Rail and road freight transport network efficiency of Canada, member states of the EU, and the USA

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Abstract

The main research problem has been analyzing and comparing the efficiencies of road and rail freight transport networks in different geographical contexts and derive policy suggestions from the results based on a dataset that spans multiple continents, covers multiple countries and covers a longer time period. For Europe, the benchmarking results for rail indicate that the efficiency of rail freight companies must be encouraged, however, the efficiency of the rail freight system should be treated on a single European level. In the SFA road model for the whole period (2000-2012), it shows that many countries are already quite efficient which suggest that policy should aim for keeping the efficiency high. In addition, a relatively lower population density leads to relatively more infrastructure needs and less efficiency which might lead certain countries to accept a lower efficiency. In Europe, rail efficiency shows that liberalization of rail freight transport does not have much impact in the sense that marked improvements in efficiency for individual countries can be observed. In the end, freight transport efficiencies in different geographical contexts have been analyzed and improvements in governance decisions have been suggested.

Keywords: freight transport; network; efficiency; optimization

1. Introduction

In scientific research, the optimization of freight transport networks has received considerable attention. The design, management and optimization of freight transport networks have been the subject of many analyses (see e.g. Crainic et al. 1986; 2009). Scientific attention also has been directed towards investments in infrastructure and the relationship with economic growth (see e.g. Witte et al. (2014). However, little is known on how efficient current freight transport networks are and how the different freight transport modalities (road, rail, and IWW) interact. Another stream of scientific literature has analyzed the efficiency of transport companies operating on freight transport networks and of certain transport sectors as a whole. This subject has, for example, been analyzed by Wilson (1997) and Wiegmans and Donders (2007) for the rail industry. The efficiency of the container handling industry (both container ports and container terminals) has also received much scientific attention in the last decades. Many scientific papers analyzed the efficiency of ports and terminals by using Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA) and related techniques to compare the respective ports and terminals on their efficiency (see for example Cullinane et al. 2006).

An important issue that is almost never dealt with in the optimization literature is the efficiency of transport systems as a whole. This is important since these efficiency measurements help governments make informed decisions regarding investments in infrastructure. On the one hand, this is linked to current performances of infrastructure networks and, on the other hand, to optimal performances of these networks. In general, current efficiency of freight transport networks is not often questioned, although severe congestion occurs at times in all freight transport networks across different geographical contexts. Furthermore, when calls for expansion of freight transport networks are made, it would be interesting to analyze current efficiencies and to connect those to proposed improvements of infrastructure and their expected impacts on efficiencies. In this paper, the efficiency issue is raised from the level of companies and sectors to the efficiency at the freight transport network level, and then related to freight transport network optimization. The research question of this paper is as follows: *'How efficient is the road and rail freight transport network in different geographical contexts and what this suggests for policy-making?'*

For this paper the focus will be on rail and road freight transport as these modes are the most important modes for continental transport and data availability is quite good. In section two, the transport networks of the most advanced Western countries Canada, Europe, and the USA are discussed. Section three discusses network efficiency and optimization theories. Furthermore, it introduces methodologies to analyze efficiency. Section four presents the data and section five presents and discusses the network efficiency results. Section six gives the conclusions of the paper and discusses further research opportunities.

2. Freight transport networks in Canada, Europe, and the USA

2.1 The freight transport network of Canada

The spatial pattern of transport in Canada is distinctive, reflecting its history of settlement and the contemporary population distribution. Most of the country's population lives within 200 km of the US border, and the transport networks have a dominant east-west orientation, from the Atlantic to Pacific

Oceans. The road, rail, airline, and inland waterway -systems all operate along a corridor that extends along the southern part of the country. The only dense transport infrastructure lies between Quebec City and Windsor following the St. Lawrence River-Great Lakes axis, encompassing the two major metropolitan areas of Montreal and Toronto. In more than 80% of the territory there is only a rudimentary transport infrastructure, with few paved roads north-south, and only two rail routes from southern Canada to Churchill, Manitoba, and Schefferville, Quebec. Road transport is concentrated at a few border crossings. For the railways the problem is less acute because both Canadian railroads (CN and CP) have acquired US subsidiaries that provide connections with major US markets. Water transport connections with the US, with the exception of the Great Lakes, are constrained either by the lack of trans-border waterways or by regulatory issues restricting cabotage on coastal short sea shipping (see Figure 1).

