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The Impact of the European Railway Reforms on Railway Efficiency

Vliv evropských reforem na efektivitu železnice

Dissertation

Supervisor:

doc. Ing. Zdeněk Tomeš, Ph.D.

Author:

Mgr. Hana Fitzová

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Author's Name: Mgr. Hana Fitzová

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Abstract

The main objective of the European railway reforms, which started in the 1990s was to enable entry of competition on the existing network to increase efficiency of railways. The aim of this study is to evaluate the impact of the European railway reforms on railway efficiency using frontier methods, a unique up-to-date dataset, and various forms of variables describing competition. The results suggest that separation of network and services decreases efficiency whereas separation of freight and passenger transport increases efficiency. Competition in freight is mostly positive for efficiency while competition in passenger transport decreases efficiency for low levels of competition; this effect changes to a positive one for significantly higher market share operated on the basis of competition. However, the reforms have to be assessed as a complex, not separately.

Abstrakt

Hlavním cílem evropských železničních reforem, které začaly v 90. letech 20. století, bylo umožnění přístupu konkurence na stávající železniční síť s cílem zvýšit efektivitu železničního odvětví. Cílem této disertační práce je vyhodnotit dopad těchto reforem na efektivitu železnice s využitím metod umožňujících odhad hranice produkčních možností, unikátního datového souboru a různých forem proměnných popisujících konkurenci. Výsledky ukazují, že separace sítě a provozování služeb snižuje efektivitu, zatímco separace nákladní a osobní dopravy zvyšuje efektivitu. Konkurence v nákladní dopravě má ve většině modelů pozitivní dopad na efektivitu. Konkurence v osobní dopravě snižuje efektivitu pro nízkou míru konkurence, ale tento efekt se mění v pozitivní, pokud je tržní podíl konkurentů vysoký. Nicméně, reformy je třeba vyhodnotit jako celek, nikoli každou zvlášť.

Keywords

Competition; DEA; Efficiency; European railway reforms; SFA

Klíčová slova

Konkurence; DEA; Efektivita; Evropské železniční reformy; SFA

Declaration

Hereby I declare that the dissertation "The impact of the European railway reforms on railway efficiency" is my own work carried out under the supervision of doc. Ing. Zdeněk Tomeš, Ph.D, and that I have duly acknowledged all sources in accordance with the law, the internal regulations of Masaryk University, and the binding internal documents of Masaryk University and of the Faculty of Economics and Administration.

Brno, March 24, 2020

signature

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Contents

1 INTRODUCTION 13
1.1 Background 13
1.2 Railway reforms 14
1.3 Existing studies 17
1.4 Important questions 18
1.5 Purpose of the thesis 19
1.5.1 Aim of the thesis 19
1.5.2 Contribution of the thesis 20
1.5.3 Research questions, hypotheses 20
1.5.4 Methods 21
1.6 Structure of the thesis 22
2 EUROPEAN RAILWAY REFORMS 23
2.1 Reform packages 23
2.1.1 First Railway Package 23
2.1.2 Second Railway Package 24
2.1.3 Third Railway Package 24
2.1.4 Transport White Paper 2011 25
2.1.5 Fourth Railway Package 25
2.2 Vertical separation 27
2.3 Horizontal separation 30
2.4 Entry of competition 31
2.5 Competition in the EU countries 33
2.5.1 Summary of the situation 33
2.5.2 Great Britain 37
2.5.3 Sweden 38
2.5.4 Italy 39
2.5.5 Germany 40
2.5.6 Austria 42
2.5.7 Czech Republic 42
2.5.8 Slovakia 44
2.6 Regulation 44
2.7 Access charges 45
2.8 Summary 46
3 LITERATURE REVIEW 47
3.1 Overview 47
3.2 Background studies 50
3.3 Studies based on the production function 53
3.4 Studies based on the cost function 59
3.5 Summary 62

4 METHODOLOGY 63
4.1 Efficiency 63
4.2 Possible approaches 64
4.3 DEA 67
4.3.1 Characteristics 67
4.3.2 Returns to scale 68
4.3.3 Orientation of the model 69
4.3.4 Classification of the units 70
4.3.5 CCR model 70
4.3.6 BCC model 72
4.3.7 Dual problem 73
4.3.8 Slacks 74
4.3.9 Bootstrap 75
4.3.10 Malmquist index 76
4.4 SFA 78
4.4.1 SFA with one output 79
4.4.2 Distance functions 80
4.4.3 Contextual variables 82
4.5 Tobit model 83
4.6 One-step approach 85
4.7 Summary 86
5 DATA 87
5.1 Problems with data 87
5.2 Dataset 89
5.3 Countries' characteristics 92
5.3.1 Non-measurable factors 92
5.3.2 West and east – overall characteristics 92
5.3.3 West and east – composition of railway transport 95
5.3.4 West, east, Baltic and small 99
5.3.5 Four CEE + four WE groups 100
5.4 Implementation of the reforms 101
5.5 Summary 102
6 RESULTS 104
6.1 DEA efficiency scores 104
6.1.1 Outputs and inputs 104
6.1.2 Outliers detection 108
6.1.3 Efficiency scores 108
6.1.4 Bootstrap test of RTS 115
6.1.5 Prevailing RTS 115
6.1.6 Analysis of slacks 116
6.1.7 Malmquist index 118
6.1.8 One-step DEA approach 119

6.2 SFA efficiency scores 121
6.3 Regression analysis 123
6.3.1 Explained variable 123
6.3.2 Reform variables 125
6.3.3 Control variables 128
6.3.4 Tobit estimations 129
6.3.5 One-step DEA approach 137
6.3.6 One-step SFA approach 139
6.4 Evaluating the hypotheses 140
6.5 Summary 142
7 DISCUSSION 143
7.1 Interpretation of efficiency scores 143
7.2 Interpretation of regression results 144
7.3 Comparison with existing studies 147
7.4 Possible problems and limitations 148
7.4.1 Problems with data 148
7.4.2 Problems with computations 150
7.5 Policy implications 151
7.6 Summary 153
8 CONCLUSION 154
RESUMÉ 160
REFERENCES 161
DATA SOURCES 172
LIST OF ABBREVIATIONS 176
LIST OF TABLES 178
LIST OF FIGURES 179

1 Introduction

This thesis deals with railway reforms and their impact on the efficiency of railways in the European Union. The following part provides historical context and fundamental characteristics of this rather specific industry.

1.1 Background

Rail transport used to be an essential economic and strategic industry in history. It represented the primary means of transport by the beginning of the 20th century. Since the end of the Second World War, rail has been in constant decline and now, its importance in the transport market is much lower – only around 7% in the passenger market and 17% in the freight market. However, rail transport still represents an integral part of the transport policy of the European Union (EU).

The product of the railway industry is characterised by its very high differentiation – in space as well as in time. However, aggregate categories of broadly similar services are sometimes more useful in practice. A standard division of the railway transport market is into two major segments – passenger and freight. For the passenger sector, the main distinction is between long-distance traffic and local traffic. Further, rail services tend to give rise to significant externalities – both positive and negative. Some of the most important of them are so-called network externalities; they affect the attractiveness of the network as a whole. Externalities can occur on the side of costs as well as on the side of demand (Seabright, 2003).

Both segments of the railway industry enable high cost, environmental, and energy savings, especially for large volumes and long distances, especially in comparison with road transport. Government interventions can help as well as hinder successful development of the railway sector. Railway sector governance affects many aspects of the industry (choice of the operators, terms of tenders, safety standards, level of financial support, infrastructure investment, etc.) to ensure adequate efficiency of the industry, level of the services, and safety and environmental standards (Worldbank, 2017).

Since the Second World War, European railways generally had the form of public monopolies which were organised as vertically integrated companies responsible for both infrastructure management and operations (Asmild, 2009). Quality of the services was deficient; companies suffered higher and higher financial losses (usually despite growing state subsidies), market

share of railways was also declining (in favour of road transport). While the total transport volume in the EU increased significantly over the last decades, the share of rail transport decreased sharply. It was evident that some reforms were needed.

The reform process started with Directive 91/440/EEC in 1991. The idea was to improve the way of operating the railways. In 1996, the European Commission (EC) published the White Paper containing a strategy for revitalising the Community's railways (European Commission, 1996). According to the White Paper, railways could do much for sustainable mobility in the 21st century. The main reason for declining rail's market share was dissatisfaction with the price and quality of rail transport and inappropriate response to market changes or customers' needs (as other modes do). Governments have a particular responsibility in this. Railways were not exposed to market forces; they did not have sufficient managerial independence and were not compensated enough by governments. Financial criteria were not also clear, and debts were growing (European Commission, 1996).

Fundamental and extensive changes started in 1998 when the European Commission presented the first three proposals which should have helped make the existing legislation more effective. They were adopted in 2001 and are known as the "First railway package". In the following years, many other proposals (another three packages) were adopted by the EC (and thus EU members) aiming at increasing the competitiveness of the railway sector (European Commission, 2019).

The European railway reforms enable quite a wide national variability in their implementation. The most significant difference lies in the form of vertical unbundling – some companies underwent a complete vertical separation of infrastructure and services; some have created only different organisational units within one holding company; some remain vertically integrated with a separated body for essential functions (European Commission, 2019). Competition implementation, which should represent the main instrument for increasing the competitiveness of railways among the other transport modes, differs significantly in particular countries.

1.2 Railway reforms

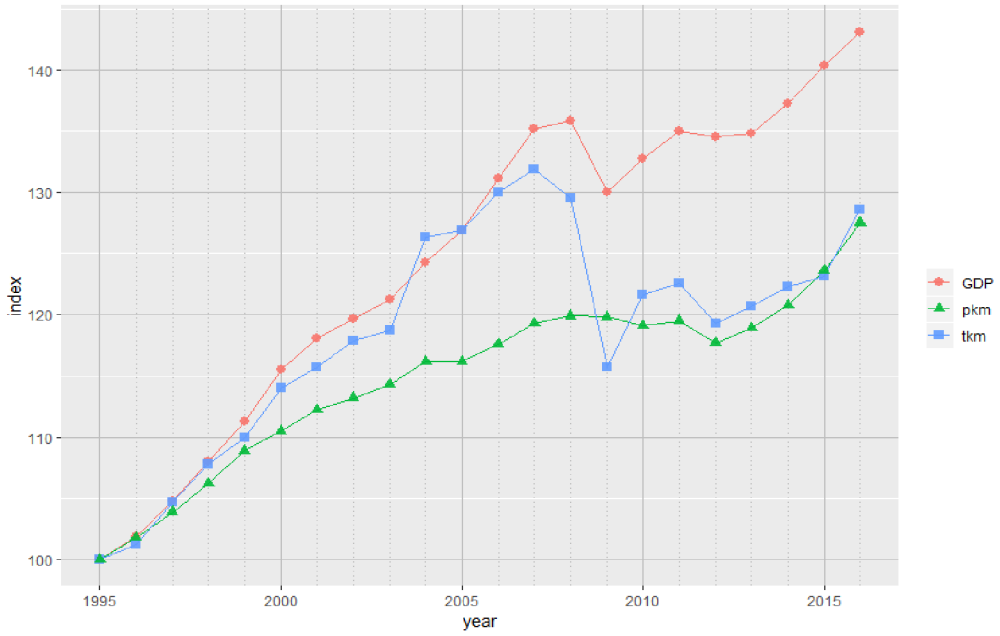
The important target of the European transportation strategy is to revitalise the railway sector and make it more competitive with other modes of transport, especially to increase the share of

railway transport on the transport market (European Commission, 2001). Commission's efforts have concentrated on three major areas: opening the rail transport market to competition, improving the interoperability and safety of national networks and developing rail transport infrastructure (European Commission, 2019).

The European railway reform efforts started at the beginning of 1990th. They responded on several problematic phenomena like growing financial losses of railway companies, declining market share, low level of services or insufficient investment, that all despite growing subsidies.

Production of the railway industry measured by total passenger-km and tonne-km was continuously growing during 1995–2007 – see Figure 1.1. The economic crisis in 2008/2009 caused a sharp decline in real GDP, as well as a decline in output in freight railway market and its values are still below the values of the pre-crisis period, despite the growing trend since 2013. The output of passenger railway market underwent a period of stagnation during 2008–2011 and was followed by a decline in 2012. The output values overcame the pre-crisis level in 2014, and the growing tendency has been restored.

Figure 1.1: Development of GDP, passenger-km and tonne-km in the EU 28 (1995 = 100)



Source: EU transport in Figures: Statistical Pocketbook 2018 + own processing

However, the modal share of freight railway transport is decreasing from 32.4% in 1970, to 21.6% in 1995, and even to 17.4% in 2016 – in favour of road transport which rises from 55.8% in 1970 to 71.6% in 1995, and to 76.32% in 2016 (see Table 1.1).

For the passenger market, the share is nearly constant (around 7%) during the period 1995-2016, with a slight rise in the past few years. The share of passenger cars is growing only slightly (from 80.6% in 1995 to 81.3% in 2016), and the share of buses slowly declines (from 10.6% in 1995 to 9.3% in 2016) – see Table 1.1 (modal split is computed as % of total tonne-km, resp. passenger-km; sea, air and pipeline transport are not included).

There is a clear downward sloping tendency of rail transport on the transport market in comparison with the values from 1970th – despite growing subsidies. There are many reasons for the decline in rail transport. Some of them are exogenous, like the transformation of other industries (declining transport of raw materials like coal, especially in Central and Eastern European countries), easier availability of cars or policies in favour of road transport. Others are endogenous – Di Petrantonio and Pelkmans (2004) and Nash and Rivera-Trujillo (2004) mention, for example, weak reliability and punctuality of shipments, lack of competition, non-transparent cost structure on international corridors, insufficient infrastructure capacity and quality, poorly defined public service obligations and compensations received ex-post.

Table 1.1: Modal split of freight resp. passenger land transport in the EU

	Freight land transport			Passenger land transport			
Year	Road	Inland waterway	Rail	Cars	Buses	Tram+metro	Rail
1970	55,8	11,8	32,4	74,5	13,0	1,9	10,6
1980	64,6	9,4	26,0	77,8	12,2	1,4	8,6
1995	71,6	6,8	21,6	80,6	10,6	1,5	7,2
2000	73,7	6,5	19,8	81,1	10,4	1,5	7,0
2005	76,0	6,0	18,0	81,7	9,9	1,6	6,8
2010	75,7	6,9	17,4	81,5	9,6	1,7	7,2
2015	75,3	6,5	18,2	81,1	9,5	1,8	7,6
2016	76,3	6,2	17,4	81,3	9,3	1,8	7,6

Source: EU transport in Figures: Statistical Pocketbook 2018 + own computations, Wetzel (2008) + own computations

The main objective of the reforms was to enable entry of competition on the existing network to raise the efficiency of the railway sector – either in the form of open access competition or competitive tenders. The philosophy of the reforms resulted from the assumption that infrastructure is considered as a natural monopoly and operation of services is implementable

via competition. Planning and financing of the infrastructure are seen as primarily a state role, while the operation of services can be performed on commercial or subsidised contractual basis (Nash, 2008). According to the EC, it was at first necessary to split the infrastructure and operation of services. European reforms separate rail infrastructure that meets the characteristics of natural monopoly, and the operation of services, that can be provided competitively. It is called vertical separation. It is sometimes accompanied by horizontal separation, which means separation of passenger and freight transport into two separate entities. The entry of competing operators to the monopoly operated rail network was considered as a way how to improve the efficiency and performance of European railways. Non-discriminatory rules for the allocation of paths and access charges are also required.

There have been four "packages" of the reforms so far. The First Railway Package (2001) especially enabled rail operators' access to the trans-European network on a non-discriminatory basis for international freight services. The Second Railway Package (2004), above all, fully opened the freight market to competition since 2007. It has increased competition and the efficiency of rail freight transport and also the competitiveness of new rail operators. The Third Railway Package (2007) introduced open-access rights for international rail passenger services by 2010 (European Commission, 2016a). Nevertheless, domestic rail passenger services have not been opened to the EU competition yet as around 90% of the European rail passenger services are subject to a public service obligation (CER, 2011). The main goal of the Fourth Railway Package (2016) is to open the market for domestic passenger services (European Commission, 2013b).

1.3 Existing studies

Implementing the reforms is a long term process, and it takes a long time to see some of the consequences in available data. Several studies concerning the impact of the European railway reforms on the efficiency of railways have been worked out. However, their conclusions differ. Available empirical studies use different samples of countries, various methods, not up-to-date data, and non-optimal form of reform variables in the analyses. Furthermore, open-access competition has become into practice quite recently. Thus its impact is not mostly included in the analysed datasets.

Driessen et al. (2006) identified a positive impact of vertical separation. Open access competition lowered efficiency while competitive tendering increased efficiency. *Wetzel* (2008) did not find any significant effect of vertical and horizontal separation. However, she identified a positive effect of competition in domestic freight while competition entry in international freight transport and passenger transport decreased efficiency. The study of *Growitsch and Wetzel* (2009) concludes that vertically integrated railways realise economies of scope and produce railway services with a higher level of efficiency. According to *Asmild et al.* (2009), both competition, as well as accounting separation, increase efficiency. *Friebel et al.* (2010) say that the reform effects depend on sequencing: introduction of multiple reforms in a package has negative impacts, while sequential reforms improve efficiency. *Cantos et al.* (2010) found out that vertical separation with horizontal separation and a new entry in the freight market enhances efficiency. *Cantos et al. (2012)* show that vertical separation effect is not statistically significant and concludes that the reforms are strongly complementary. *Van de Velde et al.* (2012) identified only a positive impact of horizontal separation; other reforms steps were not significant. *Mizutani and Uranishi* (2015) found that the impact of vertical separation depends on traffic density and horizontal separation declines costs. The effect of competition was not significant. Further, *Wetzel (2008)* and *Asmild (2009)* were the only studies concerning the differences between Western and Eastern European countries.

The evidence on the impact of the European railway reforms on costs or efficiency is entirely unclear. The main results from the most relevant studies are ambiguous, especially for vertical separation and entry of competition while horizontal separation seems to have a positive impact. It probably stems from the wide range of data samples and methods used in the studies. Further, the datasets used in many of the studies are quite old, and the form of the variables describing the situation at the railway market is not ideal. These facts provide space for further research.

1.4 Important questions

If we want to answer the fundamental question "Do the European railway reforms increase efficiency?", we should, at first, think about many aspects associated with this question, which produces other questions.

Which variable indicates it? How can we measure it? How long after the official implementation, will the effect be significant? Is it necessary to finish all the reforms, or is it possible to evaluate the impact of particular reforms separately? Which market share is necessary to consider that competition exists? Should we examine passenger and freight transport separately? Will the impact of the reforms be the same in fully developed economies with functioning market mechanisms as in former Eastern Bloc countries which experienced a transformation process? Is a division into Western and Eastern European countries suitable/sufficient? Alternatively, can we neglect all of these differences to reveal the main features?

The answers are unclear; thus, we have to take all these potential sources of ambiguities into account when formulating conclusions about the impact of the reforms on railway efficiency. It may help to understand the results of the empirical studies more accurately.

The questions mentioned above indicate the possible contribution of this thesis. The main areas include creating an up-to-date dataset with checked values and without missing values; further new variables describing competition at the railway market more precisely; and finally a broader spectrum of the estimation methods and techniques – that all to gain more precise information about the impact of the reforms on the efficiency of railways.

1.5 Purpose of the thesis

The conclusions of the available studies on the impact of the European railway reforms are significantly different, and the effect of the reforms is mostly unclear. As the reforms still have not been finished in most of the countries, the evaluation of their impact is still an essential issue. This thesis tries to overcome some of the possible sources of the ambiguous results using various time and space data samples, different forms of explanatory variables describing the situation at the market, and finally various methods and models. Furthermore, it uses a very up-to-date data sample which could contribute to explaining the impact of open-access competition which has become into practice quite recently.

1.5.1 Aim of the thesis

This thesis aims at identifying the impacts of the European railway reforms on railway efficiency. It also tries to find out significant differences among various groups of countries.

Particular goals of the thesis are the following:

- Collect as much up-to-date data as possible for individual countries.
- Propose different ways of describing the level of competition, enabling to capture the effect of competition on efficiency.
- Compute relative efficiency scores using various methods, models, and output specifications to provide robust results.
- Evaluate the impact of the reforms on the efficiency of railways.
- Formulate implications for economic policy.
- Identify possible limitations of the research.

1.5.2 Contribution of the thesis

The main contribution of this thesis comprises a collection of the unique up-to-date dataset and an application of a wide range of methods and models to ensure the robustness of the results.

Namely, a unique dataset comprising all the EU members with railways (and above that Norway and Switzerland) during 1999–2017 has been collected and consequently employed in the analyses (some variables for Great Britain, the Netherlands, Norway, Sweden and Denmark only in selected years – see section 5.2).

Various forms of variables describing competition have been constructed as an instrument for assessing the impacts of competition on railway efficiency. Different methods and models for various time and space specifications for evaluating the impact of the reforms on efficiency have been applied to provide more robust conclusions. Possible problems connected with the analysis have been explicitly specified, and limitations of the research have been discussed.

1.5.3 Research questions, hypotheses

Vertical separation, horizontal separation and entry of competition are the main features of the European railway reforms. It is not clear what their impact on the efficiency of railways is. Is it positive or negative? Or does it depend on other specific circumstances?

It was probably expected that the reforms would have a positive impact on the efficiency of railways. However, the results of the relevant studies revealed that vertical separation was not

mostly significant. It was even negative in some studies. The results indicate that vertical separation may decrease efficiency. On the other hand, the conclusions about the positive effect of horizontal separation are quite robust.

Competition in freight transport as well as in passenger transport was mostly positive, sometimes insignificant and only exceptionally negative under specific circumstances. It follows that we can expect a positive impact of competition implementation; however, other circumstances (like an adequate description of the market) may play an essential role. A variable describing the railway market more precisely was not used in the examined studies, which also creates space for further research.

Finally, two studies (Wetzel, 2008 and Asmild et al., 2009) also admitted a different impact of the reforms in Western European countries and Eastern European countries. The results were significantly worse in Eastern European countries, probably due to lower economic and technological development. However, these studies analysed quite old data (1994-2005 and 2000-2004). Thus, investigating this feature of the problem is worth analysing.

The above-mentioned aspects of the possible impact of the reforms lead to the following hypotheses:

Hypothesis 1: Vertical separation decreases efficiency.

Hypothesis 2: Horizontal separation increases efficiency.

Hypothesis 3: Competition in freight transport increases efficiency.

Hypothesis 4: Competition in passenger transport increases efficiency.

Hypothesis 5: The way of expressing the existence of competition plays an essential role in evaluating the impact of competition on efficiency.

Hypothesis 6: Efficiency differs significantly among the groups of Western European countries and Central and Eastern European countries.

1.5.4 Methods

The thesis uses a unique dataset including the period 1999-2017 for 28 European countries. Descriptive statistics enable finding relevant differences and similarities among the countries. Computing efficiency scores and identification of the determinants of efficiency follows. The applied methods correspond to the current literature on this topic.

At first, efficiency scores are computed using data envelopment analysis (DEA) for constant as well as for variable returns to scale. It enables the construction of the ranking of the countries and identification of several groups of countries with similar properties.

The concept of slacks enables identification of excess inputs of the production process. The Malmquist index describes the development of the technological progress in time – the change in the relative efficiency (better organisation of the production process) of the unit relative to the other units and the change of the frontier due to changes in technology.

The most common way to find out how contextual variables influence efficiency is tobit regression. However, different approaches exist. For more robust results, the thesis also employs the bias-corrected bootstrap DEA based on Simar and Wilson (2007) and the stochastic frontier analysis (SFA) based on Battese and Coelli (1995) incorporating a panel data structure. Both these approaches allow for the computation of efficiency as well as its factors in one step.

1.6 Structure of the thesis

This text is structured as follows: Chapter 2 introduces the main reform steps and summarises competition at the railway market in the EU countries to provide essential information of the analysed area. Chapter 3 reviews relevant literature to reveal the most important conclusions of the available studies and the most problematic areas requiring further research. Chapter 4 explains the methodology of the thesis. It draws from the available railway studies as well as shows some approaches less known and less used in the area of transport which are employed in this thesis. Chapter 5 presents the data, which is an essential element of this analysis. It enables understanding of possible ambiguities of the results as data also represent the most problematic part of railway analyses. Chapter 6 represents the main part of the thesis. It gives empirical results – computations of the efficiency scores, identification of the excess inputs, technological change in time, and finally, the impact of contextual variables. These results serve as a pillar for evaluating the effect of the reforms on efficiency. Chapter 7 discusses the results, specifies possible problems, points out the limitations of the research, and provides economic policy implications. Chapter 8 concludes the thesis.

2 European railway reforms

The creation of a Single European Railway Area without national boundaries and with the market opened to competition has been a dream of the EU policy since the early 1990s. It was necessary to adopt a long row of legislative rules to approach this aim. The reform process started with Directive 91/440/EEC. The idea was to improve the way of operating the railways. Responsibility for their own day-to-day management and financial accounting changes were introduced as the first steps towards separating train services from track management. Further, it was the beginning of the third party access in operating cross-border container freight services (Stehman and Mackay, 2003).

2.1 Reform packages

Four legislative packages were adopted between 2001 and 2016. They were aimed mostly at the gradual opening of rail transport service market for competition, enabling interoperability of national railway systems and creating a framework for a single European railway area. It seems that by 2020, it could become a reality.

2.1.1 First Railway Package

The European Commission presented three new proposals aimed at making the existing legislation more effective in 1998. They were adopted in 2001 and are known as the "First Railway Package". It enabled rail operators to have access to the trans-European network on a non-discriminatory basis. The EC underlined the need to improve the distribution of train paths, establish a tariff structure reflecting relevant costs, reduce delays at borders and introduce quality criteria (European Commission, 2019).

The recast of the 1st railway package was adopted in November 2012 and was aimed to simplify and consolidate the rules by merging three directives and their amendments into a single text. The main issues are clear rules for the funding and management of infrastructure, access to rail-related facilities (depots, maintenance, etc.), and independence and competence of regulatory bodies (European Commission, 2012). Especially, political independence of the regulatory bodies was reinforced to ensure that regulators are no longer a part of transport ministries (Smith et al., 2018).

The package comprises the following legislation: Directive 2001/12/EC on the development of the Community's railways, Directive 2001/13/EC on the licensing of railway undertakings, Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure and safety certification, recast of the 1st railway package: Directive 2012/34/EU of the European Parliament and of the Council establishing a single European railway area.

2.1.2 Second Railway Package

The "Second Railway Package" (2004) targeted primarily at opening up of the freight rail market. The freight rail market has been fully opened to competition since 2007, which sharply accelerated the liberalisation of the market. Besides, the European Railway Agency (ERA) was established. It is aimed at gradual aligning of the technical regulations, and common safety objectives in all the EU countries as technical and security regulations are often incompatible which represents a major handicap to the development of the railway sector (European Commission, 2019).

The package includes Directive 2004/49/EC on safety on the Community's railways, Directive 2004/50/EC amending Directive 96/48/EC on the interoperability of the trans-European high-speed rail system and Directive 2001/16/EC on the interoperability of the trans-European conventional rail system; further Directive 2004/51/EC amending Directive 91/440/EEC on the development of the Community's railways; and also Regulation 881/2004 establishing the European Railway Agency.

2.1.3 Third Railway Package

The "Third Railway Package" was adopted in 2007. It introduced open-access rights for international rail passenger services (by 2010). Furthermore, it strengthened the rail passengers' rights (more extensive range of rights, minimum quality standards) and induced the European driver licence which allows train drivers to circulate on the entire European network.

It encompasses Directive 2007/58/EC amending Directive 91/440/EEC on the development of the Community's railways, Directive 2001/14/EC on the allocation of railway infrastructure capacity and the levying of charges for the use of railway infrastructure, Directive 2007/59/ on the certification of train drivers operating locomotives and trains on the railway system in the

Community, Regulation 1370/2007 on public passenger transport services by rail and by road and repealing Council Regulations 1191/69 and 1107/70, Regulation 1371/2007 on rail passengers' rights and obligations, and Regulation 1372/2007 amending Regulation 577/98 on the organisation of a labour force sample survey in the Community.

2.1.4 Transport White Paper 2011

The EC also adopted another important document related to transport between the third and the fourth railway package – the Transport White Paper (2011). It adopted a roadmap of 40 initiatives for the next decade to build a competitive transport system that will increase mobility and remove significant barriers in the key areas. The proposals dramatically reduce Europe's dependence on imported oil and cut carbon emissions in transport by 60% by 2050. Key goals include no more conventionally-fuelled cars in cities, a 40% use of sustainable low carbon fuels in aviation; at least a 40% cut in shipping emissions, a 50% shift of medium distance intercity passenger and freight journeys from road to rail and waterborne transport. These will contribute to a 60% cut in transport emissions by the middle of the century. Rail should become the principal means of transport for medium-distance passenger transport and long-distance freight transport. The liberalisation of the market is a pivotal policy to achieve this, along with investment in high-speed rail and freight corridors (European Commission, 2011).

2.1.5 Fourth Railway Package

The "Fourth Railway Package" (2016) was adopted after more than five years of negotiations. It was designed to complete the single European railway area. It comprises two pillars – the market pillar and the technical pillar.

One of the main aims of the market pillar was to end the natural monopoly of the vertically-integrated railway through the compulsory unbundling of incumbent train operators and infrastructure management. However, several member states were strongly opposed (especially Germany). In 2010, the court rejected compulsory and complete separation of the infrastructure manager and train operator of the EU members as any EU legislation does not require it. Thus, a railway company with a holding structure can be considered as an independent (IRJ, 2018). Several amendments of the Fourth Railway Package were introduced in February 2014. They enable more flexibility in the choice of the governance model. The mandatory unbundling proposal was cancelled, and the integrated holding company structure maintains legal. Open-

access operators were shocked as this decision reinforces the historical role of state-owned railways (IRJ, 2018).

The main goal of the market pillar is to open the market for domestic passenger services (European Commission, 2013b). The market pillar will complete the process of market opening. It also establishes the general right for railway undertakings to operate all types of passenger services everywhere in the EU with mandatory competitive tendering for public service obligation contracts and open-access on profitable routes. It should lead to a broader range and better quality of the services and lower costs. Competitive tendering of public service contracts will enable savings of public money (European Commission, 2019). The 4th package requires a combination of both types of competition – competition for the market (competitive tendering for franchises, the only approach for subsidized services) and competition in the market (represented by open-access for new commercial operators).

The market pillar should be implemented by December 2019. Open-access operators will be permitted to run services in competition with the incumbent operator on domestic routes from December 2020. Competitive tendering for public service obligation will be obligatory in the majority of cases from December 2022. Direct awards of the public service obligation (PSO) will still be allowed under certain circumstances; however, with strict contractual requirements for service quality, frequency, and capacity. There will be a 10-year transition period for entry into force of the new rules on PSO contracts directly awarded before December 2022 (IRJ, 2018).

The technical pillar of the 4th Railway Package consists of proposals which amend the interoperability and safety directives and regulation on the ERA. The technical pillar is designed to support competition by reducing costs and administrative burden for railway undertakings operating across Europe. It also promotes transparency and lowers possible discrimination of new operators reducing the number of remaining national rules (European Commission, 2019). The crucial element of the technical pillar is the transformation of the ERA from an agency drafting technical regulation to an operational European railway authority. It represents a key feature in the creation of a single European railway area. The ERA will now grant safety certificates and vehicle authorisations for cross border operation (CER, 2018).

The fourth railway package consists of Regulation (EU) 2016/796 on the European Union Agency for Railways, Directive (EU) 2016/797 on the interoperability of the rail system within the European Union, Directive (EU) 2016/798 on railway safety, Regulation (EU) 2016/2338 amending Regulation (EU) 1370/2007, which deals with the award of public service contracts for domestic passenger transport services by rail (PSO Regulation), Directive 2016/2370/EU amending Directive 2012/34/EU, which deals with the opening of the market of domestic passenger transport services by rail and the governance of the railway infrastructure (Governance Directive), and Regulation (EU) 2016/2337 repealing Regulation 1192/69 on the normalisation of the accounts of railway undertakings.

2.2 Vertical separation

In the USA or Japan, it is common to find vertically integrated railway undertakings operating on their own infrastructure. European railways are different. So the crucial step for competition implementation in Europe was, according to the EC, to separate operation of services and infrastructure. This is called vertical separation, and it differs considerably among the EU members. Cremer et al. (2008) argue that advocating vertical separation in all cases is too simplistic an answer. Various forms of vertical separation/integration in the EU are depicted in Figure 2.1.

In vertical disintegration, competitors are allowed to operate rail services. The infrastructure remains under the control of a public or private monopolist (which requires some public regulation). Market forces are supposed to be strong enough to generate efficiency in services provision. A strong need for coordination between the infrastructure manager and the users of the infrastructure favours vertical integration. A strong need for competition in services prefers separation. This dilemma explains why, in some countries a compromise solution (sometimes called partial disintegration) was established (Seabright et al., 2003).

A third approach includes separation of accounts which does not impose any behaviour. It enables the regulator to verify whether the firm complies non-discrimination rules. If the regulator's instruments are strong enough to force the integrated firm to run its two units independently, it should be equivalent to a vertically separated company. However, accounting separation leaves scope for unfair competition, as the regulator has only limited tools to prevent

discrimination in the short run. On the other hand, integrated ownership might encourage investment. (Crémer et al., 2008).

Vertical separation in Europe has three forms – complete separation of infrastructure and operations, creation of a holding company, and a hybrid model called "separation of key powers". The first form (complete separation) is represented by a complete institutional separation of the infrastructure from operations. In this case, the infrastructure manager and incumbent are institutionally separated to ensure more efficient competition and thus lower prices and costs (Thompson, 1997). It can be found in most of the EU countries – Belgium, Bulgaria, the Czech Republic, Croatia, Denmark, Estonia, Finland, Great Britain, Greece, the Netherlands, Portugal, Romania, Slovakia, Spain, and Sweden (European Commission, 2016b and 2018).

Figure 2.1: Institutional settings in the EU (2016)

Integrated ← Organisationally → Separated

Scope of IM functions: Full ↑ Partial ↓

	Integrated	Integrated, separate body for essential functions	A holding structure with limited independence guarantees	A holding structure with strong independence guarantees	Separated	
IM in charge of all functions (incl. capacity allocation and charging)			Austria France Germany Italy	Latvia Poland Slovenia	Belgium Bulgaria Czech Republic Croatia Denmark Estonia UK (GB part)	Finland Greece Netherlands Portugal Romania Slovakia Spain Sweden
IM in charge of functions except the essential functions (capacity allocation and charging), which are under the responsibility of a separate body		Hungary Ireland Lithuania Luxembourg				
IM in charge of the essential functions, some parts delegated to railway undertaking						

Source: European Commission (2018)

The second form of vertical separation – a holding company – is less frequent than the previous case. It is represented by an accounting and division separation of the infrastructure management and operations into detached departments of one holding. This form with limited independence guarantees can be found in Austria, France, Germany, and Italy; form with strong independence guarantees in Latvia, Poland and Slovenia. In this form, planning of investment and use of capacity is integrated, and it is necessary to enable entry of the other operators (European Commission, 2019).

There is also a third hybrid form in the EU called "separation of key powers", which can be found in Hungary, Ireland, Lithuania and Luxembourg. Under this institutional setting, the infrastructure manager is responsible for some specific activities except the essential functions like capacity allocation and charging), but daily administration of the network (e. g. maintenance) is devolved to the major undertaking. European legislation now requires at least separate accounts for infrastructure and operations and separation of powers. Key decisions regarding infrastructure charging and slot allocation should not be in the hands of the infrastructure manager that is also involved in train operations as an integrated company (Nash, 2008).

Movements between the lines as well as columns in Figure 2.1 occur (e. g. France moved back to the holding company model in 2015); however, railway companies are expected to move up and right in the scheme in the future.

So, should governments introduce vertical separation? Governments undertake full separation to maintain ownership and control of the railway network while trying to encourage more contestability and private sector participation in rail transport operations (World Bank, 2017). It is also expected to enhance competition (Laabsch and Sanner, 2012). The most favourable circumstances are more extensive railway systems with multiple and separable types of train operating companies that can operate within markets that are large enough to be competitive, countries with strong implementation, administrative and regulatory capacity (United Nations, 2003). However, this option adds transaction costs and regulatory burdens. Other costs involve infrastructure maintenance or responsibility for delays (Shires et al., 1994). Van de Velde et al. (2012) showed that the effect of vertical separation on costs is dependent on train density – it does not have much effect for average train density while it increases costs at high levels of

train density. Vertical separation seems to have lower costs on less dense systems. Another important aspect is the misalignment of incentives under vertical separation which should be paid much more attention. Thus, there is no evidence to support a single structure on all railways regardless of national specifics (Van de Velde et al., 2012).

Integration of both parts enables low transparency about costs or capacity allocation. It also permits cross-subsidies when some loss activities are financed by other profitable activities, which leads to allocation inefficiency (Deville–Verduyn, 2012) that is mostly demotivating (however, when marginal costs are below average costs and there is a budget constraint, it may be good). There is also a risk of discriminatory behaviour by the infrastructure provider against the competitor. Integration complicates regulation of the infrastructure monopoly and can create lower or misguided performance incentives (Fitzová, 2017). On the contrary, integrated form facilitates better coordination of maintenance and modernization (cost savings and synergies in shared facilities and service), simplifies operational coordination and conflict settlement; it also brings better comprehension to investment incentives. The simultaneous existence of integration and competition drives technological innovation and product innovation (Ksoll, 2004). Economies of scope exist for a majority of integrated European railway companies (Growitsch and Wetzel, 2009). However, it produces discriminatory incentives and complicates regulation. The positive and negative aspects of vertical integration in railways should be weighed carefully. Economic theory does not give any definite conclusions about vertical separation or integration. Some answers can be found in the empirical analyses (see Chapter 6).

2.3 Horizontal separation

Horizontal separation will be, following the European railway reforms, considered as a separation of passenger and freight market. Horizontal separation creates more manageable business units from a monolithic structure and improves transparency in financial performance. The most favourable circumstances are large railways with separable regional freight and passenger markets (United Nations, 2003).

Profit potential in passenger and freight transportation in Europe is different. Freight transportation is expected to be profitable. Passenger transportation without subsidies is usually

unprofitable; it is generally in a loss, and it is necessary to subsidize it. Its compensation by profits from freight transportation has a negative motivation effect on freight transportation and lowers its competitiveness. Synergies from operating close types of transportation represent the main advantage of horizontal integration (Fitzová, 2017). Horizontal separation does not enable cross-subsidisation of passenger transport from the profit of freight transport and also provides more focused management.

Majority of the EU countries continues in the traditional scheme of integration of passenger and freight transportation to ensure lower costs. Countries after the horizontal separation do not gain positive synergies. On the other hand, they do not face demotivation due to cross-subsidies. Some impacts can be deduced from the available empirical studies (see Chapter 3). Most of the EU countries remains horizontally integrated. Horizontal separation has been implemented in Denmark, Estonia, Great Britain, Hungary, Latvia, the Netherlands, Norway, Romania, Slovakia, and Sweden.

2.4 Entry of competition

The entry of competition into the operation of services represents the central element of the European railway reforms. The pressure of competition forces producers to be more efficient, which is beneficial for aggregate efficiency. Growing competition means a rising number of competitors or lowering rent, it is joined with the growth of total factor productivity, and it forces producers to innovations in time (Vickers, 1995).

