for the integrated firms in Model I. Both distance values, in respect to their own frontier (2.0934) and to the separated frontier (2.2134), indicate a high level of inefficiency, suggesting a possible reduction of about 52 percent (55 percent) in inputs, on average, to reach the integrated (separated) efficiency frontier. The average ratio of the distance function values, measuring the distance between the two frontiers, is slightly greater than unity (1.0854).[17] This suggests that, on average, an efficient integrated firm needs about 9 percent fewer inputs than a 'virtually' integrated firm operating on the 'virtually' integrated frontier. This result can be interpreted as economies of scope of about 9 percent. Nevertheless, since individual economies (diseconomies) of scope may vary widely because of the input-output mix, a judgement using only the average parameter values could be misleading. Still, separating the observations into two groups, with an individual ratio of the distance function values greater than unity indicating economies of scope and below unity indicating diseconomies of scope, identifies economies for 42 observations (56 percent) and diseconomies of scope for 33 observations (44 percent). On the firm level, the results are similar: 13 firms (57 percent) exhibit economies and 10 firms (43 percent) exhibit diseconomies of scope.

Table 2.5: Bias-corrected Distance Function (Efficiency) Results – Model I

	Integrated firms				
	θ	θ_J	$\hat{\theta}$	Diseconomies of scope	Economies of scope
Weighted mean	2.0934	2.2134	1.0854	0.7777	1.3221
Maximum	4.5140	4.8501	1.8848	0.9994	1.8848
Minimum	1.1597	0.6804	0.3686	0.3686	1.0076
Number of observations	75 (100 %)			33 (44 %)	42 (56 %)
Number of firms	23 (100 %)			10 (43 %)	13 (57 %)

For Model II (Table 2.6), the estimated distance function values, in respect to both the integrated frontier (1.4289) and to the separated frontier (1.2447), indicate that, on average, an integrated firm may reduce its inputs by about 30 percent (20 percent) to reach the integrated (separated) efficiency frontier. The average ratio of the distance function values (1.4045) is greater than that in Model I, implying increasing economies of

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population density. Model I results showed a significant and positive but small influence of GDP per capita. For Model II, none of the variables had a significant influence on the efficiency scores.

[17] Note that the average ratio of the distance function values is the average of the firm-specific ratios of the distance function values, not the ratio of the average distance function values displayed in the table. The latter would lead to an incorrect conclusion since it relates two different operating points to each other: the operating point referring to the average distance function value in respect to the own frontier and the operating point referring to the average distance function value in respect to the separated frontier. This ratio does not measure the distance between the frontiers.

scope of about 40 percent, on average, when the monetary variable *OPEX* is considered instead of the physical variables *number of employees* and *rolling stock*. In addition, separating the sample into two groups, depending on whether their individual ratios of the distance function values are greater than or less than unity, reveals that 51 observations (70 percent) show economies of scope and 22 observations (30 percent) show diseconomies of scope. Separating the sample into groups related to the firm level results in 15 firms (65 percent) that indicate economies and 8 firms (35 percent) that indicate diseconomies of scope. Hence, compared to Model I, a higher proportion of observations (firms) show economies of scope.[18]

Table 2.6: Bias-corrected Distance Function (Efficiency) Results – Model II

	Integrated firms				
	θ	θ_J	$\hat{\theta}$	Diseconomies of scope	Economies of scope
Weighted mean	1.4289	1.2447	1.4045	0.7418	1.7085
Maximum	3.4616	2.6297	4.0851	0.9963	4.0851
Minimum	1.0728	0.2781	0.6007	0.6007	1.0170
Number of observations		73 (100 %)		22 (30 %)	51 (70 %)
Number of firms		23 (100 %)		8 (35 %)	15 (65 %)

Concerning the question which integrated railway firms exhibit economies or diseconomies of scope, both models provide similar results. Economies of scope are identified for integrated firms from 10 countries (Belgium, Bulgaria, Estonia, Germany, Italy, Latvia, Lithuania, Luxembourg, Romania, and Switzerland) and diseconomies can be found for integrated firms from five countries (Greece, Ireland, Spain, Slovakia, and the Czech Republic). The results of the two models differ for firms from Austria, Poland, and Hungary only. In contrast to Model I, Model II also identifies economies of scope for integrated firms from Austria and Poland and diseconomies of scope for the largest integrated firm from Hungary.

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[18] Scale differences among the integrated firms and 'virtually' integrated firms and possible related differences in returns to scale do not cause an upward bias in our economies of scope estimations. We estimated the returns to scale of the integrated firms by using the scale efficiency method (see, for example, Färe et al., 1994). Under the output-oriented approach, which conditions the scale properties on the input vector, we found decreasing returns to scale, on average, indicating a too large input-vector for the majority of the firms. Furthermore, considering that scale inefficiency is due to decreasing returns to scale, a significant but small negative correlation between scale inefficiency and economies of scope can be shown. Therefore, on average, a possible bias of the estimated scope economies of the integrated firms only applies as a downward bias, affecting the economies of scope negatively, if at all.

2.6 Summary and Conclusions

Our analysis of a sample of 54 railway companies from 27 European countries observed over the five-year period from 2000 to 2004 provides the first pan-European distance function approach addressing economies of scope in railways, confirming previous findings from the U.S. (Bitzan, 2003; Ivaldi and McCullough, 2004). Within a model using only physical measures, we find slight efficiency advantages for integrated companies on average and economies of scope for a majority of observations. When monetary figures – or, more precisely, operating expenses, – are included in a second model even more explicit results are produced, showing that integrated railway companies are, on average, relatively more efficient than 'virtually' integrated companies and that a majority (65 percent) of the railway companies observed indicate economies of scope.

Concerning possible explanations for the heterogeneous findings on the existence of economies of scope, our results on integrated firms from Greece, Ireland, Spain, Slovakia, Hungary, and the Czech Republic are interesting. According to a study from IBM on the opening of the rail markets in Europe in 2004 (IBM, 2004) Spain, Greece, and Ireland showed the lowest degree of market opening among all European countries. Interestingly enough, integrated firms from these countries feature diseconomies of scope or – in a broader context – low efficiency scores. For these firms, one might interpret the nominal absence of economies of scope rather as managerial inefficiency resulting from a lack of competitive pressure. To a certain extent, the diseconomies of scope or comparably low efficiency of integrated firms from Czech Republic, Hungary, and Slovakia support this hypothesis. Although these countries showed a slightly higher degree of market opening, they still were assigned to the group with a 'delayed status of market opening' (IBM, 2004). Confirming this interpretation, all integrated firms from countries that were assigned to the group being 'on schedule market opening' (Germany, Italy, and Switzerland) show economies of scope in our analysis. To sum up, a careful glance at the regulatory environment lets us suggest a reinterpretation of our empirical findings: Those integrated firms that are subject to competition do not significantly suffer from managerial inefficiency and are able to generate productivity advantages as a result of economies of scope.

However, since we also find economies of scope for integrated firms from countries, which showed a relatively low degree of market opening, other factors, such as privatization, the experience with competitive markets, or the proportion of passenger and freight transport within the total transport operations might be taken into account as well. For example, our result that the vertically integrated national railway in Estonia exhibits economies of scope could possibly be explained by its privatization in 2001.

Despite these results, the policy implications still remain ambiguous; indeed, economies of scope exist for a majority of integrated European railway companies. Future sector restructuring should take that issue into consideration to avoid increasing transaction costs unnecessarily. On the other hand, not disentangling the railway sector retains discriminatory incentives and complicates regulation. Policy makers should carefully weigh the positive and negative aspects of vertical integration in railways.

Further research on economies of scope in the European railway industry should address the character and source of economies of scope in detail; that is, answer questions related to whether economies of scope arise mainly between infrastructure and operations (vertical economies) or also between different types of operations (horizontal economies). Furthermore, future studies should consider the dynamic aspects of market liberalization and productivity development and in particular a company's regulatory environment and its experience, which could have a significant impact on relative efficiency. Finally, aspects of railway safety and quality of service should be incorporated in order to control for issues of particular importance that are probably negatively correlated with a company's level of cost.

3 Productivity Growth in European Railways: Technological Progress, Efficiency Change and Scale Effects

3.1 Introduction

In the last three decades of the 20th century the European railway sector faced severe losses of transportation market share. From 1970 to 1995 the modal split for rail passenger services and rail freight services within the EU-15 declined by more than 40 percent and almost 58 percent, respectively, compared to other transportation modes, like road, air or sea transport (European Commission, Directorate-General for Energy and Transport, 2003, 2007). This decline can be attributed to the poor performance of the national monopoly railway companies in terms of transportation times, service quality, and the lack of interoperability among the national railway systems. For these reasons and because of the high level of railway subsidies, the European national governments and the European Commission decided to introduce competitive elements into the European railway sector. Starting with Directive 91/440/ECC in 1991, several reforms have been introduced by the European Commission, with the last one, the so-called third railway package, implemented in 2007. The intention of the reforms has been to enhance competition by opening the market and to improve the efficiency and productivity of the European railway sector.

Several studies evaluating the efficiency and productivity of European railway companies can be found in the literature (for example, Oum and Yu, 1994; Gathon and Pestieau, 1995; Preston, 1996; Andrikopoulos and Loizides, 1998; Cantos et al., 1999; Cantos and Maudos, 2000; Coelli and Perelman, 2000; Loizides and Tsionas, 2002, 2004); however none of these studies evaluated productivity growth for the years 1990-2005, when the bulk of the deregulation of the European railway sector took place. In addition, none of the studies included railway companies from Eastern European countries, many of which started to reform their railway sector according to the EU deregulation policy well ahead of their EU accession.

The study which extends furthest into the main deregulation period is that of Cantos et al. (1999). Using a panel of 17 Western European state-owned railways covering the years 1970-1995 and applying a non-parametric estimation approach (data envelopment analysis), the authors evaluated technical change, efficiency change and productivity change in the European railway industry. The results indicated significant productivity gains, mainly based on technological progress between 1985 and 1995.

In order to fill the void in previous research and to determine the influence of regulatory changes upon the efficiency and productivity of Eastern and Western European railway industries, we apply a stochastic distance frontier approach for panel data, the so-called 'true' fixed effects model, developed by Greene (2004a,b, 2005). Compared to basic stochastic frontier fixed effects panel models this approach has the advantage of controlling for firm- and country-specific unobserved heterogeneity and to allow the inefficiency to vary over time. In addition, we use the generalized Malmquist productivity index approach proposed by Orea (2002) to decompose total factor productivity change into technological progress, efficiency change, and scale effects. The panel data set employed covers the years 1990-2005 and includes 31 railway companies from 22 Western and Eastern European countries. To our knowledge, this is the first productivity analysis of Eastern and Western European railway companies to include 16 of the last 18 years of deregulation and liberalization in the European railway sector and, more significantly, that accounts for unobserved heterogeneity.

