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Research paper

Efficiency *versus* market power in the rail industry☆

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ABSTRACT

Although an extensive literature exists that examines efficiency in rail markets, analyses that also study the market power of rail operators are scarce. We examine the effects of competition and vertical separation on efficiency and price-cost margins. In doing so we propose a two-stage procedure. Firstly, efficiency and Lerner indexes will be obtained for a sample of rail operators for the period 2000–2016. Secondly, the determinants of both indexes are jointly estimated. Results indicate that integrated incumbents not facing competition perform worst and exert the highest market power. Vertically separated and specialized in passenger services operators display the strongest improvements in efficiency levels, while integrated incumbents facing competition show the lowest market power indexes. Finally, more efficiency translates to smaller values of the Lerner index.

1. Introduction

The last decades have witnessed important structural reforms in the railway industry. Many European countries separated infrastructure management and operator services. Vertical separation can result in increased costs (Growitsch & Wetzel, 2009), have no impact (Asmild et al., 2009) or produce decreases in costs (Cantos et al., 2011). Such a restructuring measure has non-obvious implications on efficiency. However, it was meant as a prerequisite for the introduction of competition to be successful so that new entrants are not discriminated in terms of charges and capacity usage. Competition in operator services is expected to bring lower prices and be beneficial for consumers (Beria et al. (2016); Vigren (2017); Tomeš & Jandová, 2018). Thus, structural reforms affect operator price-cost margins therefore suggesting an analysis of efficiency, market power and its relationship. Have these reforms driven efficiency improvements? If so, which market structure delivers the greatest improvement? Are any decreases in costs proportionally bigger or smaller than price reductions, that is, does the market power increase or decrease with structural reforms?

Our paper empirically addresses these research questions for a sample of rail operators. At a formal level, the recent contribution by Mizutani (2020) carefully examines whether a particular vertical structure is better than another in terms of costs. Thus, separation is preferred when train density and technological effects of scope economies between operation and infrastructure activities are small; modelling competition as a cost saving effect throws indeterminate results. In another recent paper, Cantos-Sánchez et al. (2023) investigate how structural reforms affect market power of railway operators, as measured by the Lerner Index (LI), when there are economies of scale at the infrastructure level. Interestingly, the introduction of competition, that has a price effect, does not lessen the degree of market power of the incumbent operator when economies of scale are large enough. Taken together, these analyses suggest that clear conclusions cannot be reached. It is therefore worth exploring how market structure characteristics shape efficiency scores, operators' market power and their relation.

We wish to contribute to the strand of the literature that looks into the effects of structural changes on efficiency levels. Because the divergence between price and marginal cost expresses the degree of market power, we shall also investigate how vertical separation and

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competition impact the Lerner indexes of rail operators. As noted above, one wonders whether changes in efficiency are proportionally bigger than price variations, which certainly affect the Lerner index. To elucidate such interactions advises the joint estimation of the determinants of efficiency and market power. To the best of our knowledge, these questions have not yet been formally studied at the operator level thus providing a novel contribution for an informed analysis of the rail sector.

Therefore, our analysis is in two parts. Our first objective is to estimate efficiency levels and market power indexes of a sample of rail operators for the period 2000–2016. Rail reforms have provoked the promotion of different types of rail operators, i.e., specialized in freight or passenger operators and multi-service operators, vertically integrated and separated operators with operators competing with the rail incumbent in some cases, etc. We will therefore analyze if these diverse types of rail operators generate different efficiency and market power levels. Our second objective is to investigate the determinants of efficiency indexes and Lerner indexes. Two structural equations in a simultaneous way using the three-stage least squares (3SLS) method will be estimated. In addition to identifying the effects of operators' market structure characteristics, we are interested in uncovering whether improved efficiency leads to a lower degree of market power, as measured by the Lerner index.[1]

We find that, with respect to an integrated incumbent monopolist, efficiency levels increase when operators face competition either when they are integrated or separated from infrastructure providers. That is, integrated incumbents not facing competition perform the worst; besides, they are found to exert the highest market power. Vertically separated and specialized in passenger services operators display the strongest improvements in efficiency levels, while integrated incumbents facing competition show the lowest market power indexes. We also find weak evidence that more efficiency translates to smaller values of the Lerner index. In other words, more efficiency would reduce prices by more than operating costs. Regarding rail services, various measures that promote competition for or in the market may be good options to achieve both higher efficiency levels and lower market power.

The rest of this paper is organized as follows. Section 2 reviews the literature. Section 3 describes the railway reforms and conceptual background. Section 4 describes the different approaches to estimate the efficiency and the market power. In Section 5 we present the data employed in our analysis. Section 6 shows the results, providing the technical efficiency indexes and the estimates of the Lerner index in subsection 6.1, and the study of their determinants is given in subsection 6.2. Section 7 summarizes the main conclusions and offers policy recommendations.

2. Literature review

Relevant to our analysis is the recently developed literature on the evaluation of rail reforms regarding their effects on the efficiency and productivity of the rail industry. Whether reform policies about the separation of infrastructure and operations have had any impact on efficiency is unclear. Wetzel (2008) finds that none of the separation variables considered in his study shows a statistically significant influence on efficiency. Some contributions find that separation raises costs for European railways; Growitsch and Wetzel (2009) indicate that vertical integration produces better efficiency results due to improved control of scope and scale while Merkert et al. (2012) note that transaction costs increase with separation. In contrast, Asmild et al. (2009) provide empirical evidence that accounting separation improves the efficiency in the use of materials and staff costs. For a panel of European and East Asian railways, Mizutani and Uranishi (2013) find that vertical separation is the most cost-effective structure when the density of traffic is low. Finally, Smith et al. (2018) show that vertical separation combined with strong regulation allows to reduce costs too.

Other contributions have explored not only the unbundling of activities but also the effects of the introduction of competition on the level of efficiency in the rail industry. The intuition is that separation facilitates the introduction of competition promoting reductions in operation costs. Thus, the findings by Driessen et al. (2006) suggest that competitive tendering significantly improves productive efficiency. A similar result is found by Link (2016) for franchising contracts of longer duration in Germany. The positive effects on efficiency can be stronger once quality of service indicators is considered (Link, 2019). In contrast, Jensen and Stelling (2007) report that, for Sweden, vertical separation raises costs, yet competition lowers them. Similarly, Nash et al. (2014) find that costs are higher with separation for more densely used railways and those taking higher proportions of freight traffic; no evidence is obtained that an increase in competition results in lower costs. A network with several operators, which can push prices down, may not fully realize the benefits of economies of traffic density (Casullo, 2016; Nash, 2010). However, for a panel of European railways, Cantos et al. (2010, 2012) show that separation accompanied by competition lead to greater efficiency gains. Smith et al. (2018) confirm the beneficial effects of passenger competition. Finally, Lérida-Navarro et al. (2019) find evidence of a weak positive relation between EU rail liberalization and higher efficiency and note that effective competition is a key factor to realize efficiency gains.

