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European Railways: Liberalization and Productive Efficiency

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ABSTRACT

The EU Commission launched its rail liberalization policy around 2002 and since then it has been a policy extensively analyzed by the economic literature, but with unclear conclusions. Many studies are based on a loose concept of rail liberalization, which entwines legal reforms, vertical disintegration and the introduction of competition into simple dummy-variables. In this paper, we estimate efficiency frontiers based on different methodologies to analyze the relative position of 27 European rail systems. Efficiency scores are afterwards analyzed with a Tobit model, using several dimensions of the rail liberalization process plus some structural variables as explanatory factors. Our findings indicate that, globally, there is a weak positive link between EU rail liberalization and higher efficiency, and that effective competition is the most relevant factor to achieve efficiency gains. However, for some EU countries, measures adopted to liberalize railways may have resulted in lower levels of efficiency.

1. Introduction

At the end of the 1980s there was a worldwide trend towards market liberalization and privatization of public firms in many industries, but the rail sector was only marginally affected by this wave. Governments successfully transformed telecoms, energy, air transport, and many public utilities into competitive (or at least, contestable) markets, but most of the EU vertically-integrated public rail monopolies survived until the beginning of the 21st century.

However, during the 1990s the EU Commission started to introduce changes in European railways aiming to foster, in the long-term, a single rail market where different rail undertakings might provide services across and within EU countries.[1] Several legislative packages were passed to design a general framework for a policy based on the separation of rail infrastructure and services, access to rail markets for new entrants in equal conditions to incumbents, and the promotion of effective competition among rail undertakings.

In order to implement this strategy, each Member State has thereafter followed its own national plan to adapt the general framework of EU railways' policy to its particular situation. As a result, there is now a patchwork of alternative models of rail organization across Europe, which can be classified according to: (1) the degree of separation between rail infrastructure and provision of services; and (2) the degree of competition among rail carriers. Although each country presents its own particular characteristics –and some initiatives to privatize companies have been reverted over time-a global overview of models of rail organization is presented in Table 1.

What is the best model of organizing railways in terms of productive efficiency? The EU rail policy provides what it is probably the best experience around the world to try to answer this question, since each country has opted for different alternatives to liberalize the rail sector according to its own particular characteristics. The main objective of this paper is to analyze if the re-organization of EU railways has contributed or not to improve the productive efficiency of the rail industry.

The structure of the paper is as follows. Section 2 provides a review of the empirical literature analyzing rail reforms and efficiency. Section 3 briefly describes the methods used to estimate the productive efficiency of rail systems (stochastic frontiers and data envelopment analysis). Section 4 describes the data, with particular emphasis in explaining some indexes of rail market liberalization (compiled by other authors) that measure the advance of EU countries in the process of introducing reforms. Section 5 presents the results of rail efficiency frontiers' estimations, while Section 6 explores the relationship between efficiency and the degree of rail liberalization. Finally, section 7 summarizes the main results of the paper.

2. Review of empirical literature

There is a relatively large number of papers analyzing the EU rail policy and its impact on efficiency, based on different approaches and empirical data. Rather than attempting to provide a comprehensive

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survey, we review here only those empirical works which examine rail efficiency questions that are related to our paper, and try to extract some general conclusions from them.

In order to organize the empirical literature on rail efficiency, we classify the papers according to their main focus of analysis into three groups: (1) *rail deregulation,* defined as changes in the legal rules governing the market; (2) *vertical disintegration* of large rail companies providing both infrastructure and service; and (3) introduction of *effective competition* among rail companies.

Since the papers are widely diverse in terms of methodologies, scope of the analysis and data used, a brief summary of the main technical aspects of all the papers reviewed is presented in Annex 1, while in this section we present a global overview of the main results obtained by different authors on the topic of rail efficiency.

Starting with *rail deregulation,* Friebel et al. (2010) analyze if the EU rail reform policy has had an impact on efficiency, in a study based on 11 rail systems. These authors reach an interesting conclusion: the order of introduction of changes is more relevant than the global reform package implemented by each country. Rail systems exhibit better results when policy measures are implemented sequentially, rather than simultaneously. This study relies on a production boundary model (Cobb Douglas function) to measure the impact of deregulation on rail systems' output.

Wetzel (2008) focuses on rail companies, rather than on rail systems as a whole. A model is estimated with data on 31 companies from 22 countries, evaluating if policy reforms and some control variables have impacts on efficiency. Regarding reforms, none of the variables that record the institutional segregation seems to have a statistically significant influence on efficiency.

Several papers have analyzed the issue of *vertical disintegration* of EU rail companies and its impact on efficiency. However, there is no clear-cut conclusion about the optimality of this policy. On one hand, it seems that separating rail infrastructure and services can generate some efficiency gains, as found by Friebel et al. (2003); or Asmild et al. (2009), who point out that vertical segregation reduces material and labor-related costs. Cantos et al. (2010) point out that segregation enhances both productivity and efficiency, the effect being stronger when this policy is accompanied by competition. A similar finding is reported by Pham (2013), who finds a positive but weak relationship between disintegration and efficiency.

On the contrary, some other papers provide evidence about lower efficiency levels being achieved when infrastructure and provision of rail services are separated. The main reason is a loss of potential synergies between the two sides of the rail industry. Growitsch and Wetzel (2009), based on a DEA analysis performed on the cost efficiency of 54 European rail companies, report that vertical integration yields better efficiency results in the mid-term, due to the more efficient leveraging of economies of scale, which are detected in 65% of the companies.

Laabsch and Sanner (2012) conduct a study on 9 European rail systems for the period 1994–2009, using as dependent variable the rail modal share. They report that vertical segregation does not yield any positive impacts on passenger services, while those rail systems remaining vertically integrated exhibit better results. Regarding freight transport, these authors do not find any significant impacts of rail disintegration on efficiency.

Mizutani et al. (2015) propose a different approach to examine the question of separation, by considering the possibility of three models of rail organization: vertical integration, vertical separation, and the existence of a holding company comprising a separated infrastructure manager and one or several rail undertakings. Based on the estimation of a translog cost-function, these authors report that the holding

[1] The main guidelines of the EU rail reform plan were discussed in the 1996 White Paper: "A strategy for revitalising the Community's railways", COM (96) 421 final.