Figure 1. Canadian freight transport network

2.2 The freight transport network of Europe

Continental Europe has a dense network of road and rail infrastructure. Inland waterways also play a role in Europe. They can be characterized by a dense infrastructure, but this only holds for a limited number of countries such as Belgium, Germany, France, and the Netherlands in the north western part of Europe. The main land-bounded freight transport mode is road, followed by rail and inland waterways (respective market shares are 75%, 18%, and 7%). The spatial pattern of transport in Europe is concentrated in the core region encompassing the south of the United Kingdom, Netherlands, Belgium, Northern France, Germany, Switzerland, and Northern Italy, reflecting the main economic centers and population concentrations. Most transport infrastructure is oriented towards these core regions (see Figure 2).

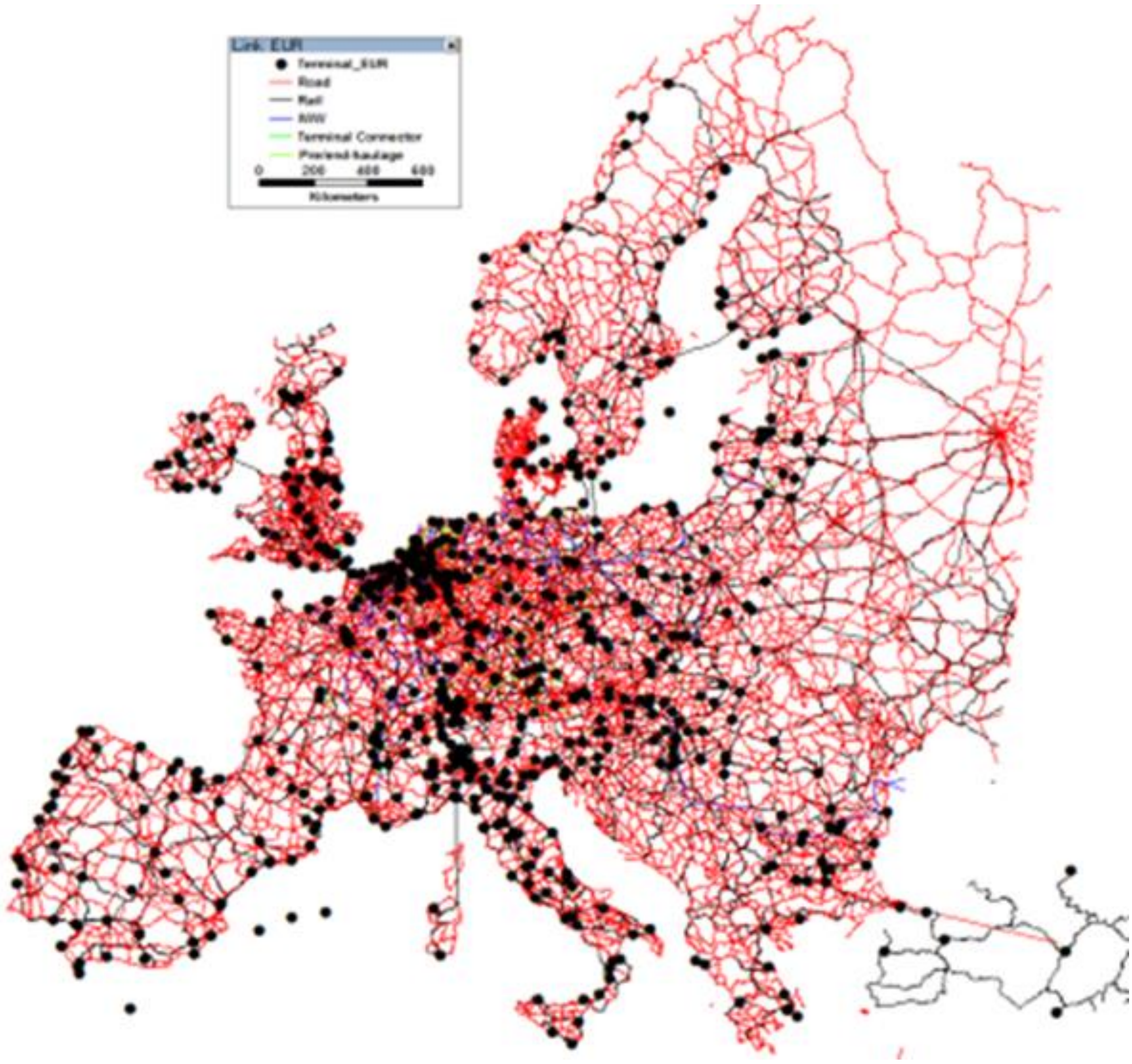


Figure 2. European freight transport network
Source: Zhang et al., 2013

2.3 The freight transport network of the USA

Due to the size of its territory and the distribution of its population, the transportation system of the United States is quite extensive. In terms of length, the country has the longest railway network, road network, and the fifth longest navigable inland waterways network in the world. Most of the transportation infrastructures are concentrated in the eastern half of the country. In the West, highways and railroads are scarcer and mostly follow an East-West axis in order to reach the most densely populated areas near the coast. Within the continental United States, 45% of the freight calculated in ton-kilometers (TKM) is moved by truck. Railways play a relatively big role compared to other countries, moving almost 30% of the freight in the US. The most impactful transportation policy in the last decades has been the deregulation of the railway transportation industry. Since the beginning of the 1980s, the volume of freight transported by rail has more than doubled because of it and its modal share has increased by more than 10%.