The paper is organized as follows. Section 3.2 provides an overview on the European railway deregulation and presents the theoretical foundations of the decomposition of total factor productivity change. The methodology is discussed in Section 3.3. Section 3.4 introduces the modeling approach and describes the data. Estimation results are presented in Section 3.5. Section 3.6 summarizes and presents the main conclusions.

3.2 European Railway Deregulation and Productivity

Since the early 1990s the European railway sector has been subject to an incremental process of deregulation and liberalization. Starting with Directive 91/440/EEC in 1991, the deregulation policy of the European Commission has focused on:

- separation of infrastructure management from transport operations,
- implementation of interoperability among the national railway systems,
- assurance of third-party access to the infrastructure, and
- introduction of independent railway regulatory systems.

Overall, the deregulation policy consists of four major steps. The first step includes Directive 91/440/ECC, Directive 95/18/EC, and Directive 95/19/ EC, which were adopted by the European Commission in 1991 and 1995, respectively. Together these three directives implemented the first elements of separation and third-party access to the infrastructure. This entails accounting separation of infrastructure management and transport operations, access rights for third parties that provide international combined goods transport or international services between the states in which they are established, as well as common rules on the licensing of railway undertakings and allocation and charging of infrastructure capacity. Transposition of these directives into national law was compulsory for all member states not later than January 1993 and June 1997, respectively. The second step, the so-called first railway package, was implemented in 2001 and includes Directive 2001/12/EC, Directive 2001/13/EC, Directive 2001/14/EC, and Directive 2001/ 16/EC. The package amended the first directives and implemented the requirement for independent organizational entities for infrastructure and transport operations. The member states were free to decide between separate divisions within one company, that is, a holding structure, or complete institutional separation, with the infrastructure section managed by a separate entity from operations. Furthermore, it implemented accounting separation between passenger and freight transport services, extended the third-party access rights for international rail freights services operating on the Trans European Rail Freight Network (TERFN), required the establishment of independent regulatory bodies within the member states, and defined measures to enhance the interoperability between the national railway systems. The whole package had to be enacted into national law not later than March 2003. The third step, the so-called second railway package, was implemented in 2004 and includes Regulation (EC) No 881/2004, Directive 2004/49/EC, Directive 2004/50/EC, and Directive 2004/51/EC. The package amended several of the previous directives and extended the third-party access rights for international rail freights services to the whole European network beginning in January 2006, and for all kinds of rail freight services beginning in January 2007. Furthermore, it defined common safety standards, established a European Railway Agency responsible for safety and interoperability, and extended measures to enhance interoperability between the national railway systems to the trans-European high-speed rail system. The transposition deadlines for the directives were April and December 2005, respectively. The fourth step, the so-called third railway package, was implemented in 2007 and includes Regulation (EC) No 1371/2007, Directive 2007/58/EC, and Directive 2007/59/ EC. It is the first package which deals with rail passenger transport and defines the minimum quality standards for rail passenger services and introduces third party access rights for international rail passenger services beginning in January 2010. The directives have to be enacted not later than June and December 2009.[1] In general, the intention of the reforms has been to enhance competition by opening the market and to improve the economic performance of the European railway sector. In addition, promoting a competitive rail transport market, which can be less polluting than other transport modes, is expected to reduce both congestion and pollution within the next decades.

Given this concise review of the elements and aims of the deregulation policy, an analysis of the efficiency and productivity development of the companies in this sector is of great interest. Evaluating the development can provide valuable results on how the companies reacted to the several reforms and how effective the first deregulation measures have been in the sense of enhancing efficiency and productivity in the sector.

Taking a closer look on technical efficiency and productivity change in a multiple-output multiple-input industry allows the decomposition of total factor productivity (TFP) change into three factors: technical change (a production frontier shift), technical

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[1] For a detailed overview on the European railway deregulation see, for example, Holvard (2006) or visit the website of the European Commission, Directorate-General for Energy and Transport (http://ec.europa.eu/transport/rail/countries/es/admin_en.htm).

efficiency change (a catch-up to the industry's production frontier), and scale effects (an alteration of the scale of operations). Figure 3.1 displays a graphical illustration of these three factors for a production technology that uses a single input to produce a single output.

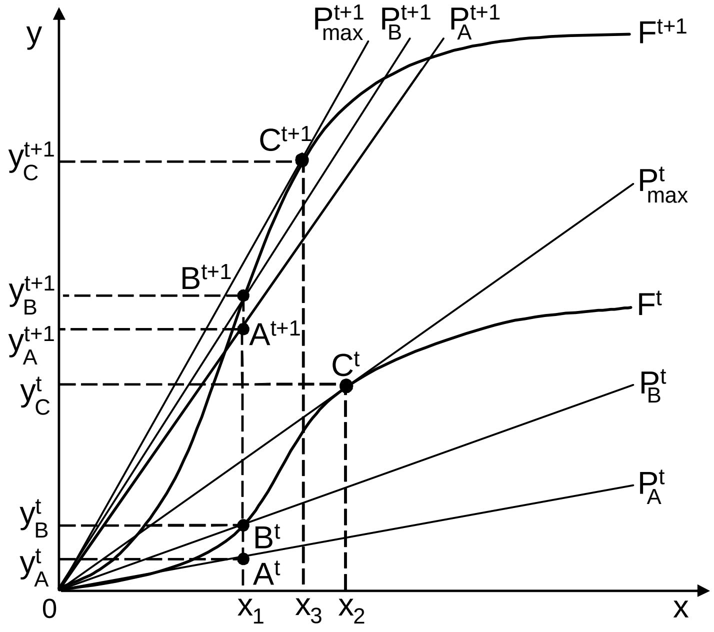

Figure 3.1: Technical Efficiency and the Decomposition of Productivity Change

First, focussing on period t the curve labeled F^t represents a variable returns to scale production frontier, that is, the maximum achievable output at each input, given a specific technology; and A^t, B^t, and C^t represent different production points. Since productivity is defined as the ratio of the outputs to the inputs, productivity at each production point can be measured by the slope of a ray through the origin and the relevant production point. For example, if a firm is operating at point B^t on the frontier it is technically efficient, whereas a firm operating at point A^t under the frontier is technically inefficient. Hence, the level of technical inefficiency can be measured by comparison of point A^t with point B^t. Furthermore, the slope of the ray at point B^t is greater than at point A^t, indicating a higher productivity at point B^t. However, the maximum possible productivity in period t is marked by point C^t, where the ray from the origin is a tangent to the production frontier F^t. Since the production frontier exhibits increasing returns to scale at any production point left of C^t and decreasing returns to scale at any production point right of C^t, a firm operating at point C^t is both technically and scale efficient. Hence, the level of scale inefficiency of a firm operating at point B^t can be measured by comparison of point C^t with point B^t. The closer a production point on the frontier is to point C^t the lower is the scale inefficiency and the higher is the productivity.

Considering the second period $t+1$, the upward shift of the production frontier F^t to the new production frontier F^{t+1} represents technical change or, in other words, technological progress. As before, A^{t+1}, B^{t+1}, and C^{t+1} mark technically inefficient, technically efficient, and both technically and scale efficient production points, respectively, with increasing productivity from the first to the last.

In terms of productivity change from one year to the next, an improvement of productivity can be the result of a single factor or a combination of three factors. For example, a firm operating in point A^t in period t moving to point A^{t+1} in period $t+1$ increased its productivity solely by technical change. Neither the scale of operations nor the distance to the respective frontier changed. If the production point of that firm moves to point B^{t+1} in period $t+1$ the productivity change is a combination of technical change and technical efficiency change. Finally, if the production point of that firm is C^{t+1} in period $t+1$ the productivity change is due to a combination of technical change, technical efficiency change, and scale effects. To summarize, firm-specific productivity change can be a result of technical change, technical efficiency change, scale effects, or a combination of all three.

Combining these theoretical aspects of decomposing TFP change with the aims of the deregulation and liberalization of the European railway sector, several hypotheses on the development and sources of productivity growth can be derived:

Hypothesis 1 Technical efficiency significantly increased in the European railway sector.

This hypothesis is supported by the fact that during the first years of deregulation most of the former state-controlled national railways gained more management independence from the state and started to developed more competitive and, hence, more efficient management structures. Furthermore, the development of employment and transportation services during the observed period shows that most railway firms significantly reduced their labor force while increasing their output level or at least keeping it constant.

Hypothesis 2 Technological progress was the main driver of productivity growth in the European railway sector.

On the one hand, this hypothesis is based on the assumption that more competition and managerial independence created incentives to develop advanced, more competitive technologies, such as high-speed railway systems, and on the other hand by developments in information technology. In particular, in infrastructure management and traffic coordination the introduction of modern computer systems should have created significant time- and labor-savings potentials.

Hypothesis 3 Scale effects only had a slight influence on productivity growth in the European railway sector.

This hypothesis is driven by the finding of most European railway studies (see, for example, Kumbhakar et al., 2007; Loizides and Tsionas, 2004) that European railways show only slight increasing or constant returns to scale. Hence, the potential for the exploitation of scale economies should have been relatively limited.

Hypothesis 4 Productivity significantly increased in the European railway sector.

The assumed positive development of technical efficiency change and technological progress should have had a positive influence on productivity growth.

3.3 Methodology

To model the multiple-output multiple-input production technology and to measure the technical efficiency of European railway firms, we apply an input distance function approach introduced by Shephard (1953, 1970). Compared to other representations of technologies, such as cost or revenue functions, this approach requires no specific behavioral objectives, such as cost minimization or profit maximization, which are likely to be violated in the case of partly state-owned and highly regulated industries like European railways (Coelli and Perelman, 2000).

Distance functions can be input- or 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 firms have a higher influence on the usage of inputs than on outputs. This assumption is supported by the substantial proportion of state-controlled public transport requirements within rail 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).[2]

An input distance function measures how much the input usage can be proportionally reduced given a fixed output vector. Assuming that the technology satisfies the standard properties of economic theory (see, for example, Färe and Primont, 1995) the distance function can be defined as:

$$D_I(x, y, t) = \max\{\theta : (x/\theta) \in L(y)\}, \tag{3.1}$$

where the input set $L(y)$ represents the set of all input vectors x that can produce the output vector y; t is a time trend introduced to account for technical change; and θ measures the proportional reduction of the input vector x. The function is non-decreasing,

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[2] 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.

linearly homogeneous and concave in x, and non-increasing and quasi-concave in y (Coelli et al., 2005). From $x \in L(y)$ follows $D_I(x, y, t) \geq 1$.