Table 1
Models of railway organization in Europe and other countries (as around mid 2000′s)

Degree of separation between rail infrastructure and services	Degree of competition in the provision of rail services	
	Null/Scarce competition	Effective competition
Vertical integration [(a)] **Public manager of infrastructure**	Lithuania, Luxembourg, Ireland, Russia, China	Germany, Austria, Italy, Poland, Switzerland, Latvia, Slovenia, Hungary, Japan [(c)]
Vertical integration Private manager of infrastructure	–	Estonia [(d)], USA
Vertical separation [(b)] **Public manager of infrastructure**	France [(e)], Spain, Portugal, Greece, Finland, Slovakia	Sweden, Netherlands Denmark, Czech Republic, Norway, Romania, Bulgaria, Belgium [(f)]
Vertical separation Private manager of infrastructure	–	UK [(g)], New Zealand [(h)], Australia

Source: Own elaboration.
Notes: (a) Countries in which one rail company remains vertically integrated, although the market can be open to new entrants.
(b) Countries in which rail infrastructure is completely separated from rail operation, and the infrastructure is managed by an independent agency/company.
(c) Most of the Japanese rail industry remains vertically integrated, although new infrastructure is provided separately. Rail undertakings have access to the infrastructure of other companies, but on the basis of negotiation rather than as of right (Mizutani et al., 2015).
(d) Infrastructure was privately managed in Estonia between September 2001 and January 2007, after the partial privatization of the rail company Eesti Raudtee. However, Estonia brought back its railways to public ownership in 2007.
(e) France is included in the group of vertical separation, although some of the tasks assigned to the infrastructure manager (Réseau Ferré de France, RFF) during the period 1997–2014 were delegated and carried out by the rail company SNCF, and a similar hybrid model between separation vs. integration applies to the Czech Republic. After 2014, France transformed its rail organization to a holding company model.
(f) Belgium switched from the holding company model to the disintegrated model in 2012, when the activity of the holding SNCB/NMBS was divided in two different and independent entities: Infrabel (infrastructure manager) and SNCB (operator).
(g) UK is the only European country that has attempted to privatize rail infrastructure, although the experience of Railtrack as a private company was not successful and it was re-nationalized in 2002.
(h) The experience of introducing a private management of infrastructure in New Zealand only lasted until 2004.

model yields small cost reductions compared to the other two models. Another interesting finding of this paper, also previously reported by the same authors (Nash et al., 2014), is that the existence of a significant share of freight traffic generates additional costs in the case of full separation between infrastructure and services.

Smith et al. (2018) modify the econometric model of Mizutani et al. (2015), by introducing the same index of rail liberalization that we also employ in this paper (described below in section 4.2). Their results indicate that vertical separation and strong regulation are both required in order to generate cost reductions. However, for very densely used rail systems, a holding company model is preferable to full separation on a costs basis. Another relevant result obtained by Smith et al. (2018) is that rail passenger competition also reduces costs.

Thus, vertical separation of rail infrastructure and services is a policy that may have some drawbacks. On one hand, it seems to generate incentives' problems, since different agents trying to maximize their own objectives may easily enter into conflicts (McNulty, 2011). On the other hand, separation introduces transaction costs that can be minimized by the holding company model (Merkert et al., 2012), or they might be fully avoided by the vertical integration model.

A third group of papers has studied the *introduction of competition* in EU rail markets and its impact on the level of efficiency achieved either by complete rail systems (cross-country studies), or by individual rail companies. In general, the existence of competition seems to provide a positive boost for efficiency, as reported by Pham (2013), and Cantos et al. (2010, 2012). Ivaldi and Vibes (2008), in a study of the Cologne-Berlin corridor, conclude that a small number of competitors is able to create a high degree of competition, to promote lower prices and to induce additional levels of traffic. However, the effects are usually small, and they depend on the way in which competition is introduced.

Driessen et al. (2006) estimate a DEA frontier to measure if total or partial (accounting) segregation and competition have an impact on efficiency. They conclude that different competition models in the operation of rail systems can affect the networks' efficiency levels. Specifically, public bidding procedures (competition *for* the market), which are usually applied in EU commuter and regional systems, seem to have a significant positive impact on productive efficiency. Similarly, Link (2016) examines the use of public funds in the system of franchising of rail passenger services in Germany, and reports that more competition to obtain a franchise and longer periods of the franchising contracts results in higher efficiency. On the contrary, the use of an unrestricted model of entry (competition *in* the market) seems to have a negative impact on the cost-efficiency of a rail system.

Summing up, the conclusions extracted from all these papers analyzing EU rail liberalization and its impacts on efficiency are not consistent. This can be partly due to the loose definition of the concept of rail liberalization, which in some cases is simply assimilated to the model of vertical disintegration, while other papers use dummy-variables to account for legal market deregulation and/or the existence of real market competition. These empirical strategies seem a poor approximation to reflect the diversity of nuances and particularities around the liberalization of rail systems.

Our approach in this paper is to consider rail liberalization as a complex process –or better as a collection of 'sub-processes- that entail a gradual lower involvement of public authorities in the provision of rail services. It is misleading to identify rail market liberalization with the mere introduction of competition and, moreover, it is highly confusing to identify rail liberalization with a particular management model of the rail system that relies on vertical segregation of infrastructure and services.[2]

3. Methodology

In this paper we use different techniques to estimate efficiency frontiers, in order to evaluate the relative position of each EU rail system when compared to other counterparts: data envelopment analysis (DEA), stochastic frontier analysis (SFA), deterministic frontier (DFA), and a distance function (DIST). Only results from the first two techniques are reported here, although the efficiency scores attained by European rail systems have been found to be generally consistent across methodologies. Countries identified as the most and less efficient in Europe are in line with previous results obtained in the literature of rail efficiency.

3.1. Data envelopment analysis (DEA)

The DEA technique is based on information on inputs used and outputs generated by each rail system, and it obtains a production frontier based on the observations of the most efficient decision units, without imposing a particular specification to the form of the frontier. The efficiency of each decision unit is measured as the distance to the frontier, with those units classified as the most efficient obtaining a score with value equal to 1. Our model follows the standard approach of Charnes et al. (1978), and among the different possibilities offered by this method, we choose a CCR approach (constant returns to scale), since we consider it more adequate for the rail industry.

Railways require the use of large infrastructure with high sunk costs. Once the construction of a rail network is completed, its output is approximately proportional to the use of inputs, therefore we may expect to classify as efficient those decision units which are able to save costs in the production of rail services, compared to other counterparts. Furthermore, the use of a CCR model avoids the convexity restriction that a BCC model (variable returns to scale) imposes to the form of the frontier.

Additionally, in line with Cantos et al. (2000), a DEA model based on CCR assumptions yields equal or higher efficiency returns than a BCC model. By definition, the constant returns to scale option is more demanding in terms of efficiency than the option with variable returns to scale.