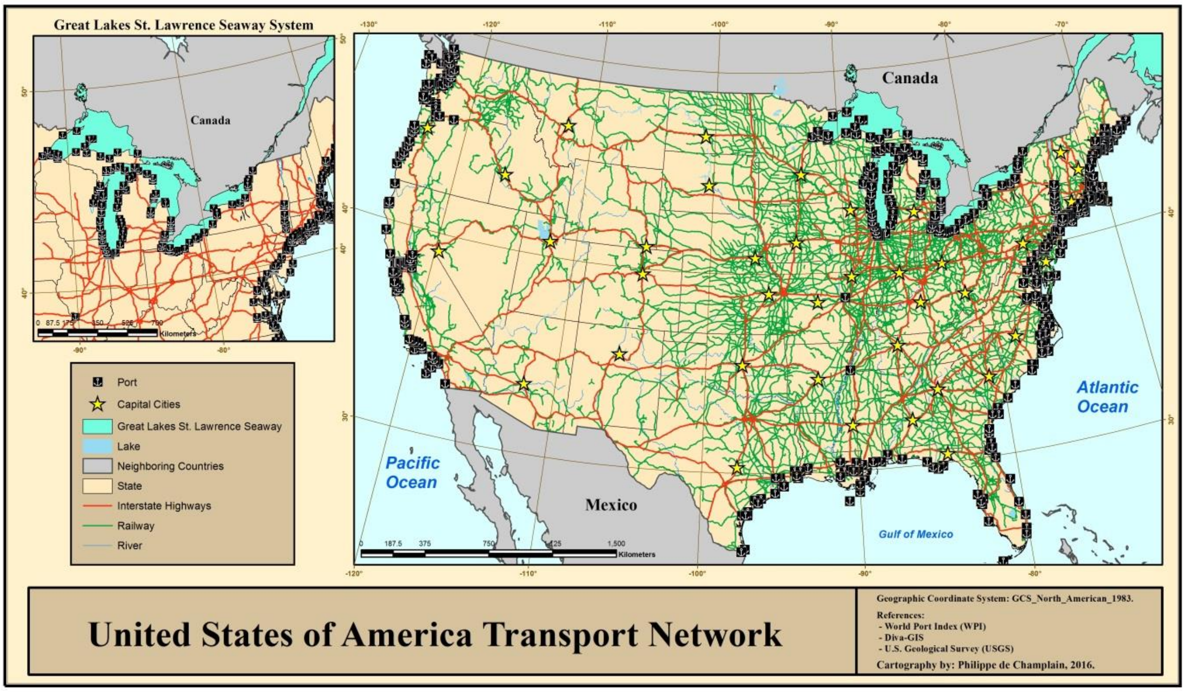


Figure 3. The United States of America freight transport network

2.4 Freight transport network similarities and differences

Trucking: when comparing the freight transport networks of Canada, Europe and the USA, several similarities and differences come to the fore. Similarities are found to be congestion, truck taxing, and truck driver shortages. In Europe, especially in densely populated areas (such as London, Paris, Brussels, Antwerp, the Randstad area, and the Ruhr area) congestion can be severe. The same problem arises in Canada, especially in cities located on the Quebec-Windsor axis. In the USA, serious problems occur on several corridors including I95 down the East Coast of the US and the I5 in California. For instance, the BOSWASH corridor has a population density at least as great as comparable regions in Europe (Rodrigue, 2004). Challenges in urban freight transport also appear to be similar. Lastly, shortages of truck drivers become an important issue although it might be (partly) countered by truck platooning. Main differences are to be found in efficiency and sustainability issues. The efficiency of trucking in Canada and the USA is much higher due to the larger trucks that are allowed to operate, while the environmental pressure on trucking is higher in Europe. *Railways:* The main differences are: track ownership, distances, traction, wagon capacity, flow type, and prioritization. In general, the distances in Europe are considerably shorter than in Canada and the USA. In North America, the tracks are owned by the operators, whereas in Europe deregulation led to open access to tracks that are maintained by state track companies. In Canada and the USA, distances between major population centers (major markets) are greater than 400-500 km which gives advantages to railroads, while in Europe shorter distances make rail freight transport less competitive. Furthermore, trains in Canada and the USA are much longer (up to 3 kms) as compared to Europe (between 600-700 meters). Traction in Europe is mainly by electricity while in North America almost all traction is by diesel-powered locomotives. The wagons in North America on average are larger than in Europe, making rail transport more efficient. Furthermore, in the USA and Canada, container trains can be double-stacked while in Europe single-stack is the maximum. For the freight flow type, rail has a focus on raw materials (such as wood, coal, grain, and oil). The interaction between freight and passengers differs remarkably between Europe and Canada and the USA. In Canada and the USA, passenger trains are of second-order importance and have to adapt their speeds to the slower freight trains. In Europe it is the other way around, freight trains show considerable delays due to the dense passenger transport service network. In such an environment it is almost impossible to operate freight transport services. The main similarity is that rail freight transport is the second important freight transport mode after trucking, although, for most European countries, the modal share of railway is much smaller than in the USA and Canada.