More competition is expected to bring substantial traffic growth (considerable expansion of services and demand), slower growth in public financial support, and also lower fares growth. However, like Nash, Nilsson, and Link (2013) show on the case of Britain, Germany and Sweden, the outcomes differ according to other circumstances like economic situation, size of the franchises, regulation, development of subsidies, etc.

Incumbents are expected to be less efficient than new entrants. It stems from several reasons like overstaffing, the suboptimal structure of the staff, neglected investment, obsolete fleet, poor circulation of information due to the large size of the company, the strong influence of labour unions, etc. (Król, 2009). Vertically integrated incumbents were usually burdened with the PSO in providing passenger transport. In Europe, PSO railway services were traditionally financed

by cross-subsidisation from freight. Market liberalisation should lead to the disappearance of this phenomenon. As new entrants are interested in the most lucrative segments of the market, their operational efficiency is higher. There are also some possible benefits for the incumbent – specialisation, restructuring or new organisational culture (Król, 2009).

Competition in the railway sector in Europe (we do not consider operating on their own network as it is common e.g. in Japan) has two forms – competition for the market and competition in the market. The first one is also called "competitive tendering", it is realized via public tenders on providing subsidized services in passenger transport. The tenders are organized by authorities like ministries or regions.

Tendering should especially lead to lower requested subsidies in comparison with direct assigning to the incumbent and also to a better quality of provided services. Further, it assures keeping some control on the range and quality of the provided services by public authorities (Fitzová, 2017). Competitive tendering is generally considered as a suitable type of competition in railway transportation. Long-lasting franchises (15 years and more) covering a not too large volume of services with the train operator leading in terms of planning, marketing and asset procurement seem to be a suitable option. Shorter gross cost contracts are appropriate in situations where a regional authority takes charge of pricing, marketing and asset procurement or other possible risks (like track access). Britain, Sweden and Germany have the most experience with this approach. Britain has adopted franchising through the competitive tender for virtually all passenger services, Sweden has adopted it for all subsidised services, in Germany the federal states are responsible for procuring all subsidised services. Demand for regional services in all these countries has grown significantly. Further, the subsidy per train km has fallen (Nash et al., 2016).

The latter form of competition is also called "open-access". In this situation, the market is open, new entrants can enter, and operations are not subsidized from public resources. This type of competition is suitable for a sufficient size of the market, and it applies to potentially profitable routes. It is developed mainly in freight transportation, as most of the passenger routes are not profitable (Fitzová, 2017). In passenger transportation, it can be found only in several EU countries and usually only on the most lucrative routes, e. g. in the Czech Republic on the route Prague-Ostrava or Prague-Brno. Generally, open-access competition produces lower prices and

a more extensive range of services. Open-access operators also perform well in terms of passenger satisfaction. The competition further stimulates efficiencies through innovations and more efficient usage of the existing capacity. Open-access operators are also able to adjust their services to maximise productivity by employing better performing trains, and by avoiding stations that add too high costs (Casullo, 2016). On the other hand, open-access competition reduces profitability and may lead to less well-integrated services. It works best where there is strong demand, spare track capacity and low track access charges (Nash et al., 2016).

However, open-access rail competition brings a risk of "cherry-picking" the supposedly profitable routes (Lodge, 2013). It often means that the new entrants often face the problem with insufficient capacity (like the route Prague-Brno), so that the timetables are in many cases non-optimal. New operators induce extra costs in the form of investment in rolling stock, staff and new technology which are necessary during the first years of operations; it also takes some time to attract passengers. The entry of new operators can also result in a loss of economies of scale and density, which harms both new entrants and incumbents. Further, network effects such as interconnection possibilities and integrated vehicle scheduling may be lost (Casullo, 2016).

There is a free entry in freight transportation since 2007 in the EU. Competition has yielded a revival in rail freight. On the other hand, direct contracting of the subsidized services to the incumbents prevails in passenger transportation. The EU countries do not open themselves to competition too much – passenger transport is not a lucrative branch, and there are persisting barriers for entry of competition. Things may change after the Fourth Railway Package comes more into practice in 2020.

2.5 Competition in the EU countries

There are significant differences in the implementation of competition in railway transport in individual EU countries.

2.5.1 Summary of the situation

Experience with competitive tendering is quite extensive in some European countries in the segment of passenger transportation, for example in Great Britain (all passenger services), Sweden (all subsidized services), or Germany (a growing proportion of subsidized regional

services). Other countries have also experience with this type of competition, but it is not too extensive; failures during the negotiating processes were not unique (e. g. in the Czech Republic). Competitive tendering represents a much higher part of the market share based on competition in the EU than open access competition.

The PSO passenger operators often provide services in other countries – IRG (2018) mentions Czech activity in Slovakia; German activity in the Czech Republic, Denmark, Poland and the UK; French activity in Germany and the UK; Dutch activity in Germany and the UK; the UK activity in Germany; Hong Kong activity in Sweden and the UK; Japanese activity in the UK.

On the other hand, experience with open-access competition in passenger transport is much more limited, and only several countries have experienced this type of competition. Open-access competition (with more than negligible market share) can be found only in seven countries – Great Britain, Germany and Sweden, Italy, Austria, the Czech Republic, and Slovakia. Moreover, only two countries have more than one competitor (plus the incumbent) – the Czech Republic and Slovakia (Fitzová, 2017).

Two types of open access competition can be observed in Europe. The first type is competition in niche markets avoiding direct competition with the incumbent (or franchise holder in the UK). The second type is represented by the head-on entry on the principal railway route (Tomeš et al., 2016). It can be found in Austria (2011-), the Czech Republic (2011-), Italy (2012-), Slovakia (2014-), Sweden (2015-). The situation in Germany is slowly changing after the entry of Flixtrain, which provides more and more services. The UK situation may change soon. Grand Central plans to expand its services on the West Coast Main Line (Blackpool-London) from spring 2020.

Table 2.1 summarizes the current state in the seven countries with open access competition mentioned above. A more detailed description of the situation in particular countries follows further.

Table 2.1: Competition in the EU countries with open-access

Country	Open-access*	Competitive tendering
Austria	Vienna West–Salzburg, (*Westbahn* Dec-11), Vienna Praterstern–Meidling–Salzburg (*Westbahn* Dec-18)	Not utilized, directly assigned to ÖBB or small operators owning local routes
Czech Republic	Prague–Ostrava (*RegioJet* Sep-11, *Leo Express* Dec-12), Prague–Brno (*RegioJet* Dec-16) Prague–Uh. Hradiště (*Arriva*, Aug-17, only 9 trains per week)	Limited
Germany	Hamburg–Cologne (*HKX* Jul-12–Mar-18, *FlixTrain* Mar-18-now), Berlin–Stuttgart (*Locomore* Dec-16–May-17, *Leo Express* + *FlixTrain* since Aug-17), Berlin–Cologne (*FlixTrain*, May-19), Leipzig–Berlin (*InterConnex* Dec-01–Dec-14)	Widespread, tenders or direct assigning (around 2/3 directly to Deutsche Bahn (Hunold and Wolf, 2013)
Great Britain	Sunderland–London (*Grand Central* Dec-07), Bradford–London (*Grand Central* May-10), Hull–London (*Hull Trains* Sep-10), Wrexham–London (*Wrexham Shropshire* Apr-08–Jan-11)	Widespread
Italy	Turin–Rome–Salerno, Venice–Rome–Salerno, Bolzano/Brescia–Verona–Salerno, Turin–Milan–Venice (*NTV* Apr-12), Milan–Turin (*Arenaways* Nov-10–Feb-12)	Limited
Slovakia	(Prague)–Ostrava–Košice, (*RegioJet* Dec-14, *Leo Express* Dec-14), Bratislava–Košice (*RegioJet* Dec-14–Jan-17)	Limited
Sweden	Malmö–Stockholm (–Åre) (*Snälltåget* Jul-09), Helsingor–Malmö–Lund (*Öresundståg* Dec-11), Stockholm-Gothenburg (*BlåTåget* Nov-11, *MTR* Mar-15)	Widespread

*New open-access entrants are written in the brackets with the date of entry, including non-existing competitors with the date of termination the competition.

Source: European Commission (2013a), European Commission (2016b), Tomeš and Jandová (2016), Tomeš et al.(2016), Fitzová (2017), https://westbahn.at/, https://www.regiojet.cz, https://www.leoexpress.com, https://www.flixtrain.com/, https://www.grandcentralrail.com/, http://www.hulltrains.co.uk/, https://www.italotreno.it/en, https://www.mtr.com.hk/en, https://www.snalltaget.se/en, https://www.blataget.com/en/, http://www.oresundstag.se/en/

Competition in some form existed at least in 15 countries in 2016; it was zero in ten countries (European Commission, 2016b). The level of competition is lower than in the freight market. In most countries, the incumbents keep a market share of over 80% (Fitzová, 2017).

Most networks have only a single operator of commercial services, but by 2016, Latvia, Germany, Poland, Hungary, France, Sweden, Austria, Italy, and the United Kingdom have had more than one (European Commission, 2019). There are even three operators in the Czech Republic and Slovakia.

In the PSO market, the share of competitors is highest in Great Britain (it is 100%, however according to the EC methodology, it is 87% after the exclusion of the biggest company), and also astonishingly in Portugal (100%) as in 2016 the only PSO contract was with the non-incumbent Fertagus. Among the countries with the highest market share in the PSO market in 2016 were Sweden (60%), Germany (25%) and Italy (23%) (European Commission, 2019). Unusually high and a bit distorting value for Poland (50%) is caused by the fact that regional services in Poland are operated by new local companies formed by regional authorities and by a company that stems from the incumbent but was municipalised by regional authorities in 2008 and ceased to have ownership relations with the incumbent (IRG, 2018).

Market share of the competitors in the freight market in 2014 (in percentage of tonne-kilometres) was highest in Sweden and Great Britain (around 55%), then in Bulgaria and Norway (nearly 50%), Romania, Italy, the Netherlands (around 40%), Hungary, France, Poland and Germany over 30%, Estonia and the Czech Republic around 30%. It was zero only in five countries (European Commission, 2016b). When we look at the percentage change during the last three years, market share of the competitors continued to increase with only three exceptions (Latvia, Estonia, and Romania). In 2016, the average share was 39%. The highest changes appeared in Romania (over 60% of the market in 2016), Bulgaria and Italy (both 55%), Germany (45%), and also in Hungary, France and Poland (all more than 40%). Only four countries (Greece, Ireland, Lithuania and Luxembourg) still had only a single domestic rail freight operator (European Commission, 2019).

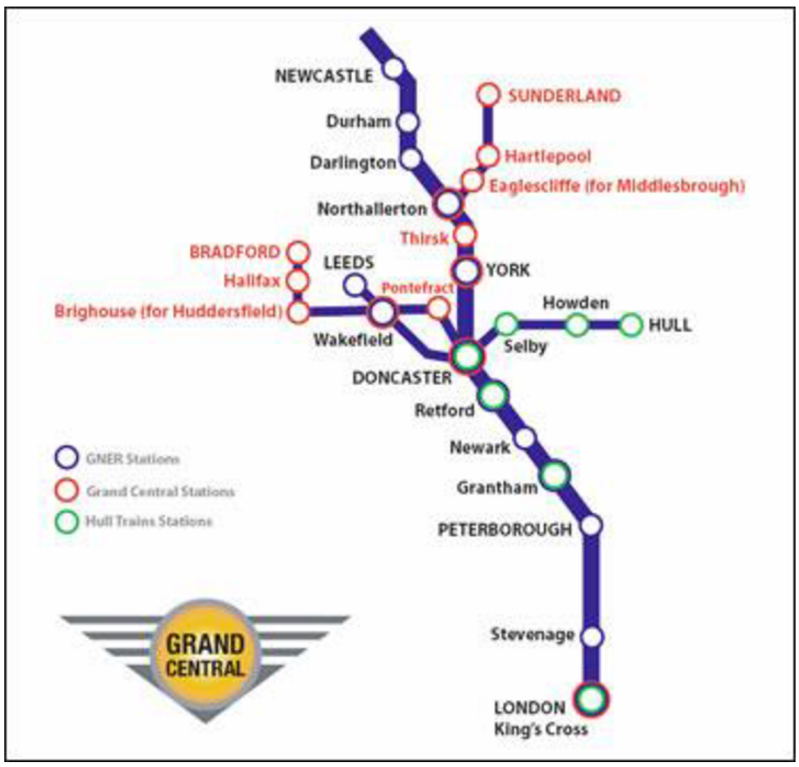
2.5.2 Great Britain

The reform of British railways began in 1994 with the separation of infrastructure from operations. All passenger services were divided into 25 companies which were franchised out by central government over the period 1994–1997. British Rail was not allowed to bid. Thus all passenger services were provided by new operators – mostly private British bus companies and foreign government-owned railways. The initial privatisation of the British passenger rail market relied on the competition for the market rather than in the market, which provided considerable protection for franchisees. The new entry of commercial operators was allowed only if it did not primarily draw revenue from franchisees (Nash et al., 2016).

The British rail industry is dominated by big franchises holding the rights to big areas for many years. There were 20 franchises in 2016 with an average duration of 9.5 years (based on data in Nash et al., 2016). Open-access competition in Great Britain is allowed but strongly regulated. It exists on routes connecting London with cities which had not previously been joined directly by railway to London (Griffiths, 2009). The market share is low – less than 1% of all operations measured via passenger-km in 2016 (Nash et al., 2016). The routes operated by open-access operators can be found in Figure 2.2.

Grand Central operates on Sunderland–London route since December 2007 and on London–Bradford route since May 2010. Hull Trains operates on Hull-London route since September 2010. Wrexham Shropshire & Marylebone operated on Wrexham-London route since April 2008 till January 2011. However, from spring 2020, Grand Central plans to expand its services on the West Coast Mainline between London Euston and Blackpool North (Grand Central, 2019). Further, by 2021, FirstGroup will offer a new travel choice for passengers between London, north-east England and Scotland (to Edinburgh) with low fares and high-quality service (FirstGroup, 2019). This development indicates a gradual extension of open access competition in Great Britain.

Figure 2.2: Open access routes in Britain

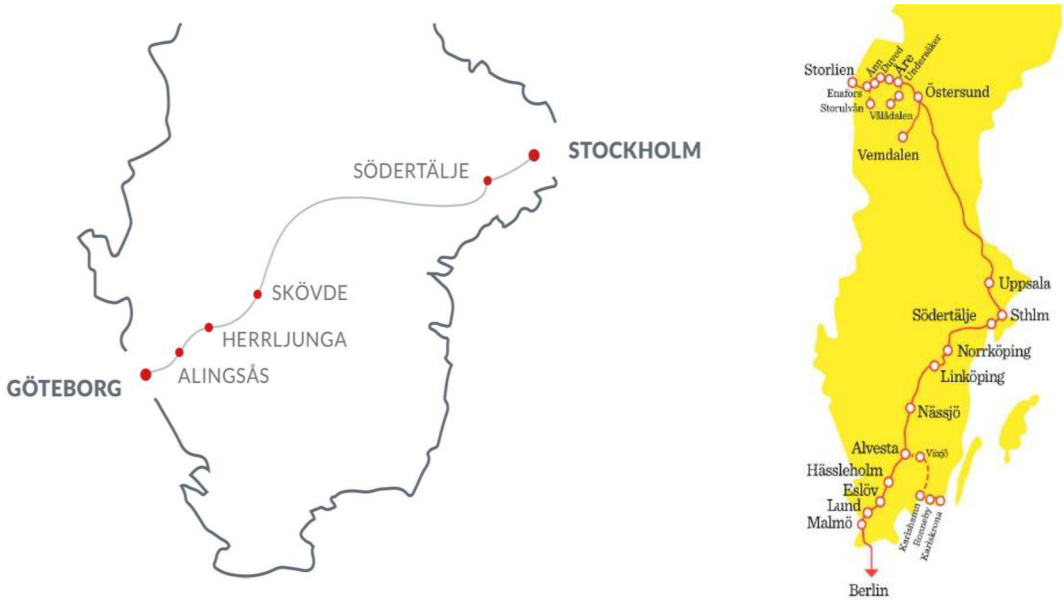


Source: http://www.projectmapping.co.uk/Reviews/Resources/Grand%20Central.jpg.

2.5.3 Sweden

Sweden was the first country which carried vertical separation and started competitive tendering of non-commercial services in 1988. Almost all regional services are franchised by means of competitive tendering. The only franchisees other than the incumbent (SJ) are foreign government-owned. The state-owned operator SJ had a legal monopoly of all commercial services until 2010 (Nash et al., 2016). The Swedish market for passenger railway services has been open to competition on commercial routes since the year 2010. Competition is not very widespread as it is mostly financially unattractive. The impact of competition on the Swedish railway market is small (European Commission, 2013a). The routes operated by open-access operators are depicted in Figure 2.3.

Figure 2.3: Swedish open-access routes



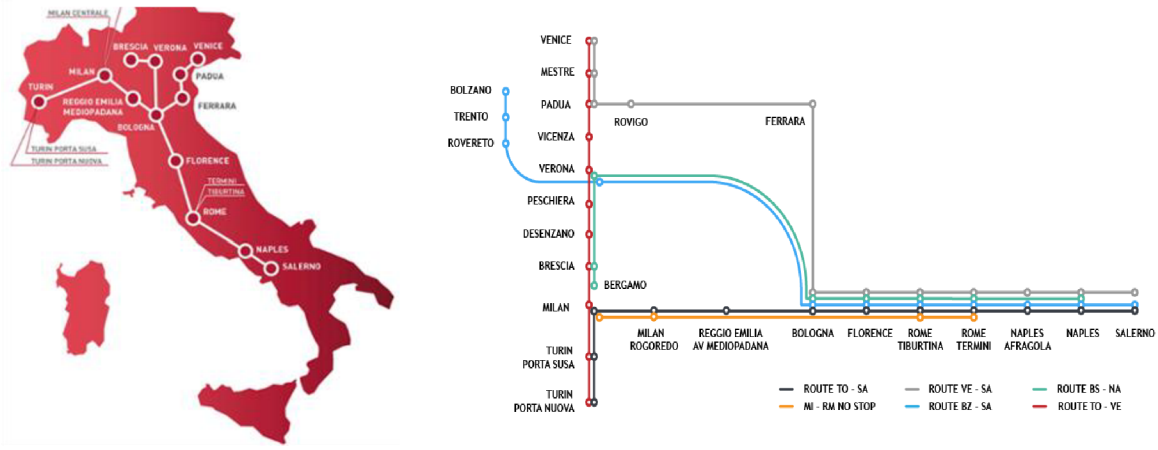
Source: http://mws2017020.mtr.com.hk/en/corporate/consultancy/ mtrexpress.html, https://www.snalltaget.se/ destinationer

The incumbent SJ has only faced substantial competition since MTR Express entered the main 457 km long Stockholm-Gothenburg line (Vigren, 2017) in March 2015. MTR have all invested in new trains to enable them to offer a high-quality service and hopes to be in profit. The income of new competitors has brought lower prices and product differentiation, and the situation is further improving after the entry of MTR. The main route Stockholm-Gothenburg operated by MTR is depicted in the left part of Figure 2.3. The right part of Figure 2.3 illustrates the routes operated by Snalltaget (open-access only Malmö–Stockholm–Åre). The Öresundståg train routes cover Helsingor, Copenhagen, Malmö, and Lund, and further lead to Gothenburg, Kalmar or Karlskrona (east coast).

2.5.4 Italy

Italy was the first European country with open-access competition on a high-speed route (Bergantino et al., 2015). It led to a significant increase in the number of passengers as the prices declined sharply (Cascetta and Coppola, 2013), by almost 40%. A new open access entrant, NTV, now runs hourly services in competition with the state-owned operator on the high-speed network (Croccolo and Violi, 2013). NTV managed to reach operating profit after three years, and it is still growing. The routes operated by NTV on the open-access basis are displayed in Figure 2.4.

Figure 2.4: Open-access routes in Italy



Source: *https://www.amadeusrail.net/blog/ntv-italy-rail-deregulation*, *https://www.italotreno.it/en/destinations-timetable*

2.5.5 Germany

Germany is the third most liberal country (after Great Britain and Sweden) with about 18% of passenger kilometres in regional and suburban traffic (in 2016) produced by new entrants and open access on commercial services. The rail infrastructure and state-owned rail operations are in the hands of separate subsidiaries of the government-owned rail company DB AG (Nash et al., 2016). The individual states have been responsible for procuring regional passenger rail services since 1996. They can use competitive tenders or direct award. The size, as well as the range of the contracts, strongly varies. In 2015, DB operated about 70% of regional passenger train-km although its share was declining. The others were mainly foreign and municipal railway companies (Nash et al., 2016) – there were six companies (besides DB) with the market share above 1%.

In Germany, regional and long-distance traffic is strictly separated. Long-distance transport is operated without subsidies and open-access competition is allowed. Despite this fact, over 99% of the market share is in the hands of Deutsche Bahn (Deville and Verduyn, 2012; Nash et al., 2016). The majority of new competitors who have tried to enter the market have not succeeded; there are only several operators in niche markets (European Commission, 2013a). It may be due to high track access charges (Link, 2004; Nash et al., 2016), discrimination against new entrants by Deutsche Bahn (Nigrin, 2014) or strong competition from air and also intercity buses in the last few years (Nash et al., 2016). Figure 2.5 portrays the routes operated by FlixTrain in Germany.

Figure 2.5: German open-access routes

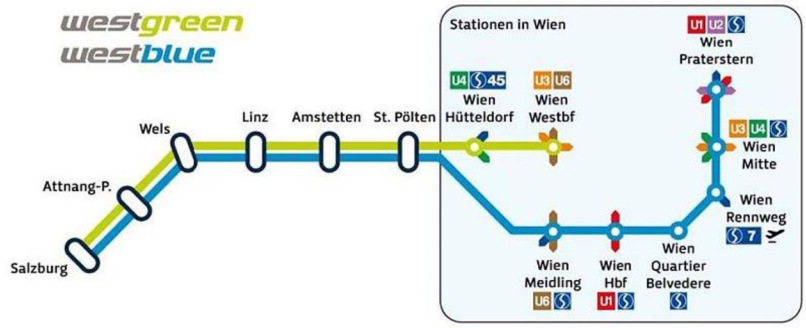
Source: https://www.flixtrain.com/

Hamburg-Cologne-Express (HKX) was forced to suspend its service in October 2018 it launched since 2012. FlixTrain launched this service in March 2018 and another service Berlin-Stuttgart in April (operated by Leo Express). A new service Berlin-Cologne operated by FlixTrain appeared in May 2019. Locomore launched Berlin–Stuttgart line only since December 2016 to May 2017 when it filed for insolvency. It was taken over by Leo Express in August 2017 and revived in cooperation with Flixbus.

2.5.6 Austria

In Austria, a major route has been operated by a private company alongside the incumbent since 2011. It resulted in a decline in prices and an increase in the frequency of connections (Komárek, 2014). Westbahn has been operating on route Vienna West–Linz–Salzburg since December 2011. It is also profitable (EBITDA of €10.6 mil. in 2017). Westbahn launched a second service (December, 2018) on the route linking three other stations in Vienna – Praterstern, Main and Meidling – with Linz and Salzburg (Railjournal, 2019). Figure 2.6 depicts the two Westbahn open-access lines.

Figure 2.6: Open-access routes in Austria



Source: https://westbahn.at/

2.5.7 Czech Republic

There has been open-access competition in the Czech Republic with two operators since September 2011 (the incumbent České Dráhy and RegioJet) and with three operators since December 2012 (Leo Express) on the Prague–Ostrava route. RegioJet (RJ) launched a second service on the Prague–Brno (and further to Vienna) line in December 2016. RJ declared its first profit after four years of operating. Its 2018 profit seems to reach a new record as well as the record of nearly 10 million of passengers. Leo Express is still in a loss; however, it is getting smaller. The RJ and Leo Express open-access routes (not only) are displayed in Figure 2.7 (yellow and black lines).

Figure 2.7: Open-access services in Central Europe

Source: *https://en.wikipedia.org/wiki/RegioJet#/media/File:D-A-Independent_inter-city_rail.png*

Tomeš et al. (2016) mapped the implications of competition implementation in the Czech Republic. A considerable decline in prices and subsequent accusations of unfair practices by the competitor, pressure on infrastructure capacity, and benefits for customers were the most significant impacts.

2.5.8 Slovakia

The situation in Slovakia is hard for competitors as students, children, and pensioners can travel at no cost from November 2014. Approximately one-third of the passengers travel for free[1]. Open-access competition in passenger transport in Slovakia began in December 2014 with the entry of the Czech operators RegioJet and Leo Express on the Prague–Ostrava–Košice line (see Figure 2.7). Prices declined immediately, while the quality of services, as well as the frequency of connections increased. RegioJet also launched a second line Bratislava–Košice (December, 2014) connecting the two biggest Slovak cities. There was a price war between the Slovak incumbent's ZSSK Inter City trains and RegioJet. Operating trains on such a distorted market (free fare for most of the travellers in Slovak trains) was not sustainable. RJ terminated its business on this line in January 2017 (Kvizda and Solnička, 2019).

2.6 Regulation

Another important element is regulation. The specific form of regulation varies from country to country. Regulation appears in three different forms (Nash, 2008). The less frequent type is a special regulatory authority model which means the existence of an independent authority. It can best ensure the implementation of the principal objectives of the EC regulatory requirements. The railway authority model represents the second form of railway regulation. It is constituted by a body whose functions are often more administrative. In this case, critical regulatory skills are often missing, and close relationships with the incumbent are not rare. The third form is the so-called ministry model. It often suffers short of staff and expertise, weak powers to do more than make recommendations, and it is also susceptible to political intervention. The last model was the most frequent, and it was usually connected with the slow progress of the reforms. It seems that no simple solution for regulation exists – there are trade-offs which can lead to different outcomes according to the circumstances, and more research is necessary. However, the recast of the 1st railway package requires regulators to be independent of government (European Commission, 2012), so it is no longer legal for the Ministry to be the regulator (Smith et al., 2018).

[1] This applies to all trains under PSO and to all EU residents; costs are compensated by the government.

Economic regulators need to be independent both of government and railway companies as governments, in most EU countries, finance railways and own the incumbent rail operator and infrastructure manager (Benedetto et al., 2017). The crucial role of the regulator lies in regulating access conditions and charges in order to ensure fair and non-discriminatory access to the infrastructure to all operators. Appropriate setting of infrastructure charges is an open question as well as whether it can vary according to particular circumstances. Setting based on marginal costs requires government subsidies. Further, two-part tariffs offer the least distorting option but risk placing barriers on entry. Another issue arises concerning to mergers of train operating companies with each other and with infrastructure managers. It can save costs, bring better quality as well as hamper competition. Whether they are desirable or should be regulated is unclear (Nash and Rivera-Trujillo, 2004).

European rail regulators, in general, exhibit many of the features of ideal regulation: independence, longevity, expertise, transparency, stability, and predictability. However, according to Benedetto et al. (2017), they could be more active in setting track access charges, maintaining non-discriminatory access, regulating the efficiency and quality of infrastructure managers, and becoming more involved in the designing stages of passenger market opening. Smith et al. (2018) constructed a multidimensional regulation index and showed that the strength of economic regulation in Europe's railways during 2002–2011 increased considerably, as measured by this index.

2.7 Access charges

As the European railway reforms have opened the rail market to new entry, a transparent and non-discriminatory system of track access charges became an essential element of the railway industry. It was necessary to separate incumbents' accounts for infrastructure and operations.

European legislation requires track access charges based on the direct costs of the services. Non-discriminatory mark-ups are permitted – they vary according to specific conditions (market segment, freight commodities, type of passenger train). Direct costs reflect short-run marginal social costs; they exclude the costs of expanding capacity. This situation may give improper incentives for long-run development of the infrastructure as the presence of scarcity charges may lead infrastructure managers to keep capacity scarce. Thus, the EU legislation

requires preparation of capacity enhancement plans where capacity is declared scarce (Nash et al., 2018).

Setting track access charges involves conflicting objectives – efficient use of existing capacity and the recovery of costs. Each country attaches a different degree of importance to these objectives. Charges for rail infrastructure can be economically optimal only if other transport modes are also appropriately charged. Wear and tear costs represent an essential component of track access charges. They vary for different conditions and are generally very low (except France). Congestion or scarcity costs are the second important part of track access charges. They represent a possible solution for routes operating at a level close to capacity. Mark-ups are also becoming an important part of track access charges. Mark-ups for freight services should vary by commodity. Mark-ups for PSO services are a political decision. For passenger services without competition, it is necessary to distinguish the routes and times as it could result in fewer services provided (Nash et al., 2018).

2.8 Summary

This chapter explained the main European railway reforms induced by the four railway reform packages during 2001–2016. The most important reform is (some form of) vertical separation of infrastructure and operation of services, which represents the first step for the implementation of competition entry. The current level of competition in the EU is not very high except for Great Britain. However, it is getting better during the last few years. The situation could change soon when open-access, as well as competitive tendering, should become more widespread as a result of the adoption of the Fourth Railway Package. A proper regulatory framework, as well as a transparent and non-discriminatory system of access charging, play an essential role in the revitalisation of the railway industry.

3 Literature review

This chapter reviews essential empirical studies concerning the impact of the reforms steps on railway efficiency. At first, a short overview presents the most often analysed issues. Further, some background studies are introduced; follows a detailed analysis of the studies based on the production function and studies based on the cost function.

3.1 Overview

Several studies provide a summary of the reforms and usually also describe the situation in several selected countries. Another group of studies investigates the situation in Europe as a whole and tries to deduce some general implications of the main reforms – vertical separation, horizontal separation and introduction of competition. Table 3.1 summarises the main features of the most important publications about the impact of the reforms.

Vertical separation is the most often discussed reform step. Half of the studies did not find any significant effect (Wetzel, 2008; Asmild, 2009; Cantos Sánchez et al., 2010, 2012; Bougna and Crozet, 2016; Van de Velde et al., 2012; Smith and Benedetto, 2018). Several studies identified a positive effect (Driessen, 2006; Friebel et al., 2010; Cantos Sánchez et al., 2010; Mizutani and Uranishi, 2013; Mizutani et al., 2015). Others found out a negative effect (Growitsch, 2009; partly Cantos Sánchez, 2001). The result is not clear. It is probably dependent on other factors – the completeness of the reforms, the sequence of the reforms, the train density, and some specific features of the country.

On the other hand, horizontal separation seems to be mostly positive (Canto Sánchez, 2001, Canto Sánchez et al. 2010, 2012; Van de Velde et al., 2012; Mizutani and Uranishi, 2013; Mizutani et al., 2015; Smith and Benedetto, 2018). It was unclear only in Wetzel (2008). Separation of both segments of railway transport does not enable cross-subsidisation, and the management is more specifically focused.

Competition is the next important issue analysed in the literature. The entry of competition seems to be beneficial in many cases in both segments of the market (passenger and freight). However, the effect is not statistically significant, or it is sometimes even negative according to other circumstances. In the passenger segment, the effect was positive in Asmild (2009), Friebel (2010), Cantos Sánchez et al. (2010, 2012), Bougna and Crozet (2016), Smith and

Benedetto (2018), and partly in Driessen (2006). On the other hand, the effect was negative only in Wetzel (2008) and partly in Driessen (2006). In freight transport, competition was beneficial in Asmild (2009), Friebel (2010), Cantos Sánchez et al. (2010, 2012) and partly in Wetzel (2008). It was negative only under particular circumstances in Wetzel (2008) and Mizutani et al. (2015).

Table 3.1: Summary of empirical studies

I. Studies based on production function

Study	Period	Sample countries	Vertical separation	Horizontal separation	Passenger competition	Freight competition
Driessen (2006)	1990-2001	13, WE	+		+ (CT) / – (OA)	
Wetzel (2008)	1994-2005	22, E	0	0	–	+(D) / – (INT)
Growitsch (2009)	2000-2004	27, E	–			
Asmild (2009)	1995-2001	23, E	0		+	+
Friebel et al. (2010)	1980-2003	12, WE	+		+	+
Cantos Sánchez (2010)	1985-2004	16, WE	+	+ (+VS)	+ (+VS, HS)	+ (+VS, HS)
Cantos Sánchez (2012)	2001-2008	23, E	0	+ (+VS)	+ (+VS, HS)	+ (+VS, HS)
Bougna, Crozet (2016)	1997-2011	17, E	0		+	0

II. Studies based on cost function

Study	Period	Sample countries	Vertical separation	Horizontal separation	Passenger competition	Freight competition
Cantos Sánchez (2001)	1973-1990	12, WE	– (F) / + (P)	+		
Van de Velde, Smith, Mizutani, Uranishi (2012)	1994-2010	24, E + 7, EA	0 (– tr. dens.)	+	0	0
Mizutani, Uranishi (2013)	1994-2007	21, E + 7, EA	+ (– tr. dens.)	+		
Mizutani, Smith, Nash, Uranishi (2015)	1994-2010	24, E+T+7, EA	0 (– tr. dens.)	+	0	– (0)
Smith, Benedetto (2018)	2002-2010	17, E	0 (– tr. dens.)	+	+	0/–

WE means Western European countries; *E* are European countries generally, *EA* denotes East Asian countries, *T* is Turkey. *F* stands for freight, *P* for passenger transportation, *CT* means competitive tendering, *OA* open-access; *D* is domestic and *INT* international transportation. The sign **+** means a positive impact, the sign **–** means a negative effect, **0** means no proved effect.

Source: Own processing

A more detailed description of the studies and possible explanations of the impacts of the reforms are provided in the following sections.

Table 3.2 provides a summary of the relevant literature on the efficiency of railways, methods, models, investigated period, number of observations, output variables, and other essential features of the studies.

Table 3.2: Summary of methods, models, and data in railway efficiency studies

Study	Method	Model	Period	Observations	Performance	Other
Production function						
Coelli, Perelman (1996)	COLS, ML	several	79/83	85	pkm, tkm	
Driessen (2006)	DEA+tobit	VRS	90/01	153	pkm, tkm	traffic density
Wetzel (2008)	1-step SFA	translog	94/05	243	pkm, tkm	W/E
Growitsch, Wetzel (2009)	DEA	super efficiency bootstrapping	00/04	75	train-km	
Asmild (2009)	MEA+tobit		95/01	156	train-km	W/E, pooled data
Friebel (2010)	OLS	CD	80/03	277	pkm+tkm	ordering, limitations
Cantos Sánchez (2010)	DEA+tobit	Malmquist index	85/04	320	pkm, tkm	traffic density
Cantos Sánchez (2012)	DEA+tobit, SFA+tobit, 1-step SFA	VRS, translog	01/08	169	pkm, tkm	CT/OA
Bougna, Crozet (2016)	SFA+tobit	translog	97/11	244	pkm, tkm	traffic density, IBM index
Cost function						
Cantos Sánchez (2001)	TC	translog	73/90	204	train-km	k = 56
Van de Velde, Smith, Mizutani, Uranishi (2012)	TC	translog	94/10	481/360 EU	pkm, tkm	k = 55, traffic density
Mizutani, Uranishi (2013)	TC	translog	94/07	420/308 EU	pkm, tkm	k = 43/47, traffic density
Smith, Nash, Mizutani, Uranishi (2015)	TC	translog	94/10	481/360 EU	pkm, tkm	k = 54, traffic density, competition
Smith, Benedetto (2018)	TC	translog	02/10	130	pkm, tkm	k = 43 (50), traffic density, competition, regulation

W/E means analysis of west versus east, *k* denotes the number of estimated parameters, *CD* is the Cobb-Douglas function, *TC* are total costs, *ML* means maximum likelihood, *OLS* ordinary least squares, *COLS* corrected ordinary least squares.

Source: Own processing

As we can see from the table, one group of the authors prefers estimation of the cost functions; the others employ the frontier estimations based on production function. Estimation of the cost functions is usually based on the translog form, which enables a highly flexible functional form. However, it also requires estimating a large number of parameters (around 50 in the available studies) while frontier estimations based on DEA contain much less variables (usually 3-6 inputs and two outputs).

The investigated period is not very up-to-date as the data are available (if ever) with a significant delay. The papers usually analyse European countries except for the cost-based articles and Driessen (2006) who also added several Japanese companies, and some other Asian companies. The average number of the observations is about 230-260 (Europe versus all observations). The authors mostly use the UIC data, often supplemented by data from own research. The most common performance measure is passenger-km for passenger transport and tonne-km for rail freight. Using train-km is less frequent. Countries are usually considered as homogenous units, only a few work concerns on west versus east locality; analysing the differences among more groups is missing. Precise analysis of the impact of the competition is also missing due to the lack of data. Traffic density is considered as an essential feature of railway transport; however, this problem is discussed only rarely in the existing literature.

3.2 Background studies

Several general studies describe the background and the impacts of the reforms. The article of *Pietrantonio and Pelkmans (2004)* inspects the main economic aspects of the EU railway reform. They mention a dramatic loss of market share of rail since the 1960s and describe arguments for the necessity of railway reform – greater competitiveness of rail, promoting rail haulage, and reduction of claims on public budgets. The paper deals with market failures in rail; it further discusses issues underlying vertical separation, and also the problems connected with introducing competition in rail services. Rail sector faces several market failures like natural monopoly, economies of density, and asymmetries of information accompanied by many legal barriers. Vertical unbundling leads to some positive effects like in other network industries (transparent costs of particular companies, the impossibility of cross-subsidisation), as well as to considerable coordination costs. Main arguments in favour of competition are a better quality of the provided services, optimal cross-border services, larger scale for cost recovery, and a decrease of rent-seeking. However, the introduction of competition depends on many factors – the size of the market, barriers of entry, proper PSO setting, etc.

Review of the reform process, the objectives of the reforms, the different models adopted, the key elements of separation of infrastructure from operations, the ways of competition (open-access and franchising), regulation and infrastructure charging are summarized in *Nash (2008)*.

He explains that European rail policy has been implemented in many ways. There are three different models of implementation – complete separation of infrastructure from operations (the most frequent form), separation of key powers (the least common form), and a holding company structure. These models can be associated with differing degrees of market competition – open-access and competitive tendering. Barriers to entry and a lack of commercial opportunities in the passenger sector for open-access are common. On the other hand, competitive tendering seems to be more successful, although many unanswered questions concerning the optimal setting of the franchises remain (contract length, ownership of rolling stock, and revenue risk). Separation of infrastructure from operations enables easier introducing of competition. However, it induces transaction costs. A vertically integrated company avoids this kind of costs; however, entry for competitors is more complicated. Further, the critical role of regulation of the industry is mentioned.

Another important study is *Deville and Verduyn (2012)*. In the first part, the authors outline reasons for railway reform and also the objectives to be achieved by opening up the rail market to competition. They sum up the European legislative framework for rail liberalisation. Next, they discuss specific features of network industries and the pros and cons of vertical separation. They stress the connection of the reforms with the economic theory relating to transaction costs and vertical integration of businesses. They conclude that there is no simple answer to the question which organisational model will produce the most significant consumer surplus as it is necessary to quantify the transaction costs, which is not easy. The second part is devoted to railway reform in Belgium, France, Germany, and the Netherlands. The way of separation of the infrastructure and the transport services varied considerably as well as the degree of opening the market to competition. The Netherlands chose full vertical separation. In France, there was a legal separation between infrastructure and operations but not a de facto one. Belgium and Germany adopted a form of holding company structure in varying forms – the one in Germany operates purely as a controlling company, on the other hand, the one in Belgium is not only the group's parent company but is also responsible for many other activities (maintaining and managing the stations, building, employing of all the railway workers). The advantages for consumers cannot be appropriately measured. Passengers' satisfaction seems to be better; however, the expected impact on prices did not come. Private rail operators faced significant

obstacles, even to gain a small share of the market. The financial analysis of the railway companies revealed wide variations in economic performance. Some major players (such as Deutsche Bahn) were better off according to the financial figures. Present acquisition policy of the big companies could lead to a higher concentration of the market and distortion of competition.