There also exist contributions that have looked into the effect of competition on prices. Bergantino et al. (2015) and Beria et al. (2016) find significant price reductions following the introduction of on-track competition in the Italian long-distance market, although incumbent's fares are higher than entrant's. Consumers also face lower prices after entry in the Swedish market (Vigren, 2017) as well as in Austria, the Czech Republic and Slovakia (Tomeš & Jandová, 2018). However, decreases in price by incumbent rail operators may respond to the exercise of market power with the purpose of excluding rivals (Chini et al., 2023).

Some contributions exist that have explored the degree of market power in transport, such as Li et al. (2019) for rail, Kutlu and Sickles (2012), Zhang et al. (2014) for US airlines and the Chinese airline industry, respectively; Zhang et al. (2020) study the impact of high-speed rail on concentration and the Lerner index in China's airline market. Specifically, Li et al. (2019) measure the degree of market power of China's railway operators and analyze its determinants. They find that Chinese rail operators exercise significant market power with an overall positive Lerner index, but there is a large heterogeneity among the different railway bureaus. In order to estimate the Lerner index, we will follow the stochastic frontier method defined by Kumbhakar et al. (2012) and employed by Li et al. (2019). This method does not require detailed price data, only aggregate data on revenue and operating costs are needed. This is a huge advantage of this approach, due to the difficulty to find information on price and financial figures for a sample of international rail operators. Recently, Chini et al. (2024) assess the market power of state-owned incumbents within open-access lines in Europe and focus their analysis on markets defined as origin-destination points. At a formal level, Mizutani (2020) analyzes the cost effects of different types of vertical structures and competition. Cantos-Sánchez et al. (2023) compare variations in the Lerner index for various organizational structures of the railway industry. As noted in the introduction, conclusions depend on certain conditions and the latter two papers are supportive of the analysis that we undertake. Specifically,

[1] To understand why increases in efficiency (reductions in marginal costs) might end up in higher or lower LI, consider the following. Given that equilibrium price is a function of marginal cost, the derivative of the LI with respect to c can be expressed as: $\frac{\partial\left(\frac{p-c}{p}\right)}{\partial c} = \frac{\partial\left(1-\frac{c}{p}\right)}{\partial c} = -\left(\frac{p-c\frac{\partial p}{\partial c}}{p^2}\right)$. Therefore, its sign depends on whether the equilibrium price function is elastic or inelastic with respect to the marginal cost. Thus, the LI increases when c decreases if and only if $E_{p,c} \equiv \frac{\partial p}{\partial c}\frac{c}{p} < 1$; the opposite otherwise.

Cantos-Sánchez et al. (2023) consider economies of scale at the infrastructure level and regulated access fees. It is shown that vertical separation and duopolistic competition downstream leads to higher levels of the Lerner index when economies of scale are sufficiently important.

Our purpose is to explore the determinants of both efficiency and market power, with an emphasis on market structure characteristics, while offering the first analysis that explores the link between efficiency indexes and price-cost margins for a sample of rail operators in Europe and Japan.

3. Railway reforms and conceptual background

The field of railway deregulation has received the attention of scholars (see Nash et al., 2010; Laurino et al., 2015; Fitzová, 2017, among others) European rail sector has experienced a notable restructuring through the separation of infrastructure from operations. The main rail operator remains integrated in Ireland, Hungary, Lithuania. Other countries such as the UK, Sweden, Spain, The Netherlands, Finland and Belgium promoted the full separation. However, a few countries (such as Germany, Italy and recently France) keep a holding model where the infrastructure manager is in charge of the infrastructure within a whole rail group. Outside Europe, most railways are vertically integrated (for example, the USA and Japan), with operators accessing the infrastructure of other companies, if at all, mainly on the basis of negotiation rather than as of right.

Several rail reforms - four EU Railway Packages between 2001 and 2016 – have been promoted to favor a more competitive and efficient behavior of the railway industry. Basically, there are two ways of promoting competition among operators: competition for the market and competition in the market. The usual procedure in the freight sector occurred through the direct entry of new rail operators. Using data from Independent Regulators' Group-Rail (IRG-Rail Independent Regulators' Group, 2018) in 2016, new freight operators competed with national incumbents in all countries except Greece, Ireland, Lithuania and Luxembourg, and in half of them, the market share of competitors was above 40 %, ranging from 13% for Slovenia to 63% for Romania, with an average of 38%.

Regarding passenger traffic and considering competition for the market, most of the competitive tendering in the EU has been awarded to operate lines under the Public Service Obligations (PSO) requirement, as in the UK, Germany, Sweden and The Netherlands.[2] The tendering procedure grants a temporary monopoly to operate a given line. This measure of public procurement has been endorsed as a way to increase competition and traffic, and also to alleviate usually tight public budgets. In 2016, just over 60% of total EU rail pass-km were PSO services. The United Kingdom is by far the one with the largest share of passenger-kilometers (pass-km) on PSO, about 97% in 2016; followed by Germany (58.5%) and Sweden (43%). Regarding relative market shares, Portugal, The United Kingdom, Sweden and Poland reported new entrants' market shares above 50% in pass-km terms. Among the six largest passenger markets, Germany and Italy reported 26% and 24%, respectively while, in France and Spain only the incumbents are operating PSO services.

Regarding competition in the market or open access, Germany was the first EU country to do it in 1994 in freight and long-distance passenger markets (Leipzig-Berlin since 2001 to 2014), which resulted in insignificant market shares for new operators in the passenger market. Similar behavior was found in UK and Sweden. There are, however, other examples such as The Czech Republic (Prague-Ostrava route since 2012) and Austria (Viena-Salzburg route since 2011) where open access competition has been implemented in a few routes with some success. In Italy, competition in the Turin-Milan-Venice and Milan-Rome-Naples HSR lines have been successful since 2012.[3] Table 1 summarizes the dates of the separation and the introduction of competition per country.

Therefore, for the sake of the empirical analysis, competition is identified when there are freight and/or passenger operators different from the incumbent running services, regardless of the mode in which competition has been introduced.

The widely used index to measure market power, is the Lerner index. Among its properties, it is theoretically well grounded and can be related to the specific competition scenario, e.g. number of competitors, symmetry, product differentiation. For the simplest case, under monopoly the LI equates the inverse of the price-demand elasticity in absolute terms while for the case of an oligopolist, it equates its market share-price elasticity ratio, and so on. Similarly, the marginal cost in the Lerner Index depends on the existence of scale and scope economies. The traditional approach to indirectly evaluate market power is operators' market shares using a Herfindahl Hirschman index (HHI) to measure market concentration. Acknowledging the fact that market power is more likely to exist if an operator has a persistently high market share, the use of concentration indexes alone may be misleading –prices can be close to marginal cost and yet the market be highly concentrated. The LI also has limitations, it measures price market power while firms may exert market power in other strategic variables such as quality or innovation. As it is to be shown in our empirical study, it is theoretically possible to find a larger LI with more operators. Also, increases in LI cannot be entirely attributed to the exercise of market power when operators enjoy increasing returns to scale.

4. The methodology

To address our research questions, we first calculate efficiency scores for a number of railway operators using Data Envelopment Analysis (DEA). The received literature has followed two approaches. We focus on DEA instead of Stochastic Frontier Approach (SFA) indices to avoid potential problems of SFA indexes due to the potential endogeneity of

Table 1
Separation and competition adoption years per country.