3. Freight transport networks: Theories and Models

3.1 Freight transport network optimization

Freight transport network optimization has a long scientific history. Crainic and Rousseau (1986) analyzed the service network design problem for multimodal multi-commodity freight transport from the angle of a single authority controlling both the service network and the movements of goods. In this respect, the authority controls and plans the supply of transportation services and the routing of the freight. The supply of transportation services consists of modes, routes, service frequencies, consolidation, and transfer policies for terminals. The problem with this model is the assumption that a single authority could be able to control and plan the freight transport network. In practice, the transportation services are offered by numerous companies which are active in different transport modes. However, from a governmental angle the network optimization might provide some input for the planning and operation of the freight infrastructure network. From a total network perspective, the objective is to reduce cost and delays and to improve service quality. Smaller freight transport networks (such as city logistics systems) can also be optimized (see e.g. Crainic et al. 2009).

Furthermore, freight transport optimization models can be used to analyze routing, transport mean size, service frequencies, and terminal locations (Crainic et al. 2009, Hsu and Hsieh 2007, Racunica and Wynter 2005). Hsu and Hsieh (2007) showed that their proposed model for container shipping could be used to determine the optimal routing, ship size, and sailing frequency. Their results showed that routing decisions tend to focus on shipping containers through a hub, as hub port charges tends to be lower or the efficiency appears to be higher. Network optimization might also present indications for locations of intermodal hubs in the freight transport network as analyzed by Racunica and Winter (2005). Recent advances in freight transport network optimization concentrate on relatively smaller-scale freight transport networks such as city distribution networks (see e.g. Crainic 2009). In these smaller scale networks, shippers, carriers and governments need to work together in a coordinated way to arrange for the freight shipments to arrive at the destination in a cost efficient way to ensure high-quality performance.

The goal of most of these optimization models is to assist and enhance the tactical and strategic planning process for the transport system under research. One of the simplifying assumptions is that there is one authority while in practice numerous actors are involved in the strategic and tactical planning of, for example, transport services and transport routes. Therefore, in addition to optimization, it is also important to be able to compare the efficiency of the current freight transport system with the suggested improvements resulting from the optimizations.

3.2 Freight transport network efficiency

In efficiency, often a distinction is being made between input, process, and output. According to Ockwell (2001), efficiency is either a minimizer or a maximizer concept. Minimizing would then be applied to inputs, whereas maximizing could be applied to outputs. Freight transport infrastructures and also freight transport services can be characterized as input minimizing industries where the focus is on cost minimization. Cantos and Maudos (2001) proved that rail freight companies that are more efficient in costs behave inefficiently with regard to revenue. In this article, therefore, the focus is primarily on inputs and less on outputs. According to Tortosa-Austina (2002), in a context of major changes, primarily due to deregulation, the estimation of efficiency depends heavily on the output specification. In Canada, Europe and the USA, this is also the case in many freight transport sectors where over the last decades deregulation has been implemented. This suggests that time series are important to analyze efficiencies of different transport sectors.

Efficiency analysis usually is performed with the final goal being efficiency improvement. The main focus in efficiency research in transport sectors has been on rail freight transport and on ports (see e.g. Wilson 1997, Farsi et al. 2005 and Cullinane et al. 2006). Wilson (1997) found for the US railroad industry that – due to deregulation – cost savings were impressive and productivity gains were large. It should be noted that this was because there existed such a large unused capacity in the regulated period, and they fired thousands of workers. Since the early 2000s the railroad companies are facing increasingly severe efficiency problems and require massive investments to upgrade tracks, equipment and operating factors (Larson and Spraggs 2000). In the meantime, the rail freight industry in Europe has also been liberalized and, here again, cost reductions and productivity gains have been realized, although to a much lesser extent than in North America. Farsi et al. (2005) concluded that unobserved firm-specific effects result in biased measurement of cost efficiency in network industries, such as rail. Cullinane et al. (2006) conclude that the multi-period analysis of efficiency in transport industries is especially important. So far, not much multi period analysis of transport industries has been performed. This gap will be filled by this paper.