A summary of the European railway reforms, railway efficiency and railway performance with a particular concern on differences of Eastern European countries can be found in *Tomeš (2014)*. He analysed the impact of the reforms on modal shares of railways (not on railway efficiency) using a panel regression. His next paper *(Tomeš, 2017)* further developed the model analysis. He tried to identify the impact of the reforms separately on modal shares in the passenger and freight sector. He did not find out any evidence that vertical separation or competition entry increase modal shares of railways. The vertical separation had a mostly negative impact (in 7 out of 8 models). The competition was not statistically significant in any of the tested models. On the other hand, horizontal separation seemed to have a positive effect (it was statistically significant in 6 out of 8 models). He also identified significant differences in the trends of Western and Eastern European countries and also a significant impact of the economic crisis in 2009.

The study of the *International Transport Forum (ITF, 2019)* contains a broad summary on efficiency in railway operations – how efficiency can be defined, measured, and changed. Further, it discusses the problem with data availability which is a very problematic issue. Most EU railways do not have the interest to release information enabling public comparisons, although they receive substantial financial support from government sources. They conclude that a lack of good quality data is a major obstacle and governments should require companies to report key data. Not only economic indicators and econometric analysis can describe the efficiency of railways. Also, a narrative of exogenous and endogenous drivers of railway performance contributes to a better understanding of differences among the countries. The most important factors which should be included into the analysis are the key functions of the railway network, the topographical characteristics, and historical policy decisions. Otherwise, the results can lead to improper policy decisions.

3.3 Studies based on the production function

This section reviews relevant literature on evaluating the impact of the European railway reforms on railway efficiency based on the production function. It draws from the study Fitzová (2017). More methodological details regarding methods, models, number of observations, etc. of the studies were presented in Table 3.2.

A number of studies about the impact of the European railway reforms on the efficiency of railways have been worked out. However, they imply different conclusions. The horizontal separation had a mostly positive effect on efficiency, the effect was not always statistically significant, or a simultaneous implementation of vertical separation was required. The impact of vertical separation is ambiguous. Some studies show a positive impact, some negative and some neutral. The entry of competition brought mostly positive effects, especially in freight transport. However, it was also negative or insignificant in some studies.

Driessen et al. (2006) carried out an analysis using data for 13 Western European countries (and Japan) during 1990–2001. They utilised the DEA with variable returns to scale (VRS) for evaluation of relative efficiency of the countries in the first phase and the tobit regression in the second phase to evaluate the impact of the reforms. They deduced that competitive tendering in passenger transportation raises efficiency while open-access lowers efficiency. A possible explanation for this result could be more complicated coordination of railway operations and also lower economies of density. The impact of vertical integration was identified as positive. The results were different for the model without and with Japan. In the model without Japan, the full vertical separation had a positive effect on efficiency; accounting separation did not bring significant effect on efficiency. However, the model with Japan, brought inverse results. Increased managerial independence was detrimental to productive efficiency. It may be because most of the incumbent railway companies are state-owned and do not face any competitive pressure; thus, increased independence without sufficient competition and adequate regulation may deteriorate incentives for production efficiency. They identified a positive impact of traffic density on efficiency. A higher share of passenger transport (measured as the share of total passenger train-km in total train-km) decreased efficiency. The impact of control variables GDP per capita and population density was not statistically significant.

Wetzel (2008) examined 22 European countries during 1994–2005. She used multiple output distance model with the translog function in four different models. She deduced that only the impact of competition entry on the domestic freight transportation market efficiency was positive. Competition entry in the international and domestic passenger transportation decreased efficiency. The negative impact on efficiency for international services suggests a low degree of interoperability among the national railway systems. The results regarding domestic transport point to cost differences between freight and passenger traffic coordination. Furthermore, competition in the freight market is quite developed, while competition in the passenger market is still low in many countries. Thus, the estimated negative effect of access rights for passenger transport on efficiency could be temporarily, and it could change when the competition is more developed. The existence of an independent regulating body increased efficiency. Neither vertical separation nor organizational or accounting separation was statistically significant. She also identified a negative effect of population density and network density on efficiency. It can be explained by higher costs for passenger transport than for freight transport and higher coordination and maintenance costs of a widely branched dense network compared to a less dense network. Also the percentage of electrified lines positively affected railways' technical efficiency. A higher proportion of electrified lines can be seen as a quality factor suggesting a technically updated railway network. It was the first study concerning differences in efficiency between the group of Eastern European countries and Western European countries. Lower scores were reached in Eastern Europe. It can be due to a still lower economic and technological development in these former communist countries.

Growitsch and Wetzel (2009) devoted their research to 54 railway companies from 27 European countries during the period 2000–2004. They applied a super-efficiency DEA bootstrapping model to test the hypothesis that integrated railways realise economies of scope and, thus, produce railway services with a higher level of efficiency. They found that economies of scope exist for a majority of European railways. They found only slight efficiency advantages for integrated companies on average and economies of scope for a majority of observations within a model using only physical measures. They included operating expenses into the second model and identified more explicitly that integrated railway companies are, on average, relatively more efficient and that a majority of the observed railway companies indicated economies of scope.

The main argument in favour of economies of scope in the railway industry is that railway services are characterised by a high level of technological and transactional interdependence between infrastructure and operations.

Asmild et al. (2009) investigated 23 European countries during the period 1995–2001. They used multi-directional efficiency analysis (MEA), which allows examining how railway reforms affect the inefficiencies of specific cost drivers. They used a two-stage approach. The MEA provides the technical inefficiencies for each cost driver for each country in each year in the first stage; a relation of changes in efficiency levels to the introduction of reforms is examined in the second stage using analysis of variance and the tobit regression. Their principal findings were that the reforms generally improve technical efficiency but differently for different cost items. Not all of the effects were statistically significant, which may be caused by too few occurrences of the introduction of the reform initiative. More significant effects belong to material costs rather than to personnel costs. Accounting separation is essential for improving the (technical) efficiency in the use of both material and staff costs, whereas other reforms only influence one of these factors. Thus at least accounting separation seems important for improving technical efficiency. Whether there is an additional benefit of complete separation remains an unanswered question. The entry of competition into passenger transportation had a positive impact (significant impact on material costs and only weakly significant on staff costs), but the competition was present only in 4 countries, so the result should not be generalized. Independent management was also significant for materials costs (management is less constrained about material costs as opposed to staff costs) so that giving the railway companies more independence from state control has a positive influence on efficiency. The effect of market opening for freight transportation had a significant impact on staff costs whereas the effect on material costs (only in one out of two models) was only weakly significant – staff expenditures may be easier to adjust for freight rather than passenger transport. They were also engaged in the differences between Western and Eastern European countries, mainly due to lower productivity of labour and lower wages in the east. However, testing of differences between the two groups of the countries was difficult because the limited number of countries which have introduced the reforms during the study period.

Friebel et al. (2010) dealt with the impact of the order of the realised reforms in 12 Western European countries during 1980–2003. They utilised the Cobb-Douglas (CD) production function and several regression models to analyse the impact of the reforms, the intensity of the reforms, and the sequencing of the reforms. They found out that competition entry, the constitution of an independent regulating body and vertical separation increase efficiency. However, the sequence of the implemented reforms is essential. Introduction of several reforms at the same time did not increase efficiency, while sequential reforms improved efficiency. Gradual reforms enable the government to learn in intermediate stages about appropriate reforms, an option that does not exist when several reforms are implemented together. They were not able to distinguish the impact of particular reforms because of lack of actual data – only official dates of implementation were known, not the actual rate of utilisation in practice. They also discussed limitations of their study due to data: omitted quality measures (only quantitative measures), using information about reforms in the law book (not different type and intensity of implementation), not taking into account a different degree of subsidisation across European countries.

Cantos Sánchez et al. (2010) engaged in the influence of the reforms on efficiency, productivity and technical change in 16 Western European countries during the period 1985–2004. They applied a two-stage approach – the DEA for determining the efficiency scores (and also the Malmquist index) and the tobit regression for the logarithm of the inverse of efficiency in the second stage. Vertical separation is understood as an institutional separation (separating the infrastructure from operations), horizontal separation is considered as a classical separation of operations (freight and passenger) as well as introducing a franchising scheme or a free entry system which is a bit problematic aspect of this study. They present average results for different periods and also for different groups of countries (according to the implemented reforms). The reforms appear to be beneficial in general, although the evidence of significantly higher efficiency levels and more significant productivity growth is only found in countries that have completed both vertical and horizontal separation. Moreover, improvements are more substantial in railway systems that reformed the industry also horizontally (the coefficient for those systems was nearly four times larger), because particular reforms are strongly complementary. Horizontal separation without other reforms did not generate significant

improvement; however, it was the case for only two systems. They also included several control variables – the share of passenger transport, traffic density and average occupation of trains. All of them increased efficiency. Further, they analysed the determinants of accumulated productivity (productivity growth, technical change and efficiency change) growth using the Malmquist index. Railway systems with both vertically and horizontally separated industry achieved significant improvement in productivity. The results suggest that reform and deregulation processes have positive effects on the railway industry. However, these effects do not seem to be immediate, and implementation of a complete programme of the reforms is essential.

Merkert, Smith, and Nash (2010) tried to analyse the role of transaction costs in determining relative efficiency performance of rail systems. They applied a two-stage bootstrapped DEA approach to a sample of 43 Swedish, German and British train operating companies. They used seven different variables as inputs (2 – 4 in particular models) and three different output variables (1 – 2 in each model) for five models based on the DEA. Input variables comprised material costs and different groups of staff – total staff, production and administrative staff, and managerial staff. Train-km, passenger-km, and tonne-km were among the output variables. In the second stage of the analysis, they also investigated the impact of monetary values of transaction costs on technical efficiency, in addition to the institutional factors (vertical separation, type of operation) and the existence of competition. They found out that vertical separation may not be the dominant factor determining relative efficiency. Including a country dummy variable did not bring any significant results. Market concentration (measured by HHI index) had a positive effect on technical efficiency. The costs of staff with transaction occupations per train-km lowers the average technical efficiency. The effect was significant in all the four models where it was employed. They also mention two limitations of their paper – possible non-homogeneity of the sample and a limited dataset of the only one fiscal year.

Cantos Sánchez et al. (2012) applied two techniques of efficiency estimation (input-oriented CCR and BCC DEA models, and SFA using translog function, both two-step and one-step) on 23 European countries during the period 2001–2008. They compare the results in order to analyse potential differences between the two approaches using Spearman's correlation test. In the second phase, they estimated the effects of the reforms on inefficiency levels (logarithm of

the inverse of the efficiency) and gained similar results for both approaches; further, they applied one-step SFA in line with Battese and Coelli (1995). The most efficient countries are those with finished main reform points because particular reforms are strongly complementary. The impact of vertical separation was positive but statistically significant only in one out of the 8 model specifications. The impact of introducing passenger tendering was positive and statistically significant but only without imposing a variable integrating all the reforms (for all four models). This variable was strongly significant with a positive impact. Similar results hold for the entry of the new operators in the freight sector. When the variable combining all the reforms is introduced, it is strongly statistically significant, and all the particular reform variables become insignificant. It indicates that the improvements of the efficiency are more significant when the whole package of reforms is introduced. They conclude that governments do not make substantial mistakes if they completely reform the industry.

Bougna and Crozet (2016) used a stochastic distance function to measure productive efficiency and productivity change for 17 European countries during the period 1997–2011. They found out that productive efficiency was very stable between 1997 and 2003. From 2004 to 2007, productive efficiency was rising, and it declined between 2008 and 2010, which can be explained by the crisis of 2008. Between 2010 and 2011, productive efficiency was rising again; however, the values were still lower than before the crisis. This development corresponds to the development of total factor productivity (TFP). The authors decomposed the total factor productivity (TFP) into technological change, pure technical efficiency change and scale efficiency change. They found out that TFP has increased by 27% during 1997–2011. The most significant technological change occurred in Germany, France, Italy, Poland, and the Czech Republic. In the second phase of the analysis, the paper investigated the relationship between rail liberalization process and productive efficiency. The authors used the limited dependent variable tobit model. They found out that vertical separation and open-access competition have no impact on efficiency while competitive tendering in passenger transport has a positive impact. They used two liberalization indices in the other two models, and they found out a significant positive impact of the liberalization process. When they included both indices, it did not bring statistically significant results. Among the statistically significant variables, we can found GDP, traffic density, average distance, average occupancy, area, and electrification. They

conclude that the liberalization process is not the key success factor for the railway industry and suggest that policymakers should give priority to productivity gains instead of focusing on rail liberalization process.

3.4 Studies based on the cost function

This section presents relevant literature based on the cost function. It draws from Fitzová (2017). Further details about the methods and models can be found in Table 3.2.

Cantos Sánchez (2001) examined 12 Western European countries during the period 1973–1990. He estimated a translog cost function. Train-km in passenger and freight transport were considered as outputs of the rail industry. Further, the model included total costs, price of labour, energy and materials and the share of passenger-km and freight-km in total train-km, length of network, and value of fixed installations. He also included dummies for individual companies. The results of the study indicate that the traffic costs of passengers and freight were independent for the estimated period. Costs deriving from freight transport and the infrastructure are complementary, while those deriving from passenger transport and the infrastructure are substitutes. There are important vertical relationships between infrastructure and operations. Vertical separation would deteriorate the efficiency of freight transportation, and it would improve the efficiency of passenger transportation. It is due to positive synergies that exist for freight transport which is operated on a limited number of routes in contrast with passenger transport which is spread on the whole network. Horizontal separation should thus enhance efficiency. However, he analysed only vertically integrated companies, which is the weakest point of this paper.

Van de Velde et al. (2012) examined the potential impact of different forms of vertical organisation of railway markets on costs and modal share in 24 European countries and 7 Asian companies during 1994–2010. They used the translog form of the cost function. They analysed the relationship between the total costs of railway industry and a set of control and test variables. Passenger-km, freight-km, total train-km, costs of price, labour, energy and capital, further length of routes and electrification were among the control variables. The group of the test variables comprised dummies for vertical separation, holding company, horizontal separation, passenger competition, freight competition and several cross terms with traffic density and the

share of freight revenue. Their econometric evidence suggests that vertical separation does not have much effect on costs at average train density levels; at high traffic densities, vertical separation increases costs while at low levels, it appears to reduce them. A holding company model produces a small cost reduction in comparison with complete vertical integration. The effect does not change with traffic density. It could result from increased transparency resulting from the internal separation. Freight traffic causes more coordination problems than passenger traffic; thus the higher proportion of freight the smaller any cost reduction effect from vertical separation. It could result from the fact that passenger services on a route are typically operated by a single operator whereas freight may involve several operators. Horizontal separation led to a very substantial reduction in costs. They also tried to assess the effect of separation on the modal share of rail as the share of rail in transport by train and truck. They included a fixed effect, trend and competition. They found no evidence that vertical separation is superior to holding company model in its impact on modal share in freight or passenger transport.

Mizutani and Uranishi (2013) studied the impact of horizontal and vertical separation on costs in 23 European and East Asian OECD countries during 1994–2007. They used the total cost function to evaluate whether or not vertical separation or horizontal separation can reduce costs. The most important variables comprised passenger-km, tonne-km, total train-km, vertical separation, horizontal separation and traffic density. Many cross-terms were included; many of them were statistically significant. The authors found out that horizontal separation declined costs – it is probably caused by diseconomies of scope between passenger service and freight service and elimination of hidden extra costs due to subsidized passenger services. The effect of vertical separation was dependent on transportation density. Vertical separation lowered costs with a low density of transportation (low coordination costs) and raised costs with a high density of transportation (high transaction costs). The results show that applying a vertical separation policy to all the EU members is not appropriate in terms of costs; it may be appropriate only for railway organisations with lower train density. For railway organizations with higher train density, vertical separation is costlier than integration.

Mizutani et al. (2015) studied the impact of different institutional settings of the railway industry and competition on costs in 24 European and East Asian OECD countries during 1994–2010. In addition to the previous study, Mizutani and Uranishi (2013), Great Britain was

included; further an intermediate form of vertical separation – a holding company – was also considered. They also added freight competition dummy variable and passenger competition index (CMP). CMP variable ranged five levels (0-4). Level 0 meant no competition; level 1 expressed that competition is possible, level 2 denoted minor competition (either competitive tendering (CT) or open-access (OA)), around 10%; level 3 expressed that competition was dominant compared to the whole network (around or more than about 25%); level 4 corresponded to all services submitted to competition. Again, they used the translog form of the cost function. The effect of vertical separation was not statistically significant in their preferred fifth model (but it was significant in three other models with a negative sign). However, the interaction term of vertical separation and train density was statistically significant, which means that the effect of separation varies with the train density. Vertical separation reduces costs below average train density levels, and above that level, vertical separation increases costs. This finding is in line with their previous work; however, vertical separation starts to raise costs at lower density levels than in Mizutani and Uranishi (2013). It could be that the addition of Britain, a vertically-separated railway where costs have increased very sharply, has led to this change in the break-even point. Holding company dummy variable increased costs, and this effect did not vary with train density. Horizontal separation reduced costs. The variables representing the introduction of freight and passenger competition do not have any statistically significant impact on costs. It might reflect the problem of specifying appropriate competition measures.

Smith, Benedetto, and Nash (2018) studied the impact of the major European railway regulation reform using a panel of 17 European railways during 2002–2010. They incorporated a multidimensional rail regulation index capturing the complexity of regulatory powers and activities into an econometric framework alongside other reform variables. The effect of regulation is stronger without including competition variables. Their results suggest that the cost-reducing benefits of regulatory reform depend on the degree of market openness, vertical structure, and the intensity of network usage. The results are in line with the previous work Mizutani et al. (2015).

3.5 Summary

Most of the examined studies investigated the effect of vertical separation, which is somewhat unclear (see Table 3.1). It is probably dependent on other factors – the completeness of the realised reforms, the sequence of the realised reforms, train density, and some specific features of the country. Horizontal separation has mostly a positive effect. The entry of competition is beneficial in most cases in both passenger and freight transportation. However, the effect is also negative or unclear according to some other circumstances. It may be caused by an inappropriate variable describing the competition in the country. The ambiguity of the results may also stem from the facts that the data samples contain different countries and periods. Furthermore, the examined period is not relevant to the countries that implemented the reforms later. Therefore, the impacts of the reforms could not have been detected in previous studies. An empirical study covering all the EU countries for a sufficiently long period after the implementation of the reforms could enable to gain clearer conclusions about the relation among the reforms and efficiency. And this is the goal of this study.

4 Methodology

Relative performance and its evaluation mean the systematic comparison of the performance of one company against the others. It is called benchmarking, and it is more and more popular. It compares entities that transform the same type of inputs to the same kind of products (Bogetoft and Otto, 2011). This chapter describes the concept of efficiency and various approaches to measuring efficiency, especially those used for railways. Further, it indicates possible ways of analysing the impact of contextual variables on efficiency.

4.1 Efficiency

In general, a situation is considered efficient if it is not possible to produce more of one good under given resources without decreasing production of another good, i.e. there is no wasting. A firm or an economy operates on the production possibility frontier (Jablonský and Dlouhý, 2004) which is specified by a production function as the maximal output obtainable from an input vector given the production technology (Oum et al., 1999). The ratio of (weighted) outputs to (weighted) inputs is a measure of the productivity of the examined production process. Production possibility frontier determines the maximum achievable rate of efficiency under available technologies (Jablonský and Dlouhý, 2004).

Many companies in the railway industry operate markedly below the production possibility frontier. Modern benchmarking represents moving from effectiveness to efficiency and thus to relative comparisons (Bogetoft and Otto, 2011). Evaluation of efficiency and identification of sources of inefficiency are the main assumptions for improving the behaviour of subjects in a competitive environment.

Generally, several inputs are utilised, and usually, more than one output is produced. When multiple outputs or inputs exist, productive efficiency consists of two components: technical efficiency and allocative efficiency (Farrell, 1957).

Allocative efficiency is measured via total welfare under the assumption of utilising inputs in the right proportions. *Technical efficiency* means not to utilise the excess amount of inputs for a given level of output (or to produce maximum output with given inputs). Technical inefficiency results from excessive use of inputs (for the given output), while allocative inefficiency results from employing inputs in wrong proportions. Full productive efficiency

requires mutual satisfaction of technical and allocative efficiency conditions (Oum et al., 1999). Further, *dynamic efficiency* includes a possibility of a technological change in time and thereby a shift of the production possibility frontier (Cooper et al., 2007).

4.2 Possible approaches

The methods usually used for evaluating the efficiency of railways include partial productivity measures, total factor productivity, estimations of econometric models, and frontier analysis – especially the data envelopment analysis (and its modifications) and the stochastic frontier analysis. The methods are based on the conversion of inputs into outputs. They differ in the necessary assumptions, the kind of the data, and the type of measures they produce.

The simplest benchmarking approach is to compare the railway's performance to its past performance. However, it is necessary to take into account changes in economic policy, organizational changes and essential external factors and adjust the results.

If we want to compare data for various companies, it is necessary to ensure a comparable kind of data – the inputs and outputs of the companies have to be similar. Further, the size of the companies should be taken into account (e. g. by enabling returns to scale to vary). This is strongly dependent on data availability.

Partial productivity measures express the ratio of the firm's output to a selected input factor of the company (e.g. the ratio of train-km to staff). This type of indicator does not take any external factors into account. It is easy to compute it; it does not require a complicated dataset and is easy to understand. However, it is not suitable for multi-input (like employees, tracks, railcars, wagons, and energy in the railway industry) and multi-output (passenger-km and tonne-km) industries as the growth of one indicator can be caused by a decline in another indicator. Using a partial measure can lead to biased and unreliable results. In a fully competitive market, the ratios should converge among railways, but in practice, the results are dependent on many exogenous factors and economic policy (ITF, 2019) which should be taken into account when evaluating the results.

Despite these facts, these indicators can provide useful insights to causes of productivity, and for identifying productivity problems. They are useful in comparisons of performance across

firms operating in similar operating environments (Oum et al., 1999). However, more sophisticated methods are usually used.

Total factor productivity (TFP) measures the total output relative to the total inputs (e. g. the Tornqvist index or the Divisia index). It captures the effect of allocative efficiency and productive efficiency. TFP requires prices for inputs and outputs, which may be difficult to gain. Also, the interpretation of the results may be difficult as the TFP growth can be attributed to several factors (Driessen, 2006).

There are two main approaches which enable to perform efficiency analysis – econometric models based on statistical approach and data envelopment analysis employing linear programming.

Econometric models employ production functions, cost functions, or distance functions. Their estimations can be used to reveal information about productivity development in time. The most common functional form is the translog function or the Cobb-Douglas function. This approach requires meeting several assumptions; especially the estimation of the translog function requires enough observations.

Traditional econometric methods for estimating cost or production functions implicitly assume that all firms are successful in reaching the efficient frontier and deviate only randomly. If they are not, then the conventional estimation method would not reflect the efficient frontier against which to measure efficiency (Oum et al., 1999). It has led to a broader use of frontier production (cost) functions that allow firms to be below (above) the efficient frontier.

The *frontier analysis* provides a measure of relative efficiency among firms. It represents a best-practice technology against which the efficiency of firms within the industry can be measured (Coelli, 1995). In contrast to the TFP, the method does not need the assumption that all firms are productively efficient, which is especially important for evaluating the performance of railways. It does not require information about prices which are usually hard to gain for railways. For these reasons, frontier analysis is the preferred approach in this thesis. Frontier methods determine the best-practise production frontier based on extreme observations (not average) – each producer is compared with the best practice. It naturally makes the methods sensitive to outliers and measurement errors. Producers are considered as homogenous so that

an optimal combination of inputs and outputs carried out by one producer can be reached by another one. Further, measurement units do not matter as efficiency is based on ratios of rays.

The frontier analysis includes both *parametric* and *non-parametric* approaches (much less restricted), which can be both *stochastic* (allowing for individual random noise) and *non-stochastic* (Coelli, 1995). *Non-parametric* methods employ linear (mathematical) programming. *Parametric* methods require a particular form of the production function or the cost function. They use econometric methods for estimating the frontier. *Deterministic* methods suppose that deviation from the frontier is caused by ineffective behaviour of the unit – i.e. all the observed deviations from the estimated frontier are the result of technical inefficiency. *Stochastic* methods distinguish two types of deviations – inefficiency and a random error, which is also a part of the estimated function.

The two most widely used techniques of frontier analysis are the data envelopment analysis (DEA) and the stochastic frontier analysis (SFA). The *DEA* is a *non-parametric non-stochastic* method without any necessity to specify a production/cost form while the *SFA* is a *parametric stochastic* method requiring a functional form characterising the production process. Both methods are able to cope with multiple inputs and outputs, which is the case of railways.

Corrected ordinary least squares (*COLS*) represent a *deterministic parametric* approach. The classical ordinary least squares (OLS) regression means that there are some observations below and some above the regression curve. However, if the line is a frontier e. g. for costs, the points below the line are not feasible. The COLS shifts the regression curve down according to the biggest negative residual so that there are no residuals below the line (no infeasible points). Thus, COLS is based on OLS estimation and the subsequent shift of the fitting line towards the best performing unit so that there is at least one fully efficient company. It turns the original OLS approach into a frontier approach. As with the OLS, a large data set is necessary in order to obtain reliable results. The regression results are sensitive to the functional form if the error term is not adequately interpreted, which can lead to widely varying conclusions. Furthermore, the results are especially sensitive to outliers, since the “best” performer along any dimension serves as the anchor for the estimate.

A *stochastic non-parametric* approach is not very common in the analysis of railways; it is e. g.: the *stochastic DEA* or the *free disposable hull* (FDH). The FDH model relaxes the convexity assumption of the basic DEA models. The computational technique to solve the FDH program considers the mixed integer programming problem compared to the DEA model with a linear programming problem (Lim et al., 2016). The following two subsections cover more details on the DEA and the SFA.

It is not clear which approach and when it is better to use. All the methods have their pros and cons. The key question in the choice between the DEA and the SFA is whether we want flexibility in the structure of the model or precision in the noise separation. Non-parametric models are characterised by their flexibility in terms of the production economic properties, while stochastic models are flexible in terms of data quality (Bogetoft and Otto, 2011).

This thesis employs the frontier approach based on the production function because of the cost data unavailability, or unreliability. It uses both passenger-km and tonne-km as well as train-km in both segments of the market as output measures of the railway industry, which enables gaining a different point of view on the efficiency and comparison of the two approaches.

4.3 DEA

Technical efficiency analyses such as the DEA have been widely used to extract information from data sets that provide quantitative but non-monetary information on the resources that are used. As prices of inputs are hardly available for railways (especially labour costs) as well as for other public transport modes, the DEA is a widely used method for measuring the efficiency of transport, especially railways. A list of transport studies based on the DEA can be found in Markovits-Somogyi (2011).

4.3.1 Characteristics

The DEA represents an application of mathematical programming. It combines the estimation of the technology with the measurement of performance. It estimates the best practice frontier and evaluates the efficiency of each investigated unit relatively to this frontier so that it brings relative efficiency scores. The DEA estimates a non-parametric frontier as an envelope of the input-output combinations that are observed in the examined sample of units. Efficiency

measures are based on the geometric distance between the input-output combination of the respective unit and the frontier (Farrell, 1957).

Models utilised within the DEA limit efficiency scores between 0 and 1. A unit with value one is considered efficient. Units with scores less than one are inefficient (Bogetoft and Otto, 2011). Efficient units produce the highest output for given inputs or provide given output with the smallest values of inputs.

As the DEA is a non-parametric method, it does not require information about prices of inputs and outputs which are hardly available for railways – it works with physical units of inputs and outputs. It assumes homogeneity of the investigated units. It is flexible in terms of production economic properties.

On the other hand, it does not enable to estimate any production or cost functions. Further, its results may be biased by outliers and measurement errors. The DEA also does not allow testing hypotheses. Further, all deviations from the frontier stem from inefficiency; random shocks are not included. The analysis is also sensitive to the selection of outputs and inputs as well as units (firms). There are no formal tests to assess the merits of including or excluding variables (Driessen, 2006). Analysed units are expected to be relatively homogenous, so that including a very different unit may distort the results. The DEA can be a powerful tool when it is used correctly. However, its limitations should be kept in mind.

The analysis operates with a production possibility set (PPS), which is created by all the possible combinations of inputs and outputs. It is bounded by the efficient theoretical frontier (we do not know it – we only estimate it). Units producing on the frontier are considered efficient. Units below the frontier are inefficient (above in case of the cost function).

4.3.2 Returns to scale

There are many types of the DEA models. They differ in the type of returns to scale (RTS). RTS express a change in outputs due to a change in inputs. If an increase of each input (**x**) causes the same proportional increase of all outputs (**y**), it represents constant returns to scale (CRS). If some combination of inputs and outputs (**x**, **y**) belongs to PPS, its multiple (a.**x**, a.**y**) also belongs to PPS (under the CRS assumption) where a is a positive real constant. Further, if the unit (**x**, **y**) is efficient, the unit (a.**x**, a.**y**) is also efficient.

CRS is the basic case. The CRS assumption is only valid when all firms are operating at the optimal scale, which means that they cannot take advantage of RTS by changing their size. If this is not the case, the VRS assumption is required to correct for scale efficiencies (Driessen, 2006). Variable returns to scale (VRS) are commonly used in the DEA railway applications as they enable changes in the type of RTS according to the volume of production. In general, under the VRS assumption, a proportional change in the outputs does not have to lead to the same proportional change in outputs. Other RTS assumptions like non-increasing RTS (NIRS) or non-decreasing RTS (NDRS) are not common in railway applications (however, their definition is straightforward).

The basic DEA model based on CRS is called the *CCR model* (Charnes, Cooper and Rhodes; 1978). This model undervalues the efficiency of units operating under VRS. The commonly used DEA model with VRS is called the *BCC model* (Banker, Charnes and Cooper; 1984). BCC scores cannot be lower than those from the CCR model (by definition). Units with the lowest (highest) amount of some input (output) create the frontier, which means that RTS can be overvalued. The share of the scores from CCR and BCC models (CCR/BCC) is called the *scale efficiency* (SE). The SE expresses a part of inefficiency flowing from the existence of VRS in the examined industry. We can also use generalised returns to scale model (GRS). *GRS model* implements VRS, but it restricts their size by linear restrictions for inputs and outputs. The resulting score is between those from the CCR and the BCC models. Setting the limits for restrictions is a fundamental question.

4.3.3 Orientation of the model

All the presented models can be either input-oriented or output-oriented. In *input-oriented* models, we minimise the inputs for a given level of the outputs, and the computed efficiency score shows the proportional contraction of all inputs necessary to be efficient. In output-oriented models, we maximise the outputs for a given level of the inputs, and the computed score expresses the proportional expansion of all outputs needed to get on the frontier.

We can also use the slack based measure (SBM) model. The *SBM* model does not need any specification about orientation. The basic form is sometimes called an additive DEA model. Additive models represent a combination of both above mentioned approaches – they tell how to lower the inputs as well as how to enlarge the outputs to be efficient. On the other hand, the

CCR and BCC models are radial models – the computed efficiencies give the necessary measure of the reduction of all inputs proportionally (for input-oriented model) to get on the frontier. The SBM model measures efficiency directly via additional variables (slacks). It represents a more realistic approach as inefficiency often flows from suboptimal shares of inputs, i.e. from allocation inefficiency (in contrast with the basic DEA models which deal only with technical inefficiency).

4.3.4 Classification of the units

Efficiency scores can serve to the construction of a ranking of companies which can help in identifying main factors of success or failure. These scores can be utilised for searching economic and other factors influencing efficiency, e. g. – product per capita, the density of railway network, implementation of the reforms, etc. Mostly, a regression analysis using the *tobit model* is employed.

Usually, several units are identified as efficient. The units can be classified using *super-efficiency models*. The development in time due to technological changes can be analysed using the Malmquist index (Malmquist, 1953).

4.3.5 CCR model

According to Agarwal, Yadav, and Singh (2010), returns to scale (RTS) do not have a clear tendency in the area of public transport. Charnes, Cooper, and Rhodes suggested the first DEA model in 1978. It is known as the CCR model. It assumes RTS to be constant. This approach utilises a sequence of linear programs, one for each unit, to construct a piecewise linear production frontier, and to compute an efficiency index for each observation relative to the frontier (Oum et al., 1999). Observations on the production frontier are considered efficient, while the others are regarded as inefficient.

Relative efficiency of the unit is defined as the ratio of its total weighted output (virtual output) to its total weighted input (virtual input). The weights (virtual multipliers) are determined by linear programming optimisation. Weights are selected to maximise the efficiency score of the investigated unit. Higher weights are assigned to (relatively) less used inputs and more produced outputs.

A relative score in the sample of n decision-making units (DMUs) with input vectors x and output vectors y can be calculated for the CCR model from the mathematical programming problem (MP_0):

$$(MP_0) \quad \theta = \max_{u,v} uy_0/vx_0 \tag{1}$$

$$\text{s. t.} \qquad uY \leq vX \tag{2}$$

$$u \geq \varepsilon, v \geq \varepsilon \tag{3}$$

where v is a (row) vector of input weights (it consists of m components); u is a (row) vector of output weights (it consists of r components); x and y are input and output vectors with m and r elements, respectively; X and Y are matrices of input and output vectors (in columns) for all of the n DMUs, respectively; ε is an infinitesimal constant which ensures that all inputs, as well as outputs are at least slightly included. The lower index "*0*" denotes the investigated DMU for which the linear programme is solved.

This problem has to be solved for all the DMUs. The model gives the optimal value $\theta^* \leq 1$. The value 1 signals a unit on the frontier. Output-oriented model is not employed in the thesis as the outputs of railways are mostly given so that they try to minimise their inputs. However, both approaches would create the same frontier, i.e. the same set of the efficient unit, although the efficiency measures of the other units may be different (Coelli and Perelman, 1996).

The objective function θ is not linear (but it is a share of two linear functions), it can be transformed using Charnes-Cooper transformation. We can *maximise the numerator* under the condition that the *denominator is equal to one* which leads to *input-oriented model* or vice versa – we can minimise the denominator under the condition that the numerator is equal to one which leads to output-oriented model. Applying the first option brings the following linear programming problem (LP_0):

$$(LP_0) \quad \theta = \max_{u,v} uy_0 \tag{4}$$

$$\text{s. t.} \qquad vx_0 = 1 \tag{5}$$

$$uY \leq vX \tag{6}$$

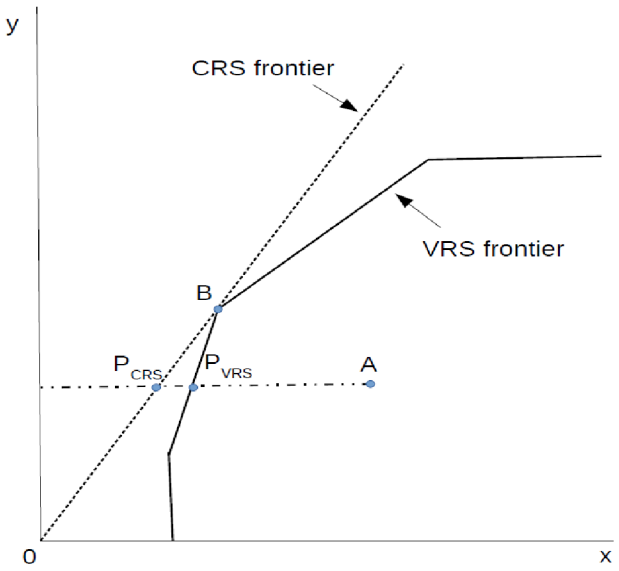
$$u \geq \varepsilon, v \geq \varepsilon \tag{7}$$

4.3.6 BCC model

A modification of the CCR model with the VRS assumption was proposed by Banker, Charnes, and Cooper in 1984 – the *BCC model*. The authors imposed a convexity constraint, which ensures that an inefficient firm is only compared against firms of a similar size. The VRS specification leads to a convex hull of intersecting planes which envelopes the data points more tightly than the CRS conical hull (Driessen, 2006). It generates higher or equal efficiency estimates than those from the CRS model.

Figure 4.1 illustrates the CRS and the VRS frontier for one input (x) and one output (y). In this example, one output is produced using one input. Inefficiency is expressed by the distance of a point from its frontier projection (orthogonal on the y-axis). Productive inefficiency of firm A is equal to the distance $|AP_{CRS}|$ under the CRS assumption. Under the VRS assumption, it is equal to the distance $|AP_{VRS}|$; it is called pure productive inefficiency. The difference between the two measures is the scale inefficiency. In point B, both scores are equal – it means that the firm is operating at an optimal scale.

Figure 4.1: VRS versus CRS in DEA



Source: Own processing

Many studies employ the more realistic and flexible VRS specification. The VRS assumption enable RTS to vary with the size of the production volume. For the general type of RTS, the

previous problem (LP_0) can be modified (for input-oriented model) by adding a constant μ to the term *uy* and *uY* in the following way (Dlouhý et al., 2018):

$$(LP_1)\ \ \theta = \max_{u,v} uy_0 + \mu \tag{8}$$

$$\text{s. t.} \qquad vx_0 = 1 \tag{9}$$

$$uY + \mu \leq vX \tag{10}$$

$$u \geq \varepsilon, v \geq \varepsilon \tag{11}$$

where

$$\mu = 0 \qquad \text{for CRS} \tag{12}$$

$$\mu \in R \qquad \text{for VRS} \tag{13}$$

Specifically, $\mu \leq 0$ for NIRS and $\mu \geq 0$ for NDRS.

4.3.7 Dual problem

DEA solvers are usually based on solving the dual problem as it is easier to solve and interpret. The dual problem for the model (LP_1) contains *(m+r+1)* restrictions and *(n+m+r+1)* variables. The dual variables are: $\lambda = (\lambda_1, \dots, \lambda_n)^T$, and θ (besides the *m+r* components of *x* and *y*). The dual problem can be expressed for a real variable θ and a non-negative vector λ as (DLP_0):

$$(DLP_0)\ \ \min_{\lambda} \theta \tag{8}$$

$$\text{s. t.} \qquad \theta x_0 - X\lambda \geq 0 \tag{9}$$

$$Y\lambda \geq y_0 \tag{10}$$

$$\lambda \geq 0 \tag{11}$$

Such a kind of model is known as the *envelopment model*. The variable θ expresses the efficiency of the DMU_0. If a DMU is efficient, both inequalities (9) and (10) must hold as equations. If we transform both these inequalities into equations using additive (non-negative) variables s^+ and s^-, we obtain (see Jablonský and Dlouhý, 2004), the following computational form of (DLP_0):

$$(DLP_1) \quad \min_{\lambda} \theta - \varepsilon(e^T s^+ + e^T s^-) \tag{12}$$

$$\text{s. t.} \quad X\lambda + s^- = \theta x_0 \tag{13}$$

$$Y\lambda - s^+ = y_0 \tag{14}$$

$$\lambda, s^-, s^+ \geq 0 \tag{15}$$

where e is a vector of ones and ε is an infinitesimal positive constant. The vector λ has to meet one of the following restrictions according to the RTS:

$$\sum_{i=1}^{n} \lambda_i \in R^{0+} \quad \text{for CRS} \tag{16}$$

$$\sum_{i=1}^{n} \lambda_i = 1 \quad \text{for VRS} \tag{17}$$

Further, the sum is less or equal to one under the NIRS assumption and the sum is greater or equal to one under the NDRS assumption. The variable θ is a measure of efficiency. The unit is efficient if the optimal value $\theta^* = 1$ and all the additional variables s^+ and s^- are equal to zero. If some of the s^+ or s^- variables are positive, then the DMU is sometimes called *slightly efficient* – it means that it is on the frontier, however, there exist another DMU which is better in some inputs or outputs. To recognize the exact kind of efficiency, the concept of slacks represents a useful tool.