Country	Vertical separation	Horizontal separation	Freight competition	Passenger competition
Belgium	2011		2002	2010
Bulgaria	2004			
Croatia	2012		2014	
Czech Rep.	2004		1995	2011
Denmark	1998	2001	1997	2003
Finland	1995		2012	
France*	2000–2013		2005	2011
Germany			1995	1997
Ireland				
Italy			2000	2007
Japan				
Luxembourg				
Norway	1997	2002	2008	2006
Spain	2004		2007	2021
Sweden	1995	2002	1992	1996
Switzerland			1999	

Source: *France SNCF integrates back in 2013. Cantos et al. (2012), Fizová (2017, 2022), IRG-Rail Independent Regulators' Group, 2018, (2018). Data for % Pass. Train-km and Pass-km in non PSO are for 2016.

[2] Although the EU Fourth Railway Package is forcing the EU members to use competitive tendering as the rule, an alternative to competitive tendering is to award the tender under direct negotiation. Notably, 41 new competitive tenders were awarded in 2016 in the EU.

[3] Spain is, since 2021, progressively introducing open access competition in its most profitable HRS lines (e.g. Madrid-Barcelona, Madrid- Valencia and Madrid-Sevilla). France lags those experiences in HSR, and it is only after December 2021 that in the Paris-Lyon connection (part of the longer Paris-Milan route) competition between Italian Trenitalia and French InOui exists.

inputs in the estimation of the production function. Another issue related to SFA has to do with the simultaneity and identification of inefficiency and market power index, which can also affect the accuracy of parameter estimates and efficiency levels. In any case, as a robustness exercise, the Appendix reports the results of our analysis assuming the efficiency scores obtained by SFA.

As for market power, Lerner indexes will be estimated following an SFA as specified by Kumbhakar et al. (2012) in Section 4.2. Once these indexes are obtained, Section 6.1 studies the effect of efficiency, among other determinants, on market power. We resort to the 3SLS method with instrumental variables to treat endogeneity grounded on simultaneity of efficiency levels and Lerner indexes in Section 6.2.

4.1. Estimates of efficiency

We follow the standard procedure in DEA, in which it is assumed that for each period t (this subscript will be removed for the sake of the presentation), a set of rail operators ($i, j = 1, \ldots, N$) is producing one output in our model with a K input vector ($k = 1, \ldots, K$). The problem to be solved is the following:

$$\begin{aligned} & Min\ \theta_j \\ & s.t.\ \sum \lambda_i y_i \geq y_j \\ & \quad\ \ \sum \lambda_i x_{ik} \leq \theta_j x_{jk}\ \forall k \\ & \quad\ \ \lambda_i \geq 0; \quad i = 1, \ldots, N \end{aligned} \tag{1}$$

From the solution of this problem for each of the N rail operators of the sample we obtain N optimal solutions. Each optimal solution θ_j is the input-oriented technical efficiency measure of each company which, by construction, satisfies $\theta_j \leq 1$, thus we denote company's j technical efficiency by TE_j, with $TE_j = \theta_j$. Those companies with $\theta_j < 1$ are considered technically inefficient, while those with $\theta_j = 1$ are catalogued as technically efficient, since they stand at the frontier. In this formulation we are assuming that productive technology exhibits constant returns to scale (CRS). If the additional restriction is introduced, i.e., $\sum_i \lambda_i = 1$, variable returns to scale (VRS) will be assumed.

In order to obtain bias corrected DEA efficiency indexes (see Simar & Wilson, 1999, 2019), we use the bootstrap-DEA method which resamples our single data to create a sampling distribution by repeatedly taking random samples from the original sample, with replacement. As a result, the bootstrap-DEA efficiency indexes have measurable accuracy and useful statistical properties that the DEA method lacks. Section 6.1 below develops more on this issue and explains the procedure to reach the bootstrap-DEA scores under CRS that will be used in the second stage analysis of Section 6.2.

4.2. The model to estimate market power

The usual way to calculate the Lerner index requires information on prices. We would need to have a separate indicator of prices for passenger and freight, or at least, information on revenue coming from passenger and freight activity. Unfortunately, this type of information is not available because data on revenue are aggregate.

To circumvent this problem, we follow the approach developed by Kumbhakar et al. (2012) and applied for the Chinese railways by Li et al. (2019). The advantage of this approach is that only data on revenue and costs are necessary. In particular, the following inequality is assumed:

$$P \geq MC = \frac{\partial C}{\partial Y}\ . \tag{2}$$

Where P denotes the price index, C stands for the operating costs, MC is the marginal cost and Y is output (for simplicity we remove subindex i as well as t). This inequality is not binding when the rail operator obtains a positive variable profit. If we multiply both sides of (2) by the term Y/C the inequality can be expressed as follows:

$$\frac{P\ Y}{C} \geq \frac{\partial C}{\partial Y}\frac{Y}{C} = \frac{\partial \ln C}{\partial \ln Y}. \tag{3}$$

If a non-negative one-sided term μ is added to equation (3), the above inequality is transformed to an equality as follows:

$$\frac{P\ Y}{C} = \frac{\partial \ln C}{\partial \ln Y} + \mu, \mu \geq 0. \tag{4}$$

In equation (4), μ captures the mark-up. Note that PY/C denotes the ratio between revenue and costs, and $\frac{\partial \ln C}{\partial \ln Y}$ denotes the cost elasticity with respect to the output (E_{CY}). Following Kumbhakar et al. (2012), the revenue-cost ratio might be affected by other unobserved variables that are captured by a symmetric two-sided noise term, ν. With the ν term included in (4), the equation becomes a stochastic frontier function, see equation (6) below. In order to estimate values for E_{CY} not having information on input prices, Kumbhakar et al. (2012) employ an input distance function formulation instead of the typical cost function approach. Applying an appropriate normalization, a transformation function as an input distance function can be defined.[4] Assuming a translog transformation function, we can write:

$$\begin{aligned} \ln x_K = {} & \alpha_0 + \sum_{k=1}^{K-1} \alpha_k \ln \tilde{x}_k + \frac{1}{2}\sum_{k=1}^{K-1}\sum_{l=1}^{K-1} \alpha_{kl} \ln \tilde{x}_k \ln \tilde{x}_l + \alpha_Y \ln Y \\ & + \frac{1}{2}\alpha_{YY}(\ln Y)^2 + \sum_{k=1}^{K-1} \alpha_{kY} \ln \tilde{x}_k \ln Y + \alpha_T T + \frac{1}{2}\alpha_{TT}T^2 + \sum_{j=1}^{J-1} \alpha_{kT} \ln \tilde{x}_k\ T \\ & + \alpha_{YT} T \ln Y. \end{aligned} \tag{5}$$

where $\tilde{x}_k = x_k/x_K$, ($k = 1 \ldots K$-1), T is a time trend, and values for cost elasticities are obtained, i.e., $E_{CY} = \alpha_Y + \alpha_{YY} \ln Y + \sum_{j=1}^{J-1} \alpha_{jY} \ln \tilde{x}_{jt} + \alpha_{YT} T$. It is important to stress that this expression is different from the conventional translog cost function using input prices. The only difference is that the normalized input prices are replaced by normalized input quantities.[5]

Noting the expression for E_{CY} above, it is easy to rewrite equation (4) in order to be estimated as follows:

$$\frac{P\ Y}{C} = \alpha_Y + \alpha_{YY} \ln Y + \sum_{k=1}^{K-1} \alpha_{kY} \ln \tilde{x}_k + \alpha_{YT} T + \mu + \nu \tag{6}$$

Note that equation (6) can be estimated in the same way as an SFA function. Therefore, we assume a "composed error term" that includes a non-negative unobservable term μ, and a standard error term ν, accounting for measurement errors and other random factors. As indicated by Kumbakhar et al. (2012), equation (5) is not a cost function and the one-sided term ($\mu \geq 0$) is not cost inefficiency. Assuming $\Phi = \frac{P-MC}{MC}$, and that $\Phi = \frac{\mu}{E_{CY}}$, the Lerner index (LI) can be expressed as follows, LI $= \frac{\Phi}{1+\Phi}$.