3.3 Methods for measuring efficiency

3.3.1 Benchmarking efficiency

Benchmarking can provide insight into relative efficiency performance of companies or freight transport networks. To be beneficial to management, the benchmark concepts must be translated into meaningful indicators (Martland, 1992). For a detailed discussion of benchmarking we refer to Wiegmans and Donders (2007). Benchmarking is, therefore, the process of making comparisons with other companies and then learning the lessons that arise. What is interesting about the dataset that has been set up for this article is the fact that it spans two continents, covers multiple countries and covers a longer time period. When performing (relative) efficiency analysis it is important to choose a relevant benchmark and then find the most similar company in terms of efficiency (Gonzalez and Alvarez, 2001). From a theoretical point of view, the relevant benchmarks will be defined for the freight transport network benchmarking. In the efficiency analysis in this article, several benchmarks of partial productivity measures are used to present a full overview of different viewpoints on the efficiency of different freight transport networks.

3.3.2 SFA and DEA to analyze efficiency

The measurement of efficiency has received considerable attention in recent decades. Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) are two much-used methods to measure efficiency. In DEA, the most important methodological contribution has been made by Charnes et al. (1981), who developed DEA, a performance measurement technique which can be used to evaluate the relative efficiency of companies. For a full methodological explanation of SFA and DEA we refer to Cullinane et al. (2006). The disadvantages of SFA are: the need to specify a distributional form for the inefficiency term; the difficulty in accommodating multiple outputs; and, the need to specify a functional form for the production function. But, the advantages of SFA over DEA are: it accounts for noise (an error term is included to take disruptions caused by e.g. weather, luck or strikes into account); and, it can be used to conventionally test hypotheses. Given that freight transport network efficiency is not realized by a 'real' company but by a country regarded as a company, the paper uses SFA and not DEA (the relative efficiency is of second-order importance). In SFA, inefficiency is estimated as a transformation of the (estimated) parameters of a postulated distribution, and can be used to explain inefficiency. Inefficiency is then determined as the distance to the stochastic frontier and it reduces the maximum feasible output for circumstances or occurrences that are beyond the control of the terminal operator (e.g. severe weather conditions, labor unrest, misinformation, X-inefficiency, congestion, etc.); as a result of these circumstances realized freight transport network output is likely to be lower. The basic production frontier model can be written as:

$$Y_{it} = X_{yt}\beta + (V_{ti} - U_{it}) \qquad (1)$$

Y_{it} is (the logarithm of) the production of freight transport network in the t^{th} time period i (it can be both ton or ton-km); X_{it} is a kx1 vector of (transformations of) N inputs (5 in the case of the freight transport network operator) in the t^{th} time period; β is a vector of technology parameters to be estimated; and V_{ti} are random variables assumed to be iid $N(0, \sigma_U^2)$, and independent of the $U_{it} = (U_i \exp(-\eta(t-T)))$, where the U_i are non-negative random variables which are assumed to account for technical inefficiency in production and to be iid as truncations at zero of the $N(\eta, \sigma_U^2)$, and η is a parameter to be estimated. The SFA model focuses on the total ton-km variable combined with the time series running from 2000-2012. Variabes used are: Motorway length (1), Other road length (2), Lorries (3), Employment (4), Motor vehicle movements (5). The software used to calculate the efficiency output is the program FRONTIER (Version 4.1c). The program follows a 3-step procedure to estimate the maximum likelihood estimates of the parameters of the stochastic production function. First, OLS estimates of the function are obtained. Secondly, a two-phase grid search of γ is conducted. Thirdly, the resulting values of the second step are used as starting values in an iterative procedure (using Davidon-Fletcher-Powell Quasi-Newton method) to obtain the final Maximum Likelihood Estimates (MLE's).

4. Data description

The data used for the SFAs and the benchmarks stems from various sources. For the transport networks of European countries, most of the information has been taken from Eurostat. It includes data about both the European Union as a whole, and each of the individual EU member states. For the USA and Canada no database of the same magnitude exists, so information had to be collected from multiple sources. The Canadian socio-economic database (CANSIM) from Statistics Canada and the annual report Transportation in Canada from Transport Canada are the main sources of information for the Canadian transportation system. For the USA, most of the data come from the National Transportation Statistics published by the U.S. Department of Transportation. In addition, the North American Transportation Statistics Database was used to complete the information about both countries. One of the main issues about this data collection is that all the different countries do not use the same metrics for their transportation systems and, when they do, they often measure them in different ways. In the end, data about six components of these countries' road and rail transportation systems with consistent reporting for the whole timespan of the study (2000 to 2012) could be collected. These are:

1. Infrastructure length (road and railroad length),
2. Number of vehicles (Trucks, locomotives and wagons),
3. Number of enterprises in the transportation sector,
4. Employment in the transportation sector,
5. Vehicle movements (Vehicle-km),
6. Freight movements (Ton and ton-km moved).