3.2. Stochastic frontier analysis (SFA)

The stochastic frontier model is based on the idea of estimating a number of parameters of a pre-specified functional form representing the production function of decision units. The function has an error term with two components: one of them with a truncated non-positive statistical distribution representing the technical inefficiency of the decision units (non-negative distribution in the case of cost functions), plus another part with a normal distribution to represent random noise. Usual specifications to estimate frontiers are the Cobb-Douglas function, and the more general Translog (Transcendental Logarithmic) function defined by Christensen et al. (1973). In this paper, we estimate frontiers based on both specifications in order to check for robustness of results, and also to compare the efficiency scores obtained by SFA with those of the DEA technique.[3]

A well-known feature is that the Cobb-Douglas specification is a particular form of a translog function, obtained by considering only first-order terms and no interactions between inputs. Therefore, it is a less demanding model in terms of the number of parameters to be estimated, but it imposes some restrictions on the results such as identical elasticities (scale, substitution) for all rail systems.

The unknown parameters of the stochastic frontiers are estimated following a three-stage procedure. First, the estimators are calculated by ordinary least squares method (OLS). The second step is a thorough search of the values obtained based on the maximum likelihood function biased by a fixed algorithm, with OLS estimates used as starting values. Finally, the selected values in the search of the previous stage are used as baseline values in an iterative procedure intended to obtain the final maximum likelihood estimators.

3.3. Hierarchical conglomerate analysis

In order to control for homogeneity of the rail systems used in our analysis –and thus to avoid results that could be attributable to heterogeneous decision units-we applied a preliminary analysis of conglomerates.

This technique is useful to search for groups of decision units with common characteristics (in our case, countries with similar rail systems). If many types of groups are detected, and each group is large in terms of number of units, it would then be advisable to estimate different frontiers to analyze efficiency, to avoid the risk of obtaining biased results due to groups' heterogeneity.

In our analysis we use the method of "inter-group linking", as it takes into account the information of all members of the

[2] This simplification would be still less accurate if we took into account the Fourth Rail Package, since the European Commission has adopted thereafter a more flexible stance on the matter of vertical de-integration of the sector, accepting the possible existence of rail holdings, provided that infrastructure managers are operationally and financially independent from the providers of rail services.

[3] The notation used in the paper is SFA (C-D) for Cobb-Douglas production function, and SFA (T-L) for Trans-Log function.

conglomerates that are being compared. This is useful for our purposes, since the conglomerates' technique is not used here as an end in itself (and therefore no refinement in the forming of homogeneous groups is required), but simply as a way to check for the consistency of EU rail systems included in the sample.

According to this method, the proximity between two groups is quantified by calculating the average of the similarities between objects of both groups. The proximity between the r–th and s–th conglomerates (d_{rs}), is calculated as the average distance between all pairs of elements (structural variables) from both conglomerates.

With an specification for the model to build only two conglomerates, our results form a first group composed of 25 countries plus a second group including only Belgium (BE) and Netherlands (NL), as countries with distinctive features in their rail systems. If a three-conglomerate specification is introduced, the group of 25 countries stays together, and each of the other two countries (BE and NL) individually form their own conglomerate.

In the case of a four-conglomerate specification, the single country units (BE, NL) remain separated from the rest and a large conglomerate comprising almost all countries in the sample stays together (22 units). A new conglomerate formed by Switzerland (CH), United Kingdom (UK) and Luxembourg (LU) is generated. Compared to BE and NL, this new group formed by 3-rail systems is closer to the large conglomerate with 22-rail systems.

In conclusion, results from the analysis of conglomerates seem to indicate that the 27 EU rail systems included in our sample exhibit a relatively high degree of homogeneity in rail inputs and outputs. Only the cases of Belgium, Netherlands, Switzerland, Luxembourg and UK are found by this technique of conglomerates to have some differential characteristics compared to the rest of European railways, but small enough to be included in the sample.

4. Data

4.1. Variables for efficiency analysis

Data used to measure the efficiency of EU rail systems was obtained from official statistics of the *Union Internationale des Chemins de Fer* (UIC, 1998–2012), which have been previously used by other authors (e.g., Mizutani et al., 2015). All variables finally included in the sample have been thoroughly examined, and some errors were corrected after comparing the UIC database with official network statements published by rail infrastructure managers. Additional data on national rail systems was collected from international organizations[4] and the database was also completed with annual reports published by rail network managers and rail undertakings.[5]

Unfortunately, our dataset does not include information about some important inputs for the rail industry, such as the consumption of energy, or different categories of railways' employees (engineers, train drivers, maintenance workers, administration and other personnel). Attempts to find information about these types of inputs from national sources failed due to the heterogeneity of data, so it was considered preferable to exclude additional inputs rather than taking the risk of introducing noise by using variables with large measurement errors.

The effect of missing variables in our estimates is probably that the efficiency scores of some particular rail systems could be affected. This limitation is somehow corrected later, when we use the efficiency scores obtained from the frontiers as dependent variables in a Tobit model, by introducing some additional structural variables of national rail systems as explanatory factors (see section 6.2).

The period used for the analysis is 2002–2011, for which it was possible to find data for all variables required to estimate the frontiers described in the previous section. Our sample is complete for that period and it includes 27 European rail systems. Table 2 presents the definition of all variables used for estimating efficiency frontiers, indicating the role that they play in the models as inputs or outputs.

The definition of rail systems' output (Y_i), which is used in the stochastic frontier models, is based on a composite index that combines information from the variables normally used in the literature: volume of passenger-kilometers (PKM) and ton-kilometers of freight (TKM) carried by all companies operating in each rail system. For the DEA model, a 2-output/3-input specification is used, as it allows a richer exploration of the use of common inputs in the production of the two types of rail services.[6]

The empirical literature on rail efficiency usually combines the two outputs into one single index defined as the sum, or the product, of PKM and TKM. This is somehow an unsatisfactory index of rail outputs, as it automatically considers that one ton-km of freight is equivalent to one pax-km. As discussed by Beck et al. (2013), the comparison of rail systems from countries with very different types of networks and services (some of them specialized in the production of freight services, with long trains that travel long distances) can lead to a misleading picture when evaluating rail efficiency. As pointed out by these authors, an international comparison of rail systems based on a simple measure of output such as Transport Units (=PKM + TKM), is biased and tends to favor countries such as US, Australia or China when compared to other European counterparts.