Figure 3.2 illustrates an input distance function for the case of two inputs x_1 and x_2.[3] $L(y)$ represents the area of all feasible input vectors x that can produce the output vector y. The area is bounded below by the isoquant Isoq-$L(y)$, which reflects all minimum inputs combinations that can produce the output vector y. That means, the isoquant is the best-practice production frontier. Input vectors that belong to the frontier have an input distance function value equal to unity while all other feasible input vectors located above the frontier have an input distance function value greater than unity. For example, the input vector x (marked as B in Figure 3.2) can produce the output vector y, but y can also be produced with the smaller input vector x/θ (marked as A). Thus, the value of the input distance function at point B is $D_I(x, y, t) = 0B/0A = \theta > 1$. In other words, the input distance function measures how efficient a firm uses a vector of inputs to produce a fixed vector of outputs.

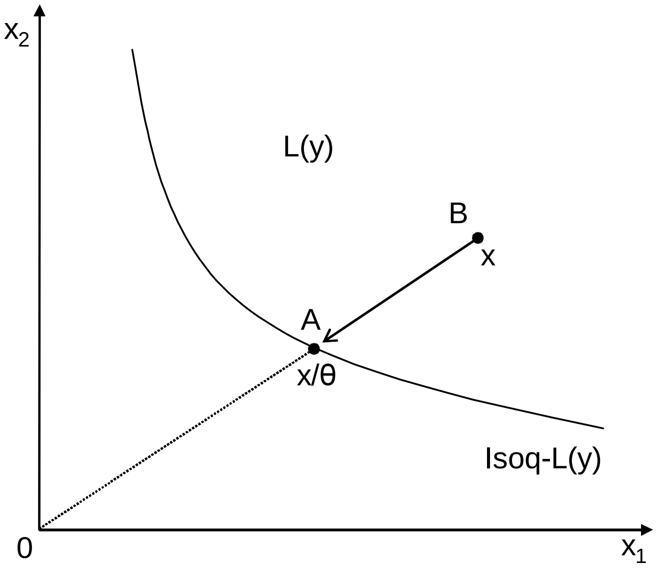

Figure 3.2: Technical Efficiency and the Input Distance Function

This concept is closely related to Farell's (1957) measure of input technical efficiency, which defines technical efficiency at point B as:

$$TE(x, y, t) = 0A/0B = 1/\theta = [D_I(x, y, t)]^{-1} < 1. \tag{3.2}$$

The input-oriented technical efficiency measure is the reciprocal of the input distance function. Technical efficiency values equal to unity identify efficient firms using an input

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[3] Figure 3.2 and its description follow Coelli et al. (2005) and Kumbhakar and Lovell (2000).

vector located on the production frontier. Technical efficiency values between zero and unity belong to inefficient firms using an input vector above the frontier.

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).

The translog input distance function for K (k=1,...,K) inputs and M (m=1,...,M) outputs can be written as:

$$\begin{aligned} ln\, D_{it}^{I} \;=\; & \alpha_0 + \sum_{m=1}^{M} \alpha_m \, ln\, y_{mit} + \frac{1}{2} \sum_{m=1}^{M} \sum_{n=1}^{M} \alpha_{mn} \, ln\, y_{mit} \, ln\, y_{nit} + \sum_{k=1}^{K} \beta_k \, ln\, x_{kit} \\ & + \frac{1}{2} \sum_{k=1}^{K} \sum_{l=1}^{K} \beta_{kl} \, ln\, x_{kit} \, ln\, x_{lit} + \sum_{k=1}^{K} \sum_{m=1}^{M} \theta_{km} \, ln\, x_{kit} \, ln\, y_{mit} \\ & + \phi_t \, t + \frac{1}{2} \phi_{tt} \, t^2 + \sum_{m=1}^{M} \psi_{mt} \, ln\, y_{mit} \, t + \sum_{k=1}^{K} \lambda_{kt} \, ln\, x_{kit} \, t + \delta_z \, z_{it}, \end{aligned} \tag{3.3}$$

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 input and output quantity, respectively; z_{it} is a network characteristic; and $\alpha, \beta, \theta, \phi, \psi, \lambda$, and δ 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

$$\alpha_{mn} = \alpha_{nm}, \quad (m, n = 1, 2, ..., M) \quad \text{and} \quad \beta_{kl} = \beta_{lk}, \quad (k, l = 1, 2, ..., K), \tag{3.4}$$

and homogeneity of degree +1 in inputs is given if

$$\sum_{k=1}^{K} \beta_k = 1, \quad \sum_{l=1}^{K} \beta_{kl} = 0, \quad \sum_{k=1}^{K} \theta_{km} = 0, \quad \text{and} \quad \sum_{k=1}^{K} \lambda_{kt} = 0. \tag{3.5}$$

The estimation method used in this paper is stochastic frontier analysis (SFA), simultaneously introduced by Aigner et al. (1977) and Meeusen and van den Broeck (1977). SFA is a parametric method which estimates a production or distance 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. In contrast 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.

In order to account for the panel structure of our data and unobserved firm-specific heterogeneity we apply the 'true' fixed effects (TFE) model recently proposed by Greene

(2004a,b, 2005). In contrast to the basic fixed effect SFA model (Schmidt and Sickles, 1984) the TFE model allows the inefficiency to vary over time and controls for firm-specific unobserved heterogeneity that is unrelated to inefficiency. Basically, the model adds a full set of firm dummy variables to the SFA model that, if included in a loglinear production function, cause a firm-specific neutral shift of the function (Greene, 2004b).

One limitation of this model is that any time-invariant inefficiency is absorbed by the firm-specific fixed effects. Hence, for short panels with presumably constant efficiency over time, the model estimates unreliable inefficiency terms and, thus, its application would be inappropriate (Saal et al., 2007). Furthermore, as the number of estimated parameters increases with the sample size the 'incidental parameter' problem arises in short panels, yielding inconsistent estimates of the firm-specific fixed effects and therefore of the inefficiency component (Greene, 2004a, 2005).[4]

However, since our panel set covers a relatively long time period of 16 years in which the European railway sector was subject to a substantial restructuring process and a variety of regulatory reforms, we follow Saal et al. (2007) and assume time-variant inefficiency. In this case the firm-specific fixed effects capture time-invariant firm-specific characteristics not specifically controlled for in the model rather than time-invariant inefficiency. Furthermore, the sample size of 31 railways companies form 22 countries, observed over 16 years should overcome the 'incidental parameter' problem, and therefore provide consistent estimators.[5]

Altogether, imposing the homogeneity restrictions in Equation 3.5 by normalizing the translog input distance function in Equation 3.3 by one of the inputs (Lovell et al., 1994), the TFE model is defined as:[6]

$$\begin{aligned} -\,ln\, x_{Kit} \;=\;& \alpha_i + \sum_{m=1}^{M} \alpha_m \, ln\, y_{mit} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M} \alpha_{mn}\, ln\, y_{mit}\, ln\, y_{nit} + \sum_{k=1}^{K-1} \beta_k \, ln\, x^*_{kit} \\ & + \frac{1}{2}\sum_{k=1}^{K-1}\sum_{l=1}^{K-1} \beta_{kl}\, ln\, x^*_{kit}\, ln\, x^*_{lit} + \sum_{k=1}^{K-1}\sum_{m=1}^{M} \theta_{km}\, ln\, x^*_{kit}\, ln\, y_{mit} \qquad (3.6) \\ & + \phi_t\, t + \frac{1}{2}\phi_{tt}\, t^2 + \sum_{n=1}^{M} \psi_{mt}\, ln\, y_{mit}\, t + \sum_{k=1}^{K-1} \lambda_{kt}\, ln\, x^*_{kit}\, t + \delta_z\, z_{it} - ln\, D^I_{it}, \end{aligned}$$

where $x^*_{kit} = (x_{kit}/x_{Kit})$. Replacing the negative log of the distance term $-ln\, D^I_{it}$ with a composed error term $\varepsilon_{it} = v_{it} - u_{it}$ yields a standard normal-half normal SFA model. That is, v_{it} is the i.i.d. normally distributed random error term that captures measurement error ($v_{it} \sim iidN(0, \sigma^2_v)$), and u_{it} is the i.i.d. half-normally distributed non-negative

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[4] In his 2005 paper Greene considers a panel set of five years as small.

[5] An alternative estimation approach could have been the 'true' random effects model, also proposed by Greene (2004a,b, 2005). However, a conducted hausman test strongly rejects the hypothesis that the firm-specific effects are uncorrelated with the regressors. In this case random effects models produce biased estimators and the use of a fixed effects model is more appropriate.

[6] The symmetry restrictions in Equation 3.4 are imposed in estimation.

time-varying inefficiency term ($u_{it} \sim iidN^{+}(0, \sigma_u^2)$). Furthermore, the error terms are assumed to be independently distributed from each other. Finally, replacing the single intercept parameter α_0 in Equation 3.3 with the firm-specific parameters α_i extents the standard SFA model to the TFE model that accounts for unobserved firm-specific heterogeneity.

The model estimates are obtained by maximum likelihood estimation. Since only the composed error term $\epsilon_{it} = v_{it} - u_{it}$ is observed, the method of Jondrow et al. (1982) is used, to obtain point estimates of u_{it} (Greene, 2004b):

$$E(u_{it}|\varepsilon_{it}) = \frac{\sigma\lambda}{1+\lambda^2}\left[a_{it} + \frac{\phi(a_{it})}{\Phi(a_{it})}\right], \tag{3.7}$$

where $\sigma = (\sigma_u^2 + \sigma_v^2)^{1/2}$; $\lambda = \sigma_u/\sigma_v$; $a_{it} = -\lambda\varepsilon_{it}/\sigma$; and $\phi(a_{it})$ and $\Phi(a_{it})$ represent the standard normal density and cumulative distribution evaluated at a_{it}, respectively. Measures of technical efficiency (TE_{it}) for each firm in each time period can then be calculated as:

$$TE_{it} = exp\{-E(u_{it}|\varepsilon_{it})\}. \tag{3.8}$$

The calculated 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 λ-parameter represents the relative contribution of the inefficiency and noise component to the total error term. If $\lambda \to 0$ all deviations from the best-practice frontier are due to noise, and if $\lambda \to +\infty$ all deviations from the best-practice frontier are due to inefficiency. In the former case using a standard estimation model (for example, ordinary least squares) with no technical inefficiency would be appropriate, whereas in the latter case a deterministic frontier with no noise results (Kumbhakar and Lovell, 2000).