Infrastructure length: The network length is measured as the length of transportation infrastructure in a country. For rail, this includes the total length of railway tracks including yard tracks, sidings and parallel lines. For road transportation, two metrics are taken into account: highway length and total road length. For most countries, the data were available, however, the reliability is sometimes questionable. In many countries, the length is estimated and when the estimation methodology changes, there can be large fluctuations in length.

Number of vehicles: All countries measure the number of vehicles, but the way it is measured gives rise to two issues. First, for road transport, there is a problem of comparison because European countries tend to use smaller trucks while North American countries mostly have larger ones. Therefore, the road transport system of European countries will appear to be less efficient in comparison to Canada and the USA because they operate more trucks that transport fewer goods. The inclusion of a metric for average load capacity would have resolved this issue, but unfortunately, no data on this subject could be found in Canada and the US. Moreover, Canadian and American data do not include small vans (under 4,5 tons of load capacity) because these vehicles are mixed with personal cars. Secondly, for rail transport, data has been collected on both the number of locomotives and the number of wagons. While data on the number of locomotives is fairly reliable, the data on the number of wagons in a country only includes those owned by railway companies (except in the United States).

Number of enterprises in the transportation sector: Only rail companies were included in the analysis because the definition of road transport enterprise changes too greatly from one country to another. The definition also varies for rail companies, but the differences are less significant. For Europe, a rail company is "any private or public enterprise acting mainly as a railway transport operator, an infrastructure manager or as an integrated company" (Eurostat, 2009). For the USA and Canada, a rail company includes enterprises operating trains on or owning class 1 freight railways, short or regional freight lines, commuter railways, intercity passenger railways and tourist railways. It was not possible to separate passenger companies and freight companies. Moreover, one of the main limitations of this metric is that it does not take into account the sizes of the railway companies. Large class 1 railway companies operating thousands of locomotives and owning hundreds of kilometers of track are valued as much as companies owning small regional lines. For this reason we could exclude the enterprise variable from the SFAs.

Employment in the transport sector: The number of employees working in both the road and the rail industry is available for most countries. The main issue with this measure is that it is sometimes unclear what each country actually considers to be an employee of the road or rail freight industry. It is therefore possible that some types of jobs are included in the data for one country, but not for the other. In the end however, this should not have a large impact on the quality of the data.

Vehicle movements: Vehicle movements are measured in vehicle-kilometer (vkm). It is determined by multiplying the number of vehicles on a network by the average length of their trips measured in kilometers. This indicator is only available for trucks and is available for most of the surveyed countries.

Freight movements: Finally, freight movements constitute the output data of this analysis. Two metrics are used: the payload quantity expressed in tons and the payload per distance measured in ton-kilometer (ton-km). These indicators are available for both modes and for all countries, but their reliability can be hard to assess. Payload quantity and payload-distance are estimated by countries through sample surveys. Therefore, the reliability of these data is based on the quality of those surveys. Depending on the methodology, these estimates may vary. For example, when the Bureau of Transportation Statistics of the United States Department of Transportation revised the way it estimated freight ton-km in 2012, the estimated volume of freight moved by freight in 2009 went from 1,8 billion ton-km to 3,5 billion ton-km. Table 1 depicts all data for road freight transport.

Table 1. Road freight transport data of Canada, Europe and the USA.

	Canada		Europe (27)		USA	
Data	**2000**	**2012**	**2000**	**2012**	**2000**	**2012**
Road length km (total)	1 080 321	1 080 370	3 343 912	3 812 516	6 334 735	6 573 761
- **Road length (highway)**	38 021	38 070	53 683	68 918	89 426	94 792
Number of lorries (and tractors)	575	755,2	26 466 277	31 296 037	8 517 480	8 190 286
Employment (persons)	312 900	348 708	1 999 726	2 413 948	1 405 800	1 349 400
Vehicle movements (vkm)*	24 153	28 106	290 432	338 095	330 752	433 247
Road ton-km (mln)	224 909	241 495	1 512 477	1 629 648	3 581 817	3 859 534
Total FT ton (1000 ton)	557 796	661 900	13 489 595	13 635 266	11 592 215	11 954 298

* Motor vehicle movements on national territory (irrespective of registration country)
Sources: CANSIM, Transportation in Canada, Eurostat, National Transportation Statistics, the US Army Corps of Engineers Navigation Data Center.
*Latvia, Turkey, Iceland and Former Yugoslavia were removed because of a lack of data.