4.3.8 Slacks

It is quite useful to know which inputs are "too big" or which outputs are "too small" and what their "optimal" size would be. For this purpose, we can use the concept of slacks. In accordance with Cooper et al. (2007), we can define the input excesses $s^- \in R^m$ and the output shortfalls $s^+ \in R^s$ and identified them as "slack" vectors by

$$s^- = \theta x_0 - X\lambda, \;\; s^+ = Y\lambda - y_0, \tag{18}$$

where $s^- \geq 0$, $s^+ \geq 0$ for any feasible solution (θ, λ) of (DLP_0).

To determine potential input excesses and output shortfalls, we solve the following two-phase linear programming problem. In the first phase, we solve (DLP_0) with the optimal value θ^*. In the second phase, θ^* is included as follows:

$$\max_{\lambda, s^-, s^+} \omega = e^T s^- + e^T s^+ \tag{19}$$

$$\text{s. t.} \qquad s^- = \theta^* x_0 - X\lambda \tag{20}$$

$$s^+ = Y\lambda - y_0 \tag{21}$$

$$\lambda \geq 0, s^- \geq 0, s^+ \geq 0 \tag{22}$$

where e is the vector of ones so that ω is the sum of all the slacks.

Only a DMU with $\theta^* = 1$ and all the slacks equal to 0 is called CCR efficient. Other units are inefficient. θ is referred to as *radial (technical) efficiency*. It means that all inputs can be reduced simultaneously without altering the proportion in which they are utilised. The inefficiencies associated with any identified non-zero slacks are referred to as *mix inefficiencies* and mean using a different proportion of inputs (Cooper et al., 2007).

This concept is beneficial for identifying the most problematic inputs in railway analyses. It will be applied, especially for the case of Eastern European countries in order to find the most redundant inputs.

4.3.9 Bootstrap

Bootstrap is a statistical method for calculating the accuracy of statistical estimates. It is based on sampling observations with replacements from the data set and creating a new "random" data set (or a "pseudo sample") of the same size (Bogetoft and Otto, 2011). This process is repeated many times and produces a sample of replicates (an empirical distribution). This distribution is used as an approximation of the true underlying sampling distribution of the estimator of interest (Coelli et al., 2005). This method was used for railway transport by Growitsch and Wetzel (2009) for testing economies of scope based on stochastic distance function. So-called smoothed bootstrap is often used to precede values repeated several times and to gain consistent estimations. The points are smoothed to imitate a continuous distribution function. This procedure was developed and further extended by Simar and Wilson (1998, 2000).

Further, this method enables to carry out a statistical test of the CRS assumption. Let H_0 be the CRS technology assumption and let H_1 be the VRS assumption. We can use the SE concept mentioned above (SE is the ratio of the CRS score and the VRS score). SE is equal to one under

the CRS assumption and is smaller than one (or equal to one for efficient unit) under the VRS assumption. We can use the statistics (Bogetoft and Otto, 2011):

$$S = \frac{\sum_{i=1}^{n} E_i^{CRS}}{\sum_{i=1}^{n} E_i^{VRS}}, \quad i = 1, \dots, n \tag{23}$$

where E^{CRS} and E^{VRS} are efficiency scores of the individual units. If the S statistics is significantly less than one, we reject H_0. As the distribution of S is unknown, we can use bootstrap method for gaining the empirical distribution and critical values of S. We can carry out the DEA analysis for many "pseudo samples" (usually several thousand) and compute the S statistics and determine particular quantiles (or critical values) from the empirical distribution. This is possible to do using the package "Benchmarking" in *R*.

4.3.10 Malmquist index

If we want to evaluate efficiency in time, it is necessary to take the changes of technology into account. New technologies enable companies to get better. However, they cannot explain the differences between units with the same level of technology. It is useful to distinguish between the two possible sources of efficiency changes – better technology and better organisation of the production process (Jablonský et al., 2018). Sten Malmquist (Malmquist, 1953) formulated the index which enables to evaluate a multi-input and multi-output production process without prices. It enables decomposition of efficiency changes in time into two components – the change in the relative efficiency of the unit relative to the other units (*catch-up effect*) and the change of the frontier due to changes in technology (*frontier-shift effect*) (Cooper et al., 2007). The index was later modified by Färe et al. (1994) who applied the DEA models in computing the index.

Let $D^t(\boldsymbol{x}^t, \boldsymbol{y}^t)$ be a function assigning each DMU efficiency under available technology in time t, for inputs $\boldsymbol{x}$ and outputs $\boldsymbol{y}$ in time t. For the input-oriented model, it is less than 1 for inefficient units and equal to 1 for efficient units. Efficient units define the frontier. Function $D^{t+1}(\boldsymbol{x}^t, \boldsymbol{y}^t)$ expresses the same for technology available in time $t+1$. Function $D^t(\boldsymbol{x}^{t+1}, \boldsymbol{y}^{t+1})$ relates inputs and outputs in time $t+1$ to technology in time t. Input oriented Malmquist index can be formulated as

$$M(x^{t+1}, y^{t+1}, x^t, y^t) = CE.FS \tag{24}$$

where CE is change in relative efficiency given by

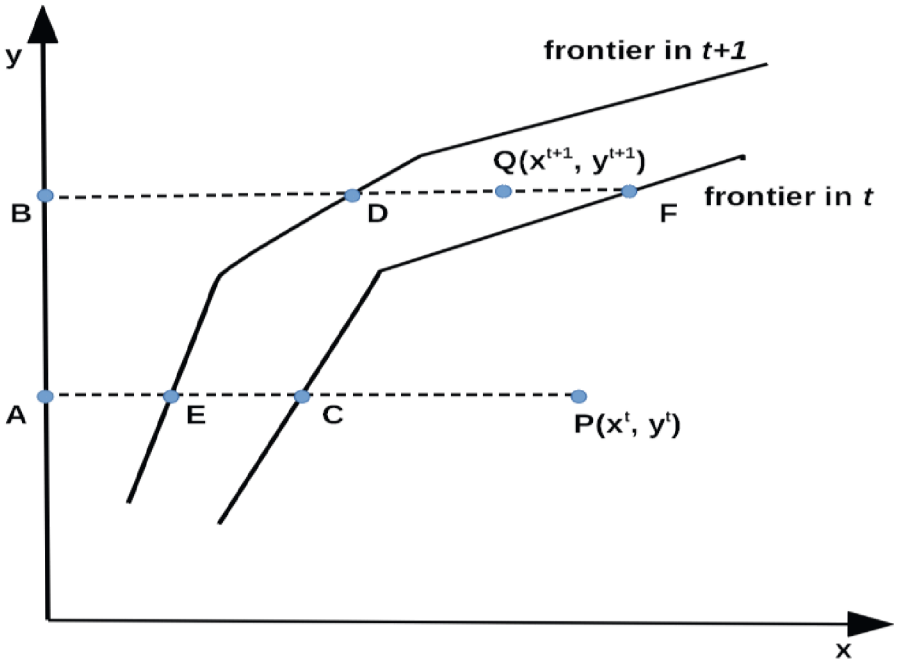
$$CE = \frac{D^{t+1}(x^{t+1},y^{t+1})}{D^{t}(x^{t},y^{t})} \tag{25}$$

while FS catches the change in the frontier and is given by

$$FS = \sqrt{\left[\frac{D^{t}(x^{t+1},y^{t+1})D^{t}(x^{t},y^{t})}{D^{t+1}(x^{t+1},y^{t+1})D^{t+1}(x^{t},y^{t})}\right]} \tag{26}$$

Computing the index requires solving four linear programs for each unit. This decomposition is explained in Figure 4.2 for the case with one input and one output.

Figure 4.2: Efficiency change in time



Source: Own processing

Catch-up effect is given by the ratio of relative efficiency in point Q in time $t+1$ to relative efficiency in point P in time t.

$$CE = \frac{BD}{BQ} \Big/ \frac{AC}{AP} \tag{27}$$

If it is greater than 1, it indicates progress in relative efficiency from period t to $t+1$. If it is equal to 1, it means no change.

Frontier shift at $(\boldsymbol{x}^t, \boldsymbol{y}^t)$ is given by AC/AE and in $(\boldsymbol{x}^{t+1}, \boldsymbol{y}^{t+1})$ by BF/BD. These ratios are ratios of the four efficiencies mentioned above (see equation 28). The total frontier shift *FS* is a geometric mean of these two elements – see equation (29).

$$\frac{AC}{AE} = \frac{AC}{AP} \Big/ \frac{AE}{AP} = \frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)}, \quad \frac{BF}{BD} = \frac{BF}{BQ} \Big/ \frac{BD}{BQ} = \frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \tag{28}$$

$$FS = \sqrt{\frac{AC}{\mathrm{AE}} \frac{BF}{BD}} \tag{29}$$

4.4 SFA

The stochastic frontier methods postulate that some firms fail to achieve their production/cost frontier, and measurable variables cannot fully explain the inefficiencies. SFA is the second, frequently used approach for evaluating efficiency. It is a stochastic parametric method for estimating the production (cost) possibility frontier. SFA was independently proposed by Aigner, Lovell, and Schmidt (1977) and also by Meeusen and van den Broeck (1977), and has been extended by Jondrow et al. (1982) and Battese and Coelli (1992).

The method incorporates two error terms – the first component represents a measurement error, the second catches inefficiency (Bogetoft and Otto, 2011). Statistical noise (standard measurement error) is generally assumed to be independently and identically distributed (IID) with the normal distribution. The second component is the inefficiency term, usually with half-normal, truncated normal, exponential or gamma distribution. There is no a priori justification for the distributional forms – the scores may be sensitive to the distributional assumptions. As it is a stochastic method, it is less susceptible to outliers than DEA. Its main advantage lies in a better explanation of the data. SFA is usually used with panel data which is useful for separating unobserved heterogeneity from efficiency (ITF, 2019).

SFA requires a specification of the production/cost functional form (usually the Cobb-Douglass or the translog). It is necessary to know the data concerning the total production or costs, and prices of all inputs for the production (cost) function. Further, a sufficient number of observations is needed. The SFA algorithms are properly developed for single-output technologies. However, their accommodation for multiple outputs is possible but usually not simply available in most of the available free software.

4.4.1 SFA with one output

The basic stochastic frontier model is given by:

$$\boldsymbol{y} = f(\boldsymbol{x}, \boldsymbol{\beta}).e^{\boldsymbol{v}}.e^{-\boldsymbol{u}}, \;\; \boldsymbol{u} \geq 0 \tag{30}$$

or equivalently (after a logarithmic transformation)

$$\ln(\boldsymbol{y}) = \ln f(\boldsymbol{x}, \boldsymbol{\beta}) + \boldsymbol{v} - \boldsymbol{u}, \;\; \boldsymbol{u} \geq 0 \tag{31}$$

where $\boldsymbol{y}$ represents output, $f(\boldsymbol{x}, \boldsymbol{\beta})$ is the deterministic part of the frontier production function, $\boldsymbol{\beta}$ are the model parameters; $\boldsymbol{v}$ is an IID noise which represents the effects of non-observable explanatory variables and random shocks (usually normal), and $\boldsymbol{u}$ is a non-negative random variable expressing the distance from the frontier (*inefficiency*). The condition $\boldsymbol{u} \geq 0$ ensures that all observations lie on or below the production frontier. The parameters of this model are estimated by the maximum likelihood method. This approach enables the estimation of standard errors and tests of hypotheses, which were not possible with the earlier deterministic models.

The combined error term can be written as $\boldsymbol{\varepsilon} = \boldsymbol{v} - \boldsymbol{u}$. Its variance is:

$$var(\varepsilon) = \sigma^2 = \sigma_v^2 + \sigma_u^2 \tag{32}$$

We can define λ as:

$$\lambda = \sqrt{\frac{\sigma_u^2}{\sigma_v^2}} \tag{33}$$

If $\sigma_u^2 = 0$, then $\lambda = 0$, and it is a classical regression. When σ_u^2 is small, it is hard to distinguish between the total error term $\boldsymbol{\varepsilon}$ and the error term $\boldsymbol{v}$. When σ_u^2 is getting larger relative to σ_v^2, the density of the total error term is broader and skewed to the negative part of the distribution. The parameter λ (as well as σ^2) is usually provided by the software, and it gives us the information about the relative relevance of the inefficiency term. The other two terms which are usually not provided can be computed from (32) and (33) as:

$$\sigma_v^2 = \frac{1}{1+\lambda^2}\sigma^2, \;\; \sigma_u^2 = \frac{\lambda^2}{1+\lambda^2}\sigma^2 \tag{34}$$

Model estimation using *R* also contains the estimation of the parameter γ, which expresses the share of the variance of the inefficiency term on the variance of the total error term:

$$\gamma = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2} \tag{34}$$

The predicted technical efficiency scores range between zero and one, like in the DEA. They are predicted taking the conditional expectation *exp(-**u**)* given the random variable *(**v**-**u**)*.

The most common specifications of the function *f(**x**, **β**)* are the Cobb-Douglas function and the translog function. Equation (31) can be written for the CD function in a log-linearised form as:

$$\ln(\boldsymbol{y}) = a_0 + \sum_{i=1}^{m} a_i \ln x_i + \boldsymbol{v} - \boldsymbol{u} \tag{35}$$

Another, more flexible form of function *f(**x**, **β**)* is the translog function. It represents the second-order Taylor approximation of *ln f(**x**, **β**)* and it can be expressed as:

$$\ln(\boldsymbol{y}) = a_0 + \sum_{i=1}^{m} a_i \ln x_i + \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{m} A_{ij} \log x_i \log x_j + \boldsymbol{v} - \boldsymbol{u} \tag{36}$$

However, this flexible functional form requires much more parameters to be estimated.

4.4.2 Distance functions

The main problem of the basic specification (31) lies in the fact that it is only usable for the only one output ***y***. If we have more than one output, as is the usual case of railways (usually passenger-km and tonne-km), a specific transformation must be performed. We apply the concept of input-oriented distance functions following the procedure described in Bogetoft and Otto (2011).

At first, we need to define several sets. Let *T* (technology) be a set of feasible production plans *(x, y)*, i.e. inputs $x = (x_1, \ldots, x_m)$ can produce outputs $y = (y_1, \ldots, y_n)$. Input (Farell) efficiency of a plan *(x, y)* relative to technology *T* is defined as:

$$E = \min\{E > 0 \mid (Ex, y) \in T\} \tag{37}$$

Output (Farell) efficiency of a plan *(x, y)* relative to technology *T* is defined as:

$$F = \max\{F > 0 \mid (x, Fy) \in T\} \tag{38}$$

It is easier to use the inverse distance – the Shephard input D_i and output D_o functions:

as:

$$D_i(x,y) = \max\left\{D > 0 |\ \left(\frac{x}{D}, y\right) \in T\right\} = \frac{1}{E(x,y)} \tag{39}$$

$$D_o(x,y) = \min\left\{D > 0 |\ \left(x, \frac{y}{D}\right) \in T\right\} = \frac{1}{F(x,y)} \tag{40}$$

For a fully efficient firm, $D_i\ (x,\ y) = 1$, for an inefficient firm, $D_i\ (x,\ y) < 1$. D_i is homogeneous of degree 1 in x. Let define u as:

$$D_i(x,y) = e^u \tag{41}$$

It means that $D_i\ (x,\ y) = e^u = 1$ for $u = 0$ and $D_i\ (x,\ y) = e^u > 1$ for $u > 0$ so that it can be interpreted as a measure of inefficiency. We can rewrite (41) as:

$$\log\big(D_i(x,y)\big) = u \tag{42}$$

Therefore

$$\log E = \log\frac{1}{D_i} = -\log D_i(x,y) = -u \tag{43}$$

It means

$$\text{E} = e^{-u} \tag{44}$$

Due to the homogeneity of D_i we have

$$x_m D_i\left(\frac{x}{x_m}, y\right) = D_i(x,y) \tag{45}$$

Taking the logarithms

$$\log x_m + \log D_i\left(\frac{x}{x_m}, y\right) = \log D_i(x,y) \tag{46}$$

Or equivalently

$$-\log x_m = \log D_i\left(\frac{x}{x_m}, y\right) - u \tag{47}$$

We can add a random error v to get

$$\log\left(\frac{1}{x_m}\right) = \log D_i\left(\frac{x}{x_m}, y\right) + v - u \tag{48}$$

We assume that v and u are independent, $v \sim N(0, \sigma_v^2)$, $u \sim N_+(0, \sigma_u^2)$. Equation (48) expresses the same form as (30). If we insert a parametric functional form for the distance function D_i, we have an estimable stochastic distance function.

One of the most commonly used function forms is the Cobb-Douglas function. It is a function linear in logarithms. Applying its form on equation (48) brings (49)

$$\log\left(\frac{1}{x_m}\right) = a_0 + \sum_{i=1}^{m-1} a_i \log\frac{x_i}{x_m} + \sum_{j=1}^{n} b_j \log y_j \quad + v - u$$

where m is the number of inputs and n is the number of outputs.

The translog function enables more flexibility than the CD function. However, it requires the estimation of much more parameters. It is similar to the CD form, but it contains second-order Taylor approximation of the logs. The translog stochastic distance function can be written as (50)

$$\log\left(\frac{1}{x_m}\right) = a_0 + \sum_{i=1}^{m-1} a_i \log\frac{x_i}{x_m} + \sum_{j=1}^{n} b_j \log y_j +$$

$$\frac{1}{2}\sum_{i=1}^{m-1}\sum_{j=1}^{m-1} A_{ij} \log\frac{x_i}{x_m} \log\frac{x_j}{x_m} + \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n} B_{ij} \log y_i \log y_j + \frac{1}{2}\sum_{i=1}^{m-1}\sum_{j=1}^{n} C_{ij} \log\frac{x_i}{x_m} \log y_j + v - u$$

4.4.3 Contextual variables

The ability to convert inputs into outputs is often influenced by exogenous variables that characterise the environment. We distinguish non-stochastic variables observable at the time of production (government regulation, type of ownership) and unforeseen stochastic variables (weather) representing a kind of risk (Coelli et al., 2005). The first type of variables is quite easy to implement into the basic SFA equation as we only add more unknown variables and parameters into the functional form:

$$\ln(\boldsymbol{y}) = \ln f(\boldsymbol{x}, \boldsymbol{\beta}, \boldsymbol{z}, \boldsymbol{\delta}) + \boldsymbol{v} - \boldsymbol{u}, \;\; \boldsymbol{u} \geq 0 \tag{51}$$

where $\mathbf{z}$ is a vector of contextual variables and $\boldsymbol{\delta}$ is a vector of parameters belonging to the variables $\mathbf{z}$.

This approach enables doing both steps of commonly used two-step analysis (evaluating the efficiency and analysing the impact of contextual variables on efficiency) at the same time. If predicted technical efficiencies are a function of contextual variables, these variables should be incorporated into the first stage which makes the second stage unnecessary. Two stage approach leads to biased estimators of parameters of the deterministic part of the production frontier and also to biased predictors of technical efficiency (Coelli et al., 2005). However, problems with the convergence of the solution are not rare.

A second approach consists in direct inclusion of the observable contextual variables to the stochastic component:

$$\ln(\boldsymbol{y}) = \ln f(\boldsymbol{x}, \boldsymbol{\beta}) + \boldsymbol{v} - \boldsymbol{u}, \;\; \boldsymbol{u} \sim \mathbf{N}^{+}(\boldsymbol{z}'.\boldsymbol{\delta}, \sigma_u^2) \tag{52}$$

The inefficiency terms have distribution that vary with **z** so they are no longer IID. The technical efficiency of production is simply *exp(-**u**)*. It can be generalized for panel data (Battese and Coelli, 1995).

An application of both approaches for transport (airlines) can be found in Coelli, Perelman and Romano (1999). The authors used the translog function, and they conclude that the results provide similar rankings of airlines but suggest differing degrees of technical inefficiency. However, if we compare the results with the SFA results without contextual variables, the statistical significance of the parameters is different, and one parameter (by the variable labour) has an opposite sign. Thus, this approach should be preferred to two-step SFA.

4.5 Tobit model

Classical OLS regression **y** =**X.** $\boldsymbol{\beta}$ **+ u** expresses a linear relationship between the explanatory variables **X** and explained (directly observable) variable **y** via the parameters $\boldsymbol{\beta}$. In some cases, there is a latent (unobserved) variable $\mathbf{y}^*$ in the model expression instead of **y**. However, we observe the only variable **y**, which is the same as $\mathbf{y}^*$ but only under certain circumstances; otherwise, we observe only one specific value (0 in the basic case).

The tobit model, also called the censored regression model, was designed to estimate linear relationships between variables where the range of the (continuous) dependent variable is constrained, i.e., censored (usually from below). Censoring in the basic tobit model means that

all negative values are substituted by zero (Verbeek, 2004). Values can be censored from below (left-censored) or above (right-censored) – all values left (right) from the lower (an upper) bound are substituted by the lower (upper) bound.

The basic tobit model (left-censored by 0) was developed by James Tobin in 1958 (Tobin, 1958). It can be written in the following way:

$$y_i^* = x_i'.\beta + \varepsilon_i, \;\; i = 1, \dots, n$$
$$y_i = y_i^* \text{ if } y_i^* > 0 \tag{53}$$
$$y_i = 0 \text{ if } y_i^* \leq 0$$

The latent (unobserved) variable y_i^* depends on the characteristics x_i. The observed variable is y_i. Error components ε_i are independent of x_i; ε_i has a standardised normal distribution.

Efficiency scores are limited between 0 and 1 with a positive probability to take on the value at the end of the interval. The system of equations would be the following:

$$y_i^* = x_i'.\beta + \varepsilon_i, \;\; i = 1, \dots, n$$
$$y_i = y_i^* \text{ if } 0 < y_i^* < 1 \tag{54}$$
$$y_i = 0 \text{ if } y_i^* \leq 0$$
$$y_i = 1 \text{ if } y_i^* \geq 1$$

The maximum likelihood estimation gives estimates which are consistent, asymptotically efficient and asymptotically normally distributed while the OLS method produces inconsistent estimations in the case of the censored observations. However, in the tobit model, a single set of parameters characterises both expressions, and the effect of a characteristic on the probability of non-zero observation and the value of the observation have the same sign (Verbeek, 2004).

If there are no censored values, the estimated parameters are the same as from the OLS estimation. The estimated parameters can be interpreted as marginal effects on the explained variable, ceteris paribus. However, such interpretation for efficiency scores as explained variables is not correct, as efficiency values are non-metric (Hirschauer and Musshoff, 2014). The DEA scores by themselves represent an ordinal-scaled variable for the units of a given

sample. Thus, we can only compare the scores of the units using relation operators (>, <, =), i.e. we can say that a unit is more efficient, less efficient or equally efficient as the other one.

If we want to express the goodness of fit of the model (its explanatory abilities), we cannot use the standard coefficient of determination (R^2) as for the OLS estimation. Quality of the model can be assessed using alternative goodness of fit measures (information criteria, the log-likelihood from the fitted model, etc.)

The tobit regression is usually used in the second phase of the analysis to identify important factors underpinning efficiency as the efficiency scores are limited between 0 and 1. The set of explanatory variables usually contains several reform variables in various forms (implementation of horizontal or vertical separation, level of competition, etc.), and further a set of operational, geographical and socio-economic variables (GDP per capita, network density, traffic density, average distance, etc.) The impact of the reforms is evaluated via the statistical significance of the estimated parameters. As a panel estimation of the tobit model is not commonly implemented in available free software, authors usually treat the data as cross-sectional. In case of sufficient size of the data sample, dummies for countries or years can be utilised. However, some criticism on this two-stage approach has appeared during the last few years (see further), especially by Simar and Wilson (2007).

4.6 One-step approach

The two-step procedure based on separate non-parametric estimations of productive efficiency and subsequent regression on contextual variables has been commonly used in similar transport studies. However, the second stage has been subject to intensive debates. Several authors have discussed the validity of the model, especially the assumptions regarding the underlying data-generating process and complicated unknown serial correlation among the estimated efficiencies (Simar and Wilson, 2007). Some research articles have provided empirical or theoretical evidence on the reliability of tobit regression in the second stage (Banker and Natarajan, 2008; McDonald, 2009).

However, Simar and Wilson (2011) show some problematic features of the model in McDonald (2009); further, they provide a list of essential differences in Banker and Natarajan (2008) approach, especially the strong assumptions regarding the noise and some more assumptions

that are more restrictive than those described by Simar and Wilson. The Banker and Natarajan's model assumes that the contextual variables only affect the frontier, but not the inefficiency process; the model described by Simar and Wilson assumes that the contextual variables only affect the inefficiency process, but not the frontier. This "separability" condition should be tested (Simar and Wilson, 2007).

Simar and Wilson (2007) suggested an algorithm for bias-correction of technical efficiency scores in DEA models. This approach employs bootstrapping which is a statistical method for calculating the accuracy of statistical estimates (for more details about bootstrap see section 4.3.9). It also enables evaluation of the impact of contextual variables. Employing one-step procedures which enable evaluation of efficiency scores as well as the impact of contextual variables in one step, provides a way of robustness check of the results gained from the two-step approach.

4.7 Summary

Benchmarking compares entities that transform the same type of inputs to the same kind of products. The most often applied methods in the area of railways comprise econometric analysis and frontier methods. Econometric analysis requires the costs of the companies which are hardly available now as the UIC stopped publishing their official reports and cost data are not available from their public database. Thus, this thesis uses two frontier methods – the DEA and the SFA – which enables a comparison of the results and makes the conclusions more robust as both methods incorporate some assumptions which have to be met to get reliable results. At first, the thesis employs a two-stage DEA approach based on the tobit model in the second phase to identify possible impacts of the reforms steps. It represents a standard approach in the area of railway efficiency research. Further, one-step DEA analysis based on Simar and Wilson (2007) is applied for robustness check. Follows the SFA analysis using Battese and Coelli (1995) approach, which also enables estimation of the efficiency scores as well as the impact of the control variables in one step.

5 Data

Using appropriate data is a necessary condition for obtaining meaningful results. However, data represents a big problem in empirical analyses in general – mainly due to hardly available or incompatible sources.

5.1 Problems with data

Most studies on the efficiency of railways use data from the International Union of Railways (UIC). There are several problems with this data source. Some of them may be overcome by collecting the data from particular national sources, which are mostly accessible, but it is very time-consuming. Furthermore, the available time span of the time series is usually different for various sources and the presented time series are often different (probably due to different methodology).

Some problems joined with the UIC data are described in Nash (2013). Data from the UIC provide only information about the UIC members. They usually cover information about the state incumbent in each country. Some new entrants are also included, especially in the latest data (e. g. freight operators in Romania for many years or the passenger operator NTV in Italy in 2019). Data from Great Britain, which is furthest in performing the reforms, is not available (particularly some variables). Some data is incomplete or misleading, e. g. – some details about the number of rolling stock and staff. Labour inputs and rolling stock can be contracted out to other companies – it is, in particular, the case of Britain, Sweden, Denmark and the Netherlands[2]. However, these countries are included only in a few models out of many in this thesis. The UIC data contains affiliates in other countries; thus if we put together geographical infrastructure and national operators, it is not consistent. Missing values or estimations based on past values are not rare. The importance of good quality data and their problematic availability is mentioned in Thompson and Bente (2014) and especially in ITF (2019).

[2] In Britain, Network Rail ceased contracting maintenance out (in the period of interest). Sweden contracts out track maintenance. Also, train operating companies may contract out rolling stock maintenance and cleaning. This may coincide with other reforms and thus may give a systematic bias.

The current state of the implemented reforms may differ from the formal date of implementation – the difference may be even several years. Open-access competition is run only on some lucrative potentially profitable routes so that the amount of available data is not too large. Nowadays, it is operated only in several countries, and its market share is small. Competitive tendering occurs more often but can be strongly regulated, and it can also be very costly to succeed in the tenders. It mostly occupies only a small piece of the market (with some exceptions like Great Britain, Sweden, and Germany). Thus only a few data concerning competition is available, which makes the analysis difficult. However, the latest published numbers indicate that the new operators (others than the incumbent) are included in the national performance indicators like passenger-km, tonne-km or train-km. Using this new information from the last few years could reveal new results. The data about the new entrants are hardly available. However, the presence of new competitors forces the incumbent to behave more efficiently; thus, we can see their impact in the incumbent's data.

The analyses usually use official dates or date of an entry of a first competitor (or issue of the first licence). However, there is not much discussion, whether it is correct and what implications it can have. Further, not all papers distinguish between a complete vertical separation, a holding company and separation of key powers.

The data is also available with a considerable delay, and the reforms are still in progress in many countries. In some of the countries, the reforms were finished, but competition implementation is a gradual process, and it takes many years to get the changes into common practice. The difference between the establishment of some arrangement and its practical usage could be quite large. It usually takes many months or several years until first outcomes are visible. It is also often not clear which dates were used in the empirical analyses regarding reforms implementation. Based on the data from IRG (2016), one can compute elapsed time from the establishment of the reform supporting competition until the first new entrants came. In the freight market, it took on average 31 months (data for 18 EU countries), in the passenger market it was around 37 months (data for 13 EU countries). We can see that it took around three years, but it must have taken much more time to reach some significant market share (for example, 1%). It could be a subject of debates about how these facts could have influenced the

results of the studies. However, also the threat of entry could improve efficiency even before entry occurs.

5.2 Dataset

The previous paragraphs mentioned many problems connected with railway data. Thus, the collection of an up-to-date and complete dataset is an essential task for further analysis, which could contribute to a more precise evaluation of the impact of the EU railway reforms on efficiency. It was also one of the goals of this thesis. Creating the database represented a very time consuming and problematic task. As the data usually appear in the form of country data (length of lines, GDP, …), this thesis applies a country-based approach. In case when more than one company operates in the area of the country (like freight operators in Romania), the values of the variables of interest are summed.

This thesis draws on the official UIC data. Many values were missing. Sometimes, a strange value appeared, and it was clear that zero or several zeros are missing or redundant. Other times, an utterly unclear course of time series appeared that it was not evident which values are correct. It was not usually clear whether it was a typing error, a consequence of a significant organizational change or some structural change like a division or takeover of the company. It was necessary to correct the problematic values using other data sources – especially the Eurostat, the European Commission, the World Bank, national statistical offices, incumbents' webpages, other transport institutions' publications, and also discussion with foreign railway experts.

Incorrect values were detected by checking the development of all the examined time series. In the case of the year-to-year change larger than 10%, the value was checked using a different (usually national) data source. Unfortunately, it was not possible in all cases. Some values are still missing; some values were approximated using available data (typically when the previous and the following value of the series were known and not too different).

The largest part of the dataset draws from the official UIC publications – International Railway Statistics 2008–2012 (UIC, 2009–2013a); UIC Statistical Tables (UIC, 2012b); Synopses published irregularly on (and also removed from) the UIC web pages (UIC, 2013b–2019b); the latest data come from the newly published UIC database Railisa (UIC, 2019a), and some data

were also gained on request directly from the UIC Statistics and Economics Unit for research purposes.

The second most important data source is the Eurostat Database (Eurostat, 2019) which provides the basic variables for railways. However, the number of missing values is quite high, and not all the necessary indicators are published. On the other hand, the Eurostat provides data in a format enabling comfortable data processing which is not true for most of the national data sources where the values have to be collected from various documents number by number.

EU Transport in Figures: Statistical pocketbooks (European Commission, 2009–2018) published by the EC represent the third most important source of information. They contain some data which are not provided by the Eurostat database; thus, a combination of the three sources provided a good basis for the dataset.

However, it was necessary to fill in some missing values or to correct some variables with the strange development (with considerable changes over time) using national data sources. A detailed list of data sources with web links can be found in section Data sources.

Austrian data were completed using the Annual reports of Austrian Federal Railways ÖBB (ÖBB, 2016–2018) and ÖBB Facts & Figures (ÖBB, 2017). Czech data were corrected using the Czech Railways Annual Reports (ČD, 2000a–2018a) and the Czech Railways Statistical Yearbooks (ČD, 2004b–2018b). Selected Danish missing values were taken from Statistics Denmark – Business sector: Transport (Statistics Denmark, 2019). German company Deutsche Bahn published Deutsche Bahn Facts & Figures (DB, 2015–2018). Latvian railway company Latvijas Dzelzcelš provides very well arranged basic performance indicators directly on their company pages (LDZ, 2005–2018) which really helped to correct Latvian data. Norwegian statistical office Statistics Norway offers some data in the section rail transport (Statistics Norway, 2019) which were also very helpful for comparison with the officially published data and for replenishing some missing values. Selected problematic Polish data were drawn from the Office of Rail Transport (Urząd Transportu Kolejowego), particularly from their annual reports (UTK, 2011–2017). Most of the Slovak railway data is accessible from the annual reports of the Slovak railways infrastructure manager ŽSR (ŽSR, 2001–2018) and the passenger transport services operator ZSSK (ZSSK, 2011–2018). Many missing Swedish values were

found in the transport analyses published by the Swedish government agency for transport policy and analysis (Trafik Analys), specifically their transport reports (Trafikanalys, 2012a–2019a) and traffic reports (Trafikanalys, 2010b–2019b). Further, selected problematic areas were directly discussed with the railway experts from Sweden. The British Data Portal of Office of Rail and Road (ORR, 2019) enabled the gaining of many missing data from Great Britain. A direct discussion with railway experts from the UK helped to complete some variables necessary for including Great Britain into some of the models.

Although the data of the new competitors is almost unavailable, their impact is reflected in the data of the existing incumbents because the presence of competitors forces the incumbents to behave more effectively – they have to adjust the amount and structure of staff, renew the fleet, continually improve their business organisation, invent new products, loyalty programs, etc. At the moment, it seems there is no better way to include the new operators entirely in the analysis. However, this way should provide usable results.

The above-described dataset was created especially for this thesis. It contains as many as possible values which were checked and also corrected if any problems were detected. The dataset comprises up-to-date values of a wide range of variables for 28 European countries during 1999–2017. These include all the 26 EU members with railways (Malta and Cyprus do not have railways) and Norway and Switzerland, which data is also available using the same methodology. Thus, a full data sample would contain 532 observations. However, some data is not available for particular variables, countries and years. Freight fleet is missing for Denmark (2008–2017), the Netherlands (2008–2017), Norway (2012–2017), the UK (2015–2017), and tonne-km for the Netherlands (2016–2017). Some variables were particularly constructed for this thesis. They comprise primarily various forms of competition variables as a suitable variable describing competition in the railway market was not found in the literature.

The thesis tries to overcome the problems mentioned above by analysing different models (not all variables included in all of them) and by making estimations for only selected years and countries (due to data availability), and comparing the differences to get at least some information about the problematic locations which are not usually analysed.

5.3 Countries' characteristics

This section presents an overview of the countries included in the analysis. As the countries are not homogenous, they are divided into Eastern and Western European countries and after that into several groups of countries with similar features. Identifying the groups with relatively homogenous countries is helpful for the following empirical part as we do not have enough observations to use a specific (dummy) variable for each country in the analyses. These divisions are based on not too many literature sources which analysed differences among the EU countries and their impact on efficiency. The findings in Wetzel (2008) and Asmild et al. (2009) revealed lower efficiency in Eastern European countries. The study of Fitzová (2018) also identified significant differences among four groups suggesting two groups of CEE countries and two groups of WE countries (see section 5.3.4). However, one more detailed division was deduced from the analysis of descriptive statistics of the individual countries (see section 5.3.5).

5.3.1 Non-measurable factors

Although it is possible to employ lots of the reform, geographical, socio-economic and other variables describing the countries, some hardly measurable factors important for the analysis still remain. Common history or traditional behaviour of passengers and producers are among them. They could be covered by individual dummy variables which would of course require much more observations. Thus grouping the countries into several groups represents a possible solution. The most common division is "west versus east". However, this thesis reveals that it is not sufficient and suggests two more detailed divisions. The first proposal assumes four groups – it earmarks three small peripheral railway systems from the group of Western European countries and three Baltic countries oriented much more on freight transport from the group of Eastern European countries. The second proposal suggests eight groups of countries – it takes into account the similarities in the historical development as well as the size of the railway system. It comprises four groups of Western European countries and four groups of Eastern European countries. The following sections tell more about the groups of countries.

5.3.2 West and east – overall characteristics

The most common division of the EU members is into "west" and "east". Specifically, the division into Western European (WE) countries and Central and Eastern European (CEE)

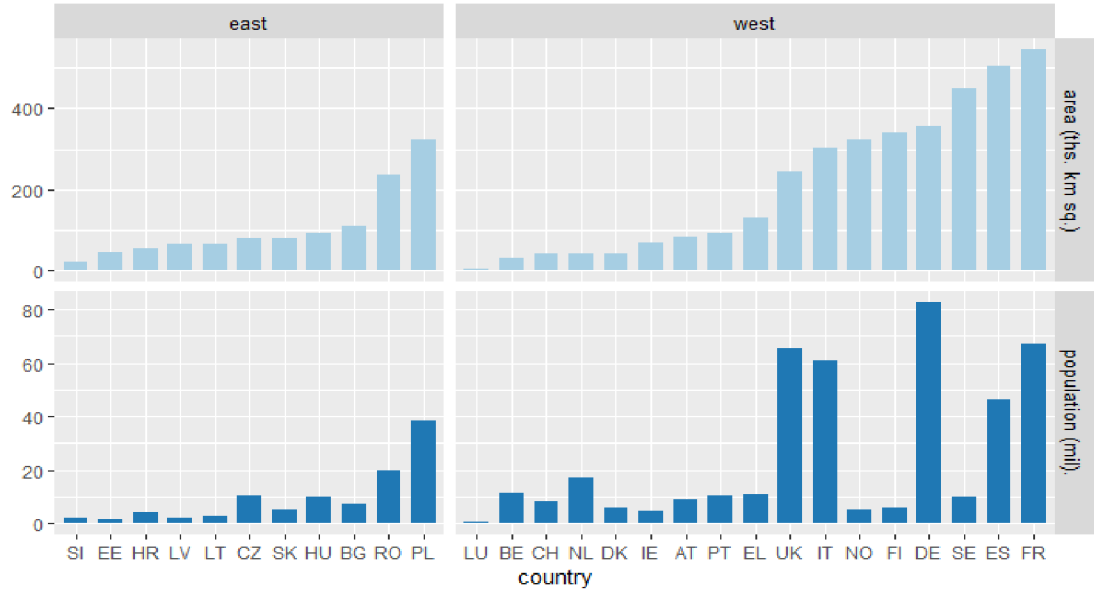
countries will be applied at first. Here and further, the country codes used by the Eurostat are utilised.

CEE countries include Bulgaria (BG), the Czech Republic (CZ), Estonia (EE), Hungary (HU), Croatia (HR), Lithuania (LT), Latvia (LV), Poland (PL), Romania (RO), Slovakia (SK), and Slovenia (SI).

WE countries comprise Austria (AT), Belgium (BE), Switzerland (CH), Germany (DE), Denmark (DK), Greece (EL), Spain (ES), Finland (FI), France (FR), Ireland (IE), Italy (IT), Luxembourg (LU), the Netherlands (NL), Norway (NO), Portugal (PT), Sweden (SE), and the United Kingdom (UK).