Once the input distance function has been estimated, the parameter estimates can be used to calculate the TFP change. Furthermore, following the generalized Malmquist productivity index approach proposed by Orea (2002), TFP change can be decomposed into a technical efficiency change component, a technical change component and a scale effect component.

According to Coelli et al. (2003), who illustrate this approach for an input distance function, TFP change for the i-th firm between the periods t and $t+1$ is calculated as:

$$\begin{aligned} ln\,(TFP_{it+1}/TFP_{it}) &= [ln\,(TE_{it+1}/TE_{it})] \\ &+ \frac{1}{2}\left[(\delta\, lnD_{it+1}/\delta\, t) + (\delta\, lnD_{it}/\delta\, t)\right] \\ &+ \frac{1}{2}\sum_{m=1}^{M}\left[(SF_{it+1}\,\varepsilon_{mit+1} + SF_{it}\,\varepsilon_{mit})\,(ln\,y_{mit+1} - ln\,y_{mit})\right], \end{aligned} \tag{3.9}$$

where the three terms on the right indicate the technical efficiency change, the technical change, and the scale effect, respectively. As shown, technical efficiency change is simply calculated by the log of the ratio of the technical efficiency scores for the i-th firm in the periods $t+1$ and t.

Technical change is measured by the mean of the partial derivatives of the input distance function with respect to time evaluated at the period $t+1$ and t data points. Given Equation 3.3 the partial derivative with respect to time for the i-th firm in the t-th period is:

$$\delta\, lnD_{it}/\delta\, t \;=\; \phi_t + \phi_{tt}\, t + \sum_{m=1}^{M} \psi_{mt}\, ln\, y_{mit} + \sum_{k=1}^{K} \lambda_{kt}\, ln\, x_{kit}. \tag{3.10}$$

The scale effect measure requires the calculation of output elasticities at the period $t+1$ and t data points. Given Equation 3.3 the output elasticity for each output for the i-th firm in the t-th period is:

$$\varepsilon_{mit} \;=\; \delta\, lnD_{it}/\delta\, ln\, y_{mit} = \alpha_m + \sum_{m=1}^{M} \alpha_{mn}\, ln\, y_{mit} + \sum_{k=1}^{K} \theta_{km}\, ln\, x_{kit} + \psi_{mt}\, t. \tag{3.11}$$

Furthermore, the input distance scale factor (SF_{it}) for the i-th firm in the t-th period is calculated as:

$$SF_{it} = \left(\sum_{m=1}^{M} \varepsilon_{mit} + 1 \right) \Bigg/ \sum_{m=1}^{M} \varepsilon_{mit} = 1 - RTS_{it}, \tag{3.12}$$

where RTS_{it} is the scale elasticity for the i-th firm in the t-th period. For an input distance function RTS_{it} is equal to the negative of the inverse of the sum of the output elasticities (Färe and Primont, 1995):

$$RTS_{it} = -\left(1 \Bigg/ \sum_{m=1}^{M} \varepsilon_{mit} \right). \tag{3.13}$$

Thus, if constant returns to scale are given, $RTS = 1$, the SF as well as the scale effect will equal 0. In this case the generalized Malmquist productivity index in Equation 3.9 is reduced to the standard Malmquist productivity index, decomposing TFP change into technical efficiency change and technical change only. In contrast, if increasing (decreasing) returns to scale, $RTS > 1$ ($RTS < 1$), are given, the SF is negative (positive), and the scale effect evaluates the contribution of scale changes on TFP change (Saal et al., 2007).

3.4 Modeling Approach and Data Description

The data set used in this paper consists of 31 railway firms from 22 European countries observed from 1990 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, including 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 (NERA Economic Consulting, 2004).

The sample is limited to the incumbent railway firms or their legal successors. Some countries separated the infrastructure from transport operations. For example, in the Netherlands, the infrastructure is managed by Prorail while freight and passenger transportation is provided by Nederlandse Spoorwegen (NS).[7] 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 352 observations having full data coverage and the lower number of 318 de facto observations resulting from missing data.

To estimate the multiple-output multiple-input production technology, we use two input variables and two output variables. The *number of employees* (emp) (annual mean) and the *number of rolling stock* (roll) are used as physical measures for labor and capital input.[8] Since revenues for passenger transportation depend on the number of passengers and the distance traveled, we measure the passenger service output using the variable *passenger-km (pkm).* Accordingly, freight transportation revenues depend on the amount and distance of tonnes transported. Hence, we measure the freight service 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 and regulatory restrictions on allocation into account.

In addition, we use *network density* (netden) (network length in km/area km^2) as a network characteristic. High density networks have a more complex shape than less dense networks and are usually located in areas with higher population density (Farsi et al., 2005). Therefore, this variable should reflect the impact of differences in network structure and density on the production process and, hence, on the input requirements.[9]

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[7] 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.

[8] 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.

[9] We tried other model specifications, for example, including network length as a third input variable or using additional network characteristics, such as percentage of electrified lines of the total network length. However, the estimated coefficients of the input distance function revealed some unexpected

Following Saal et al. (2007), the network density variable is introduced in a linear non-interactive way into the input distance function. By this specification it influences the input distance function estimates, but does not appear in the TFP calculation and the TFP decomposition.

As can be seen in Table 3.1, all variables show a significant amount of variation. This is because our sample covers a wide range of firm sizes and firms with different key activities. For example, the network length of the largest railway company in Europe, Germany's Deutsche Bahn (DB), is more than 130 times longer than that of the smallest railway company, Chemins de Fer Luxembourgeois (CFL) in Luxembourg. Furthermore, while some railway firms mainly provide freight services, others concentrate on passenger services, and still others have an equal relation between freight and passenger services. In addition, a significant part of the variation is a function of time. For example, from 1990 to 2005 the average number of employees decreased by almost 14 percent, while in the same time the average amount of passenger-km increased by more than 15 percent.

The last column in Table 3.1 presents the fraction of within variation of the overall variation for the main variables used in the estimations. The figures indicate that most variables show a significant fraction of within variation. Only for network density the fraction of within variation is relatively low. Altogether, the descriptive statistics indicate that the used variables show a reasonable between and within variation, supporting the use of panel data models and in particular the use of a TFE model.[10]

Table 3.1: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max	Variable	Fraction of within variation[a]
Number of rolling stock (10^3)	45.92	60.47	1.69	306.29	$-\,ln\,roll$	0.17
Number of employees (10^3)	60.31	72.78	3.03	355.69	$ln(emp/roll)$	0.42
Passenger-km (10^9)	13.93	19.79	0.21	76.16	$ln\,pkm$	0.16
Tonne-km (10^9)	15.67	19.33	0.29	83.98	$ln\,pkm$	0.11
Network density (10^{-1})	0.59	0.31	0.17	1.21	$netden$	0.08

[a] Within variation represents the standard deviation of firm observations from the firm's average $(X_{it} - \bar{X}_i)$. The fraction of within variation is defined as the ratio of within to overall standard deviation (Farsi et al., 2005). Source: Union Internationale des Chemins de Fer (UIC) (2004, 2005, 2006), annual reports, company statistics.

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signs and statistical significance as well as wrong curvature characteristics, probably caused by multicollinearity problems due to the strong correlation between some inputs and the included network characteristics.

[10] As stated by Kuenzle (2005), the TFE estimator is not a within estimator as in the basic FE model. Therefore, it does not solely rely on within variation. Nevertheless, Farsi and Filippini (2006) note that from their experience models that separate time-variant inefficiency from time-invariant heterogeneity, such as the TFE model, are numerically unstable or not feasible in cases with low within variation.

3.5 Results

The estimated parameters for the translog input distance function defined in Equation 3.6 are presented in Table 3.2. First, focussing on the functional form, the conducted likelihood-ratio tests reject the hypotheses – that the Cobb-Douglas functional form is a better representation of the data, that no technical change occurs, and that a Hicks neutral technical change occurs – at the 1 percent level of significance. Hence, the translog stochastic production frontier with non-neutral technical change defined in Equation 3.6 is an adequate representation of the data. Furthermore, the statistically significant coefficient of λ indicates that inefficiency effects are present in the model. This confirms the assumption that a standard estimation model with no technical inefficiency would not be appropriate.

Table 3.2: Estimation Results of the Input Distance Function[a,b]

Variable	Parameter	Coef.	T-ratio	Variable	Parameter	Coef.	T-ratio
$ln\,pkm$	α_1	-0.317^{***}	-20.48	*Sigma*	σ	0.466^{***}	34.61
$ln\,tkm$	α_2	-0.602^{***}	-25.49	*Lambda*	λ	2.681^{***}	11.53
$0.5 \cdot (ln\,pkm)^2$	α_{11}	0.004	0.25				
$0.5 \cdot (ln\,tkm)^2$	α_{22}	-0.290^{***}	-18.25	Log-likelihood function		90.65	
$ln\,pkm \cdot ln\,tkm$	α_{12}	0.101^{***}	7.67				
$ln(emp/roll)$	β_1	0.199^{***}	3.95	RTS (sample average firm)		1.088	
$0.5 \cdot (ln(emp/roll))^2$	β_{11}	2.277^{***}	8.72				
$ln(emp/roll) \cdot ln\,pkm$	θ_{11}	-0.252^{***}	-5.73				
$ln(emp/roll) \cdot ln\,tkm$	θ_{12}	0.021	0.51				
t	ϕ_t	0.025^{***}	10.51	Likelihood-ratio tests		Value	
$0.5 \cdot t^2$	ϕ_{tt}	-0.000	-0.47				
$ln\,pkm \cdot t$	ψ_{1t}	0.007^{***}	3.08	H_0: Cobb Douglas		49.29	Reject
$ln\,tkm \cdot t$	ψ_{2t}	-0.004	-1.60	H_0: No technical change		54.43	Reject
$ln(emp/roll) \cdot t$	λ_{1t}	-0.023^{***}	-2.91	H_0: Neutral technical change		168.56	Reject
$netden$	δ_1	-0.375^{***}	-32.17				

[a] The number of rolling stock has been used as the numeraire; therefore, the dependent variable is $-\,ln\,roll$. [b] All estimates are obtained by using 'Limdep 8.0'. ***Significant on the 1%-level.

As each variable is normalized by its sample mean, the first-order coefficients can be interpreted as distance elasticities at the sample mean. All first-order coefficients are statistically significant at the 1 percent level and have the expected signs. In other words, the estimated input distance function is decreasing in outputs and increasing in inputs. Furthermore, the negative of the inverse of the sum of the first-order output coefficients is 1.088, indicating slight increasing returns to scale at the sample average firm, as observed in the majority of railway studies. Evaluating the returns to scale on the firm-specific level provides similar results. The average and median value of returns to scale are 1.178 and 1.112, respectively, and 73 percent of all observations reveal increasing returns to scale.