Table 2. Rail freight transport data of Canada, Europe and the USA.

	Canada	Europe (30)	USA

Data	2000	2012	2000	2012	2000	2012
Rail track length (km)	74 412	63 104	330 143	296 868	271 231	261 206
Employment*	35 422	30 815	1 177 571	818 746	170 050	160 129
Number of locomotives	2 996	3 139	30 892	29 535	20 028	24 707
Number of wagons	104 748	64 373	663 634	503 433	1 380 796	1 316 185
Rail tonkm (mln)	207 000	256 600	345 659	376 108	2 257 582	2 519 377
Total rail ton (1 000 t)	239 481	285 617	1 435 552	1 500 953	1 729 208	1 826 671

* Employment in principal railway enterprises

Sources: CANSIM, Transportation in Canada, Eurostat, National Transportation Statistics, the US Army Corps of Engineers Navigation Data Center.

*Iceland was removed because of a lack of data.

Table 2 shows that Europe has many locomotives and relatively few wagons compared to the USA. Reasons for this are the large number of different countries in the EU with different regulations, so there is more need for more and different locomotives, and also the smaller size of the trains, which requires more locomotives. Over the years, liberalization in Europe has not made much impact on efficiency (or, alternatively, full liberalization has not taken place in practice).

5. Results and analysis of freight transport network efficiency

5.1 Benchmarking efficiency of road and rail

Table 3. Road freight transport efficiency of Canada, Europe and the USA.

	Canada		Europe (27)		USA	
Years	**2000**	**2012**	**2000**	**2012**	**2000**	**2012**
Indicators						
Ton/km road	516	613	4034	3576	1830	1818
Ton/km highway	14 671	17 386	251 282	197 847	129 629	126 110
Ton/lorry	970	876	510	436	1361	1460
Ton/employee	1783	1898	6746	5649	8246	8859
Ton/vehicle-km (mln)	23 094	23 550	46 447	40 330	35 048	27 592
Tonkm (mln)/km road	0,21	0,22	0,45	0,43	0,57	0,59
Tonkm (mln)/km highway	5,92	6,34	28,17	23,65	40,05	40,72
Tonkm (mln)/lorry	0,39	0,32	0,06	0,05	0,42	0,47
Tonkm (mln)/employee	0,72	0,69	0,76	0,68	2,55	2,86
Tonkm (mln)/ vehicle-km (mln)	9,31	8,59	5,21	4,82	10,83	8,91

Sources: CANSIM, Transportation in Canada, Eurostat, National Transportation Statistics, the US Army Corps of Engineers Navigation Data Center.

*Latvia, Turkey, Iceland and Former Yugoslavia were removed because of a lack of data.

Benchmarking the road freight sector leads to several conclusions. First, it can be observed that the performance of Europe is good in ton per km road length and per km highway length. This means that in Europe the infrastructure is quite heavily used compared to Canada and the USA. This might also be attributable to the geographical outline of Europe where freight arrives in ports along the European coastline and is then further transported inland to the core of Europe. This might lead to more connections to the economic hart of Europe handled by less densely-used infrastructure. The indicators those are less oriented towards the infrastructure and more towards the productivity of the freight transport service (e.g. ton per lorry and ton per employee) show that the USA performs the best. In terms of ton-km indicators, it can be observed that in all cases the USA is the best performer in terms of tons moved over the infrastructure and in terms of tons moved by lorry and by employee. Canada is second in the indicators oriented towards the freight transport service (lorry, employee, and vehicle-km) and Europe is second in the infrastructure related indicators. The infrastructures of the USA and Canada might also offer higher efficiency possibilities given their network structure with a smaller number of ports and concentration of people along the coast of the USA and along the border with the USA for Canada (as compared to Europe).

Table 4. Rail freight transport efficiency of Canada, Europe and the USA.

	Canada		Europe (30)		USA	
Years	**2000**	**2012**	**2000**	**2012**	**2000**	**2012**
Indicators						
Ton/km rail track length	3 218	4 526	4 348	5 056	6 375	6 993
Ton/locomotive	79 934	90 990	46 470	50 819	86 340	73 933
Ton/wagon	2 286*	4 437*	2 163	2,981	1 252	1 388
Ton/employee	6761	9269	1219	1833	10 169	11 407
Tonkm (mln)/km rail track length	2,78	4,07	1,05	1,27	8,32	9,65
Tonkm (mln)/locomotive	69,09	81,75	11,19	12,73	112,72	101,97
Tonkm (mln)/wagon	1,98	3,99	0,52	0,75	1,63	1,91
Tonkm (mln)/employee	5,84	8,33	0,29	0,46	13,28	15,73

* No data for private wagon for Canada which explains the rise in efficiency. The decrease in the number of wagons can be explained by the fact that wagons from class 1 railways have been replaced by private wagons
Sources: CANSIM, Transportation in Canada, Eurostat, National Transportation Statistics, the US Army Corps of Engineers Navigation Data Center.
*Iceland was removed because of a lack of data.