Generally spoken, WE countries are larger and more populated than CEE countries as we can see in Figure 5.1.

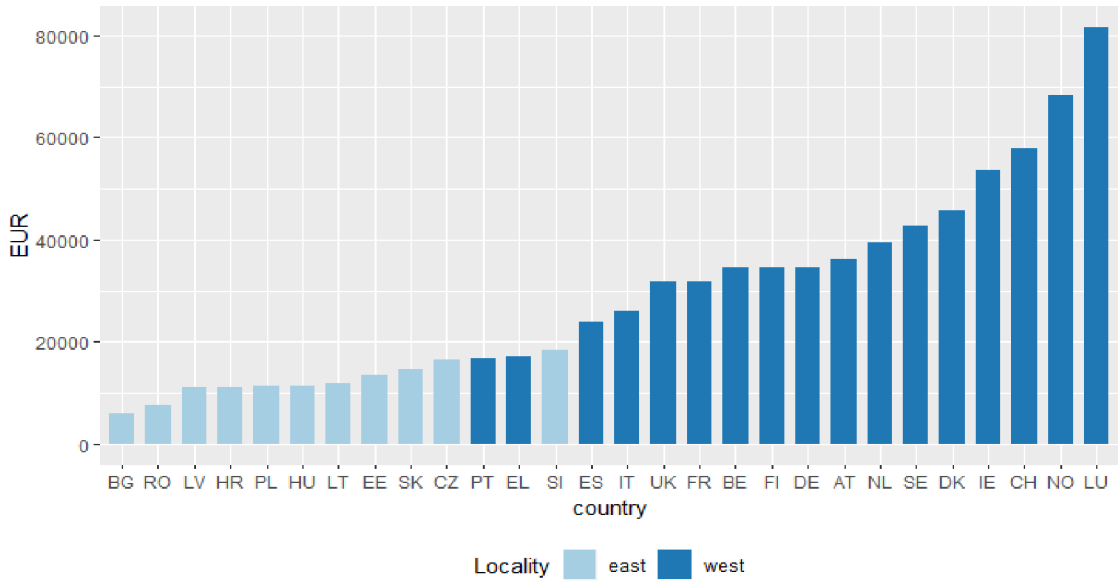
Figure 5.1: Area and population (2016)



Source: Eurostat + own processing

Further, the economic level computed as real GDP per capita is undoubtedly higher in WE countries – see Figure 5.2.

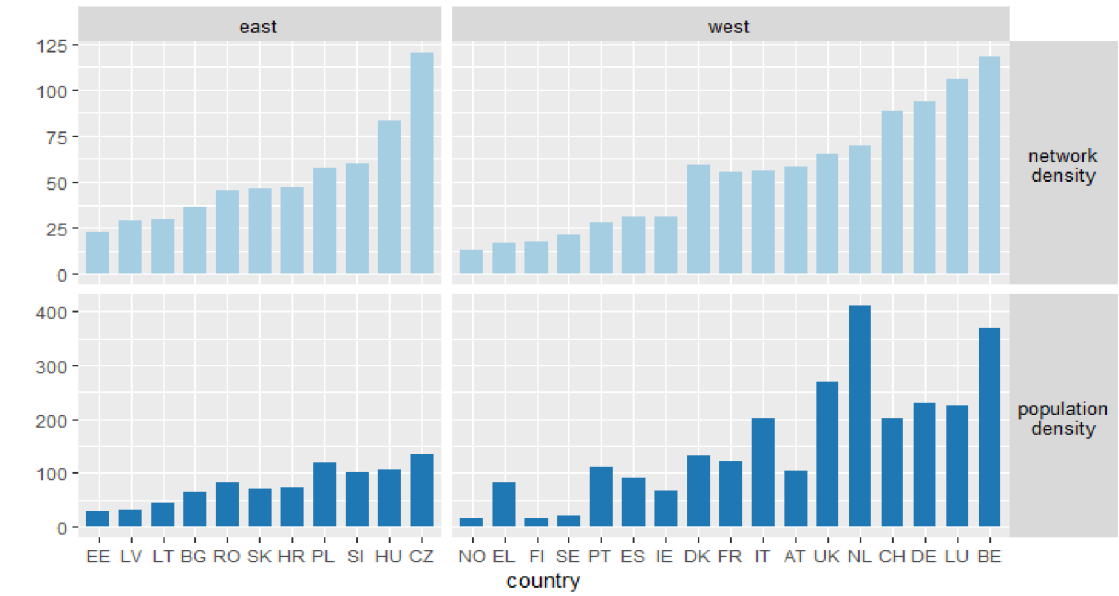
Figure 5.2: Real GDP per capita (2016)



Source: Eurostat + own processing

Network density expressed as the total length of lines (in km) divided by area (in thousands of km^2) is, on average, slightly higher in CEE countries whereas population density is mostly lower than in WE countries – see Figure 5.3.

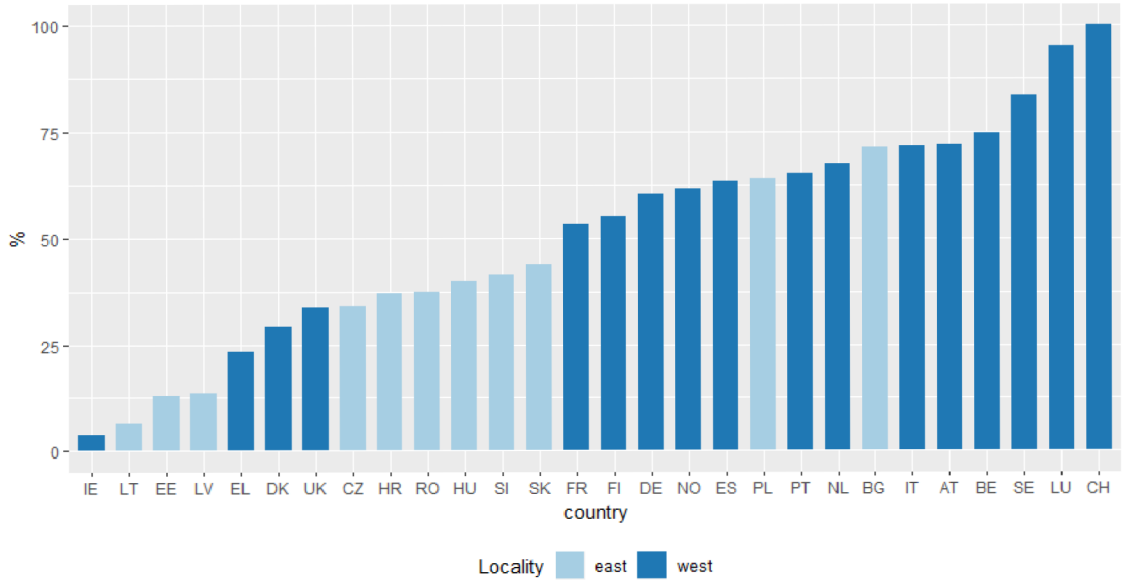
Figure 5.3: Network density and population density (2016)



Source: Eurostat, UIC + own processing

Western European countries reach higher level of electrification on average. However, several of them reach quite low values (see Figure 5.4).

Figure 5.4: Network electrification (2016)

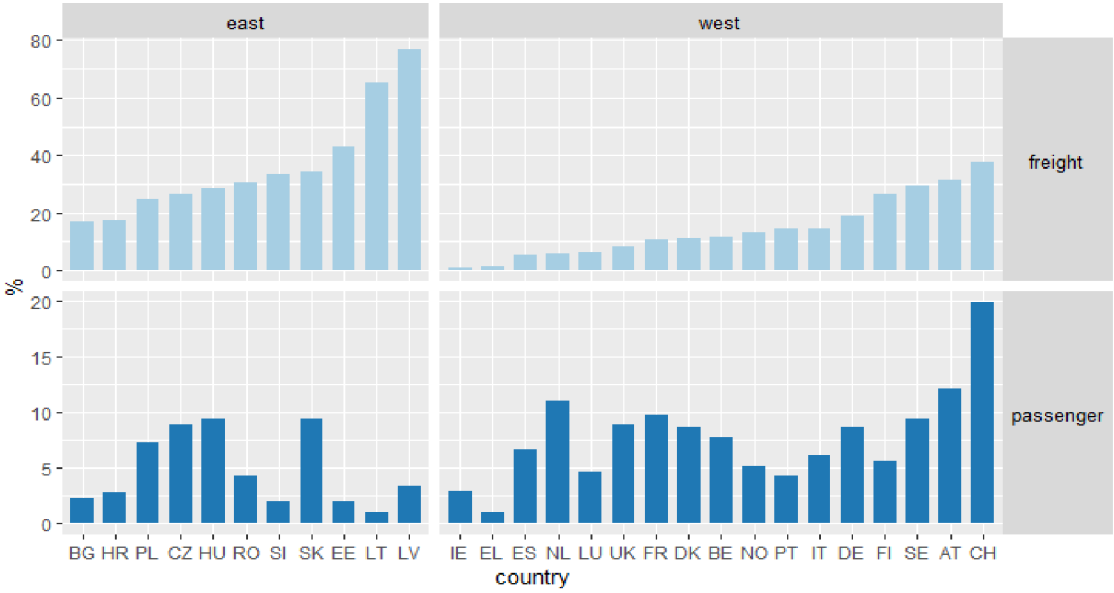


Source: Eurostat, UIC + own processing

5.3.3 West and east – composition of railway transport

The share of rail freight on total freight transport (including rail, road and inland) is significantly higher in CEE countries, especially in Baltic states – see the upper part of Figure 5.5. On the other hand, the share of passenger rail transport on total land passenger transport is higher (on average) in WE countries – see the lower part of Figure 5.5.

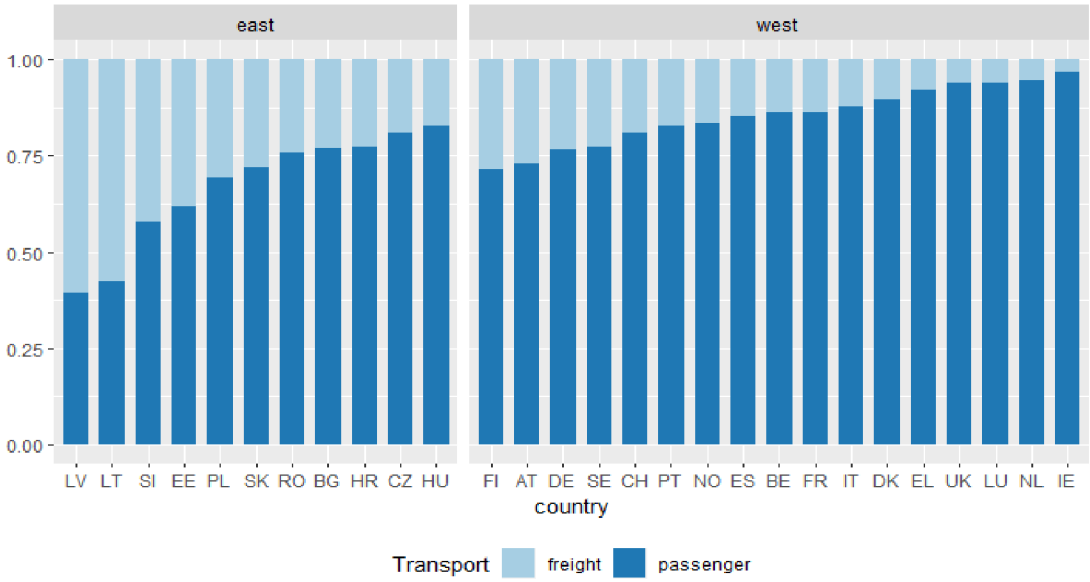
Figure 5.5: Share of railways on total freight and passenger transport (2016)



Source: Eurostat, EC + own processing

If we look at the composition of railway transport in individual countries, we can see that the share of freight (measured as the share of freight-train km on total train-km) is significantly higher only in Latvia and Lithuania – see Figure 5.6. On the other hand, the share of freight is extremely low in Ireland, the Netherlands, Luxembourg, the UK, and also in Greece.

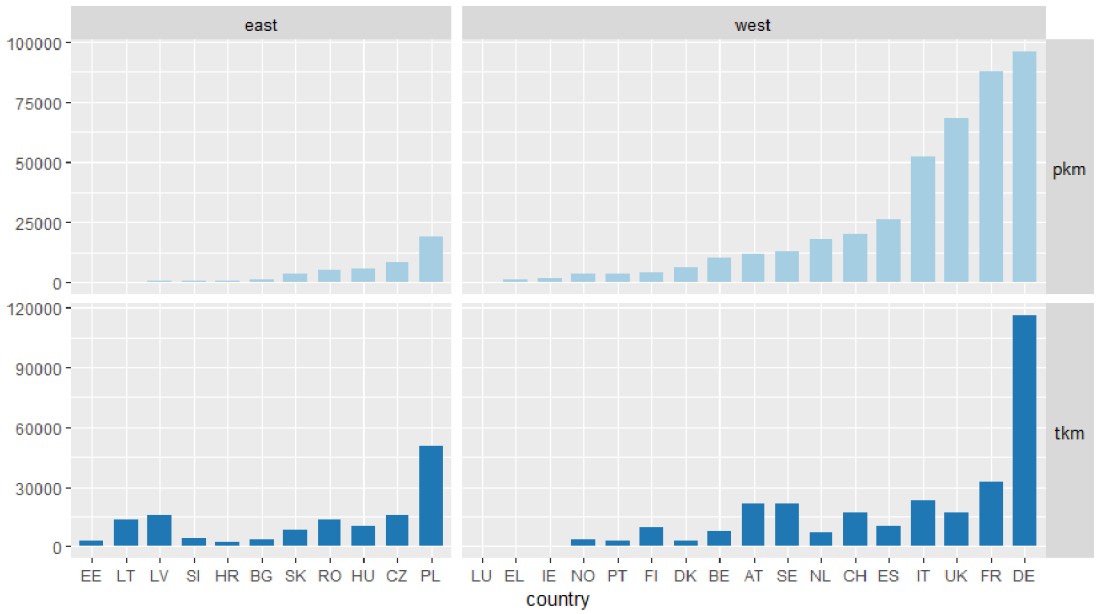
Figure 5.6: Composition of railway transport (2016)



Source: UIC data + own processing

There is a big difference in performance in the passenger rail sector – it is much higher in WE countries (see the upper part of Figure 5.7 which shows passenger-km in million). Germany reaches the highest values in both segments of the market (in 2016). Passenger sector is very strong in France, the UK, and Italy. Freight rail is significant also in France and Poland (see the lower part of Figure 5.7 which shows tonne-km in million).

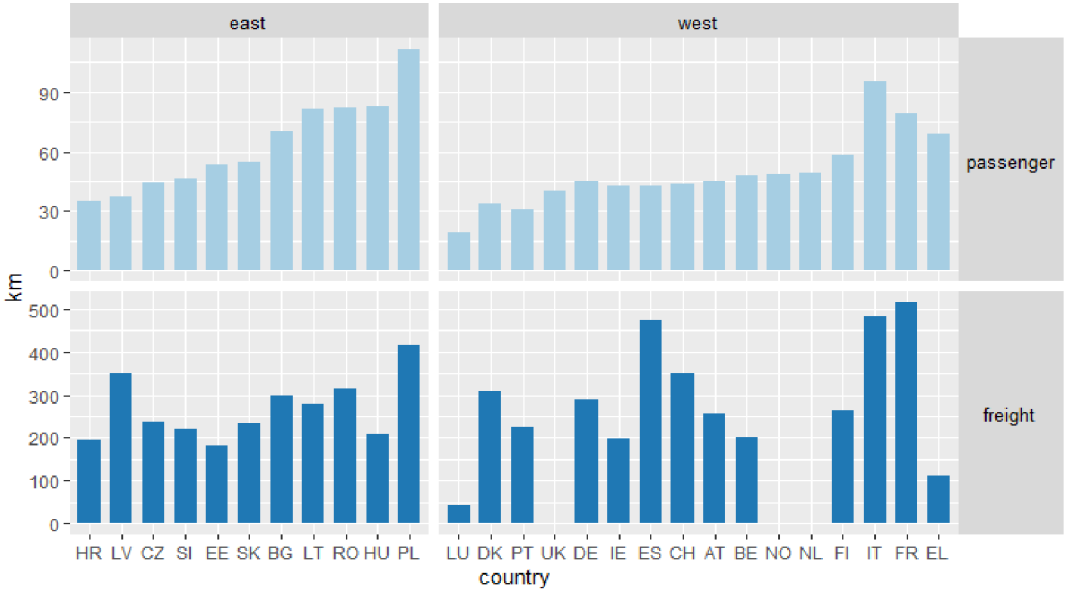
Figure 5.7: Railway performance (2016)



Source: Eurostat data + own processing

However, the average distance in passenger transport is significantly higher in CEE countries (see Figure 5.8). It may be because it is not used so often for everyday commuting as in WE countries. The average distance in freight rail is similar in both parts of Europe.

Figure 5.8: Average distance in freight resp. passenger transport (2013)



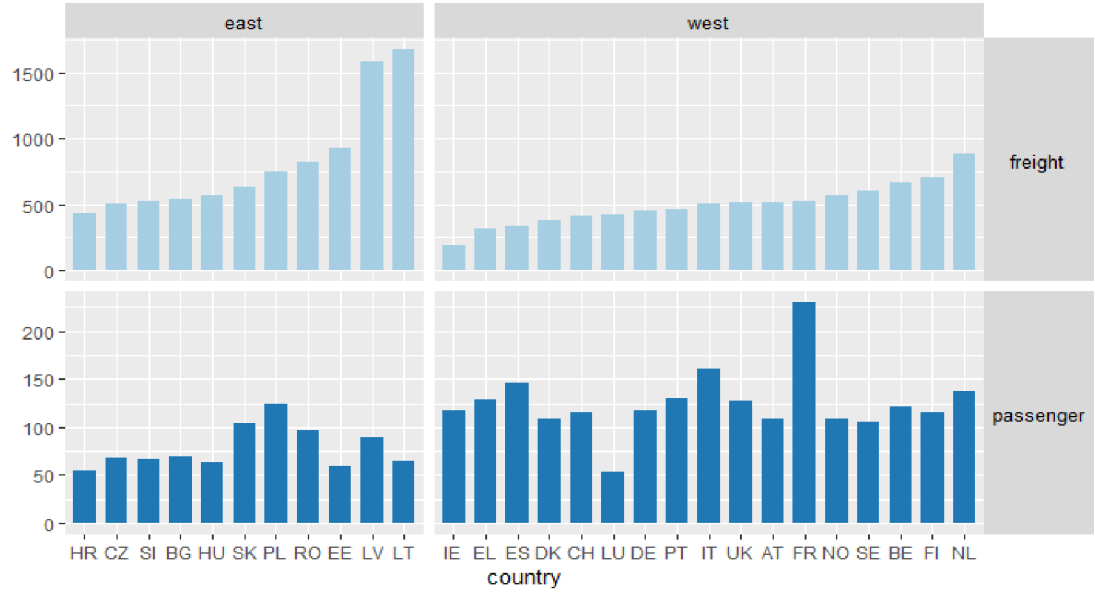
Source: Eurostat data + own processing

Another important feature expressing the performance of railway transport is so-called mean trainload. It is expressed as passenger-km divided by passenger train-km for passenger transport and as tonne-km divided by freight train-km for freight.

Figure 5.9 shows that mean trainload in freight transport is slightly higher in CEE countries (strongly higher in Latvia and Lithuania) than in WE countries. On the other hand, mean trainload in passenger transport is higher in Western Europe.

As there are many qualitative differences between the two groups of countries, the impact of the location (WE or CEE countries) will be further investigated. If a sufficient set of observations were available, a more precise division of the countries would be possible. The following two subsections describe the other two suggested divisions of the countries, including four and eight groups with particular similarities which are used later in the econometric analysis (using a dummy variable for each country is not possible due to the size of the data sample).

Figure 5.9: Mean trainload in passenger and freight transport (2016)



Source: Eurostat data + own processing

5.3.4 West, east, Baltic and small

In the paper Fitzová (2018), four groups of countries with similar features were identified. Their characteristics are presented in Table 5.1. This division represents a compromise for the required degree of accuracy and the limited number of observations.

Table 5.1: Means for basic characteristics of country groups (1999-2017)

*Group**	*Area (1,000 km²)*	*Track length (km)*	*Network density*	*Pkm (million)*	*Tkm (million)*	*Train-km (1000)*	*Passenger share (%)*
Western	**243**	10,921	45	**25,204**	18,347	**228,799**	81
Eastern	120	7,467	**62**	5,372	11,981	78,949	74
Baltic	58	1,594	27	**478**	11,403	11,710	**37**
Small	68	1,514	22	1,217	**358**	13,453	**89**

* *Western* countries comprise AT, BE, DE, DK, ES, FI, FR, CH, IT, NL, NO, PT, SE, and UK. *Eastern* include BG, CZ, HR, HU, PL, RO, and SK. *Baltic* is formed by EE, LT, and LV. *Small* represents small railway systems located on the periphery of the EU – EL, IE, and LU. *Pkm* denotes passenger-km, *Tkm* means tonne-km.

Source: Eurostat, UIC + own processing (based on Fitzová, 2018)

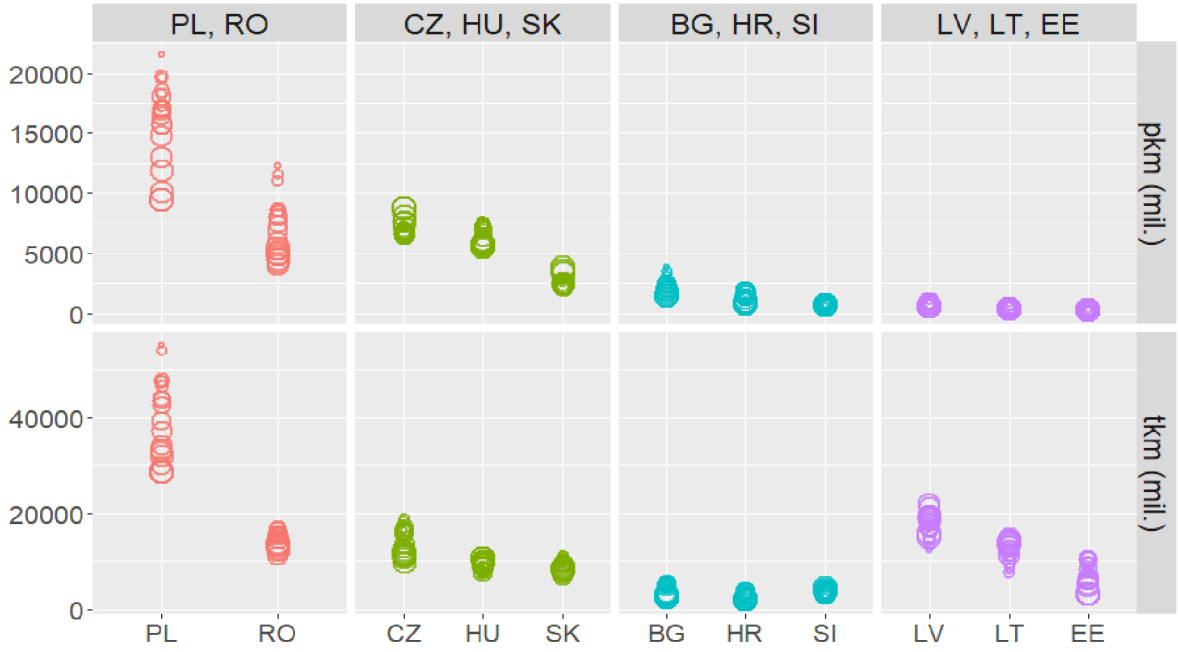
Six countries were earmarked into two extra groups (out of the CEE and WE groups mentioned above). The third group comprises Baltic states. Rail freight is strongly important there, and passenger rail transport is quite minor. The last group contains three small peripheral countries (LU, EL, IE) with minor rail freight.

5.3.5 Four CEE + four WE groups

If we had enough observations, we could divide the countries into more groups. Several groups of countries with particular similarities can be found among the CEE countries. The main common features include a similar historical development, size of the market, orientation of the railway industry, and geographical location. In Figure 5.10 and Figure 5.11, the larger the circle, the newer the value. The smallest circle corresponds to 1999, the largest circle to 2017.

Figure 5.10 depicts the performance both in the passenger (upper part) and freight (lower part) market in CEE countries. The first group contains the two largest countries – PL and RO (red circles). The second one comprises three countries with a similar geographical location, size and development since the 1990s – CZ, SK, and HU (green circles). Even though RO is much larger (three times) than CZ, its performance (in both sectors) is currently similar to CZ. The third group includes three countries on the Balkan peninsula – BG, HR and SI (cyan circles). Finally, the fourth part is represented by Baltic states (LV, LT, EE) which concern mostly on freight transport (violet circles). The figure reveals four possible groups of countries with similar characteristics inside the group of CEE countries.

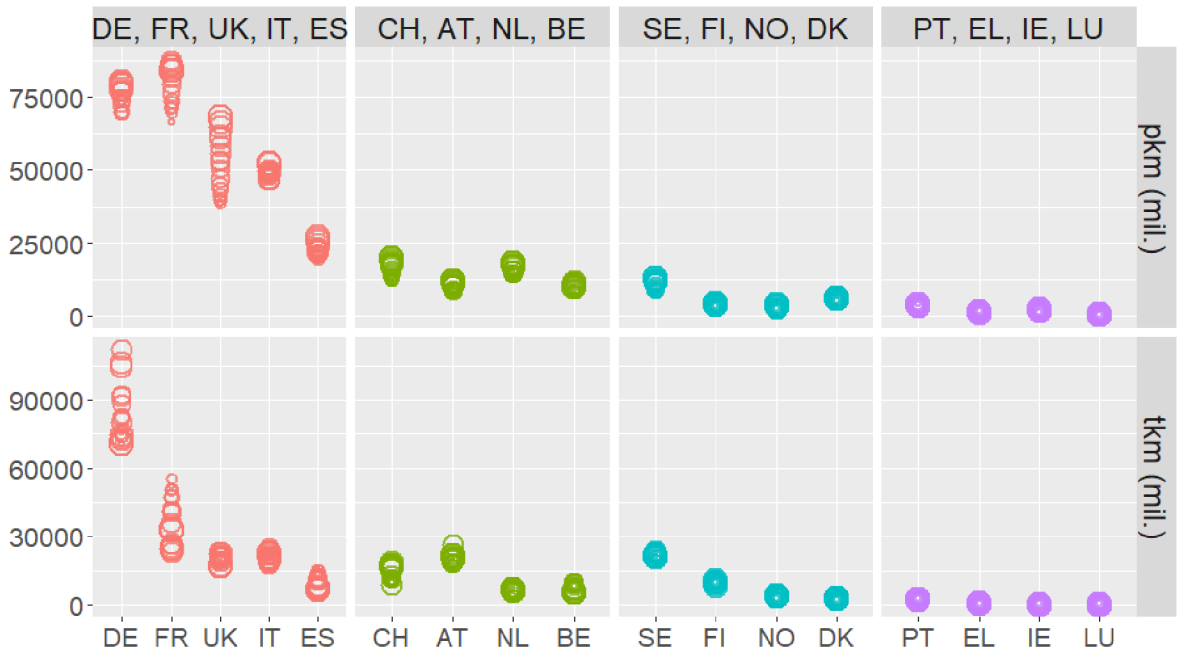
Figure 5.10: Railway performance development in CEE countries (1999–2017)



Source: UIC, EC, Eurostat + own processing

Figure 5.11 portrays performance in WE countries. The figure reveals four possible groups of countries with similar features in the group of WE countries. The first of them comprises the five largest countries – DE, FR, UK, IT, and ES (red circles) with very high performance in the passenger sector and also with a very large area. The second part contains much smaller countries, however, with relatively high performance and dense network – CH, AT, NL, and BE (green circles). The third is a group of northern European countries – SE, FI, NO, and DK (cyan circles). The last one is represented by smaller countries on the periphery of the EU – PT, EL, IE, and LU (violet circles) where rail freight is rather small.

Figure 5.11: Railway performance development in WE countries (1999–2017)



Source: UIC, EC, Eurostat + own processing

5.4 Implementation of the reforms

This section summarises the data concerning the implementation of the essential reform steps – see Table 5.2. The first column denotes countries; the second column indicates the form of vertical separation – i.e. full vertical separation, a holding company or an integrated form (with a separate body for essential functions). The third column contains the date of the separation of freight and passenger sector. The next two columns express the year of the first real entry of freight competition and passenger competition (open-access, competitive tendering),

respectively. The last three columns describe the existence of open-access competition de jure, de facto and also the existence of competitive tenders.

As we can see from Table 5.2, open-access competition in the freight sector is really widespread. Competitive tendering in passenger sector appears in 10 countries. However, open-access competition in the passenger sector with more than negligible market share is still not very common.

5.5 Summary

The railway industry is typical by hard availability of relevant data. Official data are usually at disposal with a significant delay, if ever. Another problem stems from the difference between the official date of implementation of a reform and its use in everyday practice. Thus, a prudent approach to data must be applied. Even if we had all the necessary data, the states are not homogenous so we must be very cautious before generalising any results. Further, the investigated countries show considerable differences which will be reflected in the following analysis.

Table 5.2: Implementation of the reforms (during 1999–2017)

country	vertical separation	horizontal separation	freight competition (entry)	passenger competition (entry)	open-access de jure	open-access de facto	competitive tenders
EAST				OA CT			
Bulgaria	2002–now	–	2005	– / –	N , INT	– , –	yes
Croatia	holding (2006)	–	2014	– / –	– , INT	– , –	
Czechia	2003–now	–	1995	2011 / –	N , INT	N , INT	
Estonia	holding (2009)	1997–now	–	– / –	N , INT	– , –	
Hungary	holding (2008), MÁV - VS (2008)	2008–now	2006	2007 / –	N , INT	N , –	
Latvia	holding (2010)	2008–now	2002	– / –	N , INT	N , –	
Lithuania	integrated	–	–	–/ –	N , INT	– , –	
Poland	holding (2001)	–	2003	2004 / 2005	N , INT	N	yes
Romania	1998–now	1998–now	2001	2005 / –	N , INT	– , –	
Slovakia	2002–now	2005–now	2006	2014 / –	N , INT	N , INT	
Slovenia	holding (2004)	–	2009	– / –	– , INT	– , –	
WEST				OA CT			
Austria	holding (2004) holding (2005-2013)	–	1999	2003 / –	N , INT	N	
Belgium	2014-now	–	2002	2010 / –	– , INT	– , INT	
Britain	1995–now	1996–now	1995	1994 / 1996	N , INT	N , INT	yes
Denmark	1998–now	2001–now	1997	– / 2003	– , INT	N	yes
Finland	1995–now	–	2012	– / –	– , INT	– , –	
France	1997–2015; holding (2015)	–	2006	2011 / –	– , INT	– , INT	
Germany	hold.(2000)	–	1995	1997 / 1997	N , INT	N , INT	yes
Greece	holding (2007)	–	2015	– / –	– , –	– , –	
Ireland	integrated	–	–	– / –	– , –	– , –	
Italy	holding (2000)	–	2000	2007 / –	N , INT	N , INT	yes
Luxembourg	integrated	–	–	– / –	N , INT	– , –	
Netherlands	2002–now	2001–now	1998	– / 1996	– , INT	– , –	yes
Norway	1997–now	2002–now	2008	– / 2006	– , INT	– , INT	yes
Portugal	1997–now	–	2008	– / 1999	– , INT	– , –	yes
Spain	2005–now	–	2007	2005 / –	– , INT	– , –	
Sweden	1995–now	2002–now	1992	2010 / 1996	N , INT	N , INT	yes
Switzerland	holding (2009)	–	1999	– / –	– , –	– , –	

OA means open-access, *CT* denotes competitive tendering, *N* is national, and *INT* international transport.

Source: IRG (2018), Velde et al. (2012), Cantos-Sánchez et al. (2010) + national railways' webpages + own processing

6 Results

This chapter presents the computed efficiency scores and the estimations of regression models which enable interpret the impacts of the European railway reforms. Efficiency analysis was at first conducted using the DEA (for different models and different variables). At first, the tobit model was employed with various forms of the variables describing the level of implementation of the reforms. Next, the one-step DEA analysis computing the efficiency scores and the impact of contextual variables simultaneously based on Simar and Wilson (2007) was applied. Finally, the SFA approach which also enables estimation of the efficiency scores as well as the impact of the control variables in one-step following the approach of Battese and Coelli (1995) was utilised.

The results were calculated and graphically displayed using *R* and its *Benchmarking* (Bogetoft and Otto, 2018), *frontier* (Coelli and Henningsen, 2013), *AER* (Kleiber and Zeileis, 2008), *plm* (Croissant and Millo, 2008), *rDEA* (Simm and Besstremyannaya, *2016*), *ggplot2* (Wickham, 2016), *rgdal* (Bivand, Keitt and Rowlingson, 2019), and *mapproj* (McIlroy, 2018) packages.

6.1 DEA efficiency scores

This section presents the computed efficiency scores gained from the DEA. First part describes inputs and outputs; follows computing of efficiency scores. Further, sources of wasting are analysed using the concept of slacks. Finally, technical progress in time is examined using the Malmquist index.

6.1.1 Outputs and inputs

Efficiency analysis was performed for various samples of countries and periods (due to unavailability of selected variables) using input-oriented DEA models – the performance of railways is often given by PSO thus the companies can try to lower their inputs rather than to influence the outputs. As mentioned in Coelli (1996), both the VRS input-oriented, as well as the output-oriented model, create the same frontier – the same set of efficient units. However, the produced efficiency scores may be different. The full sample covers 28 states and 19 years (1999–2017). In some cases, a model without Denmark and Netherlands, further without Norway and the UK is used.

The CCR and the BCC DEA models were employed in the first phase of the analysis. Table 6.1 shows descriptive statistics (mean, median, standard deviation, minimum, and maximum) for the model variables. Inputs comprise track length in kilometres, the number of employees expressed in full-time equivalent, the number of cars in passenger transport (passenger fleet), and the number of wagons in freight transport (freight fleet). Most of the authors uses passenger-km and tonne-km as outputs, some of them prefer train-km. Sometimes, a mixture of passenger-km and tonne-km is used – either in the form of a direct summation or some functional transformation of both variables which is not the case of this study. This thesis employs passenger-kilometres (pkm) and tonne-kilometres (tkm), both in millions of km, and further, passenger train-km and freight train-km (both in thousands), as two different types of outputs (which are used in different models for comparison).

Table 6.1: Descriptive input and output statistics

Variable	*Mean*	*Median*	*Standard deviation*	*Minimum*	*Maximum*
Inputs					
Track length (km)	7,909	3,881	8,644	274 (LU)	34,443 (DE)
Number of employees	42,501	22,838	54,853	2,978 (EE)	246,894 (DE)
Passenger fleet	4,084	2,038	5,267	195 (EE)	19,342 (DE)
Freight fleet	18,751	10,997	24,056	577 (IE)	104,439 (DE)
Outputs					
Passenger-km (mil.)	14,895	6,241	22,920	249 (EE)	82,196 (FR)
Tonne-km (mil.)	15,236	9,479	20,451	227 (IE)	101,398 (DE)
Passenger train-km (ths.)	118,879	59,342	172,678	3,664 (EE)	767,125 (DE)
Freight train-km (ths.)	29,954	14,624	44,097	957 (EE)	221,432 (DE)

Source: Own processing based on UIC and Eurostat

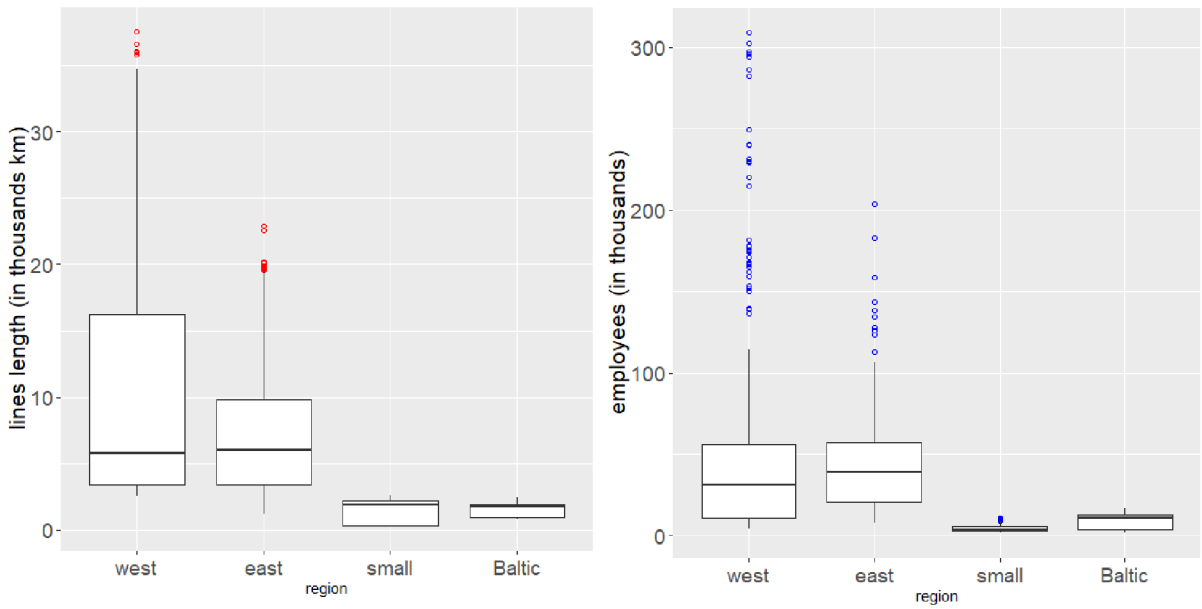
We can see quite a large variability in the data sample. However, it is mostly caused by the most significant outlier – Germany. The columns with the minimums and maximums primarily represent values for Germany (maximums), and Estonia (minimums). Without these two countries, standard deviations are much smaller. Country codes in brackets denote the country with the extreme value of the variable. Outliers will be formally tested later.

A more precise look at the inputs and outputs is beneficial. If we divide the countries into four groups (see section 5.3.4), the essence of the differences is more evident. The following three figures show boxplot diagrams for the inputs and outputs. Boxplot displays the distribution of

a variable. The central box encloses the middle 50 per cent of the data, i.e. it is bounded by the first and third quartiles. The "whiskers" extend from each end of the box for a range equal to 1.5 times the interquartile range. Observations outside that range are considered outliers and represented via circles. A line is drawn across the box at the median.

Figure 6.1 depicts the length of lines (the left part) for WE countries, CEE countries, small countries (comprising LU, EL, IE), and Baltic states, during 1999–2017 (all observations included). The difference between WE and CEE is mainly due to Germany and France (and further Spain, Italy, and the UK). The number of employees (the right part of Figure 6.1) is similar in both groups, WE and CEE countries.