The input elasticities reflect the relative importance of each input in the production process. The estimated coefficient of labor (employees) elasticity (β_1) is used to calculate the capital (rolling stock) elasticity via the homogeneity restriction presented in Equation 3.5. The coefficients of labor and capital elasticities are found to be equal to 0.199 and 0.801, respectively, implying a high capital intensity of the European railway sector. The first-order coefficient of time (t) is 0.025 and indicates a rate of technical change of 2.5 percent for the sample average firm in the mid year of the sample.[11] Referring to the cross term of employees and time, the statistically significant and negative coefficient of λ_{1t} suggests a decline in the labor elasticity over time and, hence, implies non-neutral labor-saving technical change. Finally, the statistically significant and negative coefficient of network density (δ_1) indicates that an increase in network density leads to an increase in input requirements.

The development of technical efficiency over time derived from the input distance function estimates is illustrated in Figure 3.3. Average and median technical efficiency scores show a relatively continuous increase, with average efficiency increasing by 10.8 percent from 0.74 in 1990 to 0.82 in 2005. Moreover, the development of minimum efficiency scores reveals significant catch-up effects, in particular within the early and mid-1990s. From 1990 to 2005 minimum efficiency increased by almost 70 percent form 0.39 to 0.66, while maximum efficiency decreased by around 4 percent from 0.93 to 0.89 in the same period. Overall, the difference between the minimum and maximum technical efficiency scores significantly decreased from 0.54 in 1990 to 0.23 in 2005, suggesting a convergence of technical efficiency levels within the European railways sector over time.

The results of the TFP change decomposition calculated from the estimates of the input distance function by employing the generalized Malmquist productivity index approach described in Equation 3.9 are reported in Table 3.3 and Figure 3.4. Table 3.3 displays the average growth rates of TFP and its components per year, whereas Figure 3.4 illustrates cumulative indices of average TFP growth, technical efficiency change, technical change, and scale effects, relative to the base year of 1990.

First, focussing on average technical efficiency change, it can be seen, that the development from one year to the next is quite volatile. Only between 1992 and 1995 is a persistent positive development shown. However, the cumulative average efficiency change index indicates an overall positive impact of technical efficiency change on average TFP growth. In the 1992-1997 period, right after the adoption of the first railway deregulation directive, the index shows an average TFP growth of 6 percent due to efficiency gains, compared to the base year of 1990. After that, the index fell to 102 in 2001 and finally increased again to 107 in 2005. Thus, our first hypotheses that technical efficiency significantly increased within the European railway sector is confirmed.

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[11] As noted by Saal et al. (2007), these technical change estimates are for a nonexistent hypothetical sample average firm with unchanging characteristics. Hence, they do not account for changes in inputs and outputs and should be interpreted with caution.

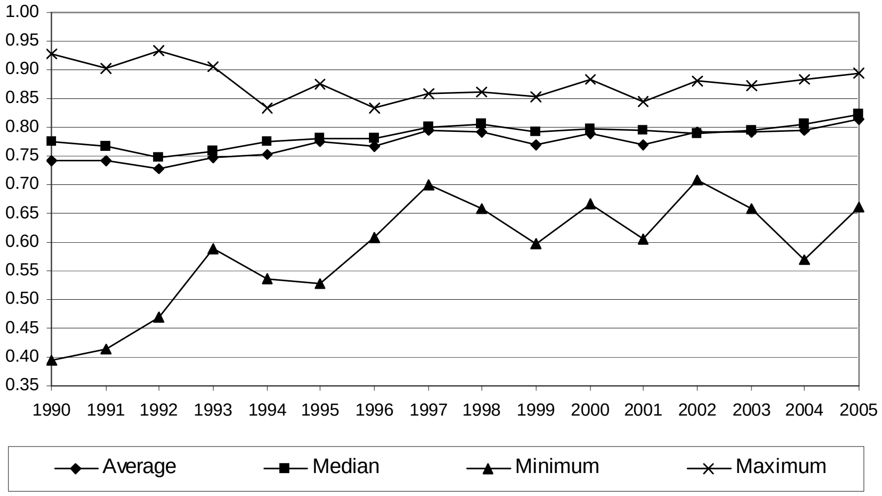

Figure 3.3: Development of Technical Efficiency Scores, 1990-2002

Table 3.3: Average Growth Rates of TFP and its Components (in %)

	Efficiency change	Technical change	Scale effect	TFP growth
1990-1991	0.58	2.16	0.71	3.44
1991-1992	-3.24	2.18	0.45	-0.60
1992-1993	1.94	2.17	-0.73	3.39
1993-1994	0.72	2.13	1.01	3.86
1994-1995	3.00	2.14	0.34	5.48
1995-1996	-0.79	2.09	-0.15	1.15
1996-1997	3.74	2.03	0.54	6.31
1997-1998	-0.42	1.98	0.42	1.98
1998-1999	-2.97	1.89	0.22	-0.87
1999-2000	1.36	1.78	0.38	3.53
2000-2001	-2.34	1.78	0.16	-0.40
2001-2002	3.10	1.74	0.05	4.89
2002-2003	-0.07	1.68	-1.33	0.28
2003-2004	-0.20	1.61	0.15	1.56
2004-2005	2.54	1.62	0.81	4.98

In contrast to the uneven development of average technical efficiency change, average technical change was always positive, though with a declining growth rate. The cumulative average technical change index shows an average TFP growth of 29 percent due to technological progress over the whole observed period. This value is more than four times higher than the average TFP growth due to efficiency gains and confirms our second hypotheses, that technological progress was the main driver of productivity growth

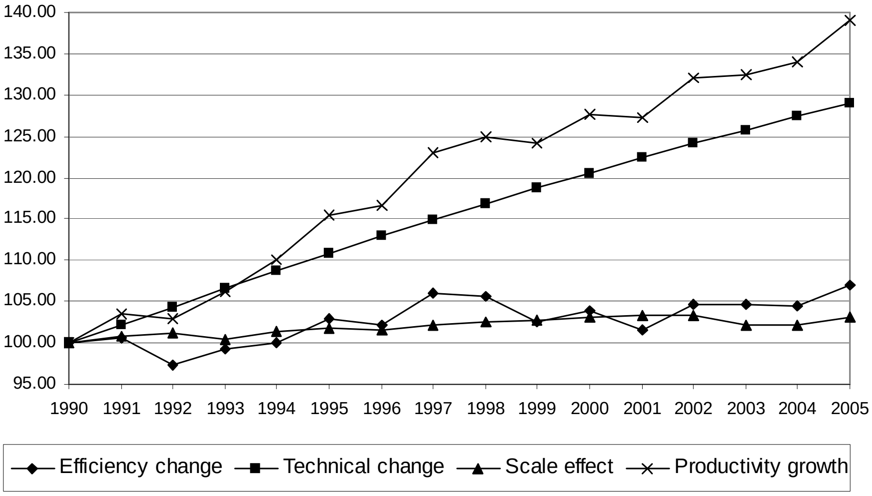

Figure 3.4: Cumulative Indices of Average TFP Growth and its Components

within the European railway sector in the observed period.

Our third hypothesis, that scale effects only had a slight influence on productivity growth, is likewise confirmed. The cumulative average scale effect index indicates a small positive influence of scale effects on average TFP growth of about 3 percent over the whole observed period. Given the estimated slight increasing returns to scale at the sample average firm, this result was to be expected.

Finally, due to the significant improvement of technological development and technical efficiency, average productivity significantly increased in the European railway sector. Considering the per year development, negative values of TFP growth are only shown for three periods, provoked by a negative development of average technical efficiency in the respective periods. The cumulative average TFP growth index indicates an average productivity growth of 39 percent over the whole observed period. Thus, our fourth and final hypothesis is confirmed.

3.6 Summary and Conclusions

In this study we analyzed the performance of the European railway sector for the years 1990-2005. In this period numerous deregulation and liberalization steps were introduced with the aim to enhance competition by opening the market and to improve the sector's efficiency and productivity. Based on a stochastic frontier model for panel data that accounts for firm-specific heterogeneity (TFE model) we estimated a translog input distance function to investigate technical efficiency and TFP change. Furthermore, we used a generalized Malmquist index approach to decompose TFP change into different components: technological progress, efficiency change, and scale effects.

In terms of efficiency comparison, our results indicate a convergence of the firm-specific technical efficiency levels over time. The difference between the minimum and maximum technical efficiency scores almost halved from 1990 to 2005. This effect primarily was a result of significant catch-up effects of the low performers in the early and mid-1990s. Our results for TFP change indicate that improvements in technology were by far the most important driver of productivity growth, though this declined over time. Over the observed period, average TFP grew by 29 percent due to technological progress. In comparison, technical efficiency change and scale effects, respectively, only contributed 7 percent and 3 percent to the evolution of average TFP. Taken as a whole, our results imply a 39 percent increase of average TFP for the European railway sector in the 1990-2005 period. Thus, the aim of the European railway deregulation and liberalization seems to have been met.

Due to different methodological approaches, sample periods, and variable definitions, the possibility of comparing our results with previous research is quite limited. Gathon and Pestieau (1995) analyzed efficiency and productivity of 19 European railways covering the years 1961-1988. By applying a stochastic production frontier model that includes cross-effects between time and inputs in a translog production function they decomposed productivity change into a technical efficiency change and a technical change component. Consistent with our results, their findings suggested that an increase of railway companies' productivity is mainly driven by technological progress and only to a lesser extent by technical efficiency change. However, one drawback of their study is that they used an aggregated output measure for freight and passenger transport services, neglecting the multiple-output production technology of railway services.

Similar results were obtained by Cantos and Maudos (2000), who estimated a stochastic cost frontier model for a sample of 15 European railways covering the years 1970-1990. Decomposing TFP change into a cost efficiency change, scale change, and technical change component, they found technical changes to be the main source of railway companies' productivity gains, followed by cost efficiency changes and, to a lesser extent, scale changes. However, as opposed to our output definition they used passenger train-km and freight train-km as output measures.

Probably, the most comparable study to our own in terms of methodology, sample period, and variable definition is that of Cantos et al. (1999). Using a sample of 17 European railways covering the years 1970-1995, the authors applied a non-parametric estimation approach (data envelopment analysis) to estimate and decompose TFP change into technical efficiency change and technical change by the means of the Malmquist productivity index. Consistent with our results, the authors found significant TFP gains, which are mainly based on technological progress and occur between 1985 and 1995.

