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

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Abstract

In this paper, we conduct a pan-European efficiency analysis to investigate the performance of European railways with a particular focus on economies of vertical integration. We test the hypothesis that integrated railways realize economies of scope and, thus, produce railway services with a higher level of efficiency. To determine whether joint or separate production is more efficient, we apply a Data Envelopment Analysis super-efficiency bootstrapping model which relates the efficiency for integrated production to a reference set consisting of separated firms which use a different production technology. We find that for a majority of European railways economies of scope exist.

Keywords: Efficiency, Vertical Integration, Railway Industry

JEL-Classification: L22, L43, L92

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1 Introduction

In the late 1980s and early 1990s, European national governments and the EU 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 (Commision 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 (e.g., 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 companies 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.

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. Section 3 discusses methodology. Section 4 introduces the modeling approach

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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.

and describes the data. Estimation results are presented in section 5. Section 6 contains conclusions and highlights policy implications and directions for future research.

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 (e.g., 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):

$$C\left(Y\right) < \sum_{i=1}^{m} C\left(Y_i\right), \quad for\, Y = \sum_{i=1}^{m} Y_1 \tag{1}$$

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

$$C\left(Y_I, Y_P, Y_F\right) < C\left(Y_I, 0, 0\right) + C\left(0, Y_P, 0\right) + C\left(0, 0, Y_F\right) \tag{2}$$

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,

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

incentives between the infrastructure provider and the transport operators have to be efficiently coordinated. For example, track access charges should consider 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 1983-97 to evaluate the cost implications of competition in the US 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 1973-90. 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. (2004) 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 companies 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 data envelopment analysis (DEA). Our pan-European data set incorporates railway firms from 27 European countries for the period 2000-04. 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. Further, 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.

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 like 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 (e.g. 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, e.g., 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 input-oriented distance measure equals the output-oriented distance measure in reciprocal terms.

By modeling a production technology as an input distance function[3] oone 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:

$$D_I\left(x,y\right) = \max\{\theta : (x/\theta) \in L\left(y\right)\}, \tag{3}$$

where the input set $L(y)$ represents the set of all input vectors x that can produce the output vector y. The function is non-decreasing, positively linearly homogeneous and concave in x, and 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

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

efficiency and scope economies of European railways, we use data envelopment analysis (DEA), a method introduced by Charnes et al. (1978). DEA is a non-parametric approach which constructs a piece-wise linear production frontier that envelopes all observed data points. This production frontier can be estimated 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 departing from optimal scale should be identified as inefficient. Further, 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]

$$\begin{aligned} &\max \theta, \\ &\text{s.t.} \qquad -y_i + Y\lambda \geq 0, \\ &\qquad\qquad x_i/\theta - X\lambda \geq 0, \\ &\qquad\qquad \lambda \geq 0, \end{aligned} \tag{4}$$

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

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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 Wilson, 2005).

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.

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:

$$D_S\left(x_j, y_j\right) = \max\left\{\theta : \left(x_j/\theta\right) \in L^S\left(y_j\right)\right\}, \quad j = 1, 2, \ldots, J \tag{5}$$

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 company'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 companies' group can take values between zero and infinity.

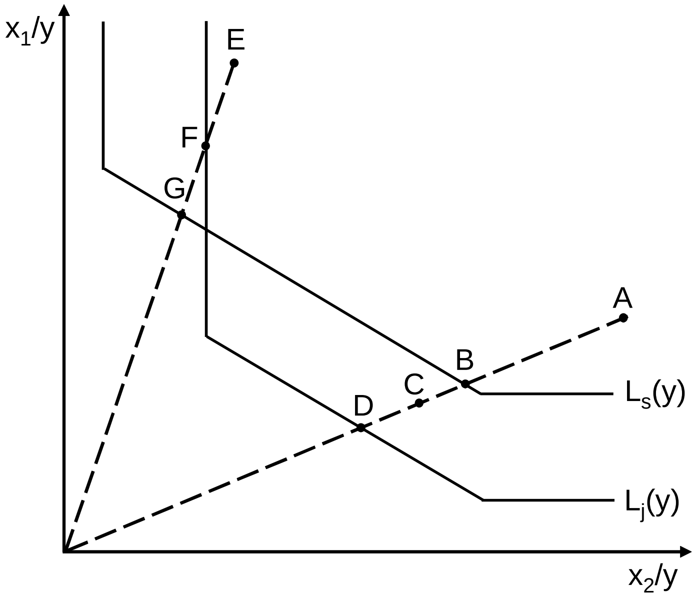
The corresponding CRS super-efficiency model is calculated by solving the linear optimization program J times for each of the integrated firms:

$$\begin{aligned} &\max \theta_j, \\ &\text{s.t.} \qquad -y_j + Y_s\lambda_s \geq 0, \qquad j = 1, 2, \ldots, J \\ &\qquad\qquad x_j/\theta_j - X_s\lambda_s \geq 0, \qquad s = 1, 2, \ldots, S \\ &\qquad\qquad\qquad \lambda_s \geq 0, \end{aligned} \tag{6}$$

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, i.e. 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 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 1, economies of scope for some observations and diseconomies of scope for other observations can be identified.