Following the literature on the construction of statistical indexes that aim to combine very different types of indicators from countries in order to make international comparisons (see OECD and JRC, 2008), we propose a new definition of rail systems' output based on a composite index that merges the total volume of freight and passenger services, plus a term aiming to reflect the interaction between them. Thus, the volume of output of each rail system is defined here as:

$$Y_{it} = \sqrt{PKM_{it}^2 + TKM_{it}^2 + PKM_{it}\,TKM_{it}} \qquad [1]$$

where PKM_{it} = Total annual pax-km and TKM_{it} = Total annual freight ton-km, of rail system i in year t.

If this new output definition Y_{it} is compared with the commonly used output $Z_{it} = PKM_{it} + TKM_{it}$, it can be observed that the definition Y_{it} of rail output is able to take into account some operative inefficiencies that a rail system may suffer when both passenger and freight trains must share rail lines, a feature that is common in many EU national networks. On the contrary, countries that have many rail lines exclusively used by passenger trains or, in other cases, they have reserved corridors just for freight trains, may provide better services due to less interference between the two types of traffic. These interactions between passenger and freight services are not reflected in output Z_{it}, since by definition it is calculated simply by adding train-kms regardless of the nature of transport, while Y_{it} introduces a small correction for this fact.

It can be easily checked that Y_{it} always yields lower values than Z_{it}, but the two variables are very close (just by multiplying by 2 the third term on the right-hand side of [1], we will obtain then that $Y_{it} = Z_{it}$). When comparing the results of the two alternative definitions of output indexes, those rail systems with a more balanced mix of PKM and TKM are slightly penalized by index Y_{it}, when compared to other

[4] Publications from EU statistics' agency (Eurostat), World Bank, and International Transport Forum were checked to confirm the validity of UIC data on rail volumes of outputs, inputs, length of tracks and other aspects of each national rail system.

[5] Corrections to the UIC data were specially required in the case of Netherlands, Norway, Sweden, UK, Denmark and Italy.

[6] A distance function was also tried for the estimation of an efficiency frontier with a 2-output/3-input specification. As explained later (see section 5), the efficiency scores obtained are positively but not strongly correlated with those from the other techniques.

Table 2
Variables used in frontier models.

Variable	Units	Type
Network [NET]: Total length of railway infrastructure in each country in operation at the end of each year.	Track-km	Input
Rolling Stock [ROS]: Number of coaches, railcars, locomotives and wagons and multiple-unit trailers available at the end of each year.	Number of units	Input
Labour [L]: Average annual number of employees in the railway system.	Thousands of employees	Input
Passenger services [PKM]: Volume of pax-km transported.	Thousands	Output
Freight services [TKM]: Volume of ton-km transported.	Thousands	Output

Source: Own elaboration.

countries with high specialization on passenger trains or freight trains. This feature is considered to be appropriate to account for the relatively higher efficiency of rail systems specialized in one particular type of train services (freight or passenger).

4.2. Data on rail liberalization

Information about the degree of liberalization achieved by each EU rail system has been obtained from detailed studies carried out by IBM-Deutschland and Humboldt University of Berlin (Kirchner, 2002, 2004; 2007, 2011). These studies compiled a large volume of information about the degree of implementation of EU Commission policy of rail liberalization across EU countries, covering some particular years during the period 2002–2011. Based on that information, the authors build an interesting rail liberalization index, with several associated sub-indexes that provide a picture of all the different dimensions of the process of EU rail reforms.

The global *liberalization index (LIB Index)* is based on 230 variables collected for each country. It is defined as the weighted sum of two subindexes that quantify both the legal and institutional changes introduced (*LEX Index*) and the real access conditions existent in the market (*ACCESS Index*). Weights assigned to these two variables to calculate the global *LIB Index* are 20% and 80%, respectively.

Within the two subindexes there is a richness of information summarized into simple indicators. Thus, in the case of the LEX Index, it includes several dimensions such as the regulation of market access (45% of the subindex), existence of regulatory authorities (30%), and the organizational structure of the national operator inheriting the public monopoly (25%).

The ACCESS Index depends on the operating barriers (with a weight of 50%), market accessibility (25%), administrative barriers (20%), and informative barriers (5%). In general, the degree of liberalization envisaged at the normative level (LEX Index) is higher than the one observed in practice regarding the access conditions for external rail undertakings (ACCESS Index). The variables and subindexes used for the calculation of the global LIB Index are described in Table 3.

The COM index is a different and separate subindex (not included in the weighted computation of the global LIB index). It provides an indication of the intensity of competition in the rail systems. For the calculation of the COM Index, the indicators used reflect the market competitive dynamics (20% of index) –measured with several indicators of change in the rail modal share in passenger and freight transport markets- and also the effective entry of competitors: number of external rail undertakings excluding the incumbent (20% of index), and the market share of these external operators (60% of index).

The scope of the rail liberalization index LIB is quite ambitious in terms of geographical coverage, since it has been calculated for all EU-

Table 3
Rail liberalization index and sub-indexes.

Index	***Advanced systems***	***Delayed systems***
LIB: Railway system liberalization index that quantifies the degree of liberalization for each national railway system	Index values > 800 points (2007 and 2011) > 600 points (2002 and 2004)	Index values < 600 points (2007 and 2011) < 300 points (2002 and 2004)
Subindexes	***Weighting***	***Subject Areas***
LEX: Identification of legal and institutional changes to promote rail liberalization in each country	20% (Internal components: a:45%, b:30%, c:25%)	(a) Regulation of market access; (b) Regulatory authority powers; (c) Organizational structures of incumbent
ACCESS: Identification of market access conditions that exist in practice	80% (Internal components d:50%, e:25%, f:20%, g:5%)	(d) Operational barriers; (e) Market accessibility; (f) Administrative barriers; (g) Information barriers
Additional Subindex	***Weighting***	***Subject Areas***
COM: Effective competition in rail markets	Not included in LIB (Internal components h:20%, i:20%, j:60%)	(h) Changes in rail market share; (i) Number of external operators excluding incumbent; (j) Market share of external operators

Source: Kirchner (2002, 2004, 2007, 2011).

28 countries with rail systems, plus Switzerland[7] and Norway.[8] Our sample of 27 countries used for estimating efficiency frontiers was selected precisely to match the number of countries covered by the LIB index studies (only Croatia could not be incorporated to our sample, due to lack of data for some of the variables). However, the rail liberalization studies are limited in their time dimension, since they were only carried out in years 2002, 2004, 2007 and 2011.