The contribution of our study is twofold. First, the sample period covers 16 of the last 18 years of deregulation and liberalization in the European railway sector. Furthermore, for the first time, railways companies of Eastern European countries are included in a productivity growth analysis of European railways. To our knowledge this is the most up-to-date data base used in this kind of study.

Second, we account for presumably high unobserved firm- and country-specific heterogeneity within a cross-country sample by using an innovative TFE estimation approach recently proposed by Greene (2004a,b, 2005). In addition, the usage of a distance function approach in combination with the generalized Malmquist index approach proposed by Orea (2002) allows to account for the multiple-output multiple-input technology of railways services and to calculate productivity influencing scale effects.

Finally, some limitations of our study and aspects for further research should be noted. 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. Similar problems apply to the incorporation of quality and safety aspects. At least on a cross-country basis there is as yet no consistent data available. Since both quality and safety are important issues for the development of railway services over time, they should be considered in future data collection and research.

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

4.1 Introduction

Since the early 1990s, the European railway sector has undergone a major deregulation and liberalization 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 deregulation and liberalization process has focused on market opening by granting non-discriminatory access to the 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 United Kingdom, 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 United Kingdom, 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 directives of the

European Commission.

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 1970-1995 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 productivity, mainly based on technical progress between 1985 and 1995. Furthermore, 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 multiple-output multiple-input 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 4.2 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 4.3. Section 4.4 introduces the modeling approach and describes the data. Estimation results are presented in Section 4.5. Section 4.6 summarizes, concludes, and highlights directions for further research.

4.2 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 deregulation and 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 4.1 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 percent from 73.4 percent to 79.5 percent, the modal split for rail declined by more than 40 percent, from 10.4 percent to 6.2 percent. For buses and coaches, as well as tram and metro, the modal split decreased by 32.8 percent and 42.1 percent, respectively. In contrast, air passenger transport increased 187.5 percent in modal split. In 2000, the 5.8 percent modal split for air passenger transport nearly reached the modal split for rail of 6.2 percent.

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 percent, from 20.1 percent to 8.2 percent. Within the same period, the modal split of the other two major players, road and sea transport, increased by 24.3 percent and 22.5 percent, respectively. By 2000, these two forms of transport already provided transport equalling more than 80 percent of the total freight transport.

Altogether, before deregulation 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 percent) in the freight transport sector.

Table 4.1: Passenger and Freight Transport - Modal Split for EU–15 (in %)[a]

	Passenger transport					Freight transport				
	Cars	Rail	Buses and Coaches	Tram and Metro	Air	Road	Rail	Inland waterways	Pipelines (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 (2003, 2007).

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 deregulation and liberalization process in European railways. Table 4.2 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,
- 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.

Table 4.2: 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 4.2: 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 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).

However, the positive or negative impact of the individual reforms – particularly vertical separation and institutional separation – on efficiency is not clear-cut. On the 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 (see, for example, 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 still exhibit a lower economic and technological development, they can be expected to show lower railway efficiency levels.

4.3 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. Furthermore, 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 than on 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, for example, Färe and Primont, 1995) the distance function can be defined as:

$$D_I\left(x, y\right) = \max\{\theta : (x/\theta) \in L\left(y\right)\}, \tag{4.1}$$

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

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[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.

function is non-decreasing, linearly homogeneous and concave in x, and non-increasing an quasi-concave 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).

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

$$\begin{aligned} ln\, D_{it}^{I} &= \alpha_0 + \sum_{m=1}^{M} \alpha_m \, ln\, y_{mit} + \frac{1}{2} \sum_{m=1}^{M} \sum_{n=1}^{M} \alpha_{mn} \, ln\, y_{mit} \, ln\, y_{nit} + \sum_{k=1}^{K} \beta_k \, ln\, x_{kit} \\ &\quad + \frac{1}{2} \sum_{k=1}^{K} \sum_{l=1}^{K} \beta_{kl} \, ln\, x_{kit} \, ln\, x_{lit} + \sum_{k=1}^{K} \sum_{m=1}^{M} \theta_{km} \, ln\, x_{kit} \, ln\, y_{mit} \qquad (4.2) \\ &\quad + \phi_t \, t + \frac{1}{2} \phi_{tt} \, t^2 + \sum_{m=1}^{M} \psi_{mt} \, ln\, y_{mit} \, t + \sum_{k=1}^{K} \lambda_{kt} \, ln\, x_{kit} \, t, \end{aligned}$$

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 $\alpha, \beta, \theta, \phi, \psi$, and λ 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

$$\alpha_{mn} = \alpha_{nm}, \quad (m, n = 1, 2, ..., M) \quad \text{and} \quad \beta_{kl} = \beta_{lk}, \quad (k, l = 1, 2, ..., K,), \qquad (4.3)$$

and homogeneity of degree +1 in inputs is given if

$$\sum_{k=1}^{K} \beta_k = 1, \quad \sum_{l=1}^{K} \beta_{kl} = 0, \quad \sum_{k=1}^{K} \theta_{km} = 0, \quad \text{and} \quad \sum_{k=1}^{K} \lambda_{kt} = 0. \qquad (4.4)$$

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. In contrast 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.

Imposing the homogeneity restrictions in Equation 4.4 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:[2]

$$\begin{aligned}
-\ln x_{Kit} \;=\;& \alpha_0 + \sum_{m=1}^{M} \alpha_m \ln y_{mit} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M} \alpha_{mn} \ln y_{mit} \ln y_{nit} + \sum_{k=1}^{K-1} \beta_k \ln x^*_{kit} \\
&+ \frac{1}{2}\sum_{k=1}^{K-1}\sum_{l=1}^{K-1} \beta_{kl} \ln x^*_{kit} \ln x^*_{lit} + \sum_{k=1}^{K-1}\sum_{m=1}^{M} \theta_{km} \ln x^*_{kit} \ln y_{mit} \\
&+ \phi_t\, t + \frac{1}{2}\phi_{tt}\, t^2 + \sum_{n=1}^{M} \psi_{mt} \ln y_{mit}\, t + \sum_{k=1}^{K-1} \lambda_{kt} \ln x^*_{kit}\, t - \ln D^I_{it},
\end{aligned} \tag{4.5}$$

where $x^*_{kit} = (x_{kit}/x_{Kit})$. Replacing the negative log of 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

$$\mu_{it} = \delta_0 + \sum_{s=1}^{S} \delta_s\, z_{sit}, \tag{4.6}$$

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

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[2] The symmetry restrictions in Equation 4.3 are imposed in estimation.

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):

$$\begin{aligned} TE_{it} &= E\left[\, exp\,(-u_{it})|\, \epsilon_{it}\,\right] \\ &= \left\{ exp\left[-\mu_{it} + \frac{1}{2}\,\sigma_*^2\right]\right\} \cdot \left\{\Phi\left[\frac{\mu_{it}}{\sigma_*} - \sigma_*\right] \Big/ \Phi\left[\frac{\mu_{it}}{\sigma_*}\right]\right\}, \end{aligned} \tag{4.7}$$

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 (for example, ordinary least squares) would be appropriate.

4.4 Modeling Approach and Data Description

The data set, presented in Table 4.3, consists of 31 railway firms from 22 European countries observed 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, including 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 (NERA Economic Consulting, 2004).

The sample is limited to the incumbent railway firms or their legal successors. Some countries separated the infrastructure from transport operations; thus, more than one firm may be listed for these countries in Table 4.3. For example, in the Netherlands, the infrastructure is managed by Prorail while freight and passenger transportation is provided by Nederlandse Spoorwegen (NS).[3] For the purpose of comparison, observations

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[3] 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,

Table 4.3: Sample Descriptive Statistics: Average Values during the Period 1994-2005

Country	Railway firms	Inputs: No. of Employees (10^3)	Inputs: No. of Rolling stock (10^3)	Inputs: Network length (km)	Outputs: Passenger-km (10^6)	Outputs: Freight tonne-km (10^6)
Austria	ÖBB/SCHIG	53.0	29.8	5,648	8,233	15,218
Belgium	SNCB	40.9	24.2	3,463	7,606	7,520
Czech Rep.	SZDC/CD	88.3	68.8	9,443	7,249	18,106
Denmark	BD/DSB	15.1	5.4	2,273	4,979	1,920
Finland	RHK/VR	13.3	14.7	5,839	3,318	9,708
France	RFF/SNCF	176.2	137.3	30,384	66,807	48,989
Germany	DB	261.5	229.1	37,579	71,104	75,820
Greece	CH (OSE)	10.3	6.8	2,426	1,709	387
Hungary	MAV	52.4	26.5	7,720	7,047	6,936
Ireland	CIE	5.4	2.3	1,928	1,467	482
Italy	FS	114.7	86.0	16,027	44,766	22,571
Latvia	LDZ	17.2	10.9	2,350	1,012	13,815
Lithuania	LG	15.2	14.6	1,882	749	9,169
Luxembourg	CFL	3.1	3.0	274	293	560
Netherlands	Prorail/NS	26.6	9.5	2,776	14,524	3,297
Poland	PKP	188.0	139.2	21,921	19,564	55,930
Portugal	Refer/CP	11.7	5.9	2,829	4,091	2,107
Slovakia	ZSSK/ZSR	47.7	34.4	3,663	3,145	11,299
Slovenia	SZ	9.1	7.2	1,213	681	2,731
Spain	Renfe	34.4	32.5	12,460	17,778	10,907
Sweden	BV/SJ	19.3	21.3	9,811	6,513	16,193
Switzerland	CFF	29.7	26.0	2,981	12,514	9,134

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

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.

To estimate the multiple-output multiple-input 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

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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.

for labor and capital input.[4] Since revenues for passenger transportation depend on the number of passengers and the distance traveled, we measure the passenger service output using the variable *passenger-km (pkm)*. Accordingly, freight transportation revenues depend on the amount and distance of tonnes transported. Hence, we measure the freight service 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 4.3 show that our sample covers a wide range of firm sizes and firms with different key activities. For example, the scale of operations (measured in network length) of the largest railway company in Europe, DB in Germany, is more than 130 times larger than that 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 year-2000 US dollars and purchasing power parities (PPP)) 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 4.4 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 independent regulation.[5] Table 4.5 displays the year of regulatory change for each variable and each country between 1994-2005.

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

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[4] 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 .

[5] 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 4.4: Definition of Regulatory and Environmental Variables

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	100.0
GDP	Gross domestic product per capita (10^3) (year-2000 US-$ and PPP)	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).

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 (NERA Economic Consulting, 2004). Therefore we do not consider an institutional (full) separation for France. In fact, such a mixed or ‘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.