As we are interested in finding the determinants of the mark-up and, it is true that parameter μ, the mark-up, may be affected by other effects including efficiency, this forces us to properly address this problem in order to avoid biases in our estimates. In particular, in the second-stage analysis, we will employ LI along with technical efficiency indexes obtained from DEA as dependent variables in a joint equation system with instrumental variables to address a potential endogeneity problem linked to the interdependence between those dependent variables. This

[4] The duality between the input distance function and the cost function was first proved by Shephard (1953). This meaning that they contain the same information about the production function. It can be shown that the derivatives of the cost and the input distance function with respect to the output are linearly related, see Färe and Primont (1995), pages 47 to 52 for details.

[5] This approximation to the cost function, where input quantity data are employed instead of input prices, has been used to estimate the cost elasticity (see Coelli, & Perelman, 1999; Karagiannis et al., 2004; Tsionas et al., 2015).

procedure will be explained in Section 6 below.

5. Data

The data used for our analysis are taken from the official rail statistics provided by the UIC (*Union Internationale des Chemins de Fer*), in particular, from RAILISA database (RAIL Information System and Analyses, UIC statistics). Additionally, qualitative information has been taken from information available at particular companies' webpages, own statistical reports and some studies by international entities (OECD, 2013, p. 24; IRG-Rail Independent Regulators' Group, 2018). The data cover the period 2000–2016, but many companies report missing data for many years, and the whole sample reduces a lot for this reason. It is important to stress that the information is related to each rail operator and there is no aggregate information about the rail network or the country. So far most of the efficiency analyses have been conducted using data for national networks, assessing the differences in efficiency at the national or country level.

A good review describing the shortcomings and problems with international rail data appears in Van de Velde, & NashSmithMizutaniUranishiLijesenZschoche, 2012). It is important to clearly distinguish those variables denoting the activity for the incumbent from those related to the global rail activity. Also, it is important to check that the definition of the variables is consistent and homogeneous across all the companies in the sample.[6] For instance, some variables can be affected by problems like external services or contracts, that can be accounted in a different way by the rail operators. In view of these the database has been conveniently cleaned up at the expense of losing data in the sample.

Table 2 below reports the mean values for the output and input variables as per rail operator and additional descriptive statistics. The *output* used in the DEA analysis is the number of train-km (TKT). This is an aggregate measure of the production offered by the rail companies. RAILISA data do not identify the distance in km completed in different countries by each company. According to EUROSTAT,[7] international passenger traffic in thousands of passengers was 0.5% of total passenger traffic in Germany as of 2016, Similar patterns appear for large countries such as Italy (0.3%), France (3.1%), Spain (0.2%) and UK (1.1%). Consequently, we do not distinguish if kms are run in different countries given that each operator's markets are mainly in its country. Besides, unfortunately disaggregated data separating passenger from freight (expressed in passenger-km and tons-km) or other types of rail services are very scarce, and we have chosen train-km as an aggregate output measure.

With the constraint of data availability, the sample includes European and Japanese operators. The choice of Japanese (JR, HRC and WJRC) and Eastern Europe companies (BDZ from Bulgaria, HZ from Croatia and DZ from The Czech Republic) obeys comparison purposes with Western rail operators. Japanese companies are mostly private, integrated, operating on their own rail tracks and basically specialized in passenger services (Mizutani, 2022). Eastern operators have a higher specialization in freight transport compared to Western rail operators. The latter are incumbents either specialized only on passengers or offering both types of services. Summarizing, we establish a sample of European rail operators with the objective to join a set of similar railways, although with differences in the type of operators' structure.

As *input variables* in both the DEA analysis and in the estimation of equation (6), we use the following:

STAFF: stands for the number of workers devoted to rail operations. RAILISA distinguishes between staff employed in rail operations from that employed in infrastructure activities, although this distinction is missing for some years, which has reduced our sample size in a significant way.

LOCS: stands for the number of electric and diesel locomotives used by each rail operator. These are the tractive units owned (or hired) by the railway used for moving and hauling other vehicles.

RCARS: measures the number of electric and diesel rail cars both for passenger or freight.

Additionally, the rightmost column in Table 2 specifies the availability of data period for each operator. The third column in Table 2 identifies the different type of rail operators in the sample according to their market structure characteristics, that is, their vertical structure, the range of services offered and whether they face competition in any service.

The description is as follows:

IM denotes a market structure where infrastructure and rail operations are vertically integrated and there is no competition in the network where the rail company is operating. This category includes some European operators and Japanese rail operators (HRC, WJRC and JR).

IC stands for the vertically integrated companies facing competition in any service type either through open access or a tendering process. A holding model is considered as a vertically integrated structure.[8] FS (Italy), DB-AG (Germany), SBB-CFF-FFS (Switzerland) and SNCF (France, only from 2013) are the companies with this structure facing competition.

SPF indicates rail operators that are separated from infrastructure offering jointly passengers and freight services and facing competition in any service type either through open access or a tendering process. RENFE (Spain), NSB (Norway), Finland (VR), SNCF (up to 2013), CD (Czech Republic from 2004), BDZ (Bulgaria from 2004) and SNCB (Belgium from 2011) fall under this category.

Finally, SP differs from SPF in that operators are specialized only on passenger services. DSB (Denmark) and SJ (Sweden) are in this category. Note that these companies are the traditional state-owned rail incumbents which, besides the vertical separation, undertook horizontal separation between passenger and freight, and the incumbent kept the management of passenger operations.

Also, we provide in Table 2 information about the ratio between revenue and operating costs (the dependent variable in equation (6)). We follow the definition of rail operating costs and operating revenue as given in the reports of UIC (RAILISA). Rail operating costs include supplies and external services, staff costs and other costs as infrastructure charges, taxes and depreciation and amortization. Revenues include income from passenger and freight traffic, other traffic receipts, and subsidies from Government of other public institutions. Regarding costs, note that these are basically variable costs related to the operation and working of the trains and not to rail infrastructure costs, which are mainly fixed. It is nevertheless true that fixed costs would enter the Lerner index expressions under some types of price regulation.

6. Results

We present the results in two subsections. Firstly, we offer the technical efficiency indexes as well as the estimates of the Lerner indexes. Secondly, the joint estimate of the determinants of technical efficiency and Lerner indexes is discussed.