The starting year for the calculation of the LIB index (2002) is related to the EU Commission policy of reforms for the rail industry, and it is connected to the so-called “First Rail Package”, consisting of Directives 2001/12, 2001/13 and 2001/14. The purpose of this package was to enable the EU rail market to be opened up to competition and to guarantee the independence of railway infrastructure managers. Based on these directives, it is possible to establish the official starting point of the EU rail market liberalization.[9]

To our knowledge, the IBM-Humboldt index of rail liberalization has only been previously used in empirical works on rail efficiency in recent papers by Bougna and Crozet (2016), and Smith et al. (2018). Compared to these papers, our estimates are based on a larger sample of countries (27 European rail systems) and we use several different techniques for the estimation of efficient frontiers, with

[7] Although Switzerland does not belong to the EU, this country is subject to EU regulations in the area of rail liberalization, by virtue of the agreement signed between the European Community and the Swiss Confederation regarding the transport of freight and passengers by rail and road.

[8] The purpose of Directive 2001/13 is to expand the EU provisions to all rail companies established in the EU to harmonize the conditions under which they operate and prevent licenses from becoming a market access barrier. This directive determines that a license obtained in any of the EU countries, Iceland, Liechtenstein, Norway and Switzerland is valid across all EU territories.

[9] Germany, UK and Switzerland kicked off their transition processes towards a liberalized model before 2002, following Directive 91/440/EEC, which required a compulsory accounting segregation between infrastructure managers and rail undertakings, as well as a voluntary institutional separation.

results being afterwards compared. Our empirical strategy to relate rail efficiency to liberalization is similar to Bougna and Crozet (2016), who also estimate a Tobit model to explain rail efficiency results, while Smith et al. (2018) introduce the LIB index (renamed in their paper as regulation index, REG) into a translog cost function, jointly with some dummies aimed to measure competition and market access conditions.

4.3. Rail systems' and countries' structural variables

In order to take into account for the fact that some relevant inputs for the rail industry (e.g. use of energy) could not be measured, we completed our database with several variables that reflect structural conditions of countries and their rail systems. All data for this third group of variables was collected from the official EU Statistics Agency (Eurostat).

These additional variables are described in Table 4, and all of them were tried in different specifications of the Tobit model presented later in Section 6, although not all variables were significant in the final specification of the model.

Table 4
Structural variables.

Country Variables	**Definition**
GDP	Gross Domestic Product (million €, constant prices base-year 2010)
GDPpc	GDP per capita (thousand €, constant prices base-year 2010)
Population	Thousand inhabitants
Area	Total squared-km
Density	Inhabitants per squared-km
Urbanisation	% population living in cities
Rail Sector Variables	**Definition**
Single-track	% of rail network with single-track lines
Electrified-track	% of rail network with electrified lines
Cargo_international	% of total ton-km with origin or destination in other countries
Cargo_transit	% of total ton-km of transit traffic
Rail share_pax	Share of rail mode over total movements of passengers (%)
Rail share_freight	Share of rail mode over total movements of freight (%)

Source: Eurostat.

5. Efficiency frontiers' results

Table 5 presents detailed results of the efficiency scores obtained from the estimated stochastic frontier (SFA-TL, trans-log specification) and the DEA frontier, for all 27 rail systems included in the sample. Frontiers were estimated for the whole period 2002–2011, but only the scores for years 2002, 2004, 2007 and 2011 are presented in the table, since those are the dates for which the rail liberalization LIB is available.

Data shown in Table 5 allows comparing, on one hand, the technical efficiency results obtained from the two different techniques to estimate frontiers (SFA with translog specification and DEA). On the other hand, the efficiency scores can be contrasted with the quantitative index of rail liberalization (LIB), in order to analyze the effectiveness of this policy.

The efficiency scores measure the relative distance of each rail system to the estimated efficient frontier. The lower the efficiency indicator, the higher is the inefficiency of a national rail system compared to other countries. A value of one (1.00) indicates that a rail system is fully efficient. With respect to the liberalization index, the maximum value that a country can reach is 1,000 points.

In order to compare the degree of similitude in the ranking of countries obtained by SFA and DEA frontiers, we calculate the Spearman's rank correlation coefficient[10]. If the value of this coefficient is close to one, it means that the efficiency rankings obtained by the different methods are similar. Results are presented in Table 6, and it can be observed that positive and statistically significant rank correlations are found for DEA and SFA efficiency scores).[11]

The rail systems that present the highest efficiency scores in all years considered are United Kingdom, Netherlands, Estonia and Latvia. Some of these countries are well advanced in the process of liberalization, as measured by their values of the LIB index in 2011 (e.g. UK and NL). However, it is also possible to find cases with modest liberalization advances, which seem to be compatible with excellent efficiency results (e.g. Estonia, Latvia and Switzerland).

On the other hand, those rail systems with low degrees of liberalization are usually among the most inefficient. Greece, Ireland, Bulgaria and Romania are countries where this effect is more clearly observed. These results on the most and less efficient rail systems in Europe are in line with those previously obtained by other authors (for example, see Coelli and Perelman, 1999; De Jorge-Moreno and Garcia, 1999; Christopoulos et al., 2000; Loizides and Tsionas, 2002; Hilmola, 2007; Asmild et al., 2009).

Another remarkable result is observed when analyzing the evolution over time of technical efficiency. Several rail systems that made significant progress in the liberalization process exhibit lower levels of technical efficiency in the last years of the sample (e.g. Hungary, Italy, Norway, Poland and Spain).

It is difficult to extract general conclusions on the impact that the process of reforms has had on EU rail efficiency by casual examination of particular cases. In general, highly liberalized rail systems obtain good results in terms of efficiency, but not all efficient rail systems are found in countries that are more advanced in the process of liberalization. On the other extreme, rail systems from countries with low liberalization are generally inefficient, but some exceptions can also be found.

6. Impacts of rail liberalization on efficiency

In order to study the relationship between the EU policy of rail liberalization and the efficiency of national rail systems in a more systematic way, in this section we follow two different strategies.

First, the association between advances in rail liberalization and efficiency scores is analyzed with a preliminary Kruskal-Wallis test. In order to do that, we divide the 27 EU countries in the sample into three groups, according to the classification defined by authors of the LIB index studies (advanced countries, delayed countries, and intermediate cases). This test provides evidence for the existence of a positive link between liberalization and efficiency.