Table 4.5: Regulatory Variables, 1994-2005

	Separation			Third party access			
Country	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
Slovakia[a]	1994		2002	1997	1994	1994	
Slovenia	1999	2004			2003	2003	
Spain	1994		2005	1998	2005		
Sweden[a]	1988		1988	1995	1996		2004
Switzerland	1997			2000	2000	2000	2005

[a] Incomplete time-series; [b] Or earlier. Source: Commission of the European Communities (2006), IBM (2004, 2006), Conway and Nicoletti (2006), NEA (2005), Steer Davies Gleave (2004, 2005), NERA Economic Consulting (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.

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. In contrast, 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.[6]

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

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[6] Note that the year specifications of these variables listed in Table 4.5 refer to the first complete year in which the law was valid rather than the exact enactment date.

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):[7]

$$\begin{aligned}
-\,ln\,net_{it} \;=\;& \alpha_0 + \alpha_1\, ln\,pkm_{it} + \alpha_2\, ln\,tkm_{it} + \frac{1}{2}\,\alpha_{11}\;(ln\,pkm_{it})^2 + \frac{1}{2}\,\alpha_{22}\;(ln\,tkm_{it})^2 \\
&+ \alpha_{12}\, ln\,pkm_{it}\, ln\,tkm_{it} + \beta_1\, ln\,(emp_{it}/net_{it}) + \beta_2\, ln\,(roll_{it}/net_{it}) \\
&+ \frac{1}{2}\,\beta_{11}\;(ln\,(emp_{it}/net_{it}))^2 + \frac{1}{2}\beta_{22}\;(ln\,(roll_{it}/net_{it}))^2 \\
&+ \beta_{12}\, ln\,(emp_{it}/net_{it})\; ln\,(roll_{it}/net_{it}) \qquad (4.8)\\
&+ \theta_{11}\, ln\,(emp_{it}/net_{it})\; ln\,pkm_{it} + \theta_{12}\, ln\,(emp_{it}/net_{it})\; ln\,tkm_{it} \\
&+ \theta_{21}\, ln\,(roll_{it}/net_{it})\; ln\,pkm_{it} + \theta_{22}\, ln\,(roll_{it}/net_{it})\; ln\,tkm_{it} \\
&+ \phi_t\, t + \frac{1}{2}\,\phi_{tt}\, t^2 + \psi_{1t}\, ln\,pkm\, t + \psi_{2t}\, ln\,tkm\, t \\
&+ \lambda_{1t}\, ln\,(emp_{it}/net_{it})\; t + \lambda_{2t}\, ln\,(roll_{it}/net_{it})\; t + v_{it} - u_{it}
\end{aligned}$$

and,

$$\begin{aligned}
\mu_{it} \;=\;& \delta_0 + \delta_1\, NetDen_{it} + \delta_2\, Electrified_{it} \\
&+ \delta_3\, ln\,GDP_{it} + \delta_4\, ln\,PopDen_{it} + \delta_5\, East_{it} \\
&+ \delta_6\, SepAcc_{it} + \delta_7\, SepOrg_{it} + \delta_8\, SepFull_{it} \qquad (4.9)\\
&+ \delta_9\, IntAccess_{it} + \delta_{10}\, DomFreight_{it} + \delta_{11}\, DomPass_{it} \\
&+ \delta_{12}\, RegBody_{it} + \delta_{13} Time.
\end{aligned}$$

4.5 Results

As described in the methodology section (see Section 4.3), 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

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[7] 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.

the generalized likelihood-ratio test, we evaluate several alternative specifications of our model. The test statistic, λ, is defined by

$$\lambda = -2\left[lnL(H_0) - lnL(H_1)\right], \tag{4.10}$$

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 4.6. 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 4.8 is an adequate representation of the data.

Table 4.6: Tests of Hypotheses[a]

Null Hypothesis	Log-likelihood	λ	Critical value $\chi^2_{0.99}$	Decision
Model I	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
$H_0 : \gamma = \delta_0 = ... = \delta_{13} = 0$	84.00	283.42	29.93*	Reject H_0
$H_0 : \delta_3 = \delta_6 = \delta_7 = \delta_8 = 0$	222.13	7.16	13.28	Accept H_0

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

Null hypotheses four and five refer to the parameters of the technical inefficiency model defined by Equation 4.9. 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 coefficient of the variance parameter γ for Model I (see Table 4.7). The γ-coefficient 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 of 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 4.7.

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 4.7.[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 at the 1 percent level 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 sample average firm, as observed in the majority of railway studies. Finally, the statistically significant and positive coefficient of time (t) is 0.039 and implies technological progress at a rate of 3.9 percent for the sample average firm in the mid year of the sample.[9]

The coefficients of the inefficiency model are reported in the lower part of Table 4.7. For Model II, all coefficients except the coefficient of the constant are significantly different from zero at the 5 percent level. Among the estimates for the environmental variables, the positive coefficients of 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 of δ_5 suggests a significantly lower technical efficiency of railways in Eastern Europe than in Western Europe. In contrast, the coefficient of 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 of 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 railways providing passenger services. In contrast, the negative coefficients of 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 of δ_{13} points to a decrease in technical efficiency over time.

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[8] Altogether, 15 out of the 21 coefficients of Model I are statistically different from zero at the 5 percent level. As we are primarily interested in the inefficiency effects, we do not report all coefficients to conserve space.

[9] As noted by Saal et al. (2007), these technical change estimates are for a nonexistent hypothetical sample average firm with unchanging characteristics. Hence, they do not account for changes in inputs and outputs and should be interpreted with caution.

Table 4.7: Parameter Estimates

		Model I		Model II		Model III		Model IV	
Variable	Parameter	Coef.	T-ratio	Coef.	T-ratio	Coef.	T-ratio	Coef.	T-ratio
Production frontier									
Constant	α_0	0.204***	8.7	0.216***	8.7	0.237***	10.8	0.128***	3.7
ln pkm	α_1	-0.326***	-12.5	-0.344***	-13.9	-0.370***	-16.0	-0.227***	-8.2
ln tkm	α_2	-0.606***	-25.3	-0.586***	-24.5	-0.571***	-27.0	-0.642***	-25.6
ln (emp/net)	β_1	0.352***	4.3	0.352***	4.1	0.157*	1.8	0.490***	5.8
ln (roll/net)	β_2	0.450***	7.0	0.425***	5.5	0.540***	7.7	-0.009	-0.1
t	ϕ_t	0.040***	8.6	0.039***	8.0	0.038***	10.0	0.064***	7.2
Inefficiency model^{a}									
Constant	δ_0	0.256***	2.6	0.198*	1.8	0.583***	7.5	-1.031	-1.5
NetDen	δ_1	2.736**	2.5	3.448***	3.2	0.831	1.0		
Electrified	δ_2	-0.817***	-6.3	-0.920***	-6.9	-1.260***	-11.1		
ln GDP	δ_3	0.099	0.9						
ln PopDen	δ_4	0.314***	5.9	0.324***	5.9	0.440***	10.0		
East	δ_5	0.409***	4.1	0.364***	6.1	0.407***	7.5		
SepAcc	δ_6	-0.054	-1.0						
SepOrg	δ_7	-0.080	-1.4						
SepFull	δ_8	-0.074	-1.1						
IntAccess	δ_9	0.201***	3.9	0.204***	3.7			1.205*	1.9
DomFreight	δ_{10}	-0.258***	-4.5	-0.253**	-2.3			-0.024	-0.2
DomPass	δ_{11}	0.282***	3.9	0.257**	2.2			-0.201	-1.6
RegBody	δ_{12}	-0.231***	-3.6	-0.255***	-4.8			-0.052	-0.8
Time	δ_{13}	0.029***	3.1	0.026**	2.5	0.038***	5.6	0.098***	5.5
Sigma-squared	σ^2	0.021***	6.4	0.021***	6.7	0.029***	8.0	0.055***	4.4
Gamma	γ	0.955***	49.8	0.946***	44.2	0.952***	71.3	0.865***	18.2
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. ***, **, and *: Significant on the 1%-, 5%-, and 10%-level.

Two alternative models are also reported in Table 4.7. 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.[10] Within the production frontier estimates, the first-order coefficient of β_1 of Model III is statistically significant at the 10 percent level only. In Model IV the first-order coefficient of 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.

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[10] 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 $= 4$).

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 percent level in Model II to insignificant in Model III. In contrast, in Model IV, all coefficients of the regulatory variables except of δ_9 are statistically insignificant. Furthermore, the coefficient of 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 4.8 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.

Table 4.8: Model II: Technical Efficiency Scores

		Average efficiency by period (in %)				Efficiency change (in %)
Country	Railway firms	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.

Comparing the first and last sub-periods indicates that technical efficiency decreases for most of the firms. Only SZ in Slovenia (12.5 percent), ÖBB in Austria (6.2 percent), and Refer/CP in Portugal (0.8 percent) 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 percent, 25.7 percent, and 24.7 percent, respectively. Among the Western European firms, CFL in Luxembourg shows a 25.7 percent, CIE in Ireland a 22.7 percent, and CH in Greece a 22.2 percent decline.

4.6 Summary and Conclusions

Based on a multiple-output multiple-input distance function 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 transport 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 over time (Table 4.8) with the regulatory variables (Table 4.5) 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 just two of the listed regulatory reforms – namely, accounting separation and international access. This group is followed by two railway firms (RFF/SNCF and SNCB) with relatively high efficiency losses located in countries that implemented organizational separation along with accounting separation and international access. However, none of these five countries implemented third-party access rights for domestic railway services or established an independent regulatory body. By contrast, all Western European railway firms located in countries that started to implement the first reforms early, in the mid-1990s (for example, Austria and Germany), and/or institutionally separated infrastructure management form transport operations (for example, Portugal and Finland) show only a slight decrease or even an increase in technical efficiency over time. All of these countries except

Finland also implemented at least third-party access rights for domestic railways providing freight transport services. This pattern indicates that, despite single negative effects of specific regulatory reforms on technical efficiency, none or just two or three small reforms are even worse; further, comprehensive and early reforms can at least keep efficiency at an almost constant level. Altogether, the results point to significant implementation and adjustment problems in many European countries probably caused by a still relatively low degree of interoperability among the national railway systems and the low levels of competition within the passenger transport sector. Further deregulation policy should consider these issues and focus particularly on the improvement of interoperability among the national railway systems and the enhancement of competition within the passenger transport sector.

From a technical perspective, 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, distorted estimations 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.