[6] Van de Velde, and NashSmithMizutaniUranishiLijesenZschoche (2012) develop a questionnaire submitted to rail operators' managers in order to correct possible inconsistencies.

[7] https://ec.europa.eu/eurostat/databrowser/product/page/RAIL_PA_TYPEPAS_custom_6841011.

[8] It is known that a holding structure means a first step in the separation between infrastructure and rail operations. In fact, most railways opting for an integrated structure have chosen this model (Germany and Italy from 2000, Switzerland from 2009, Hungary from 2008, Poland from 2001, and Croatia from 2006 among others).

Table 2
Descriptive statistics for the output and input variables and type of market structures.

Acronym	Country	Type	TKT	STAFF	LOCS	RCARS	Rev/C	Years
SNCB/NMBS[a]	Belgium	IM/SPF	98105	20860	756	749	0.947	2000–09
BDZ[a]	Bulgaria	IM/SPF	35100	19197	588	91	0.944	2000–10
HZ	Croatia	IM	27168	8014	280	88	1.003	2001–12
CD[a]	Czech Rep.	IM/SPF	146026	50181	1937	889	1.063	2000–16
DSB	Denmark	SP	59642	8769	73	422	–	2000–09
VR	Finland	SPF	49271	9444	524	159	1.045	2000–16
SNCF[a]	France	SPF/IC	496147	97822	4105	2665	1.116	2000–13
DB AG	Germany	IC	879363	151252	5091	8975	1.040	2000–16
CIE	Ireland	IM	16661	3371	80	318	0.859	2000–08; 10
FNM	Italy	IM	8434	1229	53	146	–	2006–09
FS	Italy	IC	272934	35674	2256	735	1.095	2012–16
HRC	Japan	IM	36870	4339	47	376	0.736	2009–13; 16
JR	Japan	IM	774816	80274	1183	4927	1.241	2000–09
WJRC	Japan	IM	185962	15784	68	250	1.125	2010–14
CFL	Luxembourg	IM	7236	1648	83	40	1.010	2000–09
NSB	Norway	SPF	29571	3455	60	222	1.073	2000–11; 14
EUSKOTREN	Spain	IM	4817	754	6	74	0.509	2000–04
FEVE	Spain	IM	9920	989	56	75	0.769	2005–11
FGC	Spain	IM	9004	835	10	145	0.663	2000–14
RENFE	Spain	SPF	179106	14277	602	1011	1.050	2005–16
SJ	Sweden	SP	46582	3245	136	124	1.078	2000–16
SBB CFF FFS	Switzerland	IC	158384	16243	1439	273	1.043	2000–16
Mean value			241555	83192	2599	2269	0.993	
St. Dev.			383662	275140	4224	3192	0.195	
25% Percentile			34065	10180	469	194	0.953	
Median			59777	28311	1189	760	1.021	
75% Percentile			182505	96997	2793	3010	1.074	
Skewness			2.392	4.212	2.986	1.691	−0.143	

[a] SNCB/NMBS: IM from 2000, changes to SPF in 2011; BDZ IM from 2000, changes to SPF in 2004, CD: IM from 2000, changes to SPF in 2004; SNCF: SPF from 2000, changes to IC in 2013.

6.1. The first stage: estimates of technical efficiency and Lerner indexes

6.1.1. Estimates of technical efficiency indexes

As Simar and Wilson (1999 and 2019) suggest, serial correlation and bias problems of DEA indexes can be reduced using a bootstrapping technique in the DEA computation. For this reason, we calculate the efficiency indexes by averaging the efficiency scores obtained over 500 bootstrap replicates. We applied this method for the two technology alternatives, CRS and VRS. A first check to be done is to run an independence test to contrast the hypothesis that the measure of technical efficiency and mix of inputs is independent or not, that is, whether to use homogeneous or heterogeneous bootstrapping. Both for CRS and VRS technologies the independence assumption cannot be rejected at the 5% significance, because p-values are not statistically different from 0, indicating that homogeneous bootstrap can be used when performing input-based technical efficiency measurement. Therefore, we employ smoothed homogeneous bootstrap in order to calculate DEA scores as efficiency indexes. The third and fourth columns in Table 5 show the efficiency indexes obtained by Bootstrap-DEA under CRS and VRS, respectively.

A second issue is whether the data show CRS or VRS technologies. Therefore, we test the null hypothesis considering that the technology is globally CRS (versus VRS), assuming that there are no significant differences between results obtained by CRS and VRS (see Simar & Wilson, 2002). Assuming smoothed homogeneous bootstrap and from the 257 final observations we obtain that the p-value of the test is 0.945, indicating that the null hypothesis assuming that technology is characterized by CRS cannot be rejected. Therefore, we choose the scores under CRS for the analysis of the determinants of efficiency.

Next, it is known that DEA scores may be biased due to the existence of outliers. This problem can be important in the calculation of DEA indexes. For this reason, we have calculated the DEA indicator for efficiency excluding 64 observations corresponding to the 5% of the lowest and highest values of the variable TKT (the number of train km). In this way, we estimate efficiency indexes with and without potential outliers (assuming the hypothesis of CRS). In order to test the equality of both distributions we use the Kolmogorov-Smirnov test (K-S test). The p-value of the combined K-S test provides a value of 0.972, obtaining that the highest difference between both distributions is hardly 0.045. For this reason, we cannot conclude that both distributions are different. Therefore, we will use the indexes obtained including all observations.

A last point in the calculation of DEA scores is to check, using a separability test, whether the operator market structure variables defined above can affect not only the efficiency scores, but also the shape and position of the production possibilities set. In particular, we calculate Conditional-DEA indexes where the three variables IC, SPF, and SP are included. Then, we will compare the Bootstrap-DEA scores obtained previously with the Conditional-DEA scores.

Once both sets of efficiency scores have been obtained, a separability test is implemented using the Kolmogorov-Smirnov test (see Mergoni, 2022). This test assesses whether the robust and the conditional scores have a significantly different distribution. In case that the robust and the conditional scores have a similar distribution, it is possible to conclude that the separability condition holds. Conditional efficiency measures are also a way to obtain causal inference as they allow to identify the effect of the external variables on the production function, therefore on the efficiency. Recently, Daraio et al. (2018), have defined a fully nonparametric test of this assumption that relies on the central limit theorem and on the bootstrap.

The results of the Kolmogorov-Smirnov test provide a p-value figure of 0.054. Therefore, although marginally, we do not reject the null hypothesis of independence at the 0.05 level. Therefore, Bootstrap-DEA efficiency scores under CRS will be used in the second stage analysis.

Despite the differences coming from the size and time period of the sample, the results are similar to those previously obtained in the literature (see Cantos et al., 2012; Fitzová, 2017; Lérida-Navarro et al., 2019). Some of the rail operators in Sweden, Switzerland, Spain and Norway also show in this case good scores in terms of efficiency. Japanese rail operators show high levels of technical efficiency. On the contrary, rail companies operating in Eastern European countries (like Bulgaria, Croatia and The Czech Republic) show low scores in terms of technical efficiency.