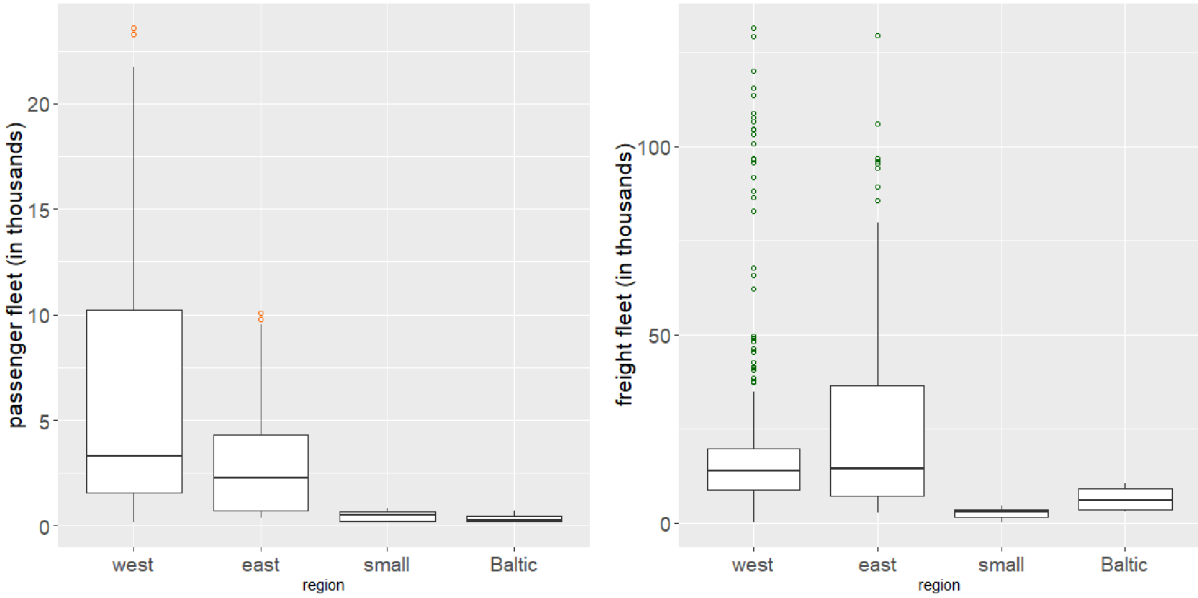
Figure 6.1: Length of lines and number of employees (1999–2017)



Source: Own processing

Passenger fleet (the left part of Figure 6.2) is more extensive in WE countries than in CEE countries while the opposite is true for freight fleet (the right part of Figure 6.2) – it is still probably an inheritance from the socialistic era. Median values can be considered similar for both variables.

Figure 6.2: Passenger fleet and freight fleet (1999–2017)

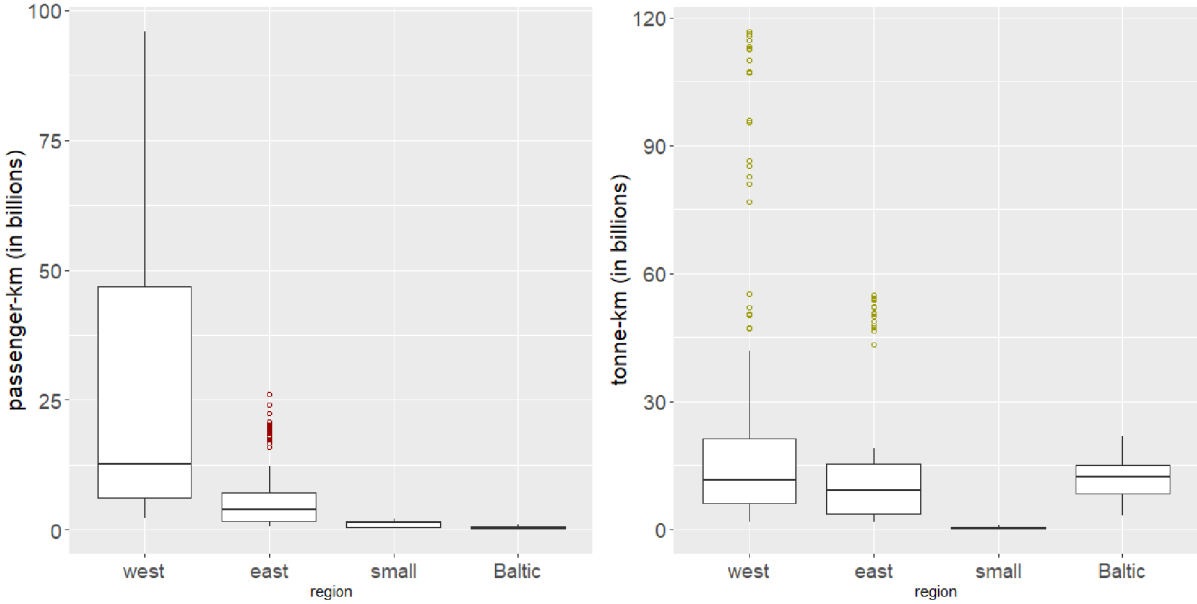


Source: Own processing

Figure 6.3 portrays the range of passenger-km and tonne-km which are used as outputs in the following analysis. WE countries are strongly oriented to the passenger segment of rail transport (see the left part of the figure). Rail freight performance is relatively comparable in WE countries, CE countries and even in Baltic countries while in states with small rail systems it is only negligible (see the right part of the figure).

As a result of this visual inspection, we can expect problems stemming from several outliers – especially Germany and small countries. Thus, the computations will be conducted for different samples of countries to ensure more reliability of the results.

Figure 6.3: Passenger-km and tonne-km (1999–2017)



Source: Own processing

6.1.2 Outliers detection

Outliers detection was carried out using the procedure described in Bogetoft and Otto (2011) in *R*. This approach omits $r = 1, 2, 3, \ldots, k$ units gradually from the sample and indicates the units which could be the most probable outliers. In our sample, two countries – Germany and France – are suspected to be outliers. This result was taken into account at further estimations.

6.1.3 Efficiency scores

This subsection contains the results of various DEA models. The scores were always computed under the CRS as well as the VRS assumption. The analysis was conducted for two types of outputs – (A) passenger-km and tonne-km at first, (B) for passenger train-km and freight train-km. Some years, countries and variables were gradually excluded according to the scheme in Table 6.2, so that six different compositions of the sample were used + one where the data is considered regardless the time dimension (as used e. g. in Asmild, 2009). This was done for all the four model specifications (CRS-A, VRS-A, CRS-B, VRS-B); thus 28 models were estimated. This procedure was repeated for a data sample without DE, and then without DE and FR.

Table 6.2: Analysed DEA models

I. CRS		II. VRS	
A. passenger-km, tonne-km	**B.** passenger train-km, freight train-km	**A.** passenger-km, tonne-km	**B.** passenger train-km, freight train-km
countries, variables		*period*	
1) all (28)		1999-2007	
2) without DK, NL		1999-2011	
3) without DK, NL, NO		1999-2014	
4) without DK, NL, NO, UK		1999-2017	
5) all, without freight fleet		1999-2015	
6) all, without freight fleet and NL		1999-2017	
7) cross-section without DK, NL, NO, UK		1999-2017	
Once again without potential outliers DE, FR			

Source: Own processing

The following Table 6.3 summarises the efficient DMUs for the estimated DEA models. Units, which are efficient under the CRS assumption, have to be efficient under the VRS assumption as well. Thus, columns with VRS models contain only those units which are efficient only under the VRS assumption. Models 1–6 were estimated for each year separately. Model 7 treated the data as a cross-section. The first column shows the number of the model (1–7) and the total number of observations (*n*).

Model 1 (all countries, 1999–2007) is not the best option as it contains quite old data. However, DK and NL can be included, and they are fully efficient (as well as EE) under both RTS specifications. AT, CH and SE (and also UK) are efficient only when train-km is regarded as the measure of performance. The total number of units efficient under the VRS assumption is high.

Model 2 (without DK, NL, 1999–2011) contains a bit newer information. It provides still a lot of efficient units under the VRS assumption. Fully efficient units are EE, FR, CH, SE, UK (and almost LV). DE, IE, LU, and NO do not produce the optimal level of production as they are efficient only under the VRS assumption (DE is too big, the others are too small). DE is efficient in both specifications A and B (under VRS).

Table 6.3: Efficient units in the analysed DEA models

Model	CRS-A	VRS-A	CRS-B	VRS-B
1) n = 252	DK, NL, EE efficient	13 efficient units (SE, LV, CH, UK, FR, IT, DE, IE, PL, LU)	AT, DK, CH, NL, SE (EE, UK) efficient	12 efficient units (DE, NO, FR, LU, IE)
2) n = 338	EE, FR, CH, SE, UK (LV) efficient	10 efficient units (NO, DE, IE, LU)	AT, DE, CH, SE, UK (NO) efficient	11 efficient units (EE, FR, IE, LU, SI)
3) n = 400	EE, FR, CH, SE, UK (LV) efficient	9 efficient units (DE, IE, LU) , PL 0.98	AT, DE, CH, SE, UK efficient	10 efficient units (EE, FR, IE, LU, SI)
4) n = 456	ES, FR, CH, SE (LV) efficient;	10 efficient units (EE, DE, IE, LU, IT), PL 0.98	AT, DE, CH, SE (ES) efficient	10 efficient units (EE, FR, IE, LU, SI)
5) n = 476	NL efficient	9 efficient units (DE, EE, CH, FR, LU, LV, SE, UK), PL 0.98	AT, CH, NL, SE (DE) efficient	9 efficient units (EE, LU, SI, UK)
6) n = 513	SE, CH, UK (EE) efficient	8 efficient units (FR, DE, LV, LU), PL 0.98	AT, CH, SE, UK (DE) efficient	8 efficient units (EE, LU, SI)
7) n = 456	No unit efficient in all periods (SE 0.96)	1 unit efficient in all periods (LU)	No unit efficient in all periods (SE 0.98)	1 unit efficient in all periods (LU)

Source: Own processing

Model 3 (without DK, NL, NO, 1999–2014) includes newer data than all the other above mentioned studies on this topic. Its results are very similar to model 2. However, there appears one extra nearly efficient unit – PL. Its average score is about 0.98. It is probably too big for the CRS assumption.

Model 4 (without DK, NL, NO, UK, 1999–2017) contains the most up-to-date data. However, four countries are missing. ES is efficient in both model specifications A and B. Other results are very similar to model 3.

Model 5 (without freight fleet, 1999–2015) gives the only one unit which is fully efficient in all the specifications during the whole period – NL. Including the input freight fleet seems to be crucial.

Model 6 (without freight fleet, without NL, 1999–2017) which is the same as model 5 only without NL, brings similar results as the early mentioned models. It may indicate that NL is an outlier or that there is some problem with the NL data. Thus, NL (DK as well) will not be included in the following computations.

Model 7 (cross-section from model 4) does not contain any DMU efficient during the whole period. However, the units which create the frontier are similar to those gained from the previous models – especially EE, LV, CH, SE. Among the other observations forming the frontier are FR (2012, 2016), ES (2015, 2017), IT (2016), and BE (2017). It seems that the role of the units is changing in time. This model without the time dimension is not probably the most appropriate candidate.

Considering the above results and the fact that an up-to-date analysis is desirable, model 4 and model 3 (older data than model 4, but the UK) seem to be the best choice for further analysis. Both RTS specifications, as well as both output measures, provide important but slightly different conclusions so that all the four specifications are worth investigating.

The following Table 6.4 shows the Spearman correlation between the rankings from different model specifications. The scores from the models with the specification A (pkm and tkm as outputs) under the CRS and VRS assumption reach correlation around 0.80 while the specification B (train-km as outputs) exhibit much higher correlation – around 0.90. Further, the results under the CRS assumption with a different type of outputs (A, B) have a correlation around 0.70 and under the VRS specification around 0.80, regardless of the data sample.

Table 6.4: Spearman correlation of the scores from 2-step DEA

Model	CRS-A / VRS-A	CRS-B / VRS-B	CRS-A / CRS-B	VRS-A / VRS-B
1	0.80	0.88	0.74	0.83
2	0.84	0.92	0.76	0.84
3	0.80	0.95	0.75	0.81
4	0.82	0.93	0.74	0.86
5	0.82	0.92	0.71	0.79
6	0.81	0.93	0.71	0.74
7	0.73	0.91	0.77	0.86

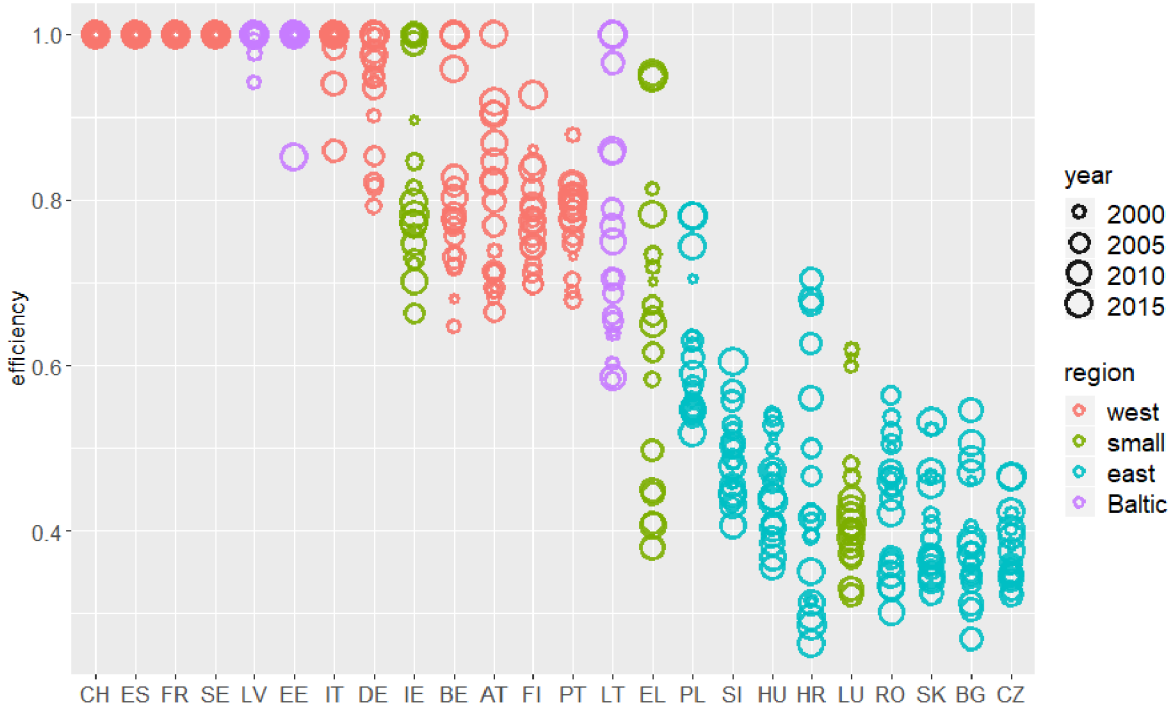
Source: Own processing

The scores obtained under various assumptions from DEA are very similar. A comparison between the results from DEA and SFA follows further (see section 6.2).

Figure 6.4 depicts the development of the computed efficiency scores for particular countries based on the CRS-A model 4 during 1999–2017. Countries are ordered according to their average scores. The larger the size of the circle, the newer the value.

WE countries (red circles) and Baltic states (magenta circles) form the upper part of the "frontier" while CEE countries (cyan circles) generate the lower part of the "frontier". Small WE countries (green circles), EL and LU, have the scores more like CEE countries (IE performs worse in other models).

Figure 6.4: Efficiency scores, CRS-A (pkm, tkm), model 4 (1999–2017)



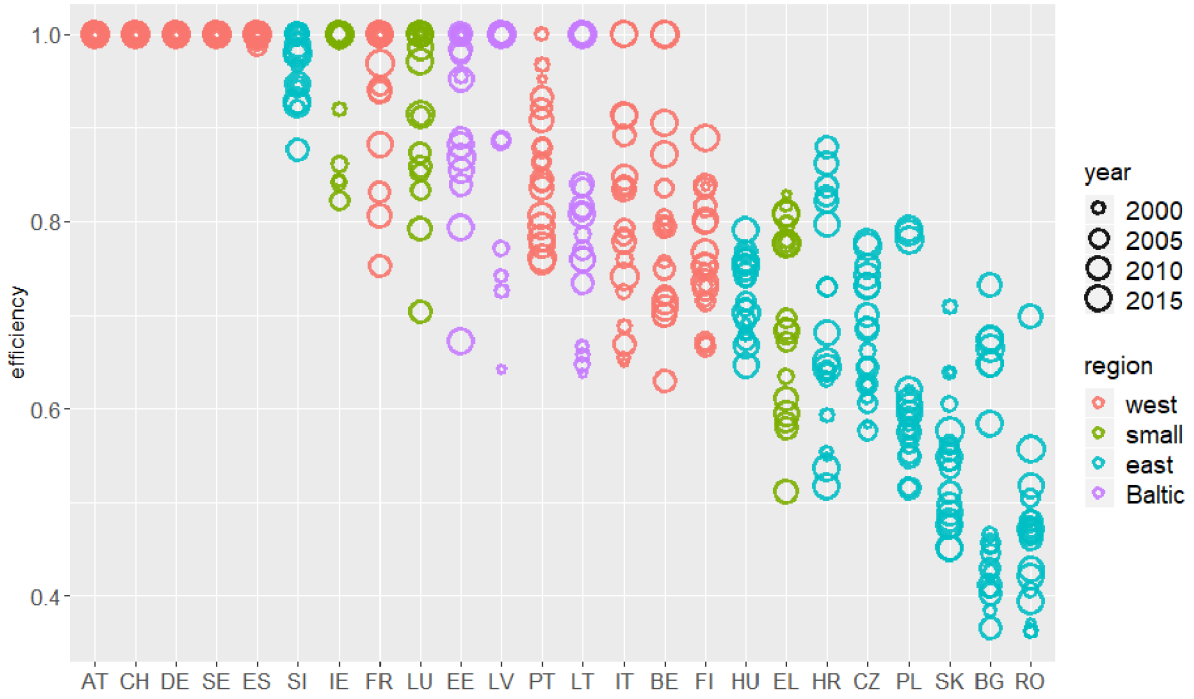
Source: Own computations

Some countries are very efficient at the whole time (CH, ES, FR, SE, and almost LV and EE). In some countries, there are significant changes in efficiency (in both directions), usually due to a substantial decline of staff during some crisis or due to other dramatic changes in the industry (EL, HR, LT, IE). The graph for the VRS-A model 4 looks similarly except for the fact that much more units are fully efficient.

Figure 6.5 portrays the same as the previous figure but for passenger train-km and freight train-km as output (specification B). The most notable change was made by SI, which is now very efficient. Further, LU has moved significantly closer to the frontier, DE and AT are now fully efficient. However, IT performs much worse (as the trains here are probably full). Finally, CZ is not any more the worst performing country (with the scores around 0.4) – it has moved four

positions forward. Its scores are now about 0.7 (which indicates not full trains), and the scores are getting better in time.

Figure 6.5: Efficiency scores, CRS-B (train-km), model 4 (1999–2017)



Source: Own computations

What is better – *pkm* and *tkm* or *passenger train-km* and *freight train-km* as a measure of performance? Some authors claim that train-km are more suitable as they represent the real performance of railways and that considering *pkm* and *tkm* as a measure could mean crowded, uncomfortable trains. However, it is more the case of developing countries (e. g. the famous pictures of the trains from India or Egypt). On the other hand, high values of train-km without any passengers or load would not be desirable. It could be solved using variables describing mean trainload in the regressions. Mean trainload is associated with the length of train and train type – e. g. long-distance versus branch line passenger trains; for freight, it depends very much on the commodity (coal versus containers). So that mean trainload reflects much more than just how full the train is. Not to omit any essential information, both types of output variables will be considered in further analysis.

And which type of RTS shall we use – constant (CRS) or variable (VRS)? The concept of scale efficiency, which is the ratio of both scores, can help to decide. Table 6.5 shows the average

efficiency scores for both model 4 CRS-A and VRS-A specification. Further, it shows the SE ratio. Low values of SE indicate that the country does not exhibit CRS. It is especially the case of Poland, Slovenia and Luxembourg and it also seems important for other four countries (IE, PT, EL, HR). However, the results of Poland, Slovenia and Luxembourg may be influenced by the overvaluation of VRS, which happens due to the minimum input or maximum output[3] (Huber et al., 2019).

Table 6.5: Average efficiency scores and SE ratio for model 4, specification A

Rank	Country	CRS	VRS	SE	Rank	Country	CRS	VRS	SE
1	France	1	1	1	13	Portugal	0.776	0.970	0.801
1	Spain	1	1	1	14	Lithuania	0.760	0.824	0.923
1	Switzerland	1	1	1	15	Greece	0.651	0.886	0.735
1	Sweden	1	1	1	16	Poland	0.610	0.986	0.619
5	Latvia	0.995	1	0.995	17	Slovenia	0.488	0.801	0.609
6	Estonia	0.992	1	0.992	18	Hungary	0.449	0.472	0.953
7	Italy	0.989	0.995	0.993	19	Croatia	0.441	0.635	0.695
8	Germany	0.941	1	0.941	20	Luxembourg	0.433	1	0.433
9	Ireland	0.842	1	0.842	21	Romania	0.432	0.441	0.979
10	Belgium	0.803	0.819	0.981	22	Slovakia	0.404	0.438	0.921
11	Austria	0.787	0.831	0.947	23	Bulgaria	0.389	0.494	0.787
12	Finland	0.778	0.823	0.946	24	Czech Republic	0.378	0.409	0.926

Source: Own computations

Table 6.6 shows the same as the previous table but for train-km as output (specification B). The problem with the RTS is much less – the SE values are higher (the minimum is now 0.770). It further shows the most significant changes (in green) of the specification B versus the specification A – SI, AT and CZ move significantly up; IT moves down. SI is even nearly fully efficient (corresponding changes in Table 6.5 in green as well).

Efficiency analysis without the potential outliers DE and FR did not bring any significant changes in comparison with the results gained above. In specification A, excluding only DE as

[3] If we have more inputs and more outputs and we define efficiency as Pareto-optimal efficiency, we determine the unit with the smallest input or the biggest output (in the input-oriented model) as efficient in the VRS DEA model. It is simply a consequence of the fact that corner points cannot be expressed as a convex combination of other points.

well as excluding both DE and FR caused only negligible changes of the scores, thus nearly no changes in the ranking. In specification B, excluding DE (or DE and FR) moved CZ two ranks up (above EL and HR), further changes were negligible. Thus, we can conclude that the units can stay in the dataset.

Table 6.6: Average efficiency scores and SE ratio for model 4, specification B

Rank	Country	CRS	VRS	SE	Rank	Country	CRS	VRS	SE
1	Austria	1	1	1	13	Lithuania	0.817	0.849	0.962
1	Germany	1	1	1	14	Italy	0.806	0.870	0.927
1	Switzerland	1	1	1	15	Belgium	0.788	0.800	0.985
1	Sweden	1	1	1	16	Finland	0.762	0.798	0.955
5	Spain	0.999	1	0.999	17	Hungary	0.720	0.732	0.983
6	Slovenia	0.967	0.996	0.971	18	Greece	0.706	0.917	0.770
7	Ireland	0.962	1	0.962	19	Croatia	0.690	0.770	0.897
8	France	0.951	1	0.951	20	Czech Republic	0.672	0.678	0.992
9	Luxembourg	0.931	1	0.931	21	Poland	0.610	0.778	0.784
10	Estonia	0.930	1	0.930	22	Slovakia	0.542	0.570	0.951
11	Latvia	0.929	0.945	0.983	23	Bulgaria	0.510	0.574	0.888
12	Portugal	0.861	0.964	0.894	24	Romania	0.462	0.473	0.977

Source: Own computations

6.1.4 Bootstrap test of RTS

The bootstrap method was employed for the statistical test of the type of returns to scale. The null hypothesis was CRS, and the alternative was VRS. The test is described in the methodology chapter (section 4.3.9). The gained p-values for 1000 replications are between 0.28 and 0.54 for individual years. Thus, we cannot reject the null hypothesis of CRS on any conventional levels of significance. However, the following analyses will be done for both types of RTS, not to neglect any essential features of the investigated issue.

6.1.5 Prevailing RTS

According to Zhu (2014), it is possible to determine the prevailing types of RTS for each DMU. This is based on the sum of the optimal lambdas gained from the optimization process. If the sum is equal to one, the DMU exhibits CRS. If the sum is less than one, increasing returns to scale (IRS) prevails. If the sum is greater than one, decreasing returns to scale (DRS) prevails.

The sum is different for each linear program (for each year), so that a commented summary may be more useful than 19 numbers for each country. The sum is equal to one for the countries which are efficient under the CRS assumption – ES, FR, CH, SE, LV, mostly EE, IT, and LT. It is greater than one for companies with prevailing DRS – only DE and PL (with the exceptions when DE was efficient and the sum was equal to one). The companies are probably too big. The sum of the lambdas is less than one (which means prevailing IRS) for the rest of the countries. The sum is very small (0.01-0.3) for LU, EL, IE, PT, HR, BG, and SI; it is around 0.3-0.6 for AT, BE, FI, HU, and SK (except for the case when BE and AT were efficient and the sum was equal to one); it is close to one for CZ and RO.

6.1.6 Analysis of slacks

This section analyses redundant inputs of the inefficient units using the concept of slacks (for more details, see part 4.3.8). The computed slacks show the excess amounts of particular inputs (as an input-oriented model was applied) besides the necessity for a radial lowering of all inputs represented by the efficiency scores – see Table 6.7. For clarity, the information is presented in a condensed form representing more than 400 values.

The first two columns show the range of the computed efficiency during 1999–2017 and the number of years when the unit was fully efficient, respectively. The next four columns express the size of the slacks of particular input variables.

Table 6.7: Slacks for inputs – model 4 with CRS, specification A

Country	Efficiency	Fully efficient	Lines length	Staff	Passenger fleet	Freight fleet
West						
Austria	0.68–1	2x	0	large till 2011, then 0	0	large
Belgium	0.64–1	2x	0	large till 2015, then 0	small or 0	small till 2008, then growing,
Germany	0.79–1	7x	0	medium till 2011, then 0	0	0 till 2004 and since 2012
Finland	0.69–0.92		medium	large till 2010, then 0	0	medium
France	1	19x	0	0	0	0
Italy	1	16x	0	0	0	0, 2008–2011 large
Portugal	0.66–0.87		low	low	low	low
Spain	1	19x	0	0	0	0
Sweden	1	19x	0	0	0	0
Switzerland	1	19x	0	0	0	0
Small						
Greece	0.40–0.95		medium	large till 2006, then 0	0 till 2006, then medium	medium
Ireland	0.66–1					
Luxembourg	0.32–0.61		0	medium	0	medium
Baltic						
Estonia	0.85–1	18x	0	0	0	0 or small
Latvia	0.94–1	15x	0 or medium	0 (or large)	0 or small	0
Lithuania	0.58–1	3x	0	large till 2007, then 0	0 or low	medium
East						
Bulgaria	0.26–0.54		0 or small	large	0	large till 2014, then 0
Czech Republic	0.32–0.46		0	large till 2009, then 0	0 till 2009, then large	small
Croatia	0.26–0.70		0 till 2006, then medium	large till 2013, then small	0	large till 2011, then small
Hungary	0.37–0.53		0 till 2008, then medium	medium till 2007, then small	0	medium till 2003, then 0
Poland	0.54–0.78		0 or small	large till 2009, then 0	0	large
Romania	0.33–0.56		small	large	0	large, declining
Slovenia	0.43–0.56		small	large till 2009	0 or low	large till 2009, then low
Slovakia	0.32–0.53		0	medium till 2011, then 0	0	medium

Source: Own processing

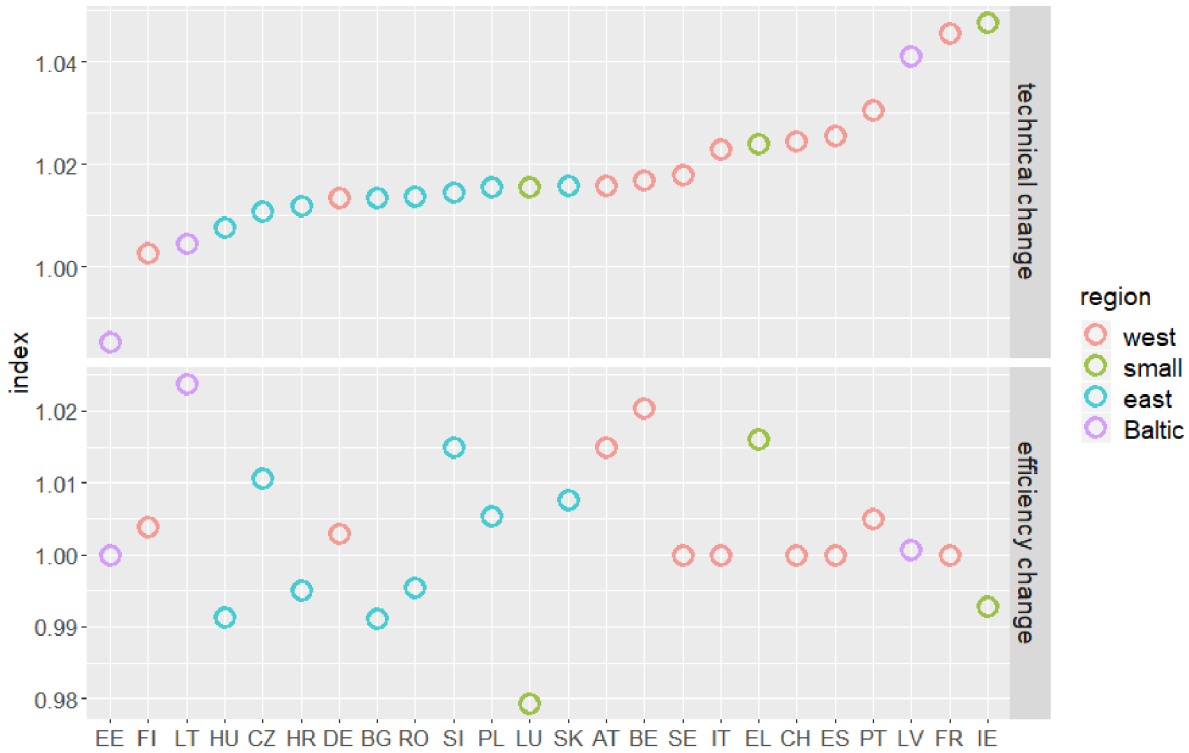
Neither lines length nor passenger fleet represented a problem as the slacks were mostly small or zero. However, the slacks for the number of employees (staff) and freight fleet were quite large for most countries and most years (except for the efficient units, of course). The trend for those problematic variables was good, although not fast enough. The economic crisis during 2008–2009 has probably contributed to the positive development of the slacks for employees (significantly declining number of staff). The size of the slacks for freight fleet began to decline significantly later, after 2010. Especially, freight fleet in post-communist CEE countries seemed to be very high in some cases, but this often represented a large number of wagons as a remanent from the communist era. This fact may have contributed to the low scores of efficiency of CEE countries. Slacks for the CRS specification B and both VRS specification A and B express similar tendencies.

6.1.7 Malmquist index

This part decomposes efficiency changes in time into two components – a change in the relative efficiency of the unit relative to the other units and a change of the frontier due to changes in technology (more details in part 4.3.10). This procedure was introduced by Malmquist (1953) and later reformulated using the DEA models by Färe et al. (1994). The following results are based on the CRS DEA model, specification A, other specifications provide very similar results.

Figure 6.6 depicts the decomposition of efficiency in time for individual countries. The upper part shows the technical change; the lower part catches the relative change in efficiency in accordance with the definitions caught by equations (26) and (25) in 4.3.10. Both variables are expressed in the form of index so that value higher than one means growth and value lower than one means decline of the variable. The presented values are the average values for the whole period. Countries are arranged according to the technical change index.

Figure 6.6: Average technical and efficiency change using the Malmquist index



Source: Own computations

All the countries except for Estonia went through a positive change in technology during the investigated period. CEE countries (cyan circles) exhibit lower change than WE (red circles) countries (except Germany and Finland). The average change is about 2% per year. Relative change in efficiency seems to be completely uncorrelated with the technical change (correlation is -0.13 and is not statistically significant). There are four CEE countries (HU, HR, BG, RO) and only two WE countries (LU, IE) with the value slightly less than 1. The average relative change in efficiency is 0.3%.

Nearly all the countries move their frontier further due to better technology during the whole period where WE countries move it faster. If CEE countries want to perform better, they have to try hard to get closer to the frontier as well as improve their available technology.

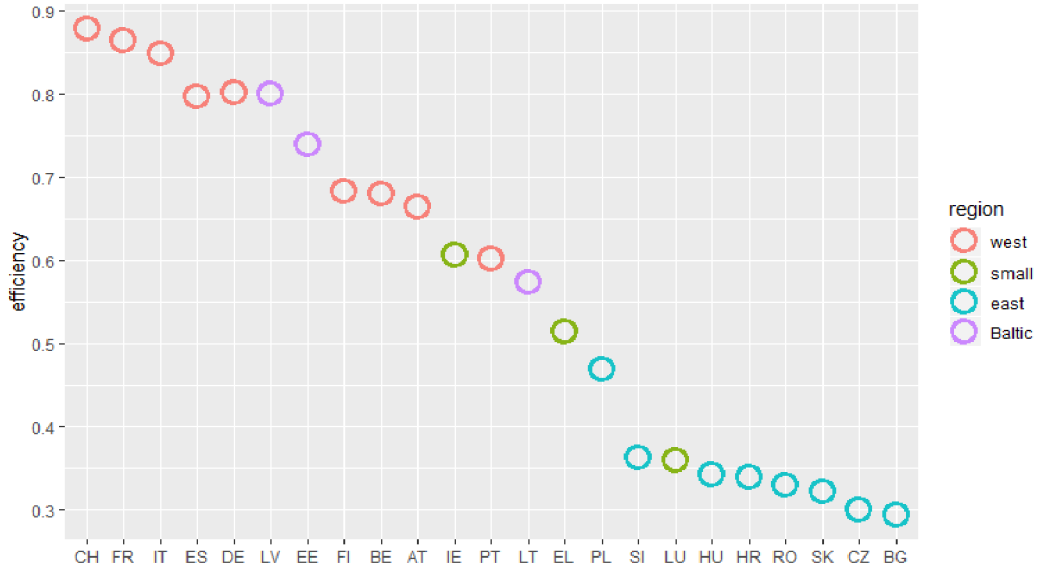
6.1.8 One-step DEA approach

The one-step approach (computing efficiency scores and the impact of contextual variables simultaneously) brings efficiency scores with a very similar ranking of the countries as the two-stage approach. These scores are lower because this approach includes the impact of contextual

variables on inefficiency and simultaneously estimates their impact on production (results with different contextual variables are very similar). However, it is not possible to compare these two different measures of efficiency due to various underlying assumptions of the models. Further, this approach does not enable to incorporate a panel data structure in the estimations; including dummies for individual countries was not possible due to the insufficient number of observations. Thus, these facts must be taken into account when evaluating the results.

Figure 6.7 illustrates the average scores (1999–2017) based on model 4 using CRS A specification. Again, WE countries perform much better than CEE countries; Baltic states are still more like WE countries while the group of small countries performs more like CEE countries. Only minor differences in the ranking of the states are apparent in comparison with the previous approach.

Figure 6.7: Average CRS scores from the one-step DEA approach[4]



Source: Own computations

[4] Only for illustration; it includes these explanatory variables: vertical separation, horizontal separation, interval competition dummies, 4 regional dummies, and mean train load; results with different explanatory variables are qualitatively similar.

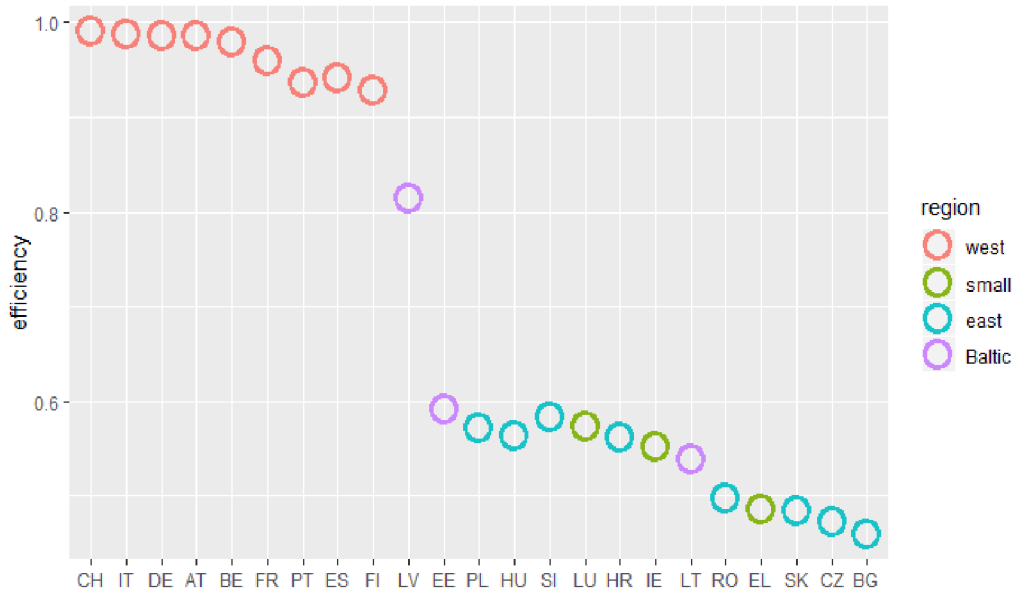
6.2 SFA efficiency scores

This section presents the scores from the SFA, including both input variables as well as contextual variables (for more details see the methodology chapter, section 4.4.3). The following estimations are based on equation (52) which consists in direct inclusion of the observable contextual variables into the stochastic component. The second approach based on equation (51) where contextual variables are incorporated directly into the production function was not possible to employ due to problems with the convergence of the solution.

Estimations were carried out for the Cobb-Douglas production function and the translog production function. As we have two output variables, a transformation using the stochastic distance function concept was applied (for more details see the methodology chapter, section 4.4.2).

Figure 6.8 shows the average efficiency scores (2002–2017) from the one-step SFA approach using the Cobb-Douglas production function.

Figure 6.8: Average scores from the one-step SFA (Cobb-Douglas)[5]



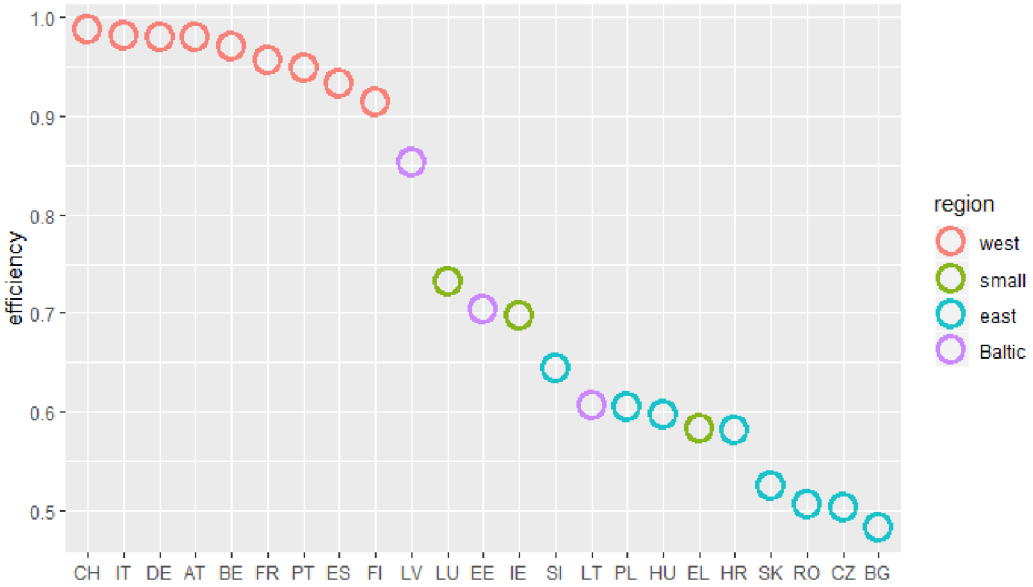
Source: Own computations

[5] Only for illustration; it includes these explanatory variables: vertical separation, horizontal separation, competition dummies, 4 regional dummies, and mean train load; results with different explanatory variables are qualitatively similar (more details in section 6.3.6).