Based on this result, on a second stage we proceed to estimate a Tobit model that uses the efficiency scores obtained from the DEA frontier analysis as a dependent variable. The following explanatory factors are introduced in the model: (i) a set of structural variables (country characteristics), (ii) some other variables measuring characteristics of the railways' network and the relevance of rail over total transport

[10] The Spearman Rank correlation can be calculated as

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$$

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$$

, where n is the number of observations of the two series to be compared (in our case, n = 270, corresponding to the rail efficiency scores of 27 countries evaluated over 10 years), and d_i is the difference between the two ranks of each observation pair (efficiency scores obtained by the two techniques that are compared).

[11] A deterministic approach (DFA) and a distance function (ln d_i) were also used to estimate efficiency frontiers, but results differ from the other two techniques (SFA, DEA), with low and non-significant correlations measured by the Spearman rank coefficient. In the case of DFA, which is based on the identification of one most efficient rail system that defines the frontier, the best country was Switzerland, one of the countries identified by the conglomerate analysis in section 3.3 as having special features in its rail system).

Table 5
Technical efficiency and rail liberalization.

RAILWAY SYSTEM	*2002*			*2004*			*2007*			*2011*		
	SFA-TL	DEA	LIB	SFA-TL	DEA	LIB	SFA-TL	DEA	LIB	SFA-TL	DEA	LIB
Austria	0.889	0.544	432	0.701	0.564	579	0.703	0.562	788.6	0.658	0.639	806.2
Belgium	0.358	0.610	392	0.493	0.658	461	0.551	0.654	648.8	0.497	0.588	753.6
Bulgaria	0.142	0.209	–	0.429	0.223	–	0.239	0.227	652	0.265	0.158	718
Czech Republic	0.220	0.289	–	0.407	0.282	548	0.560	0.291	738	0.497	0.260	738
Denmark	0.410	1	712	0.429	0.820	693	0.677	0.802	788.2	0.796	1	825.2
Estonia	0.621	1	–	0.757	1	257	0.751	1	691	0.724	1	729
Finland	0.310	0.472	414	0.400	0.414	542	0.509	0.617	636	0.512	0.502	671.4
France	0.257	0.689	336	0.465	0.684	305	0.310	0.543	573.4	0.774	0.462	611.6
Germany	0.261	0.648	752	0.683	0.596	728	0.706	0.604	826.6	0.698	0.677	842.2
Greece	0.052	0.260	204	0.150	0.206	162	0.216	0.210	559	0.421	0.327	571.8
Hungary	0.343	0.265	–	0.585	0.279	366	0.562	0.224	637	0.499	0.201	658
Ireland	0.023	0.337	316	0.122	0.278	149	0.153	0.306	332.8	0.108	0.288	467.6
Italy	0.228	0.728	556	0.484	0.724	688	0.514	0.533	675.8	0.269	0.426	736.6
Latvia	0.305	1	–	0.608	0.966	516	0.600	1	650	0.648	1	587
Lithuania	0.102	0.679	–	0.439	0.674	222	0.440	0.960	684	0.460	0.946	592
Luxembourg	0.142	0.353	272	0.446	0.362	467	0.425	0.251	580.6	0.218	0.251	585
Netherlands	0.689	1	716	0.669	1	695	0.681	1	809	0.838	1	816.6
Norway	0.539	0.664	384	0.721	1	589	0.492	0.859	698	0.480	0.452	729
Poland	0.198	0.371	–	0.564	0.399	549	0.507	0.365	739	0.331	0.313	737
Portugal	0.294	0.455	376	0.328	0.418	668	0.641	0.419	706.6	0.513	0.368	737.6
Romania	0.118	0.255	–	0.441	0.278	–	0.272	0.232	722	0.500	0.192	726
Slovakia	0.343	0.390	–	0.506	0.359	458	0.469	0.358	700	0.503	0.304	738
Slovenia	0.388	0.340	–	0.489	0.378	326	0.680	0.420	665	0.548	0.393	672
Spain	0.282	0.605	196	0.583	0.516	148	0.413	0.529	630.2	0.405	0.461	583.4
Sweden	0.336	0.730	756	0.625	0.483	729	0.615	0.574	825	0.742	0.777	872
Switzerland	0.526	1	644	0.579	0.917	677	0.725	1	756.4	0.597	0.969	740.4
United Kingdom	0.923	1	804	0.754	1	781	0.771	1	826.6	0.777	1	865.6
AVERAGE	**0.344**	**0.589**	**486.0**	**0.513**	**0.573**	**492.1**	**0.525**	**0.576**	**686.7**	**0.529**	**0.554**	**707.8**

Source: Own elaboration.

Table 6
Spearman's rank correlation.

Spearman Coefficient		SFA-CD	SFA-TL	DEA
SFA C-D	Correlation	1.000	0.461(*)	0.427(*)
	Sig. (bilaterally)	--	*0.016*	*0.026*
SFA T-L	Correlation	0.461(*)	1.000	0.569(**)
	Sig. (bilaterally)	*0.016*	--	*0.000*
DEA	Correlation	0.427(*)	0.569(**)	1.000
	Sig. (bilaterally)	*0.026*	*0.000*	--

Source: Own elaboration.
Notes: * Significant correlation level: 0.05 (bilaterally).
** Significant correlation level: 0.01 (bilaterally).

markets, and (iii) the progress in rail reforms made by each country, as reflected by the LIB index, and also by subindexes LEX, ACCESS and COM.

6.1. Kruskal-Wallis test

A Kruskal-Wallis test is a non-parametric method that can be applied to analyze if several groups of individuals can be considered to belong to the same statistical distribution, or alternatively, if there exist significant differences among groups. It is a test based on the ranks of individuals, and therefore, it is considered valid for our purposes since we have a sample of 27 rail systems ranked by the levels of efficiency achieved.

The groups of countries are defined by the progress they made over time in implementing the EU liberalization strategy, which established a calendar for countries to adopt particular policy measures which were considered milestones of the process (e.g., creation of independent rail infrastructure managers, accounting separation between infrastructure and services, and so forth). We consider here the same division as defined by Kirchner (2002, 2004, 2007, 2011), and divide our sample into three separate groups: advanced countries, delayed countries, and countries that were on-schedule according to the EU strategy timeline. The inclusion of each country in one of the groups is based on the values attained in its global LIB index (see Table 3 above, for information on the limit values applied to define the three groups).

The Kruskal-Wallis statistic is calculated from this expression:where $N = 27$ is the total number of observations, n_i is the number of observations in each of the three groups, r_{ij} is the rank (among all observations) of country j in group i, $\bar{r}$ is the average of all ranks r_{ij}, and $\bar{r}_i$ is the average of ranks within group i. The distribution of this statistic is a Chi-squared with g-1 degrees of freedom, with $g = 3$ (number of groups).