6.1.2. Estimates of Lerner indexes

Next, we present the different steps to obtain the Lerner index. Table 3 shows the results of the stochastic frontier in equation (6). From this estimation, we can calculate the value of the Lerner Index for each rail operator and each year. Table 4 presents the mean values for the Lerner index and its different components. Likewise, the mean value of the Lerner indexes per company is shown in the rightmost column of Table 5.

Note that a potential endogeneity issue associated to Ln TKT may be relevant in the estimation of equation (6). To address it, two instrumental variables (GDP and population) have been introduced (considering that both variables are significantly correlated with train-km, but not with the dependent variable, the ratio between revenue and costs). Given that the endogeneity test applied indicates that endogeneity need not be corrected, we have used the estimates of μ where instruments are not introduced (see Table 3).

Ideally the Lerner Index should be estimated for each particular market (passenger *versus* freight, for instance). This would require having separated data for prices (or for revenues) coming from passenger or freight services, which are not available. Therefore, we have opted to use an aggregate Lerner Index, as in Li et al. (2019), using aggregate revenues and costs for the estimation of equation (6). Another possible approximation is to define a weighted-average Lerner Index (*LIw*), as in Das and Kumbhakar (2016), where $LIw = 1 - \frac{C}{R}\sum_{i=1}^{m}\varepsilon_{ci}$, C stands for costs, R revenue and ε_{ci} denotes cost elasticity of product i and m is the number of products.[9]

There are but a few references on rail Lerner index estimations. Li et al. (2019) obtain a mean value of 0.28 for the 18 Chinese railway bureaus for the 1995–2014 period. On the contrary, Ivaldi and McCullough (2007) obtain higher values ranging from 0.44 in inter-modal to 0.95 in bulk, for a sample of U.S. Class I Railroads between 1981 and 2004. Our results provide a mean value of 0.40, with a minimum of 0.35 and a maximum of 0.48. At any rate, the results show a high degree of market power, which can be explained (among other factors) by the absence of a clear or appropriate competitive framework. Taking as a reference the market share achieved by the rail entrants in freight transport, the following intuition about the values of the Lerner Indexes can be given. Looking at data from 2016 (where the mean value for a sample of European companies was 35%),[10] rail companies such as FS, DB-AG and SNCF that operated in countries with higher market shares of entrants (Italy with 55%, Germany with 46% and France with 41%, respectively) exhibit lower values of the Lerner Index. However, CFL and CIE (with marginal market shares of entrants), most of the Spanish operators (with market shares around 15% and 28%, respectively) show Lerner Indexes that are clearly higher. A comment of this type is difficult to be made with regard to passenger transport, since the introduction of competition is fairly recent and the information in our sample about the market share of entrants is very limited for the period 2000–2016.

Once we have estimated the individual efficiency and Lerner indexes, we complete the analysis by presenting, in a second stage analysis, the determinants of efficiency indexes and the market power of each rail operator, including the effect of efficiency indexes among the determinants of market power.

Table 3
Estimated results of equation (6).

		Estimates (without IV)	Estimates (with IV)
Constant	α_Y	−4.854 (5.795)	−5.001 (6.260)
Ln TKT	α_{YY}	0.0666*** (0.014)	0.0612*** (0.012)
Ln (LOCS/STAFF)	α_{jY}	0.0577*** (0.023)	0.0541*** (0.022)
Ln (RCARS/STAFF)	α_{kY}	−0.0349** (0.017)	−0.0299** (0.015)
TIME TREND	α_{YT}	0.0003 (0.005)	0.0002 (0.005)
Log likelihood		71.899	81.188
Mean *one-side* term	μ	0.8094	0.8104
#observations		164	
Endogeneity test		Chi-2 = 0.46, p = 0.499	

Table 4
Main statistics of Lerner Index and its components.

Variable	Mean	Std. Dev.	Min	Max
μ	0.8094	0.0704	0.67382	0.9454
Φ	0.6791	0.1086	0.4649	0.9836
$1/E_{CY}$	0.8527	0.0940	0.6899	1.1337
LI	0.4020	0.0379	0.3173	0.4958

Table 5
Bootstrap-DEA under CRS, under VRS, Conditional-DEA under CRS and LI.

Acronym	Country	CRS	VRS	Cond-CRS	LI
SNCB/NMBS	Belgium	0.3995	0.4233	0.3628	0.4169
BDZ	Bulgaria	0.2620	0.2841	0.2036	0.3863
HZ	Croatia	0.2736	0.2880	0.2123	0.3977
CD	Czech Rep.	0.2401	0.2732	0.2439	0.3849
DSB	Denmark	0.4657	0.4833	0.4210	–
VR	Finland	0.3732	0.3756	0.3053	0.4037
SNCF*	France	0.4179	0.4758	0.3994	0.3654
DB AG	Germany	0.3747	0.6725	0.5296	0.3507
CIE	Ireland	0.2929	0.3099	0.2133	0.4365
FNM	Italy	0.3833	0.4041	0.3570	–
FS	Italy	0.4928	0.5798	0.6102	0.3799
HRC	Japan	0.5682	0.5724	0.7920	0.4102
JR	Japan	0.6306	0.7803	0.6470	0.4149
WJRC	Japan	0.7261	0.7958	0.7081	0.4344
CFL	Luxembourg	0.2839	0.2989	0.2224	0.4543
NSB	Norway	0.6074	0.6239	0.7071	0.4654
EUSKOTREN	Spain	0.4143	0.6100	0.6071	0.4412
FEVE	Spain	0.5688	0.5904	0.5536	0.4106
FGC	Spain	0.6026	0.6908	0.7717	0.4623
RENFE	Spain	0.6664	0.8085	0.6291	0.4060
SJ	Sweden	0.7438	0.7541	0.5551	0.4315
SBB CFF FFS	Switzerland	0.5721	0.6293	0.7134	0.3680
Mean		0.4720	0.5336	0.4755	0.4021
St. Dev.		0.208	0.246	0.310	0.0379
25% Percentile		0.299	0.327	0.315	0.3565
Median		0.402	0.528	0.445	0.3930
75% Percentile		0.665	0.771	0.689	0.4251
Skewness		0.317	0.012	0.547	0.4971
# Observations		257	257	257	164
Test CRS *versus* VRS (*p-value*) **0.945**					
Separability test Kolmogorov-Smirnov (*p-value*) **0.054**					

6.2. The second stage: determinants of technical efficiency and Lerner indexes

Much of the literature has explored the determinants of efficiency separately from the determinants of the degree of market power. Note that changes in market structure that have occurred in the rail sector (separation of infrastructure from operations and the different ways to introduce competition) definitely affect the costs of rail operators, which are an element of the definition of the Lerner index. Furthermore, how efficiency variations translate to prices also affect the Lerner index, which is an important issue worth analysing.

As indicated above, the term μ in equation (6) employed to estimate the Lerner Index is not exogenous. We acknowledge that this variable may include other factors different from market power like efficiency.

[9] We have calculated the weighted-average Lerner Index for our data and the results obtained with this approximation are qualitatively similar (i.e., the Spearman ranking correlation is 0.79), thus we have opted to present the aggregate Lerner Index approximation that has a lower standard deviation and allows us to keep a larger sample.

[10] Market share data are only available for 2011 and 2016 (see IRG-Rail Independent Regulators' Group, 2018).