The difference between the group of Western European countries and the other states is much bigger than in the previous one-step DEA approach. Small countries as well as Baltic states are ranked significantly lower.

Figure 6.9 shows the average scores (2002–2017) from the one-step SFA approach using the translog production function. The results are quite similar to those with the Cobb-Douglas production function. However, the jump between the scores of the WE countries and the other states is not so significant. Further, small countries, LU and IE have a noticeably better ranking than all CEE countries, and also EL performs much better. The results suggest that interactions between the inputs and the outputs in the production process are significant.

Figure 6.9: Average scores from the one-step SFA (translog)[6]



Source: Own computations

The following Table 6.8 shows the Spearman correlation of the rankings obtained from various methods. The same set of explanatory variables as in the previous three figures was used in all the one-step models.

[6] Only for illustration; it includes all linear and quadratic terms and selected cross terms in the production function; further these explanatory variables: vertical separation, horizontal separation, competition dummies, 4 regional dummies, and mean train load; results with different explanatory variables are qualitatively similar (more details in section 6.3.6).

We can see that the scores from obtained with the same method under different assumptions are very similar – the correlations for the SFA and the one-step DEA are 0.91 and 0.94 respectively. However, the results from different 1-step methods are much less correlated – 0.61and 0.51 for the 1-step DEA CRS and the SFA, and the 1-step DEA VRS and the SFA, respectively. It is not possible to compare the results for the 1-step and 2-step DEA directly as the 2-step approach includes a set of explanatory variables while the 1-step approach does not. However, the correlations are quite high – 0.71 for CRS and 0.84 for VRS assumption.

Table 6.8: Spearman correlation for different methods

Method, model	Correlation
SFA CD / SFA Translog	0.91
1-step DEA CRS A / 1-step DEA VRS A	0.94
1-step DEA CRS A / SFA Translog	0.61
1-step DEA VRS A / SFA Translog	0.51
1-step DEA CRS A / 2-step DEA CRS A	0.71
1-step DEA VRS A / 2-step DEA VRS A	0.84

6.3 Regression analysis

This section investigates the relationship between the gained efficiency scores and several reform and control variables. At first, a common approach employing two-limit tobit regression was applied in this (second) phase of the analysis.

6.3.1 Explained variable

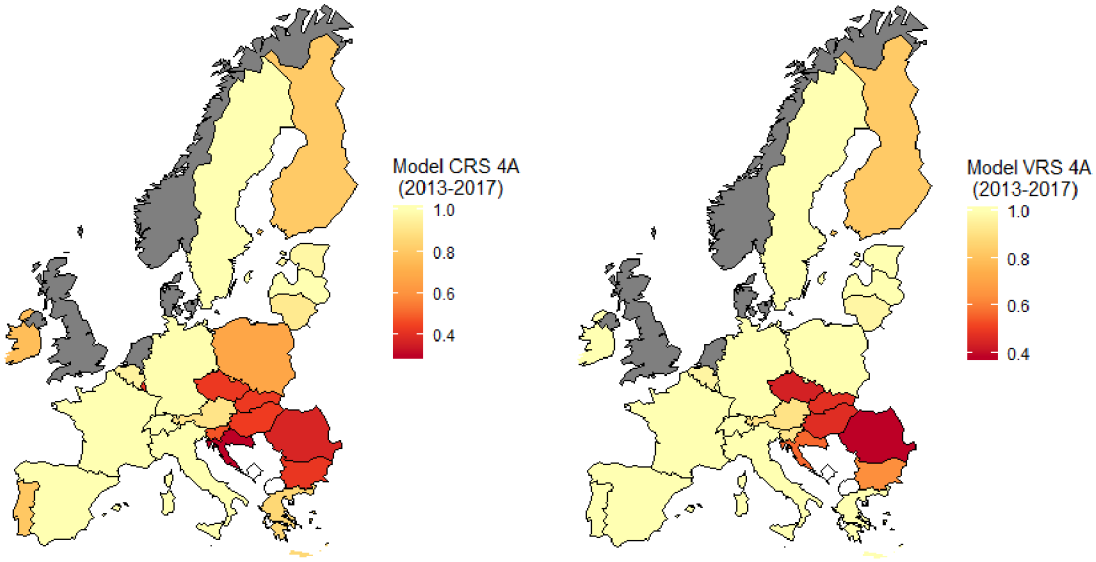
Efficiency scores from the DEA, both under the CRS and VRS assumption, with two types of outputs (specification A and B) were analysed as an explained variable. The following maps show the spatial distribution of the efficiency levels under various assumptions[7].

There are more efficient units in the VRS – A than in the CRS – A model, which represents the main difference. Further, small railway systems like Luxembourg, Ireland, Portugal or Slovenia achieve significantly better results under the VRS assumption, which captures their situation

[7] Only one model (model 4) was selected as an illustration of the main differences.

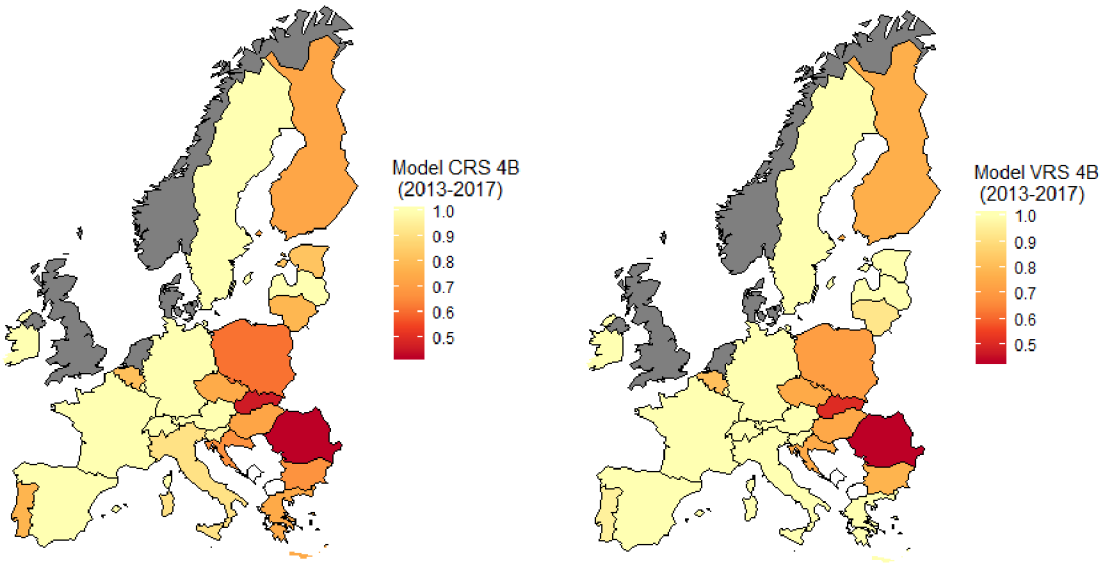
better. Of course, the scores from the VRS model are always higher or the same as from the CRS model (by definition) – see Figure 6.10.

Figure 6.10: Efficiency scores CRS 4A (left), VRS 4A (right), average 2013–2017



Source: Own processing

Figure 6.11: Efficiency scores CRS 4B (left), VRS 4B (right), average 2013–2017



Source: Own processing

Figure 6.11 enables comparison of the results under the specification A (passenger-km and tonne-km as outputs) mentioned above and the specification B (train-km as outputs). As was mentioned earlier, specification B is more favourable especially for Slovenia, Luxembourg, the

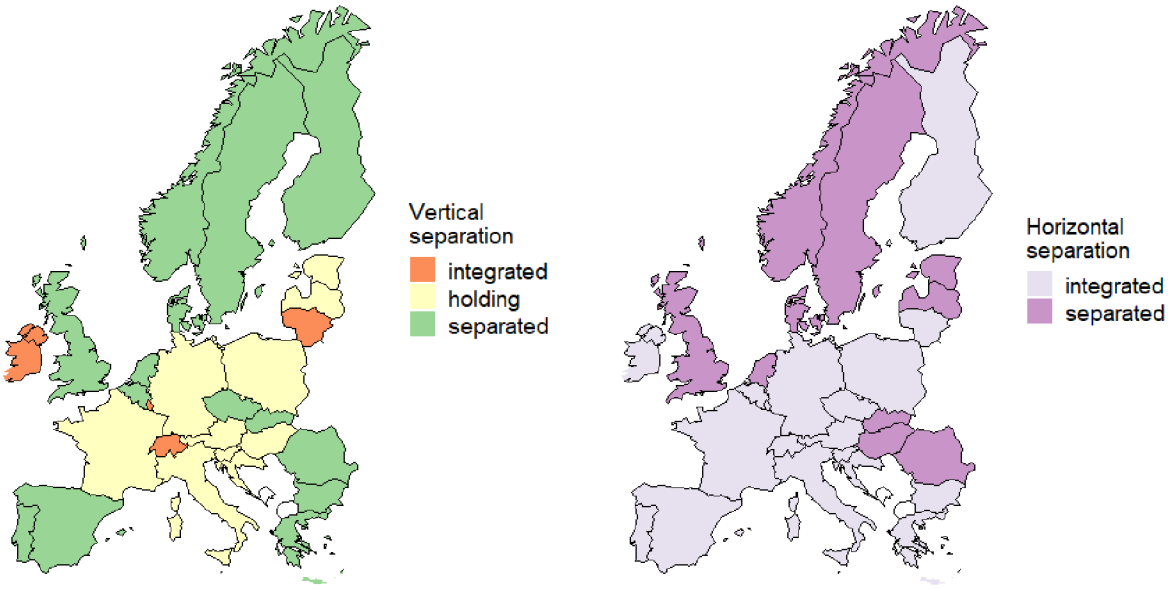
Czech Republic, and Croatia. The results from other models (and even methods), including the missing countries, are very similar – the missing countries (DK, NL, NO, UK) are nearly always fully efficient, but the period is much less up-to-date.

6.3.2 Reform variables

This section presents the current situation of the implementation of the main reforms – vertical separation, horizontal separation and competition implementation. This information serves for the construction of the fundamental explanatory variables for the linear regression model.

The left part of Figure 6.12 relates to vertical separation – whether a country has carried out a complete institutional separation of the infrastructure manager and the incumbent operator. We can see that most of the countries have just undergone it (green states). However, there are many countries in the form of a holding company (accounting and division separation of the infrastructure manager and operations into detached departments). Further, some countries remain integrated (with a separate body for essential functions) (European Commission, 2018). This variable is employed in the form of dummies for the particular degrees of separation (only two of them can be included).

Figure 6.12: Vertical and horizontal separation in Europe (2017)



Source: Own processing

The right part of Figure 6.12 describes horizontal separation – a complete institutional separation of the freight and passenger operations of the national incumbent operator. As it is

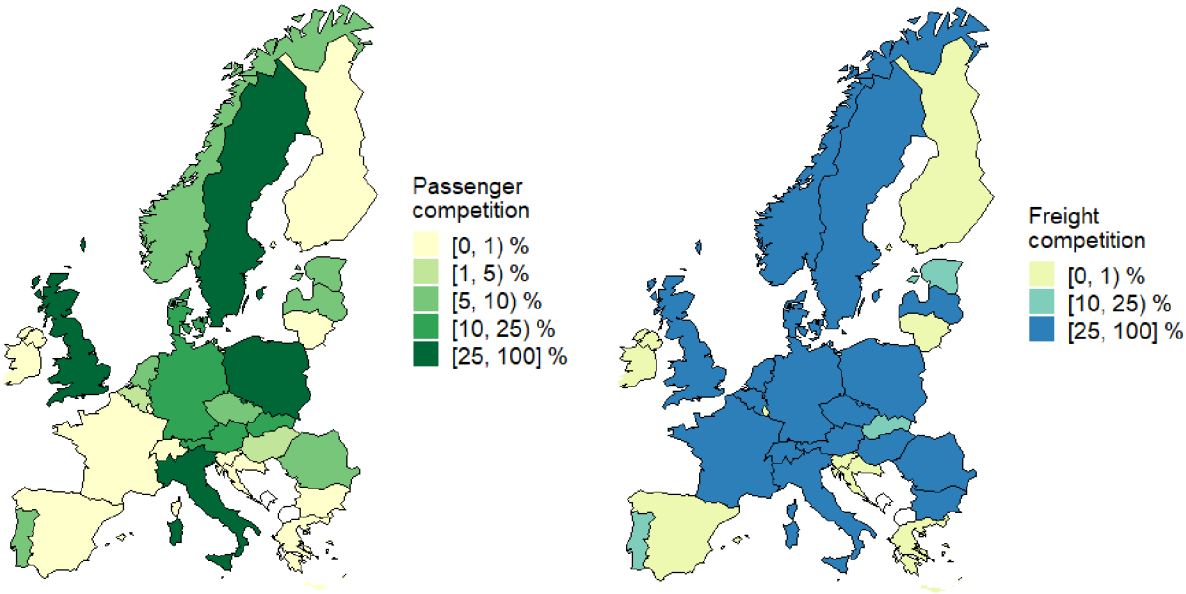
clear from the figure, most of the countries remain horizontally integrated in 2017. This variable is used in the form of a dummy variable where 1 means horizontal separation.

The existing papers on railway efficiency usually use only official dates of competition implementation or the date of the first entry. It is not the best option as at least some significant level of competition may be necessary to induce some positive effects. Thus, special competition variables have been created to capture the level of competition in individual countries. On the other hand, even a threat of competition could influence the environment.

Figure 6.13 depicts competition implementation in individual countries. The exact market shares are not published; they are only estimated. The correct percentage values are not relevant rather than the fact whether competition is rare, slight, common or very strong. Thus, interval indices based on surveys conducted by the EC and using other national sources were constructed to catch different levels of competition in particular countries. They express the market share of non-incumbent operators, irrespective whether this share was achieved by tendering or open-access. There are five intervals for each segment of the market. The intervals were set to cover the whole range of competition in the investigated countries and periods reasonably.

Competition in the passenger segment of railway market is depicted in the left part of Figure 6.13. It depicts five levels: [0, 1)%; [1, 5)%; [5, 10)%, [10, 25)%; [25, 100]%. The darker the green colour, the stronger competition appears. As it is clear from the map, competition is, in fact, present in Great Britain, Italy and Sweden. The dark colour of Poland is a bit confusing. High market share of the new entrants is due to the fact that regional services are operated by new local companies formed by regional authorities (22% of whole market share) and by Przewozy Regionalne (also 22%), a company that stems from the incumbent but was municipalised by regional authorities in 2008 and ceased to have ownership relations with the incumbent (IRG, 2018). This fact was consulted with railway experts from Poland, and the values were corrected to express the situation better. Further in Italy, there is a number of franchises where the winner is a subsidiary of FS (Italian State Railways) plus the regional operator rather than a true new entrant. Thus, the level of competition may not be so high in fact, as it seems to be according to the EC methodology.

Figure 6.13: Competition in Europe (2017)



Source: Own processing

The right part of Figure 6.13 portrays competition in rail freight using the same five levels. The darker the blue colour, the stronger competition exists. The second and the third level is missing in the data from 2017. However, it appears in the previous years. As the figure is quite dark blue, it is clear that competition in the rail freight market is now prevailing. The highest values are slightly below 70% (BG, RO). Competition is still missing in several countries (ES, IE, SI, HR, EL, LT, FI).

Table 6.9 shows descriptive statistics of the explained variable (model 4, 1999–2017) and explanatory reform variables. Competition indices are summarised in the condensed form 1–5 (for particular levels) but are used as dummies in the model estimations. Further, these dummies appear in two ways – at first, a dummy variable expressing a particular interval; second – a dummy variable representing "not less than" (more details further). Finally, four dummy variables describing the entry of competition were used – freight entry, competitive tendering entry (CT entry), open access entry (OA entry), and OA head-on entry[8].

[8] *OA entry* means the existence of an open access operator. *OA head-on entry* draws from the list of countries and dates in Table 2.1 and means direct competition on the principal railway route with the incumbent/franchise holder.

Table 6.9: Descriptive statistics of explained variables and explanatory reform variables

Variable	Unit	Mean	Median	Minimum	Maximum	Std. deviation
Efficiency CRS 4A	%	0.71	0.74	0.26	1	0.25
Efficiency VRS 4A	%	0.82	0.96	0.32	1	0.23
Efficiency CRS 4B	%	0.81	0.83	0.36	1	0.18
Efficiency VRS 4B	%	0.86	0.96	0.37	1	0.18
Vertical separation	Binary	0.33	0	0	1	0.47
Vertical integration	Binary	0.35	0	0	1	0.47
Holding company	Binary	0.32	0	0	1	0.47
Horizontal separation	Binary	0.16	0	0	1	0.37
Passenger competition	1 – 5	1.66	1	1	5	1.15
Freight competition	1 – 5	2.11	2	1	5	1.19
Freight entry	Binary	0.57	1	0	1	0.50
CT entry	Binary	0.12	0	0	1	0.32
OA entry	Binary	0.28	0	0	1	0.45
OA head-on entry	Binary	0.07	0	0	1	0.25

Source: Own processing

6.3.3 Control variables

As the selected countries are not homogeneous regarding their geographical and socio-economic characteristics, several control variables also appear in the model specification. Descriptive statistics of those variables are in Table 6.10.

The most important features could be covered by these available variables: *real GDP per capita* (in thousands of Euro, logged), *population density* (population divided by area), and *employment rate* (the share of employed people to the sum of employed and unemployed people).

Further, *network density* (length of lines divided by area), *traffic density* (total train-km divided by length of lines), *mean trainload in passenger transport* (passengers per train), *mean trainload in freight transport* (tonnes per train), *average passenger distance* (train-km in passenger transport divided by passengers), *average freight distance* (train-km in freight transport divided by tonnes), *share of passenger transport* (train-km in passenger transport divided by total train-km), *electrification* (proportion of electrified lines), *cars* (number of cars per 1000 inhabitants), *infrastructure* (length of lines divided by the sum of length of lines and length of motorways), and *time* (time trend).

Finally, there are dummies for the location of the country in Europe (different divisions). The first location variable *east* expresses whether the country belongs to CEE countries. The second division (region 4) divides the countries into four groups mentioned earlier – *west*, *east*, *Baltic* and *small*. The last location variable (location 8) covers eight groups of the countries introduced in 5.3.5. Al the variables describing location are further utilised in the form of individual dummies. Using such variables describing regions with similar features enables expressing some location-specific features while does not require estimating so many parameters as using dummy variables for individual countries.

Table 6.10: Descriptive statistics of control explanatory variables

Variable	Unit	Mean	Median	Minimum	Maximum	Std. deviation
Real GDP p. c.	log(euro)	16.8	17.0	14.9	18.3	0.76
Population density	inhabitants/km^2	115	101	15	372	74
Employment rate	%	0.66	0.65	0.51	0.82	0.06
Network density	km/km^2	57	54	17	121	31
Traffic density	train-km/km	16	13	4	59	10
Mean trainload in passenger transport	passengers	129	106	44	236	37
Mean trainload in freight transport	tonnes	598	471	42	2042	387
Avr. pass. distance	km	60	48	16	577	47
Avr. freight distance	km	256	239	31	650	107
Share of pass. trans.	%	0.72	0.76	0.04	0.98	0.18
Electrification	%	0.49	0.51	0.02	1	0.26
Cars	cars/1000 inhabit.	438	456	137	671	107
Infrastructure	%	0.78	0.80	0.45	1	0.14
East (x west)	binary	0.48	0	0	1	
Region 4	1, 2, 3, 4 (factor)					
Location 8	1, …, 8 (factor)					
time	year (factor)					

Source: Own processing

6.3.4 Tobit estimations

The most common way how to evaluate the impact of contextual variables is using the tobit model as the efficiency scores represent censored values – both from the left (by zero) and from the right (by one). This approach should enable to answer the research questions – whether and how vertical separation, horizontal separation, and competition influence the efficiency of railways. However, as this approach has been subject to intensive debates (for more details see

section 4.6), the other two approaches were employed to provide robustness check of the results (see the following two subsections).

It is not clear which available data could provide adequate information about the impact of the railway reforms. Thus, the following model estimations were performed for all the model specifications mentioned above – two types of RTS, two different output specifications and seven different time and space specifications for the DEA estimations; i.e. 28 specifications in total. All these versions of the explained variable were employed in more than 30 different regression models, which gave several hundred model specifications. Further, the models were also estimated for some subsamples.

The following tables present only the essential results which enable comparisons among different model specifications. The CRS 4A specification is presented at first as it includes the most up-to-date sample, and the CRS assumption was not rejected by the bootstrap RTS test mentioned earlier. Next, follow the results of various RTS and output specifications of model 4. Finally, proceed all the seven model specifications (for the different time and space samples) under the CRS assumption.

The *population density* variable was highly correlated with both network density and traffic density so that it was not utilised. The *employment rate* variable as well as *time trend* were almost never statistically significant. The variables *share of passenger transport*, *electrification*, *cars*, and *infrastructure* did not bring any significant results and further exhibited strong correlations with other variables. Thus, these variables were not further employed as well. A similar problem was mentioned in Link (2016) for the variables *cars* and *unemployment rate*.

Table 6.11 displays the results for the explained variable under the CRS 4A specification (24 countries, 1999–2017, pkm and tkm as outputs) – specifically the six models where at least some parameters by reform variables were statistically significant. The total number of observations was 456.

The upper part of the table contains reform variables – vertical separation and integration (a holding company is the reference level), horizontal separation, and various forms of competition variables. The next part of the table includes regional dummies. The last three lines

show the value of log-likelihood, model fit computed as the square of the correlation between the actual and fitted values, and the Wald statistics.

The first two models (model 1 and model 2) contain dummy variables expressing the entry of competition in freight transport (*freight entry*), entry of competitive tendering (*CT entry*), open-access competition (*OA* entry), and open-access head-on competition (*OA head-on entry*).

Next, interval competition variables were constructed and employed in model estimations. The two middle columns (model 3 and model 4) express competition in the form of dummies for particular (percentage) intervals while the last two columns (model 5 and model 6) describe competition in the form "at least or more" – specifically passenger competition at least 1% and freight competition at least 5%[9].

In all cases, two types of regional variables were considered – a dummy for CEE countries with WE countries as the reference level, and a division into four regions (dummies for *east, Baltic*, and *small* with *west* as the reference level). The results with the variable *Location 8* (using eight regional dummies) are described separately below.

The first table with the results contains only the variables related to the reforms and regional variables to show the basic tendencies. Vertical separation decreased efficiency (in comparison with the reference level, which is a holding company) and this result was very robust for all the models. Vertical integration contributed to higher scores, but this form is scarce in the data sample and was not always statistically significant. Horizontal separation had a positive impact on efficiency in all the tested models.

The variables *freight entry* and *CT entry* were statistically significant (CT only in Model 1) with a positive sign which means that competition in freight as well as competitive tendering increase efficiency. *OA entry* was significant with a negative sign for the level of significance 10% only in the model with the west-east regional dummy. *OA head-on competition* was significant with a positive sign in both cases which suggests a positive impact of competition when it is more developed.

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[9] Other levels of competition were also tested; however, they did not provide any significant and robust results.

Table 6.11: Tobit models (CRS 4A) with reform and regional variables, 1999–2017

Explanatory variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Vertical separation	–0.131***	–0.063***	–0.070**	–0.057***	–0.088***	–0.056**
Vertical integration	+0.039	+0.003	+0.079**	+0.013	+0.091**	+0.014
Horizontal separation	+0.237***	+0.099***	+0.105**	+0.053*	+0.167***	+0.084***
Freight entry	+0.090***	+0.040*				
Competitive tendering entry	+0.081**	+0.020				
Open access entry	–0.074*	–0.010				
Open access head-on entry	+0.116**	+0.064*				
Passenger competition 1-5%			–0.198***	–0.113***		
Passenger competition 5-10%			–0.034	–0.052*		
Passenger competition 10-25%			+0.200***	+0.052		
Passeng. competition 25-100%			+1.585	+0.879		
Freight competition 1-5%			–0.025	–0.042		
Freight competition 5-10%			+0.184***	+0.054		
Freight competition 10-25%			+0.173***	+0.075**		
Freight competition 25-100%			+0.210***	+0.152***		
Pass. competition 1-100%					–0.031	–0.040
Freight competition 5-100%					+0.208***	+0.109**
East (x west)	–0.389***		–0.356***		–0.386***	
Region 4 – Baltic		–0.006		–0.037		–0.019
Region 4 – small		–0.305***		–0.304***		–0.301***
Region 4 – east		–0.538***		–0.516***		–0.537***
Log-likelihood	–145	10	–99	38	–134	17
Model fit	0.37	0.73	0.43	0.74	0.39	0.73
Wald statistics	215	831	271	851	245	849

Asterisks denote statistical significance at the levels of 1% (***), 5% (**), and 10% (*). Number of observations 456, censored observations 142.

Source: Own computations

Using interval form of competition variables brought mostly a statistically significant positive impact in freight for the levels of competition higher than 5%. Competition in the passenger market produced a significant negative effect on efficiency for lower levels of competition (1–10%). This effect turned to a positive one for higher levels; however, it was not mostly significant. It could be caused by the fact that the implementation of competition in the passenger market produces high costs in the form of many negotiations, new trains, employees, attracting new passengers, etc. When a new operator establishes itself in the market and gains a bit larger market share, the effect of competition turns to a positive one. Using various cross-terms of the reform variables did not bring any robust and statistically significant results. Using

a variable integrating all the reforms was not suitable as it would serve as a dummy for the only one or two countries. Further, it is not clear which exact level of competition should be used for a country with "really implemented" competition.

CEE countries performed worse than WE countries. In the case of four regions, Baltic countries were not statistically different from WE countries while location among small or CEE states decreased efficiency (in comparison with the reference level).

Further, several operational and socio-economic variables were included besides reform, competition and regional dummies as in the previous step – see Table 6.12. This step caused significantly higher values of log-likelihood, Wald statistics and model fit, and also lower statistical significance of vertical separation and horizontal separation.

The signs of the reform and competition variables were very similar as in the previous case. The impact of GDP per capita was positive and statistically significant. Higher network density lowered efficiency while higher traffic density increased efficiency. More passengers per train increased efficiency. The impact of mean trainload in freight transport varied. It was positive in the models with a dummy for east (and also without it) while it was negative in the models with four regional dummies. It is probably caused by the very high value of the coefficient for the Baltic dummy – Baltic states are very efficient and also reach very high values of freight trainload while the other efficient units reach much lower values of freight trainload. Further, PL, RO, and SK are above the third quartile of the mean trainload in freight and they exhibit very low efficiency scores.

Table 6.12: Tobit models (CRS 4A) with control variables, 1999–2017

Explanatory variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Vertical separation	–0.042*	–0.023	–0.038*	–0.028	–0.028	–0.022
Vertical integration	+0.034	+0.035*	+0.050**	+0.038*	+0.052**	+0.045**
Horizontal separation	+0.340	+0.066***	–0.022	+0.022	+0.010	+0.051**
Freight entry	+0.038*	+0.035**				
Competitive tendering entry	+0.056**	+0.044**				
Open access entry	–0.016	+0.015				
Open access head-on entry	+0.73**	+0.042				
Passenger competition 1-5%			–0.010	–0.008		
Passenger competition 5-10%			–0.074***	–0.064***		
Passenger competition 10-25%			+0.005	–0.001		
Freight competition 1-5%			–0.025	–0.027		
Freight competition 5-10%			+0.184***	+0.082***		
Freight competition 10-25%			+0.173***	+0.081***		
Freight competition 25-100%			+0.210***	+0.164***		
Pass. competition 1-100%					–0.006	–0.040
Freight competition 5-100%					+0.095***	+0.084**
East (x west)	–0.023		–0.032		–0.029	
Region 4 – Baltic		+0.053***		+0.529***		+0.512***
Region 4 – small		–0.187***		–0.207***		–0.204***
Region 4 – east		–0.057		–0.089**		–0.078**
Log GDP p. c.	+0.142***	+0.179***	+0.148***	+0.177***	+0.143***	+0.178***
Network density	–0.004***	–0.002***	–0.004***	–0.002***	–0.004***	–0.002***
Traffic density	+0.011***	+0.004***	+0.009***	+0.002	+0.010***	+0.003**
Passenger mean trainload	+0.005***	+0.004***	+0.005***	+0.005***	+0.005***	+0.005***
Freight mean trainload	+0.0004***	–0.0001***	+0.0004***	–0.002***	+0.0004***	–0.0001**
Log-likelihood	83	150	95	166	85	153
Model fit	0.76	0.83	0.75	0.82	0.76	0.82
Wald statistics	1079	1584	1098	1621	1076	1577

Asterisks denote statistical significance at the levels of 1% (***), 5% (**), and 10% (*). Number of observations 456, censored observations 142.

Source: Own computations

Table 6.13 captures the signs of the parameters which were statistical significant (or zero if they were not significant) for the specifications utilised in model 1, 3 and 5, for different RTS (CRS, VRS) and output specifications (A – pkm, tkm, B – passenger train-km and freight train-km), at first without contextual variables (GDP, densities and trainloads) and if the sign is different for the case with contextual variables, it is shown behind the slash. The results for

model 2, 4 and 6 are very similar, only with slightly lower statistical significance of some competition variables.

Table 6.13: Tobit models, different forms of explained variable, 1999–2017

Variable	CRS 4A			VRS 4A			CRS 4B			VRS 4B		
Vertical separation	–	–/0	–/0	–	–	–	–	–	–	–	–	–
Vertical integration	0	+	+	0	+	+	+	+	+	0	+	+
Horizontal separation	+/0	+/0	+/0	+/0	+/–	0/–	+/0	0/–	+/0	+/0	0/–	0/–
Freight entry	+			0			0			0		
CT entry	+			+			+			+		
OA entry	–/0			–/0			0/+			0		
OA entry head-on entry	+			0			+/0			+/0		
Ps. comp. 1-5%		–/0			–/0			0/+			–/0	
Ps. comp. 5-10%		0/–			0			–/0			0	
Ps. comp. 10-25%		+			0			+			+	
Ps. comp. 25-100%		0						0			0	
Fr. comp. 1-5%		0			– /0			0/+			0/+	
Fr. comp. 5-10%		+			0/+			+			+	
Fr. comp. 10-25%		+			+			+			+	
Fr. comp. 25-100%		+			+			+			+	
Pass. comp. 1-100%			0			0			0			0
Freight comp 5-100%			+			+			+			+
Censored observ.		142			225			163			231	

The sign "+" means a positive impact, "– "a negative impact and "0" denotes statistically insignificant parameter. The number of observations was 456.

Source: Own computations

The results for various RTS and form of output variables show very similar tendencies. Some of the parameters lost their significance in comparison with the basic CRS-A case. Horizontal separation represents the only significant difference. It lost its significance or it was even negative for some VRS models and models under specification B. It could be caused by the facts that specification B strongly favours CEE countries, as was shown above (especially CZ, SI, HR) and also by the large number of censored observations in VRS models which causes low variability of the explained variable. On the other hand, the signs of the contextual variables were the same for all the models and were in accordance with the intuition shown above.

All in all, the CRS 4A specification using four regional dummies, which provides the highest values of model fit and log-likelihood (very similar values for all the three types of competition variables), seems to be the most appropriate candidate for deducing some conclusions.

Table 6.14 shows the estimations using the *Location 8* variable under Model 1 specification where it was used instead of the variable *east*. The group comprising DE, ES, FR, IT, represents the reference level.

Table 6.14: Tobit models, 8 location variables, reference level = (DE, FR, ES, IT)

Location variable	CRS 4A	VRS 4A	CRS 4B	VRS 4B
LV, LT, EE	+0.238***	+0.257**	+0.322***	+0.553***
AT, CH, BE,	–0.105***	–0.385***	–0.021	–0.140**
CZ, HU, SK	–0.110**	–0.167**	+0.117*	+0.129
BG, HR, SI	–0.141***	+0.021	+0.140**	+0.268***
FI, SE	–0.260***	–0.288***	–0.216***	–0.267***
PL, RO	–0.267***	+0.027	–0.018	+0.173**
LU, PT, EL, IE	–0.311***	–0.056	–0.168***	–0.007
Log-likelihood	195	82	99	54
Model fit	0.82	0.77	0.45	0.55

Asterisks denote statistical significance at the levels of 1% (***), 5% (**), and 10% (*).

Source: Own computations

Baltic states gained the highest (positive) values of the parameter in all the model specifications while the size of the location parameters significantly differs for the other groups. Including all these variables into the regression model causes much lower statistical significance of most of the other variables or even statistical insignificance of some of them. However, the signs of the parameters were mostly the same. We would probably need much more observations to use so many regional dummies. Thus, such model specifications were not further investigated.

Table 6.15 shows the signs and statistical significance of the parameters (for the Model 3) using various time and space specifications 1A–7A described earlier in Table 6.2 (high levels of passenger competition in passenger transport are missing in some models).

Table 6.15: Tobit estimations – CRS models 1A–7A

Variable	Data sample						
	Model 1 1999-2007, all	Model 2 1999-2011, x DK, NL	Model 3 1999-2014, x DK, NL, NO	Model 4 1999-2017, x DK, NL, NO, UK	Model 5 1999-2015 x fr. fleet	Model 6 1999-2017, x fr. fleet, NO	Model 7 cross section from 4A
Vertical separation	0	– **	– **	0	– ***	– **	0
Vertical integration	+ ***	+ ***	+ **	+ *	+ ***	0	0
Horizontal separation	+ ***	+ ***	+ ***	0	+ ***	+ ***	– *
Pass. comp. 1-5%	+ **	0	– **	0	0	– ***	0
Pass. comp. 5-10%	0	– ***	– ***	– **	– ***	– ***	– ***
Pass. comp. 10-25%	x	x	0	0	+ ***	0	+ ***
Pass. comp. 25-100%	x	x	x	x	0	x	+ **
Freight comp. 1-5%	0	0	0	0	0	0	0
Freight comp. 5-10%	0	+ ***	+ ***	+ ***	+ **	+ *	+ ***
Freight comp. 10-25%	+ **	+ ***	+ ***	+ ***	+ **	+ **	+ ***
Freight comp. 25-100%	+ *	+ ***	+ ***	+ ***	+ ***	+ ***	+ ***
Region 4 – Baltic	0	+ ***	+ ***	+ ***	+ **	+ ***	+ *
Region 4 – small	– ***	– ***	– ***	– ***	– ***	– ***	– ***
Region 4 – east	0	0	– **	– **	– ***	– ***	– ***
Pass. mean trainload	+ ***	+ ***	+ ***	+ ***	+ ***	+ ***	+ ***
Freight mean trainload	+ **	– *	– ***	– ***	+ ***	0	+ ***
GDP p. c.	+ **	+ ***	+ ***	+ *	+ ***	+ ***	+ ***
Network density	– ***	– ***	– ***	– ***	– ***	– ***	– ***
Traffic density	+ ***	+ ***	+ **	0	+ ***	+ ***	+ **
Log-likelihood	105	130	159	166	240	158	361
Model fit	0.80	0.83	0.83	0.82	0.85	0.83	0.85
Number of observations	252	338	400	456	476	513	456
Censored observations	54	105	122	142	89	149	28

The sign "+" means a positive impact, "– "a negative impact and "0" denotes statistically insignificant parameter. Asterisks denote statistical significance at the levels of 1% (***), 5% (**), and 10% (*).

Source: Own computations

Model fit was quite good in all the models. The signs of the parameters were mostly in accordance with the previous results and quite robust among all the models for all the variables (with the same exceptions described above). Altogether, these results can serve for the evaluation of the impact of the railway reforms.

6.3.5 One-step DEA approach

This section provides results from the one-step DEA approach, where efficiency scores are computed simultaneously with the impact of contextual variables. However, the available

procedure does not enable incorporating the panel data structure so that the data was considered as cross-sectional. Thus, this analysis serves rather more as an illustration based on different approach providing possible comparisons of the obtained signs of the parameters; it does not represent the essential approach in this thesis. The estimations were computed several times for 1000 replications. Results are shown in Table 6.16.

Table 6.16: One-step DEA estimations (n = 437)

Variable	CRS 4A				VRS 4A				CRS 4B				VRS4B			
Vertical separation	–	–	0	–	–	–	–	–	–	0	0	0	–	0	–	0
Horizontal separation	0	0	0	0	0	0	–	–	–	–	–	–	–	–	–	–
Pass. comp. 1-100%	0				0				+				+			
Freight comp 5-100%	+				+				+				+			
Freight entry		+				+				+				0		
Competitive tendering entry		0				+				+				+		
Open access head-on entry		+				0				+				0		
Passenger competition 1-5%			0	0			0	0			+	+			0	0
Passenger competition 5-10%			0	0			0	0			0	0			0	0
Passenger competition 10-25%			+	+			+	0			+	+			+	+
Passenger competition 25-100%			+	0			+	+			+	0			+	+
Freight competition 1-5%			0	0			0	0			0	0			0	0
Freight competition 5-10			+	0			0	0			+	+			+	+
Freight competition 10-25%			+	+			+	+			+	+			+	+
Freight competition 25-100%			+	+			+	+			+	+			+	+
Region 4 – Baltic	0	0		0	+	+		+	+	+		+	+	+		+
Region 4 – small	–	–		–	+	+		+	–	–		–	0	0		0
Region 4 – east	–	–		–	0	0		–	0	0		0	+	+		+
Passenger trainload	+	+	+	+	+	+	+	+	–	–	–	–	–	–	–	–
Freight trainload	+	+	+	+	+	+	+	0	0	0	+	0	0	0	+	0
GDP p. c.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Network density	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Traffic density	0	0	+	0	+	+	+	+	0	0	+	+	+	+	0	+

The sign "+" means a positive impact, "– "a negative impact and "0" denotes statistically insignificant parameter.

Source: Own computations

Results are again similar to those obtained from the two-step procedure. The main difference is in the sign of horizontal separation, which was varying with insignificant or negative coefficients. Competition variables were statistically significant more often and had positive signs. The signs and statistical significance of the regional dummies and passenger trainload

were also varying. However, the results under the CRS 4A specification are mostly in line with those from two-step approach.

6.3.6 One-step SFA approach

This section summarises the results from the one-step SFA approach. Different variables were gradually eliminated from the model in order to find the problematic ones which caused the problems with the convergence of the solution. The translog production function caused more problems than the Cobb-Doublas production function because the translog form requires estimating more parameters. The results are presented in Table 6.17. The number of observations was 397.