5 Conclusions

In the early 1990s the European Commission and the national governments of the EU member states initiated an extensive deregulation and liberalization process in the European railway industry. Prior to this process, the European railway industry was characterized by loosely connected national monopoly railway companies which faced severe losses of transportation market share and required increasing subsidies. Overall, this system was not what a single European market needed: an integrated transport system that provides reliable and fast cross-border transportation of goods, services, and people. The main elements of the reforms have been the separation of infrastructure management from transport operations, the implementation of interoperability among the national railway systems, the assurance of third-party access to the infrastructure, and the introduction of independent railway regulatory systems. In general, the intention of the reforms has been to enhance competition by opening the market and to improve the economic performance of the European railway industry.

The objective of this thesis is to analyze the effectiveness of the European railway deregulation process in enhancing efficiency and productivity in the European railway industry. For that purpose, non-parametric and parametric benchmarking methods, namely, data envelopment analysis (DEA) and stochastic frontier analysis (SFA), were used to evaluate the impact of different production technologies and country- and firm-specific environmental and regulatory conditions on efficiency and productivity.

Chapter 2 analyzed whether there are economies of scope in vertical integrated railway firms that own the infrastructure and participate in the transport segment. Since a central element of European railway deregulation is vertical separation, the existence or non-existence of vertical economies of scope is of particular interest. If economies of scope exist, institutional separation will result in cost disadvantages which might exceed the beneficial effects of institutional separation: that is, the elimination of third-party discrimination incentives of vertically integrated firms and the enhancement of competition and efficiency. In this case, an integrated sector structure would be more advantageous. The results obtained by applying an innovative two-stage DEA super-efficiency model to a unique sample of 54 integrated and separated railway companies form 27 European countries indicate an efficiency advantage of integrated firms on average and economies of scope for a majority of the integrated firms. Furthermore, connecting these results to an IBM study on the opening of rail markets in Europe in 2004 (IBM, 2004) reveals that all integrated firms located in countries that were assigned in the IBM study to the group with an ‘on schedule market opening’ show economies of scope in our analysis. Further, diseconomies of scope are found only for integrated firms located in countries that were assigned to the groups with a 'pending departure or delayed status of market opening'. In this context, the observation of diseconomies of scope for some integrated firms can be interpreted instead as managerial inefficiency resulting from a lack of competitive pressure. Overall, the results indicate that integrated firms operating in a competitive environment do not significantly suffer from managerial inefficiency and can realize productivity advantages from economies of scope. Further deregulation policy should bear this issue in mind and weigh the advantages and disadvantages of institutional separation carefully.

In Chapter 3, we tested several hypotheses on the development and sources of productivity growth in European railways during the deregulation period of 1990-2005. Based on the TFE model recently proposed by Greene (2004a,b, 2005) and the generalized Malmquist index approach proposed by Orea (2002), we separated firm- and country-specific unobserved heterogeneity from efficiency measures and decomposed productivity growth into technological progress, technical efficiency change and scale effects. All four hypotheses – that productivity significantly increased in the European railway sector, that technical efficiency significantly increased in the European railway sector, that technological progress was the main driver of productivity growth, and that scale effects had only a slight influence on productivity growth – were confirmed by the estimation results. Altogether, an average productivity growth of 39 percent is found in the observed period of deregulation. The main part thereof is due to technological progress, with an overall increase of 29 percent on average, although the average rate of technological progress is declining. Average technical efficiency estimates indicate an increase in technical efficiency of 7 percent within the observed period. Compared to the consistently positive development of average technical change, the change in average technical efficiency from one year to the next tends to be volatile. In the periods 1992-1997 and 2002-2005, we find an increasingly positive contribution of technical efficiency change to average productivity growth, whereas in the intervening period, this contribution declined. Furthermore, the estimation results reveal a convergence of the firm-specific technical efficiency levels over time; from 1990 to 2005, the difference between the minimum and maximum efficiency scores almost halved, primarily as a result of significant catch-up effects in the early and mid-1990s among those operators whose initial performance was sub-par. Finally, the influence of scale effects on average productivity growth is found to be limited to 3 percent in the observed period. Relative to further sector deregulation, policy makers should consider these issues and focus particularly on the promotion of further technology improvements as the main driver of productivity growth.

Chapter 4 investigated the influence of regulatory and environmental conditions on the efficiency of European railways. Based on a time-varying inefficiency effects stochastic frontier model for panel data proposed by Battese and Coelli (1995), we analyzed the impact of regulatory and other environmental factors on the technical efficiency of 31 European railway firms from 22 European countries during the period 1994-2005. With environmental factors taken into consideration, our findings indicate a positive influence on technical efficiency from the enforcement of regulatory reforms by an independent regulatory body on the national level. However, we find no significant influence on technical efficiency from accounting, organizational, or institutional separation. The estimated results for third-party access rights differ between passenger and freight transport, as well as between international and domestic services. While access rights for domestic railways providing freight transport services are found to have a positive influence on technical efficiency, access rights for international services according to Directive 91/440/EEC and those for domestic railways providing passenger transport are found to have a negative influence on technical efficiency. In the case of international services, these results indicate a continuing low degree of interoperability among the national railway systems, which results in higher network coordination and management costs for international transport services compared to those of domestic transport services. The different results for domestic passenger and freight transport services could be attributable to either higher network coordination and management costs of passenger transport services compared to freight transport services or to the very low development of competition within the passenger transport segment in most European countries. In the latter case, the estimated negative impact of third-party access for domestic railway firms providing passenger services could be a temporary effect that might disappear or even turn positive given the development of more competition over time. This interpretation is also confirmed by the analysis of the development of firm-specific technical efficiency levels over time. Our findings reveal that the five Western European railway firms with the most severe declines in technical efficiency over the observation period are located in countries that implemented just two or three of the investigated regulatory reforms. In contrast, all Western European railway firms located in countries that started to implement the first reforms early in the mid-1990s and/or implemented a comprehensive reform program that included institutional separation and, in most cases, third-party access rights for domestic railways providing freight transport services, show only a slight decrease or even an increase in technical efficiency over time. This pattern indicates that, although individual regulatory reforms have negative effects on technical efficiency, the effect of implementing no reforms at all or only two or three small reforms is even worse; further, comprehensive and early reforms can at least keep efficiency at an almost constant level. Altogether, these results point to significant implementation and adjustment problems in many European countries probably caused by a still relatively low degree of interoperability among the national railway systems and the low levels of competition within the passenger transport sector. Further deregulation policy should consider these issues and focus particularly on the improvement of interoperability among the national railway systems and the enhancement of competition within the passenger transport sector. Finally, the estimation of two alternative models with and without regulatory and environmental factors indicates that the omission of environmental factors causes substantial changes to the parameter estimates. This finding emphasizes that an analysis of regulatory factors within the European railway industry should incorporate environmental factors as well to avoid distorted results.

Combining the findings of the three empirical analyses leads to several conclusions on the effectiveness of the European railway deregulation process. First, and probably most important, the reforms seem to have had an overall positive effect on the productivity development of European railways. This conclusion is supported by the results of Chapter 3 and 4, both of which indicate productivity enhancing positive technical change over time, and Chapter 3, which indicates significant productivity growth based primarily on technological progress.

Addressing the development of technical efficiency over time, the analyses of Chapter 3 and 4 provide rather heterogenous findings. While the TFE model in Chapter 3 indicates an average technical efficiency increase, the inefficiency model in Chapter 4 indicates a technical efficiency decrease for most of the firms. However, it must be noted that the models follow different assumptions on the observability and incorporation of heterogeneity into an efficiency analysis. The TFE model in Chapter 3 estimates technical efficiency by accounting for firm-specific unobserved heterogeneity beyond managerial control. In this case, it is assumed that each firm faces a different production frontier and that firm-specific deviations from the frontier are due only to managerial inefficiency. Hence, the obtained efficiency scores are ‘net’ efficiency measures that incorporate the influence of the deregulation process as a whole on managerial efficiency, but do not explicitly indicate the impact of individual regulatory or environmental factors. In contrast, the inefficiency effects model in Chapter 4 incorporates observable heterogeneity variables in order to measure their individual impact on efficiency. In this case, the obtained efficiency scores are ‘gross’ efficiency measures for which it is assumed that all firms face a common production frontier, and that firm-specific deviations from this frontier are influenced by managerial inefficiency and individual regulatory and environmental factors. However, the inefficiency model does not account for unobserved heterogeneity.

The differences in the estimation assumptions and obtained efficiency measures inhibits a direct comparison of the technical efficiency results. Nevertheless, it allows the following conclusions to be drawn. First, it can be assumed that the TFE model accounts for additional firm- or country-specific factors not included in the inefficiency effects model, which positively influence the development of managerial efficiency over time. Referring to the problem of differences between ‘law on the books’ and ‘law in action’, this could include in particular country-specific law enforcement and real day-to-day practice, as well as the influence they exert on the development of competition. Additionally, other factors, such as competitive tendering for regional passenger services or horizontal separation of freight and passenger services might be taken into account as well. Overall, the results of the TFE model indicate an average technical efficiency increase resulting from managerial efficiency gains within the observed deregulation period. Second, the results of the inefficiency model point to significant implementation and adjustment problems. Only firms subject to an early and comprehensive reform program were able to increase or to at least maintain their ‘gross’ efficiency levels at an almost constant level. This indicates that these firms compensated efficiency losses as a result of some individual reforms either with efficiency gains by other reforms, or by an increase in managerial efficiency. Overall, the results of both models point to a positive effect of European railway deregulation on efficiency, although with a considerable time lag. That delay was probably caused by implementation and adjustment problems as a result of a relatively low degree of interoperability among the national railway systems and the low levels of competition within the passenger transport segment. Further, from a technical perspective, the varying results of the two models show the sensitivity of efficiency measures to different estimation specifications. If permitted by the data set further research should combine both models and estimate efficiency under the assumption of both unobserved and observed heterogeneity.

The results of the specific problem of institutional separation and economies of scope remain ambiguous. Despite the finding of economies of scope for a majority of integrated European railway companies in Chapter 2, we found no significant negative or positive influence of institutional separation on technical efficiency in the analysis in Chapter 4. Therefore, the question of whether the loss of economies of scope in case of institutional separation outweighs the efficiency gains from more competition and, hence, whether an integrated or an institutional separated sector is more advantageous remains open for further research.

Finally, considering the further development of the European deregulation process, our results, as well as the observable market development, indicate that, in many European countries, competition has not yet fully developed and that interoperability among the national railway systems still has significant room for improvement. The second and third railway packages adopted in 2005 and 2007, respectively, point in this precise direction. The national implementation of the directives therein should enhance the development of more competition, particularly within the passenger transport sector, and promote the further development of the European railway industry towards a competitive integrated European railway system that offers an efficient transportation of goods, services and people within the single European market.

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