This can create an endogeneity problem in the estimation of the determinants of both technical efficiency and Lerner indexes.

To address these, we propose a "common" second stage analysis which consists of estimating two simultaneous structural equations using the three-stage least squares (3SLS) method. This is a form of instrumental variables estimation that allows for correlations of the unobserved disturbances across equations and improves upon the efficiency of equation-by-equation estimation by considering such correlations across equations. In our model specification, the efficiency indexes are considered as an explanatory variable of the Lerner Index. This point is a key result in our paper, because we are interested in finding whether there is a significant (positive or negative) relationship between efficiency levels and market power.[11]

In order to increase the efficiency of the estimates and given the endogeneity of the variable standing for the efficiency level in the equation of the determinants of the Lerner Index, two instruments were added in the estimation process: the one period lagged of the corresponding efficiency index and a variable defined as a ratio between the total train km supplied and the number of employees. We employ a series of dummy variables capturing the typology of rail operators market structures (IM, IC, SPF and SP).

Apart from variables denoting operators structure we introduce two additional country specific variables which may affect efficiency and market power. In particular, we introduce a variable denoting the share of passenger train-km with regard to total train km for the whole rail network in a given country, or passenger traffic intensity (PPASS). This information (coming from IRG-Rail Independent Regulators' Group, 2018) is only available for 2011 and 2016, but it allows us to capture whether the rail industry is more focused on passenger or freight services. This is important because technologies and level of regulation are different for each service. Secondly, we use a variable denoting the percentage of passenger-km operating in non-PSO rail activities. This is a way to take into account whether a higher or lower presence of PSO in the country affects operators' efficiency and their market power. Note that the higher the number of passengers travelling on non PSO services, the higher the volume of passengers travelling on purely commercial services in which operators set prices freely. To take this effect into account, we introduce a dummy variable (denoted COM) which takes value one if the percentage of passengers in non-PSO services is higher than 50%.

Regarding PPASS the mean value in our sample is 84%, with a minimum value of 72% for Bulgaria and Croatia, and a maximum value of 97% for Ireland. These figures indicate that the European rail industry is more focused on passenger transport, although Eastern railways show a higher share in freight transport. Regarding the percentage of passenger-km operating in non-PSO rail activities, Sweden, Spain and France show shares of 51%, 57% and 62% respectively. In contrast, Croatia, Czech Rep., Denmark, Finland, Ireland, Luxemburg and Norway show percentages below 5%. Admittedly, the complexity of rail operations cannot be accurately captured by using an aggregate measure of the production offered by the rail companies. The inclusion of the aforementioned country specific variables is meant to partially address such limitation.

Finally, two dummies are introduced in order to capture regional effects. These variables are introduced for comparative purposes. The variable JAPAN takes value one for the three Japanese rail operators in our sample, whereas EASTEUR takes value one when the rail operator is from Bulgaria, Croatia and the Czech Republic.

Table 6 reports the results of the estimates of the two equations capturing the determinants of efficiency and the Lerner Index. Note that,

Table 6
Three-stage least squares (3SLS) and IV. Determinants of efficiency and Lerner Index.

	Det TE	Det LI
CONST	0.3923[a] (0.2608)	0.2527[a] (0.028)
TE		−0.0131* (0.008)
IC	0.2205** (0.043)	−0.0356[a] (0.005)
SPF	0.0223 (0.032)	−0.0129[a] (0.004)
SP	0.2667[a] (0.045)	0.0416[a] (0.006)
PPASS	−.0.0059** (0.003)	0.0019[a] (0.000)
COM	0.0748[a] (0.036)	−0.0133[a] (0.004)
JAPAN	0.3079[a] (0.049)	0.0122** (0.006)
EASTEUR	−0.2469[a] (0.055)	0.0061 (0.006)
# Observations	134	134
R^2	0.5063	0.7794
Hausman Test (p value)	81.03 (0.00)	

[a] ** and * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively.

as DEA scores and as we previously explained, Bootstrap-DEA indexes under CRS will be employed (see third column in Table 5). In Table 6 we provide information on the Hausman test about the validity of our instruments. The results show that the null hypothesis must not be accepted, and the estimates with the additional instruments must be considered.

Starting with the analysis of the determinants of rail efficiency our results show that (taking as reference the integrated incumbent monopolist, IM operator type) the coefficients for IC and SP are positive and statistically significant, and positive but non statistically significant for SPF. In particular, the biggest efficiency scores are obtained by vertically separated and specialized rail operators (SP) with around 0.27 points more than the score for IM operators. Secondly, integrated rail operators facing competition (IC) show increases in efficiency around 0.22 points as well. However, vertically separated and multi-service operators show efficiency scores not significantly different from those obtained for the IM operators. These results are similar to those reported by Fitzová (2017, 2022) in recent reviews about the liberalization process in the EU. First, not all types of vertical separation increase efficiency, while competition does favor a more efficient behavior. Second, once vertical separation occurs, specialization in one type of service promotes higher efficiency. Therefore, our findings shed light on the lack of a consensus regarding the efficiency impact of separation and competition noted in Section 2; it is a precise combination of both structural measures that may deliver efficiency improvements.

Regarding the PPASS variable, we observe that railways operating in networks with higher passenger traffic intensity show a decrease in efficiency by 0.06 points. The fact that the passenger market is more regulated may explain this result. On the other hand, the variable COM affects positively and is statistically significant. Rail operators in countries with a higher share of commercial (non-PSO) services are clearly more efficient. Finally Japanese rail operators are more efficient than the rest (similar to the results by Marchetti & Wanke, 2019), and Eastern European railways exhibit lower levels of efficiency (Fitzová, 2022).

Next, we provide some discussion about the determinants of the Lerner index in Table 6. Note that in this case the indexes of efficiency are included among the determinants. We find that the coefficient of the efficiency is negative, but only significant (and at the margin) at 0.1 significance level. Hence, we find that more efficient rail operators are associated to lower market power, although this negative relationship between efficiency and market power is not strong. In other words, we can conclude that rail operators with a better efficient performance translate more than proportionally this advantage to prices so that market power is finally lower.

Secondly, we observe that, taking as reference the IM rail operators, the coefficients for IC and SPF operators are negative and statistically significant, while the coefficient for SP operators is positive and

[11] As a robustness check we have run the second-stage with a model specification that considers the reverse, i.e. the Lerner Index considered as an explanatory variable of efficiency indexes, with no qualitatively different results.

statistically significant. IC operators are those with lowest market power, indicating that competition favors not only efficiency but also is associated to lower market power. This happens also for SPF operators, but in clear smaller magnitude. However, SP operators show higher values for the Lerner Index, which may be due, as before, with the fact that the passenger market is clearly more regulated and intervened than the freight market.

Regarding the control variables, PPASS is positive and statistically significant, denoting that railways operating in networks with higher intensity in passenger services show a small increase in market power. Interestingly, we find that the effect of the COM dummy is negative and statistically significant showing that railways operating in countries where the presence of PSO is low have lower market power levels. In particular, their Lerner Index is lower by 0.013 points. PSO are usually activities more regulated than commercial ones and with high state support, which can explain this result. Regarding variables that measure regional effects, Japanese operators show higher levels of market power. It is worth emphasizing that Japanese rail operators' efficiency gains seem to translate more to costs rather than to prices. Finally, the coefficient for Eastern Europe countries is positive but not statistically significant.