Figure 1: Economies and diseconomies of scope



For example, assume an integrated firm operating at point A in Figure 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

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[7] Figure 1 and its description follow Cummins et al. (2003).

occur for firm A, we calculate the ratio of the two distance function (efficiency) values:

$$\hat{\theta} = \frac{\theta}{\theta_j} = \frac{0A/0D}{0A/0B} = \frac{0B}{0D} \tag{7}$$

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 formula 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, e.g., 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

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

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=1000 bootstrap replications. [9]

4 Modeling approach and data description

The data set consists of 54 railway firms from 27 European countries throughout 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 the Union Internationale des Chemins de Fer (2004; 2005) and combined with information from the companies' annual reports and companies' statistics.

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 time tables. 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

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[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).

[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 taken to approximate the value.

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 financial 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

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

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 1.

Table 1: Construction of a "virtually" integrated firm from separated firms

	Input variables				Output variables		
Type of activity	No. of employees	No. 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 and 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 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 5808 "virtually" integrated firms for Model I.

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 4968 "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, 2508 observations were dropped, leaving 3330 observations of "virtually" integrated firms. Data for Model II is adjusted for 2160 outliers, leaving a total of 2808 observations of ”virtually” integrated firms.[13]

Table 2: Model I – Summary statistics

	Integrated firms			”Virtually” integrated firms		
	Mean	Max	Min	Mean	Max	Min
No. of employees	50517	249251	952	12870	36192	3465
No. of rolling stock	40351	219574	223	4981	11893	747
Network length (in km)	7331	36588	180	4665	9882	2047
Passenger-km (in millions)	11494	74459	126	4653	6621	2204
Tonne-km (in millions)	14258	76815	14	4952	13120	107
Train-km (in thousands)	134764	988200	2382	63158	128000	22667
No. of observations		75			3300	

Table 3: Model II – Summary statistics

	Integrated firms			”Virtually” integrated firms		
	Mean	Max	Min	Mean	Max	Min
OPEX (in millions of PPS)	3281	29669	79	1439	3927	329
Network length (in km)	7474	36588	180	4055	5854	2273
Passenger-km (in millions)	11779	74459	126	4795	14666	7
Tonne-km (in millions)	14400	76815	14	5854	13120	456
Train-km (in thousands)	137999	988200	2382	45151	64341	36442
No. of observations		73			2808	

5 Results

In this section, we present the results of the estimated models by, first, analyzing the technical efficiency results obtained by the DEA bootstrap procedure, then extending the discussion to the evaluation of contingent economies of scope.

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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.

Analysis of the DEA bootstrap estimations (Table 4) allows several conclusions to be drawn. For both models, the bias-corrected distance function values are, on average, greater than the original efficiency scores, 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 4: Summary statistics of original and bias-corrected distance function (efficiency) results*

	Integrated firms		"Virtually" integrated firms	
Model I	Original	Bias-corrected	Original	Bias-corrected
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
	Integrated firms		"Virtually" integrated firms	
Model II	Original	Bias-corrected	Original	Bias-corrected
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

*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 a monetary value *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

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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).

countries – we consider the estimated function of Model II as a better approximation of the real production technology.[16]

Table 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 less 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 mislead-ing. 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.

For Model II (Table 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 scope of about 40 percent, on average, when *OPEX* is considered instead of the physical measures *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

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

Table 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
No. of observations		75 (100 percent)		33 (44 percent)	42 (56 percent)
No. of firms		23 (100 percent)		10 (43 percent)	13 (57 percent)

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]

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, Estland, Germany, Italy, Latvia, Lithuania, Luxembourg, Romania and Switzerland) and diseconomies can be found for integrated firms from 5 countries (Greece, Ireland, Spain, Slowakia 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 instance 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.

Table 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
No. of observations		73 (100 percent)		22 (30 percent)	51 (70 percent)
No. of firms		23 (100 percent)		8 (35 percent)	15 (65 percent)

6 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. Up 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 which 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, i.e., 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, particularly 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.

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