Results of the Kruskal-Wallis test –calculated for each of the four years and based on the three groups of countries according to their situation in the process of rail liberalization-are presented in Table 7.

The interpretation of results in Table 7 is that the differences between efficiency scores among the 3 groups are positively related to

Table 7:
Kruskal-Wallis statistics.

Year	2002	2004	2007	2011
KW *(p-value)*	6.259 *(0.012)*	3.438 *(0.064)*	5.044 *(0.025)*	8.571 *(0.003)*

Source: Own elaboration.

the situation of countries when implementing the EU rail liberalization strategy. Although there may exist some rail systems in the middle rank of liberalization, for which this relationship is not immediately clear, the observations at the top and low parts of the liberalization ranking seem to be driving this result.

Therefore, our main finding from the Kruskal-Wallis test is a significant difference between the groups of advanced/delayed rail systems in terms of their efficiency scores. This result proves the existence of a positive effect on the productive efficiency of European rail systems induced by the EU rail liberalization policy, and it invites to explore in more detail which are the dimensions of the liberalization process that have a stronger influence on rail efficiency, a purpose to which we devote the next sub-section.

6.2. Tobit model

Our final step in the analysis of rail efficiency is to develop a model capable of explaining the efficiency scores previously obtained from the efficiency frontiers.

As the results of the SFA and DEA techniques are similar, we present here only an analysis based on the DEA efficiency scores. These scores are in the range (0, 1], with a censored statistical distribution at the top since, by definition, a rail system located at the efficient frontier achieves a value equal to 1. Our results indicate that, over the period 2002–2011, several EU rail systems reached in some years the maximum level of efficiency, so the use of a Tobit model is justified, since carrying out a OLS regression would yield inconsistent estimates.

The specification of the Tobit model is the following:

$$\ln\left(DEA\_Score_{it}\right) = \alpha_0 + \sum_{j=1}^{N} \beta_j \ln\left(Index_{jit}\right) + \sum_{k=1}^{M} \gamma_k \ln\left(V_{kit}\right) + u_{it} \quad [3]$$

where:

DEA_Score_{it}: efficiency level of the rail system of country i in year t, measured with respect to the estimated DEA efficiency frontier (See Table 5).

$Index_{jit}$: value of rail liberalization index LIB ($j = 1$), of country i in year t. In other model specifications, liberalization subindexes are also introduced: LEX ($j = 2$), ACCESS ($j = 3$), and COM ($j = 4$) (for definitions, see section 4.2).

V_{kit}: vector of structural variables from country i, plus some structural variables of its rail system, measured in year t (For the list of variables, see Table 4).

u_{it}: random error

The model is specified in logs, in order to have the possibility of quantifying the impact of changes in the rail liberalization index (LIB) and its sub-indexes LEX, ACCESS and COM on the efficiency levels.

As the LIB index is constructed based on LEX and ACCESS –and it also exhibits a high correlation with the subindex COM-it is not feasible to use several liberalization variables simultaneously as explanatory factors in the model. The rail liberalization indexes are sequentially introduced, as alternative independent variables, together with a vector of structural variables V_k.

Similarly, not all the structural variables enter the model at the same time, and the best model to fit the data was obtained with a vector of structural variables with $M = 4$, where V_k = {*GDPpc, density, electrified-track, rail share_freight*}.

The results of the different estimations of the Tobit model, as defined by equation [3] and based on the introduction of different liberalization indexes, are presented in Table 8.

All estimated models provide a good fit, and the four specifications obtain very similar results for the parameters. This is explained by the high correlation that exists between the LIB index and its components LEX and ACCESS (with values above 0.90) –a fact that precludes the possibility of including simultaneously several liberalization indexes to estimate a model. The two indexes LIB and COM are not so strongly correlated ($\rho = 0.756$), but even though COM is not used to calculate the global index LIB, the Tobit model cannot be estimated with the simultaneous introduction of both variables due to collinearity.

The most remarkable result from the estimated Tobit models is that positive values are obtained in all cases for the coefficients affecting the rail liberalization indexes. This implies that the more advanced is a country in the process of reforming its rail sector, following the EU Commission strategy, the higher is the positive impact induced on rail efficiency.

However, this relationship is found to be statistically weak, since the estimated coefficients require the use of a 90% confidence interval to be significant. Only in the case of Model D, which uses the COM index as dependent variable, the link between the liberalization

Table 8
Results of alternative Tobit models.
Expand

VARIABLES	Model A $Index_1$ = LIB	Model B $Index_2$ = LEX	Model C $Index_3$ = ACCESS	Model D $Index_4$ = COM
ln ($Index_j$)	0.26077 * (0.14458)	0.32326 * (0.16878)	0.24695 * (0.12827)	**0.33996** ** (0.09000)
ln (GDPpc)	0.50677 ** (0.09134)	0.52215 ** (0.09097)	0.49883 ** (0.09141)	0.49882 ** (0.08702)
ln (Density)	0.14522 ** (0.06699)	0.15248 ** (0.06626)	0.14336 ** (0.06683)	0.09543 (0.06534)
ln (Electrified-track)	−0.26799 ** (0.07853)	−0.27486 ** (0.07912)	−0.26859 ** (0.07812)	−0.25888 ** (0.07333)
ln (Rail share_freight)	0.30721 ** (0.06919)	0.31247 ** (0.06787)	0.30618 ** (0.06874)	0.25638 ** (0.06667)
constant	−9.15347 ** (1.40193)	−9.15347 ** (1.58202)	−8.96759 ** (1.32695)	−8.94775 ** (1.17465)
LR chi2(5)	*37.33*	*37.75*	*37.77*	*48.12*
Prob > chi2	*0.0000*	*0.0000*	*0.0000*	*0.0000*
Pseudo R^2	0.2055	0.2078	0.2079	0.2649
Sigma	*0.48895 (0.04089)*	*0.48813 (0.04082)*	*0.48750 (0.04076)*	*0.46548 (0.03875)*

Notes: Dependent variable for all Tobit models: ln (DEA_Score_{it}).
Total number of obs. = 96 (78 uncensored; 18 right-censored). Some missing values due to lack of data for variable *Rail share_freight*.
Numbers in parentheses below coefficients, standard errors.
** Statistically significant at 5%.
* Statistically significant at 10%.
Source: Own elaboration.

policy and its impact on efficiency is quite strong (the estimated coefficient would be statistically significant even at 1%). The COM index reflects the introduction of effective competition in rail markets. Therefore, the conclusion from Models A-D is that, among all policy measures implemented by EU countries, competition seems to be the more relevant factor in terms of efficiency.