7. Conclusions and policy implications

The European Commission 1996 White Paper, "A strategy for revitalising the Community's railways" (COM (96) 421 final), presented the main guidelines for railways to be more efficient, customer oriented, and attractive to users. In this context, during the 1990s, EU countries undertook plans to separate infrastructure from rail operations, and/or favor the promotion of effective competition among rail companies. It is nevertheless true that each Member State has implemented its own plan under the umbrella of the general framework of EU railway policy. This paper has inquired into the effects of such restructuring process in a unified manner for a sample of railway operators.

Specifically, we find that traditional integrated monopoly operators are the most technically inefficient in our sample. On the other hand, specialized operators on passenger services are the most efficient operators; to be operating in higher passenger traffic intensity countries does not further efficiency, whereas a higher share of commercial services in the country does. Similarly, our analysis discloses that traditional integrated monopoly operators exhibit higher Lerner indexes, and hence, behave less competitively. Competition has encouraged a reduction in the price-cost margins, especially for the case of integrated incumbents face. Finally, we find weak evidence that efficient rail operators behave more competitively in the market. We may conclude that cost savings, due to improved efficiency performance, are proportionally smaller than price reductions thus leading to lower market power.

Our analysis is based on a comprehensive comparative analysis of a sample of European railways, in contrast with traditional studies conducted for individual countries on certain routes or for certain operators. We have further investigated how structural reforms have impacted the degree of market power in a thorough way and, in a novel approach, the interplay between efficiency and market power has been examined. However, our analysis does not come without any qualifications. It is fair to recognize the limitations of employing accounting data and the use of train-km as an output measure. Besides, there are methodological issues in the econometric specification that must be noted. All of these may certainly relativize the conclusions.

Notwithstanding, our results offer a preliminary approximation to further understand the links between the degree of market power and efficiency suggesting some relevant policy implications. The various measures of the rail sector liberalization process adopted by policy makers appear to have had a significant positive effect on efficiency levels. Yet not all types of vertical separation increase efficiency. Furthermore, these measures have resulted in lower market power. The conclusion that improved efficiency does not obstruct the intensity of competition is certainly relevant, yet their impacts crucially depend on market structure characteristics. Specifically, vertically separated operators that specialize in passenger services are more efficient but exhibit higher market power when facing competition.

Although the outcome of this study throws instructive observations, further research is needed. Having disaggregated data for passenger and freight traffic as well as more control variables would have been desirable. Also, our analysis has disregarded performance at the infrastructure level, non-price competition variables and environmental issues. Similarly, detailed information about the size and the type of government subsidies to the rail industry would enrich the analysis of the efficiency and market power question. Future analyses may consider how infrastructure charges impact competition in a multimodal setting to have a more faithful picture to assess the viability of further liberalization measures.

CRediT authorship contribution statement

Óscar Álvarez-SanJaime: Writing – review & editing, Supervision, Data curation, Conceptualization. **Pedro Cantos-Sánchez:** Writing – original draft, Supervision, Methodology, Data curation, Conceptualization. **Rafael Moner-Colonques:** Writing – original draft, Investigation, Formal analysis, Conceptualization. **Jose J. Sempere-Monerris:** Writing – original draft, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Appendix. Stochastic frontier approach (SFA) for the estimation of efficiency indexes and second-stage empirical analysis

To check for robustness, we estimate the inefficiency indexes using the usual stochastic frontier approach (SFA) and employing the same output and inputs considered in the DEA described in the main text. In particular, a translog production function with one output and three inputs can be estimated as given in equation (A1):

$$ln\, y_{it} = \beta_0 + \sum_{k=1}^{K} \beta_k \, ln\, x_{kit} + \frac{1}{2} \sum_{k=1}^{K} \sum_{l=1}^{K} \beta_{kl} \, ln\, x_{kit} \, ln\, x_{lit} + v_{it} - u_{it} \tag{A1}$$

where y_{it} stands for the number of train-kms of rail operator i at period t, and x_{kit} stands for the input k for each rail operator. As usual, a "composed error term" (ε_{it}) is assumed, including a standard error term v_{it}, accounting for measurement errors and other random factors, as well as a non-negative unobservable term u_{it}, representing technical inefficiency. Formally: $v_{it} \sim N\left(0, \sigma_v^2\right)$, $u_{it} \sim N^{+}\left(u, \sigma_u^2\right)$. In particular the technical efficiency of the *i-th* operator in the *t-th* time period (TE_{it}) can be predicted using the following expression:

$$TE_{it} = E[exp(-u_{it})/\varepsilon_{it}]. \tag{A2}$$

The estimates of equation (A1) are in the next table.

Table A1
SFA estimation

	Coefficients
CONSTANT	4.9052*** (1.231)
Ln STAFF	0.4453* (0.251)
Ln LOCS	0.6555*** (0.172)
Ln RCARS	0.0242 (0.176)
0.5*Ln STAFF*Ln STAFF	0.0230 (0.090)
Ln STAFF*Ln LOCS	−0.3353*** (0.0631)
Ln STAFF*Ln RCARS	0.0242 (0.046)
0.5*Ln LOCS*Ln LOCS	0.3263** (0.049)
Ln LOCS*Ln RCARS	−0.0939** (0.043)
0.5*Ln RCARS*Ln RCARS	−0.0612*** (0.021)
Ln LENGTH	0.1115** (0.051)
TIME TREND	0.0105* (0.006)

Standard errors are in parentheses; ***, ** and * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively. Individual effects per firm are included.

Next table displays 3SLS estimates when bootstrap-DEA (left) and SFA (right) efficiency scores are employed. There are no qualitative difference.

	$TE_{\text{bootstrap-DEA}}$		TE_{SFA}	
	Det TE	Del LI	Det TE	Del LI
CONST	0.3923*** (0.2608)	0.2527*** (0.028)	0.7496*** (0.2442)	0.2586*** (0.030)
TE		−0.0131* (0.009)		−0.0169 (0.012)
IC	0.2205** (0.043)	−0.0356*** (0.005)	0.1680*** (0.040)	−0.0392*** (0.005)
SPF	0.0223 (0.032)	−0.0129*** (0.004)	0.0616* (0.038)	−0.0151*** (0.004)
SP	0.2667*** (0.045)	0.0416*** (0.006)	0.1626** (0.074)	0.0284*** (0.006)
PPASS	−.0.0059** (0.003)	0.0019*** (0.000)	−0.0106*** (0.003)	0.0018*** (0.0003)
COM	0.0748*** (0.036)	−0.0133*** (0.004)	0.0457** (0.023)	−0.0126*** (0.004)
JAPAN	0.3079*** (0.049)	0.0122** (0.006)	0.2536*** (0.045)	0.0072* (0.004)
EASTEUR	−0.2469*** (0.055)	0.0061 (0.006)	−0.2241*** (0.051)	0.0075 (0.006)
# Observ.	134	134	134	134
R^2	0.5063	0.7794	0.546	0.750
Hausm. Test (p value)	81.03 (0.00)		77.05 (0.00)	

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