Table 6.17: One-step SFA estimations

Variable	Cobb-Douglas A			Translog A			Cobb-Douglas B			Translog B		
Vertical separation	–	–	–	–	–	–	–	–	–	–	–	–
Horizont. separation	+	+	+	0	+	+	+	+	0	+	+	0
Pass. comp. 1-100%	0			0			–			0		
Freight comp 5-100%	+			0			0			0		
Freight entry		+			0^+			–			–	
CT entry		+			0			0^+			0	
OA head-on entry		+			+			+			+	
Ps. comp. 1-5%			0			0			0^-			0
Ps. comp. 5-10%			0			0^+			–			0
Ps. comp. 10-25%			+			+			0			+
Fr. comp. 1-5%			–			0			0			0
Fr. comp. 5-10			+			+			0			0^+
Fr. comp. 10-25%			0			0^+			0			0
Fr. comp. 25-100%			+			0^+			–			
Region 4 – Baltic	–	–	–	–	–	–	–	–	–	–	–	–
Region 4 – small	–	–	–	–	–	–	–	–	–	–	–	–
Region 4 – east	–	–	–	–	–	–	–	–	–	–	–	–
Passenger trainload	0	0	0	+	+	0	–	–	–	–	–	–
Freight trainload	–	–	–	0	0	–	0	0	0	–	–	–
Network density	0	0	+	+			+	+	+	+	+	+
Traffic density	0	+	+	0	0^+	+	+	+	+	0	0	0
Loglikelihood	149	169	186	201	210	216	-18	-3	-15	101	114	112

The sign "+" means a positive impact, "– "a negative impact and "0" denotes statistically insignificant parameters, "0^+" and "0^-" means statistically insignificant parameters with p-values slightly higher than 0.10.

Source: Own computations

The translog production function describes the data better as it produces higher values of likelihood in comparison with the Cobb-Douglas production function (separately for the specification A and B) and at least some of the quadratic terms were statistically significant.

The signs of vertical separation and horizontal separation were the same as in the two-step DEA approach. Competition entry had a mostly positive or insignificant impact. All the regional variables lowered efficiency. The signs of the trainload variables were varying. GDP, as well as network density, often caused problems with the convergence of the solution. When network density was included, it had an opposite sign as in the previous approaches; exclusion of network density had nearly no impact on other parameters.

6.4 Evaluating the hypotheses

The thesis aimed to answer six research questions. The first hypothesis says that vertical separation decreases efficiency. The results gained from the regressions above do not reject this hypothesis. The parameter by the variable for vertical separation was negative and statistically significant in nearly all the tested models, which provides quite a robust support for this hypothesis. Separating the infrastructure and operations brings coordination complications and especially misalignment of incentives – everyone is incentivised to do what is best for their own company rather than for the system as a whole; thus vertical separation lowers efficiency. However, it can promote competition, so that the reforms cannot be considered separately but as a complex of changes.

The second hypothesis argues that horizontal separation increases efficiency. The model estimations (for all the models with CRS-A specifications from two-stage DEA and one-step SFA approach) do not indicate rejection of this hypothesis. The parameter by the variable for horizontal separation was positive and statistically significant in most of the investigated models. Elimination of possible cross-subsidisation of passenger transport from mostly profitable freight transport, removal of the situation where passenger operations always take precedence over freight transport, and more focused management are beneficial for overall efficiency. However, the effect was insignificant (or even negative) when VRS were considered or when train-km were used as output instead of passenger-km and tonne-km.

The third hypothesis guesses that competition in freight transport increases efficiency. The regressions above show that the parameters by the competition indices for freight transport were mostly positive and statistically significant, especially for the market share higher than or equal to 5%. The results were robust for various time and space samples and are in favour of this hypothesis. Rail freight represents a segment of the industry which does not contain as substantial barriers as passenger segment and can be operated on the basis of market forces.

The fourth hypothesis assumes that competition in passenger transport increases efficiency. The results are not uniform. Competitive tendering and open access head-on entry mostly increased efficiency. However, the impact of competition was negative or insignificant for low levels of competition when interval competition indices were used. This impact turned to positive values for higher levels of competition (more than 10%). This result can be caused by the fact that an entry of a new competitor means at first higher costs for the industry because it is necessary to buy new trains, gain and train new employees and it also takes some time to attract customers. The loss of economies of scale represents the other key reason when small competitors enter the market. Thus, we can expect a positive impact of competition when it becomes more widespread. These considerations may also apply to freight; however, they seem to be not so significant as for the passenger market.

The fifth hypothesis supposes that the way of expressing the existence of competition plays an essential role in evaluating the impact of competition on efficiency. As was shown in the previous sections, using the dates of the first entry of competition provide often different results than using a more detailed description based on the interval competition dummies. Especially, freight entry was insignificant for VRS-A, VRS-B and CRS-B specifications while separate interval competition dummies indicated a positive impact of competition in the freight segment of the market. Further, interval dummies revealed a varying impact of competition in the passenger market according to the size of the market under competition. Thus, using the more precise form of competition variables provides more thorough information about the effect of competition, which is consistent with this hypothesis.

The last hypothesis expects differences in efficiency among the groups of Western European countries and Central and Eastern European countries. The results above revealed statistically significant differences between CEE countries and WE countries. WE countries reached

significantly higher efficiency. Further, two sub-groups of countries were identified in these groups. The Baltic states from the CEE group are more like WE countries while small railway systems from WE group are closer to CEE countries.

The impact of the reforms may be different in particular countries as their institutional, historical, geographical, and socio-economic background is different. Thus, some degree of freedom in the implementation of the railway reforms is necessary.

6.5 Summary

This chapter presented the results concerning efficiency scores and evaluated the impact of the railway reforms using regression models, which consequently enabled evaluating the hypotheses. Efficiency scores were computed using the DEA with two different types of RTS under two different output specifications for various time and space samples of countries according to data availability. The results enabled to identify the possible impact of different reform changes on the efficiency – a negative impact of vertical separation, a positive impact of horizontal separation, a varying impact of competition in the passenger market according to the level of competition, and a positive impact of competition in the freight market. WE countries gained significantly higher efficiency scores than CEE countries. Finally, the results show that the reforms should be considered as a complex and not separately, as a positive effect of one measure may require some other changes which itself can seem as negative.

7 Discussion

This chapter discusses the results gained in the previous chapter. A comparison of the results with those in existing studies follows. The last part of this chapter discusses possible problems and limitations of the research.

7.1 Interpretation of efficiency scores

The efficiency scores were computed using the DEA in the first part of the analysis. The analysis considered two types of RTS and two types of outputs. Further, seven different time and space specifications were applied due to data availability for each of the specifications.

France, Spain, Switzerland, Sweden, Latvia, Estonia, Italy, and Germany are the best performing countries regardless of the type of the employed model. These countries comprise six developed WE countries and two Baltic countries oriented on rail freight. However, the structure of railway industry is quite heterogeneous in these countries – two of them are vertically separated, three of them are horizontally separated, and the level of competition varies between zero and very high levels. Austria moves significantly up with *train-km* as an output while Italy notably declines. We can conclude that advanced market mechanism or a strong focus on rail freight enabled by specific geographical characteristics are among the main features of the best-performing countries in the railway industry.

On the other hand, CEE countries are the worst-performing – the Czech Republic, Bulgaria, Slovakia, Romania, Croatia, Hungary, Slovenia, and Poland have the lowest ranking. Poland and Slovenia reach much better results under the VRS assumption as their size of production does not probably meet the CRS assumption. Further, the Czech Republic and Slovenia reach somewhat better ranking when *train-km* is used as an output. Thus, some negative features still pertain in post-communist CEE countries despite the improving tendencies.

The slack analysis further revealed the potential sources of low efficiency of CEE countries analysing excess inputs of the inefficient companies (besides the necessity for a radial lowering of all inputs represented by the efficiency scores). Large values of slacks suggest non-optimal proportion of inputs in the production process. Lines length and passenger fleet did not represent a problem as the slacks were mostly small or zero while the slacks for the number of employees and freight fleet were large for many countries and periods. The enormous stock of

freight fleet in post-communist CEE countries could be one of the main factors declining their efficiency as well as the only slowly declining slack of the number of employees.

Application of the Malmquist index enabled the analysis of efficiency in time. All the countries except for Estonia went through a permanent positive change in technology where the change was more significant in WE countries than in CEE countries. The technology was improving at the rate of 2% per year. On the other hand, the rate of relative approaching the frontier was close to zero.

7.2 Interpretation of regression results

Linear regression helped to answer the research questions – whether and how vertical separation, horizontal separation, and competition implementation influence the efficiency of railways. Model estimations were performed for different time and space specifications and also for different contextual variables.

As the RTS test did not reject the CRS assumption, the CRS-A specification was selected as the basic specification. However, the other three specifications (CRS-B, VRS-A, VRS-B) were also taken into account with mostly similar conclusions.

The CRS 4A specification, which contains the most up-to-date data, shows the following. Vertical separation (institutional separation of the infrastructure from operations) lowered efficiency in comparison with the companies in the form of a holding company. However, including the four regional dummies and a set of contextual variables lowered its statistical significance. The impact was not significant in some model specifications based on the on-step DEA using train-km as output and also in some models using four regional dummies which usually lowered statistical significance of vertical separation. On the other hand, the one-step SFA approach revealed a robust negative impact of vertical separation in all the examined models. The integrated form enabled even higher efficiency scores; however, it expressed mostly the efficiency of Switzerland and Latvia.

Horizontal separation (separation of passenger and freight operations) increased efficiency in most of the models. It is considered beneficial for freight transport as it does not enable cross-subsidisation of passenger transport from the profit of freight transport and also provides more focused management. However, the effect was insignificant or even negative in the one-step

DEA approach, which is the less preferred one as it does not allow incorporating the time dimension into the model. The negative impact also appeared in some models using VRS or train-km as outputs in the two-step approach while the insignificant effect appeared in the two-step DEA approach based on competition indices including a set of contextual variables.

Using the dates of the first entry into freight transport, the first occurrence of competitive tendering or open-access competition entry provide similar results for models with CRS-A specification while the results under the other three specifications brought more insignificant coefficients. Employing the interval competition indices provided a more detailed explanation about the possible impact of competition on efficiency.

Competition entry in freight transport had a positive impact on efficiency for almost all levels of competition except for very low levels. Only the one-step SFA approach based on train-km as outputs did not reveal any significant effect. The results were similar for all the three types of expressing the presence of competition – the first entry, competition indices, and competition more than a given level.

Competition in passenger transport lowered efficiency as long as the level of competition was low. The parameters changed to positive values for higher levels of competition (more than 10%); however, they were statistically significant only in some model specifications. Using the dates of the first entry suggest a mostly positive impact of competitive tendering as well as open-access head-on entry.

The results imply that competition is beneficial for both segments of rail transport and promoting the competition should finally produce better outcomes.

Although the coefficient by the vertical separation variable was negative, it was mostly counterweighted by the positive coefficients by the competition variables, especially for freight transport. It indicates that the reforms should be evaluated as a complex rather than each step individually.

The group of control variables brought mostly the expected and overall accepted impacts of the variables. Countries with higher GDP per capita tend to reach higher efficiency scores. Higher network density lowers efficiency, which is especially the case of many CEE countries. It may be caused by higher coordination and maintenance costs and it stems mostly from historical

circumstances (however, the reduction of the amount of tracks would clearly lead to a loss of some traffic). On the other hand, higher traffic density increases efficiency as the network is utilised more intensively. Mean trainload in passenger transport increased efficiency in all models based on the two-step DEA approach and in specification A (using passenger-km and tonne-km as outputs) in both one-step models. It suggests that more passengers on the train usually mean more efficient railways in the EU. Mean trainload in freight transport is unclear. The effect was positive when only two regional dummies (west and east) were employed while it was insignificant or even negative with four regional dummies. It can be caused by the fact that Poland, Romania, and Slovakia are above the third quartile of the mean trainload in freight and all these countries exhibit very low efficiency scores. Exclusion of the Baltic states from the CEE group means that the rest of CEE countries have significantly lower scores, which is probably mirrored by this negative coefficient.

Further, differences among some groups of countries were examined. The first division based on the available studies Wetzel (2008) and Asmild et al. (2009) used two groups – WE and CEE countries. It revealed significantly lower efficiency scores in CEE countries which can be caused by lower economic and technological development in these former communist countries. The second – more detailed – division of countries into four groups based on Fitzová (2018) showed that the two above mentioned groups are not homogeneous. Especially small railways systems on the periphery of the EU were significantly less efficient than the rest of WE countries while Baltic countries, strongly oriented on long heavy freight trains transporting raw materials from Russia to seaports, were very efficient, rather like WE countries. Even more detailed division of the countries into eight groups indicated by the analysis of the descriptive statistics of the countries did not bring any crucial conclusions; it only caused significantly lower statistical significance of the reform variables.

The differences in efficiency stem probably partially from the heterogeneity of the states rather than only from the institutional differences induced by the implementation of the reforms. However, the number of observations is not sufficient to use dummy variables for all the countries.

The analysis developed for seven different time and space samples of the countries confirmed most of the conclusions provided by the benchmark CRS 4A specification. The signs of the

parameters were mostly the same with nearly the same statistical significance, and the model fit was rather good. However, the models with older data did not allow for using the competition dummy for the highest levels. Further, it is necessary to take into account that the models with newer data do not include so many states as the models with older data. On the other hand, we are interested more in the current effects of the competition; thus, the models based on newer values are the preferred ones.

7.3 Comparison with existing studies

The results of this thesis are mostly consistent with the existing literature; however, the thesis brings some new findings and points of view.

Literature sources do not provide any clear explanation of the impact of vertical separation on efficiency – they revealed a positive, a negative, and most often an insignificant impact, sometimes dependent on another variable. This thesis has identified a robust negative effect of vertical separation regardless of the method and model specification. It was not significant only in some model specifications out of many (especially the model using the oldest part of the dataset or some models using train-km as output).

On the other hand, horizontal separation increased efficiency in most of the model formulations, which is in line with most of the results in the existing studies. However, it was also insignificant or even negative in some model specifications, especially in some models based on the one-step DEA approach which is, however, the less preferred one due to impossibility of handling the time dimension of the data.

Available studies do not offer any unique explanation about the impact of competition on efficiency. Competition in the freight segment was mostly identified as increasing efficiency while the effect of competition in passenger transport was entirely ambiguous.

The results of this thesis confirmed a positive impact of competition in freight transport on efficiency regardless of the form of the variable describing competition in the two-step DEA approach. This effect was not significant only for very low market shares and also for the one-step SFA approach using train-km as output.

The effect of competition in passenger transport was found as dependent on the situation on the market. It was negative for low market shares and positive for higher levels of competition, especially in the models based on the one-step approach. The way of expressing the situation on the market was beneficial – a more detailed description enabled to reveal essential features of the market. Further, the analysis indicates, that competitive tendering was mostly positive and the impact of open access entry was not significant while the open access head-on entry increased the efficiency in most of the analysed models. These findings may provide an explanation of the ambiguous results in the available studies as they used mostly the official dates of the first entry (except for Mizutani et al., 2015).

The only two studies investigating the differences between the group of WE and CEE countries revealed lower efficiency in CEE countries which is in line with the results of this thesis. Above that, this thesis suggests that this division may not be sufficient as the models with two more groups exhibited better explanatory properties. Particularly, Baltic states were more like WE countries while small WE states at the periphery of the EU exhibited results more like CEE countries.

7.4 Possible problems and limitations

This section discusses possible problems and limitations of the conducted research. It may seem that the most problematic issue is data availability and the choice of appropriate method and model. However, an essential question should be answered before choosing any models. Is it possible to reach a significant degree of competition without enormous costs? Things that work at certain times and in specific industries do not necessarily work elsewhere at a different time (Pittman, 2005). The following subsections draw from Fitzová (2017).

7.4.1 Problems with data

Most studies dealing with the efficiency of railways use data from the International Union of Railways. The main problems associated with the UIC were discussed in section 5.1. They comprise especially missing variables, data only for the incumbents, the inclusion of the subsidiaries in other countries (like Deutsche Bahn in the UK). A researcher also faces a problem with missing or incorrect values which are evident from the development of the examined time series (e.g. missing “zeros” at the end of the numbers).

Eurostat provides many data; however, some variables are entirely missing. Further, some values are not available, and a combination of several other data sources is necessary. Some problems concerning data may be overcome by collecting data from respective national sources, but this is highly time-consuming and often not possible. Also, train operating companies may contract out rolling stock maintenance and cleaning, which is not mentioned in most of the time series collections.

Further, some special circumstances may arise in particular countries, like in Slovakia. Children, students and pensioners travel free of charge since November 2014. It produces full and dirtier trains. Does it really mean higher efficiency? It is an example showing why passenger-km is not always an ideal output measure. Further, trainloads also depend on government policy on fares and pricing of other modes; thus, these factors should be taken into account in the analyses. The problem with a bit confusing Polish data was discussed earlier (seemingly high level of competition). Greece and Luxembourg data are hard to gain, they are not very up-to-date, and their development is at least strange, as the numbers are the same for several following years which is unusual – they apparently represent the last available value. Some countries significantly differ by their underlying characteristics from the other countries in the sample. Their exclusion from the dataset may be correct; on the other hand, it would significantly lower the number of observations.

Further, data is available with a substantial delay. Reforms are still in progress in many countries. Although reforms have been completed in some countries, it takes many years to get the changes into everyday practice. The difference between the establishment of a given arrangement and its practical use could be quite vast. It usually takes several years until the first outcomes become visible in the data. It is also often not clear which dates were used in the empirical analyses of the reforms.

The open-access competition operates mostly on some potentially lucrative routes. Thus, the amount of available data is rather small, and the market share of the new operators is still low. Competitive tendering has been implemented more frequently; however, it mostly occupies only a small share of the market (except for Great Britain, Sweden, and Germany).

7.4.2 Problems with computations

The methods utilized for efficiency evaluation stand on some assumptions which are not always met in reality. Violation of some of these assumptions is not necessarily crucial, but some of them may be essential and fundamental. The method which is utilized most often is the DEA. It supposes the homogeneity of the investigated units (countries). Eastern and Western European countries differ quite a lot, as they have come through different development. Due to this fact, they have different structures of the market, industry, transport, institutional environment, quality of staff and capital equipment. Some countries are spacious with low network density, while others, such as the Czech Republic, are small with high network density. Some countries are oriented towards freight transport, particularly for transporting raw materials (as is the case of Baltic countries), while others are instead oriented towards passenger transport (as is the case of Spain). Also, data concerning the variables for the DEA are a bit debatable. The DEA does not work with prices but with physical units. Is it possible to consider a train in Austria the same as a train in Romania? Alternatively, a worker in France identical to one in Bulgaria?

The choice of the model, particularly the type of returns to scale in the DEA, is also somewhat controversial. Should they be constant or variable or in any way alternatively defined? Each type of model has its pros and cons. However, how shall we decide based on available data? Use of the SFA is also somewhat problematic as the particular form of the production (cost) function is unknown. For railways, however, it is particularly hard to obtain data concerning costs, so this disadvantage may, in some cases outweigh the advantages of using the SFA. The SFA is typically employed with the translog function, which includes many parameters. It often causes problems with the estimation as the number of observations is usually not large enough, especially for railways. Further, problems with the convergence of the solution appear in the one-step SFA approach, as was mentioned earlier (see section 6.3.6).

This thesis tried to overcome as many problems as possible using various methods, models and time and space specifications.

7.5 Policy implications

Were the European railway reforms suitable and beneficial? The impact of the European railway reforms varies according to various circumstances in individual countries. The European railway reforms influence the efficiency of national railways; however, other factors (geographical or socio-economic), play a significant role. The legislative framework should set fundamental rules to ensure fair play across Europe.

The reforms as a complex can be viewed as positive – there is a gradual although a slight increase in the volume and in some countries even in the preference of rail transport, at least in the last ten years. Nevertheless, the prevailing effects of introduced competition are positive – a more economical use of scarce resources, expansion of the range of the services provided, better quality of services, and sometimes even lower prices for customers. However, the modal share of both passenger and freight rail transport is stagnating and the volume of rail freight, which fell sharply during the economic crisis in 2008/2009, still has not reached the pre-crisis level. The EU expects the revival of rail transport to be even more extensive in the future when the fourth railway package comes more into practice.

The expected positive effect of vertical separation is not evident at first sight. Vertical separation causes coordination complications and especially misalignment of incentives where everyone is incentivised to do what is best for their own company rather than for the system as a whole. Though, this reform step, more specifically, some degree of vertical separation, was considered as a necessary condition for a higher level of transparency providing a fair playfield, especially for financing and competition. Complete vertical separation is not always joined with a higher level of competition; on the other hand, a considerable degree of competition appears in countries with a holding company structure. A holding company model has some benefits in terms of efficiency, but these may be offset by lowered competition. Some negative effects are often necessary to induce much higher positive effects. Thus, the reforms should be evaluated as a complex, not separately.

Horizontal separation, which is not required by the reforms, further contributes to better performance as it does not produce demotivating effects due to cross-subsidies and promotes the industry, especially via more focused management. As most of the countries remains

horizontally integrated, separating of both parts of the market seems to be an important policy recommendation.

Rail freight represents a segment of the industry which does not contain as substantial barriers as passenger market and can be operated on the basis of market forces. However, the situation in passenger transport is a bit more complicated. Competition becomes favourable for larger market shares based on competition. The negative impacts for lower market shares could have been caused by the loss of economies of scale, higher costs for the industry due to the necessity to buy new trains, gain and train new employees and some time necessary to attract customers. Further factors comprise inappropriate conditions for the competitors (especially too strong dominant operator, e. g. in Germany), a suboptimal form of the tenders (e. g. in the Czech Republic) or just by low attractivity of the route. It is also possible that the reforms have not been sufficiently implemented to be reflected in the data, especially in the passenger market.

The analysis of slacks provides the policymakers with some clues for future policy – the number of the employees was identified as the most redundant input especially in CEE countries; thus some organizational changes in the companies could be desirable. Further, the results about the changes in time suggest that improving technology is a necessary condition for better-performing companies.

The governments now have to pay more attention to railway data collection as it is required by the EU regulation 2015/1100 which sets up a questionnaire to be filled annually by the EU members for the purpose of monitoring the technical and economic conditions and market developments in the rail transport sector. It should gradually lead to more consistent and coherent data after the end of the transitional period in 2018 (EC, 2019). These changes could contribute to a more transparent environment in the railway market. Further, future analyses should not be based on the results from the only one model as a single feature of the model can bias all the results.

Despite many problems and failures, the economic policy supporting the reforms steps can significantly contribute to rail transport recovery; nevertheless, national specifics should still be kept in mind.

7.6 Summary

This chapter discussed the results of this thesis and its possible limitations. The most developed WE countries and Baltic states were among the best-performing countries. CEE countries (except the Baltic states) reached significantly lower efficiency scores. Various regression models enabled to answer the research questions. Vertical separation decreased efficiency while horizontal separation increased efficiency. Competition in freight transport increased efficiency. Competition in passenger transport reduced efficiency for low market shares while it was beneficial when it became more widespread. A more accurate description of competition via competition indices gave more detailed information about the impact of competition on efficiency. The positive effect of competition was mostly higher than the negative effect of vertical separation. WE countries reached significantly higher efficiency than CEE countries. The reforms, as a whole, can be viewed as positive despite many problems and failures accompanying the reform process. The economic policy represents an essential instrument for revitalising rail transport in particular by defining clear and stable rules, supporting data publication and technological improvement.

8 Conclusion

This thesis aimed to identify the impacts of the European railway reforms on railway efficiency. The main objective of the reforms was to enable entry of competition on the existing network to raise the efficiency of the railway sector. The European Commission considered it necessary to split the infrastructure and operation of services. On the other hand, the separation of passenger and freight transport into two separate companies was not mandatory. The entry of competition was expected to raise the efficiency of railways.

There have been four packages of the reforms so far, which gradually induced many steps toward a more efficient market. They enabled rail operators' access to the trans-European network on a non-discriminatory basis for international freight services. Further, they opened the freight market to competition (2007); it was followed by opening the passenger market for international services (2010). Finally, the domestic passenger market should fully enable competition by 2022.

The available empirical studies do not provide a unique conclusion about the impact of the reforms. Vertical separation, which means separation of infrastructure and operation of services, has a completely unclear impact on efficiency. Horizontal separation, which means separation of passenger and freight services, seems to be mostly positive. The impact of competition is also unclear – it is mostly positive for freight while ambiguous for the passenger market. However, the studies used different periods, samples of countries, methods, and models. They were not mostly interested in the differences among groups of countries. Further, the form of variables describing competition was not mostly ideal. These finding produced many questions about the possible sources of the ambiguities of the results and stimulated the formulation of the six research hypotheses of this thesis.

The methodology used in this thesis drew on the methods and techniques available in the relevant studies. The DEA and the SFA were applied to determine the production frontier. However, due to problems with the convergence of the solution using the SFA, the DEA approach is more developed. As it is not clear from the available studies which kind of returns to scale is more appropriate, both CRS and VRS assumptions were considered. The two-stage DEA approach employing the tobit model represents the first methodological line. Further, one-

step approaches based on the DEA as well as the SFA allowing for computation of efficiency and its factors in one step provide a way of robustness check of the results. The concept of slacks, which is not often used in the studies, suggests the most problematic inputs of the production process and can serve as a guide for policymakers. The Malmquist index indicates two important components of efficiency in time – a technological change in time and a change in the organisation of the production process. Again, it can provide some suggestions which could help the railway companies to a better outcome.

An up-to-date dataset containing reliable values was the necessary element in this analysis. It comprised collecting data from various sources covering the period 1999–2017, revision of all the gained values and consequent replacement of suspicious values from other data sources. Descriptive statistics revealed many essential features of the investigated countries, especially several geographical, socio-economic and operational similarities and differences. They implied a division of the countries into several groups. Finally, an overview of the official dates of the implementation of the reforms in particular countries as well as the first real entries of a competitor for different types of competition helped to construct new competition indicators. These variables especially together with a wide range of methods and models, provide a good background for deducing robust conclusions about the impact of the reforms.

Empirical results enabled evaluating the hypotheses formulated in the introduction of the thesis. Possible problems stemming from the variables utilised for evaluating the efficiency were discussed using boxplots of inputs and outputs. Possible outliers were explained and incorporated into further computations as they could represent a possible source of the ambiguous results.

Relative efficiency scores from the DEA under two types of RTS, for seven different space and time specifications, provided a ranking of the countries. The RTS test did not reject the CRS hypothesis; however, both RTS specifications were considered for further comparisons. Developed WE countries and Baltic countries were the best-performing countries regardless of the type of the employed model. On the other hand, the rest of CEE countries (except for the Baltic states) were the worst-performing. The way of measuring the competition mattered. Using train-km instead of passenger-km and tonne-km significantly changed the ranking of some countries. It notably improved the results of Slovenia, the Czech Republic, and Austria;

on the other hand, it worsened the position of Italy where the trains are probably much more full. Further, employing the VRS assumption instead of CRS enhanced the scores of Luxembourg, Ireland, and Poland. However, this approach produces a large number of efficient units which means low variability of the explained variable in the second stage of the analysis. The results indicate two features underpinning the high relative performance of the countries in the railway industry in Europe – either an advanced market mechanism or a strong focus on rail freight enabled by specific geographical features.

The analysis of slacks showed the potential sources of inefficiency. It revealed excess inputs of inefficient companies. The most problematic variables were the number of wagons and also the number of employees, especially in the post-communist CEE countries. These excesses were declining most of the time but not fast enough. The analysis of efficiency in time found out that all the states except for Estonia went through a permanent positive change in technology – 2% per year on average. The change was more significant in WE countries than in CEE countries. On the other hand, the rate of relative approaching the frontier was close to zero. The findings imply that supporting technological progress represents an important element in raising the efficiency of railway companies.

The second stage of the analysis based on tobit models enabled to answer the research questions – whether and how vertical separation, horizontal separation, and competition implementation influence the efficiency of railways. Several hundred model estimations were performed for different time and space data samples and also for different explanatory variables to ensure the robustness of the results. The most robust results are provided using the scores from DEA under the CRS assumption and demand-based outputs (passenger-km and tonne-km). However, the other three specifications brought mostly similar conclusions. Different samples of countries and periods brought qualitatively identical conclusions.

The conducted analysis implies that the reforms as a complex can be viewed as positive. Vertical separation lowers efficiency. A holding company model has some benefits in terms of efficiency, but these may be offset by lowered competition. The overwhelming effect of horizontal separation is mostly positive. As it is present only in a few countries, it represents an important measure to enhance efficiency. Using the official dates of the first entry of competition suggests a positive impact of competition in freight, positive or insignificant impact

of the competitive tendering, insignificant effect of introducing open-access competition. In contrast, open-access head-on competition exhibits a positive impact on efficiency. Using competition indices describing the particular market share operated on the basis of competition brought more detailed conclusions. Competition entry in freight transport has a positive impact on efficiency for almost all levels of competition (except very low levels). Competition entry in passenger transport lowers efficiency for low levels of competition, and its impact is positive for significantly higher levels of competition. However, these results were statistically significant only in some model specifications. The negative effect could be temporary, and it could change to a positive one when the competition is more developed. Competition seems to be beneficial for both segments of rail transport; however, it takes some time and government effort to gain all the possible benefits.

The second group of the results identified differences among several groups of countries. The division into WE countries and CEE countries earlier used by Wetzel (2008) and Asmild et al. (2009) indicates that CEE countries exhibit significantly lower scores. It is probably due to still lower economic and technological development, lower productivity of labour, and traditional behaviour. However, the more detailed division into four groups based on Fitzová (2018) shows that Baltic countries are very efficient and produce results more like WE countries while small WE countries on the periphery of the EU are significantly less efficient. The more detailed division into eight groups was not beneficial for the analysis as the regional dummies took over most of the statistical significance of the reform variables.

The results of the thesis are mostly in line with the existing studies. However, the thesis brings new possible explanations based on the unique dataset, various range of the methods and models, a more precise description of the railway market, and a more detailed division of the countries. While vertical separation has a completely unclear impact on efficiency in the literature, this thesis has identified a robust negative effect regardless of the model specification. The mostly positive effect of horizontal separation in the studies is in line with the overwhelming results of the thesis as horizontal separation increased efficiency in nearly all the model formulations. The impact of competition is unclear according to the available literature. The authors consider competition in the freight market mostly as increasing efficiency. In contrast, the impact of competition in passenger transport is ambiguous. The results of the thesis

confirm a positive impact of competition in freight transport on efficiency for levels higher than 5% while the effect of competition in passenger transport depends on the situation on the market. It can be either negative (for low market shares), either positive (for high levels). Thus, the results indicate that the way of expressing competition matters as a more detailed description of the market structure reveals different outcomes than a simple date of the first entry. Further, the thesis explains that it is not desirable to assess each reform step separately, as some unpopular steps may be to induce larger positive impacts. The conclusions suggesting lower efficiency in CEE countries agree with those in available studies. More aspects were revealed by a more detailed division of the countries. However, the impact of competition may be an open question as competition in the EU is not still very widespread. The implementation of the fourth railway package could help to clarify some of the ambiguities induced by the literature.

The conducted analysis implies that policymakers could contribute to the higher efficiency of the railway industry in many ways. They could support some organisational changes in the (state-owned) companies, especially regarding employment. They should also stimulate the implementation of new technologies to enable railways to be more competitive with other transport modes. The governments should also ensure regular and more consistent publication of railway indicators as it is now required by the EC (2019). It could contribute to a more transparent environment in the market. Further, empirical analyses should not be based on the results from the only one model as the results can be susceptible to a selected model specification.

Future research should be based on up-to-date data sources, including the new open-access operators, which could reveal some other features of the reforms. Especially the limits of the intervals describing the intensity of competition should be further explored. It would also be interesting to consider features of the franchisees in individual countries as was analysed for Germany in Link (2016). Namely, the aspects as the size of the franchise, contract duration, the type of contract, etc. and their impact on the efficiency of the rail system worth investigating. However, such an analysis is entirely dependent on data availability. Next, introducing a dummy variable indicating the countries where all the reforms have been implemented could be beneficial if it was the case of more than one or two countries. Further, using other variables describing intermodal competition like the number of car-km on the road, a variable standing

for the competition from airlines or some variable about the intensity of use of the air network could also be interesting to consider and could help to gain more detailed results. A more extensive range of methods based on both outputs and costs of the industry could also contribute to the more robust conclusions. However, new findings will probably be revealed after the last railway package will come more into practice in 2022 or perhaps much later.

The European railway reforms seem to have an ambiguous impact at first sight; however, closer inspection of the complex problem indicates that the reforms could be assessed as positive. Their impact differs in individual countries as they are different in many aspects. The differences in efficiency stem probably also from the heterogeneity of the states rather than only from the institutional differences induced by the implementation of the reforms. The legislative framework should enable some degree of freedom to set the particular form of railway industry according to local circumstances. The economic policy represents an essential tool for revitalising rail transport in particular by defining clear rules and by ensuring the observance of the established rules. Despite many problems and failures, the reforms have brought a gradual revival of rail transport which was one of their main targets.

Resumé

Hlavním cílem evropských železničních reforem, které začaly v 90. letech 20. století, bylo umožnění přístupu konkurence na stávající železniční síť s cílem zvýšit efektivitu železničního odvětví. Cílem této disertační práce bylo vyhodnotit dopad těchto reforem na efektivitu železnice s využitím různých metod a modelů, unikátního datového souboru a několika forem proměnných popisujících konkurenci.

Důležitým reformním krokem byla vertikální separace infrastruktury a provozování služeb, která představuje zásadní prvek pro zavedení konkurence. Dle existujících studií není dopad vertikální separace na efektivitu odvětví zřejmý. Na druhou stranu horizontální separace, která odděluje provozování osobní a nákladní dopravy, má ve většině literárních zdrojů pozitivní vliv na efektivitu. Dopad konkurence je též nejasný, i když v nákladní dopravě je většinou pozitivní. Rozdílnost výsledků může být způsobena různými datovými vzorky, jak již z hlediska časového tak i prostorového.

Tato práce se snažila překonat slabiny dříve provedených studií využitím více metod, různých modelů a časoprostorových specifikací s cílem poskytnout co nejvíce robustní výsledky. Hlavní metodou byla tzv. dvoukroková analýza využívající metodu DEA k určení skóre efektivity a tobit model k vyhodnocení vlivu kontextuálních proměnných; dále pak byly využity také jednokrokové přístupy využívající bootstrap DEA metodu a následně SFA, které obě umožňují odhad efektivity i vlivu reformních a kontrolních proměnných zároveň.

Dle provedené analýzy má vertikální separace negativní dopad zatímco horizontální separace má pozitivní dopad na efektivitu železnice. Vliv konkurence v nákladní dopravě byl identifikován jako pozitivní zatímco vliv konkurence v osobní dopravě závislý na míře konkurence v odvětví. Kromě reformních opatření hrají v efektivitě železnic také socio-ekonomické charakteristiky zemí a další specifika jako podobný historický vývoj. Reformní kroky je však třeba vyhodnocovat jako celek, neboť negativní dopad jednoho opatření může vést k větším pozitivním dopadům jiných opatření.

I přes řadu problémů a selhání, ke kterým v průběhu implementace reforem došlo, se zdá, že reformy přispěly k postupnému oživení železniční dopravy. Hospodářská politika hraje při tomto procesu důležitou roli.

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List of abbreviations

CD Cobb-Douglas

CE competition entry

CEE Central and Eastern European

COLS corrected ordinary least squares

CRS constant returns to scale

CT competitive tendering

DEA data envelopment analysis

DMU decision making units

DRS decreasing returns to scale

EC European Commission

ERA European Railway Agency

EU European Union

FDH free disposable hull

GB Great Britain

HHI Herfindahl Hirschman index

HS horizontal separation

IID independent identically distributed

IM infrastructure management

IRS increasing returns to scale

ITF International Transport Forum

LRM linear regression model

LP linear programming

MEA	multi-directional efficiency analysis
NDRS	non-decreasing returns to scale
NIRS	non-increasing returns to scale
OA	open-access
OLS	ordinary least squares
PPS	production possibility set
PSO	public service obligation
RTS	returns to scale
SBM	slack based measure
SE	scale efficiency
SFA	stochastic frontier analysis
TFP	total factor productivity
UIC	International Union of Railways
VRS	variable returns to scale
VS	vertical separation
WE	Western European

List of tables

Table 1.1: Modal split of freight resp. passenger land transport in the EU 16
Table 2.1: Competition in the EU countries with open-access 35
Table 3.1: Summary of empirical studies 48
Table 3.2: Summary of methods, models, and data in railway efficiency studies 49
Table 5.1: Means for basic characteristics of country groups (1999-2017) 99
Table 5.2: Implementation of the reforms (during 1999–2017) 103
Table 6.1: Descriptive input and output statistics 105
Table 6.2: Analysed DEA models 109
Table 6.3: Efficient units in the analysed DEA models 110
Table 6.4: Spearman correlation of the scores from 2-step DEA 111
Table 6.5: Average efficiency scores and SE ratio for model 4, specification A 114
Table 6.6: Average efficiency scores and SE ratio for model 4, specification B 115
Table 6.7: Slacks for inputs – model 4 with CRS, specification A 117
Table 6.8: Spearman correlation for different methods 123
Table 6.9: Descriptive statistics of explained variables and explanatory reform variables 128
Table 6.10: Descriptive statistics of control explanatory variables 129
Table 6.11: Tobit models (CRS 4A) with reform and regional variables, 1999–2017 132
Table 6.12: Tobit models (CRS 4A) with control variables, 1999–2017 134
Table 6.13: Tobit models, different forms of explained variable, 1999–2017 135
Table 6.14: Tobit models, 8 location variables, reference level = (DE, FR, ES, IT) 136
Table 6.15: Tobit estimations – CRS models 1A–7A 137
Table 6.16: One-step DEA estimations (n = 437) 138
Table 6.17: One-step SFA estimations 139

List of figures

Figure 1.1: Development of GDP, passenger-km and tonne-km in the EU 28 (1995 = 100) ..15
Figure 2.1: Institutional settings in the EU (2016) 28
Figure 2.2: Open access routes in Britain 38
Figure 2.3: Swedish open-access routes 39
Figure 2.4: Open-access routes in Italy 40
Figure 2.5: German open-access routes 41
Figure 2.6: Open-access routes in Austria 42
Figure 2.7: Open-access services in Central Europe 43
Figure 4.1: VRS versus CRS in DEA 72
Figure 4.2: Efficiency change in time.....77
Figure 5.1: Area and population (2016).....93
Figure 5.2: Real GDP per capita (2016) 94
Figure 5.3: Network density and population density (2016) 94
Figure 5.4: Network electrification (2016) 95
Figure 5.5: Share of railways on total freight and passenger transport (2016).....96
Figure 5.6: Composition of railway transport (2016) 96
Figure 5.7: Railway performance (2016).....97
Figure 5.8: Average distance in freight resp. passenger transport (2013) 98
Figure 5.9: Mean trainload in passenger and freight transport (2016) 99
Figure 5.10: Railway performance development in CEE countries (1999–2017).....100
Figure 5.11: Railway performance development in WE countries (1999–2017) 101
Figure 6.1: Length of lines and number of employees (1999–2017).....106
Figure 6.2: Passenger fleet and freight fleet (1999–2017).....107
Figure 6.3: Passenger-km and tonne-km (1999–2017).....108
Figure 6.4: Efficiency scores, CRS-A (pkm, tkm), model 4 (1999–2017).....112
Figure 6.5: Efficiency scores, CRS-B (train-km), model 4 (1999–2017).....113
Figure 6.6: Average technical and efficiency change using the Malmquist index 119
Figure 6.7: Average CRS scores from the one-step DEA approach.....120
Figure 6.8: Average scores from the one-step SFA (Cobb-Douglas).....121

Figure 6.9: Average scores from the one-step SFA (translog) 122
Figure 6.10: Efficiency scores CRS 4A (left), VRS 4A (right), average 2013–2017 124
Figure 6.11: Efficiency scores CRS 4B (left), VRS 4B (right), average 2013–2017 124
Figure 6.12: Vertical and horizontal separation in Europe (2017) 125
Figure 6.13: Competition in Europe (2017) 127