As the Tobit model is specified in logs, a quantitative interpretation can be easily obtained from its results: an increase of 50 points in the LIB rail liberalization index (which is approximately a 10% increase in the value of LIB, for a country located on the sample average in 2004, see Table 5), would have generated an improvement of around 3% in terms of rail efficiency, measured as the distance of the rail system to the production frontier. Similar interpretations can be made from the estimated coefficients for LEX, ACCESS and COM subindexes, which can also be used as elasticities.

Finally, it can be observed from the estimated coefficients that rail systems in countries with a high rail share in total transport of freight, high population density, and high per capita income (GDPpc) tend to be more efficient compared to others. A surprising result is the negative sign obtained for the percentage or electrified rail network, which is consistently obtained in all models. A possible explanation for this fact is that countries with low percentages of rail electrification require less rail workers for supervision and maintenance of electrical infrastructure, compared to others with a higher percentage of services being provided by diesel trains.

7. Conclusions

A thorough evaluation of the EU policy of rail reforms requires a comprehensive approach to the concept of liberalization. Most empirical studies on this policy rely on simple solutions, such as the use of dummy variables to identify the dates when legal reforms were introduced, or when large public rail companies changed their organizations. Moreover, it is frequently found that rail liberalization is assimilated to the particular model of vertical disintegration of public rail companies. Not surprisingly, the survey of the empirical literature on the topic of rail efficiency carried out in this paper does not provide definitive conclusions.

Our aim in this work is to try to contribute to the literature on rail liberalization, by exploring the impact of this policy on rail efficiency. The obtained results provide some evidence for the existence of a positive relationship between these two variables. We also identify that effective competition among rail undertakings seems to be the most relevant aspect of the rail liberalization process, in terms of achieving efficiency gains.

The empirical strategy used is to examine, on a first stage, the relative efficiency of 27 European rail systems for the period 2002–2011. For this purpose, several techniques are used to estimate efficiency frontiers based on production functions: stochastic econometric analysis (SFA) and data envelopment analysis (DEA). Other techniques were also tried (deterministic frontier analysis, and a distance function), and they yielded fairly consistent ranks of countries, but the SFA with a translog function and the DEA frontiers are the best models fitting the data.

On a second stage, the obtained efficiency scores from the DEA frontier are contrasted with the situation of each country in the rail liberalization process. For this purpose, only the four years for which the liberalization index is available (2002, 2004, 2007 and 2011) can be used. A preliminary Kruskal-Wallis test provides evidence for the liberalization process to have induced positive effects, as the groups of advanced, intermediate, and delayed countries in implementing the EU rail reform policy present significant differences in their respective levels of efficiency.

This result is finally confirmed by a Tobit model, in which the DEA efficiency scores enter as the dependent variable, and the rail liberalization index (LIB), and its subindexes LEX, ACCESS and COM are sequentially introduced as explanatory factors, together with a set of structural variables. Our main finding from the Tobit model is that all liberalization indexes are significant, and have a positive impact on rail efficiency, being the COM subindex the one that is more relevant.

Summing up, all the different aspects of the rail sector liberalization process promoted by the EU Commission (legal reforms, elimination of operational and informational barriers to access the markets, reorganization of traditional public monopolies, and so forth) seem to have had a global positive effect on the efficiency of EU rail systems. Nevertheless, it is the real intensity of competition in the market (as reflected in the values of the COM subindex), which is found to be the most important factor contributing to increase rail efficiency.

ANNEX 1. Technical summary of empirical papers on rail efficiency

Paper	Methodology	Sample and period	Main results
Asmild et al. (2009)	Multi-directional Efficiency Analysis (MEA)	23 systems; 1995–2001	Vertical segregation reduces material and labor-related costs
Cantos et al. (2010)	Malmquist Productivity Index. DEA	16 systems, 1985–2004	Segregation improves both productivity and efficiency. Impacts are stronger if accompanied by competition
Cantos et al. (2012)	DEA, distance function	23 systems; 2001–2008	Existence of competition enhances efficiency. Effects are usually small, and they depend on the way in which competition is introduced
Driessen et al. (2006)	DEA	14 systems; 1990–2001	Competition for the market seem to have a significant positive impact on productive efficiency
Friebel et al. (2003)	Regressions, LISREL	11 systems; 1980–2000	Separating rail infrastructure and services can generate some efficiency gains
Friebel et al. (2010)	Boundary model (Cobb Douglas function)	11 systems; 1980–2003	Rail systems exhibit better results when measures are implemented sequentially
Growitsch and Wetzel (2009)	DEA	54 companies; 2000–2004	Vertical integration yields better efficiency results in the mid-term, due to the more efficient leveraging of economies of scale
Ivaldi and Vibes (2008)	Nested Logit Model	4 companies from air mode, 1 for rail mode and car mode.	The introduction of a new low-cost railway operator company induces a decrease of all modes prices. A small number of competitors is enough to create a high degree of competition.
Laabsch and Sanner (2012)	Regressions	9 systems; 1994–2009	Vertical segregation does not yield any positive impacts on passenger services, while rail systems remaining vertically integrated exhibit better results.
Link (2016)	DEA	German federal states units; 1996–2010	Franchising contracts in long periods result in higher efficiency. An unrestricted model of entry seems to have a negative impact on the cost-efficiency.
Merkert et al. (2012)	Bottom-up model for a transaction cost measurement analysis	42 companies; 2006–2007	Vertical separation introduces transaction costs that are minimized by the holding company model

Mizutani et al. (2015)	Translog cost-function. Seemingly Unrelated Regressions (SUR)	33 companies; 1994–2010	Holding model yields small cost reductions. A significant share of freight traffic generates additional costs in the case of full separation.
Nash et al. (2014)	Translog cost-function	33 systems; 1994–2010	Vertical separation works best for lower density railways, but that a holding company model or complete vertical integration is best at high densities and where there is a high proportion of freight traffic
Pham (2013)	Frontier model (Cobb Douglas function)	12 systems; 1985–2008	Positive but weak relationship between disintegration and efficiency
Smith et al. (2018)	Translog cost-function. Seemingly Unrelated Regressions (SUR) method	17 systems; 2002–2010	Vertical separation and strong regulation are required in order to generate cost reductions. For very densely used rail systems, a holding company model is preferable
Wetzel (2008)	SFA	31 companies; 1994–2005	None of the variables that record the institutional segregation has a statistically significant influence on efficiency

Source: Own elaboration.

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