In the rail freight sector, the performances and their differences are more striking. In terms of the ton-related indicators, it can be observed that the USA performs better then Canada and Europe. This also holds for the ton-km related indicators. Overall, it can be concluded that the result for road freight transport show some mixed results, but depict a clear performance difference between Canada and the USA versus Europe. For rail, the indicators linked to infrastructure (rail track length) deserve a further analysis because in North America freight has priority over passengers which means that most of the infrastructure length can be attributed to freight. In Europe, on the contrary, rail passenger transport has priority over freight meaning that the majority of track length is attributable to passenger transport. The indicators that are more 'productivity' oriented (locomotives, wagons and employees) all do show that the USA is more productive than Canada and Europe. This is logic given the long-term tradition of liberalization in North America resulting in more efficiency. Furthermore, the different gauges, electricity voltages, and different safety systems do not encourage efficiency and productivity in the member states of the European Union.

5.2 Road Stochastic Frontier Analysis

In the Stochastic Frontier Analysis applied to the road freight transport sector, the data are used to build SFA models and compare the respective efficiencies of countries. To obtain a sufficient number of countries (and thus a sufficient number of Decision Making Units DMUs), Europe has been split in the individual countries. On the one hand, this leads to a quite wide diversity in DMUs. On the other hand, it is needed while otherwise the number of countries would be only three which is insufficient for the analysis. When interpreting the results this needs to be taken into account. For road freight transport, the following inputs have been used: road length km (total), road length (highway), number of lorries (and trucks), the employment, and the vehicle movements. One SFA model has been estimated: the model with the dependent variable being the ton-km. The model has been estimated using the time series ranging from 2000 to 2012.

Table 5. Road freight transport efficiency ranking, 2000-2012*

Road transport technical efficiency estimates, 2000 - 2012					
Ranking	**Country**	**Efficiency (Tonkm)**	**Ranking**	**Country**	**Efficiency (Ton)**
1	Poland	0,996	1	Netherlands	0,945
2	Netherlands	0,991	2	Finland	0,944
3	United Kingdom	0,990	3	Belgium	0,936
4	Germany	0,989	4	Sweden	0,909
5	Italy	0,971	5	Austria	0,907
6	Canada	0,964	6	Switzerland	0,903
7	Belgium	0,918	7	Czech Republic	0,897
8	Romania	0,915	8	United Kingdom	0,896
9	United States	0,911	9	Germany	0,891
10	France	0,899	10	Poland	0,882
11	Czech Republic	0,892	11	Canada	0,882
12	Spain	0,849	12	Norway	0,850
13	Sweden	0,845	13	Ireland	0,839
14	Austria	0,822	14	Denmark	0,833
15	Finland	0,793	15	Romania	0,833
-	Mean	0,752	16	Italy	0,813
16	Hungary	0,747	17	Hungary	0,805
17	Portugal	0,740	-	Mean	0,770
18	Slovakia	0,714	18	Portugal	0,766
19	Denmark	0,693	19	Slovakia	0,756
20	Norway	0,639	20	France	0,752
21	Lithuania	0,626	21	Spain	0,729
22	Bulgaria	0,599	22	Bulgaria	0,690
23	Ireland	0,595	23	United States	0,678
24	Switzerland	0,563	24	Croatia	0,631
25	Slovenia	0,536	25	Slovenia	0,561
26	Croatia	0,516	26	Luxembourg	0,495
27	Luxembourg	0,491	27	Lithuania	0,479
28	Estonia	0,391	28	Cyprus	0,442
29	Cyprus	0,205	29	Estonia	0,397

*Latvia, Turkey, Iceland and Former Yugoslavia were removed because of a lack of data.

This analysis of road freight transport network efficiency shows that Poland, the Netherlands, the UK, Germany, Italy and Canada are efficient (all above 95%) in ton-kms as compared to the other countries. Poland and the Netherlands are important countries in road freight transport while the UK, Germany and Italy are economic important countries in Europe which might result in large freight flows being transported efiicienctly by road in these countries. A comparable reasoning might hold for Canada. The overall efficiency is quite good with a mean of 0.75. Also the USA performs quite efficient (0.911). For road freight transport policy this suggests that for the top fifteen efficiency performers the road freight transport in these countries might be performing quite optimal. A further increase in efficiency performance might be difficult to realize. The SFA analysis for the road network gives the following MLE results (Table 6 ton-km).

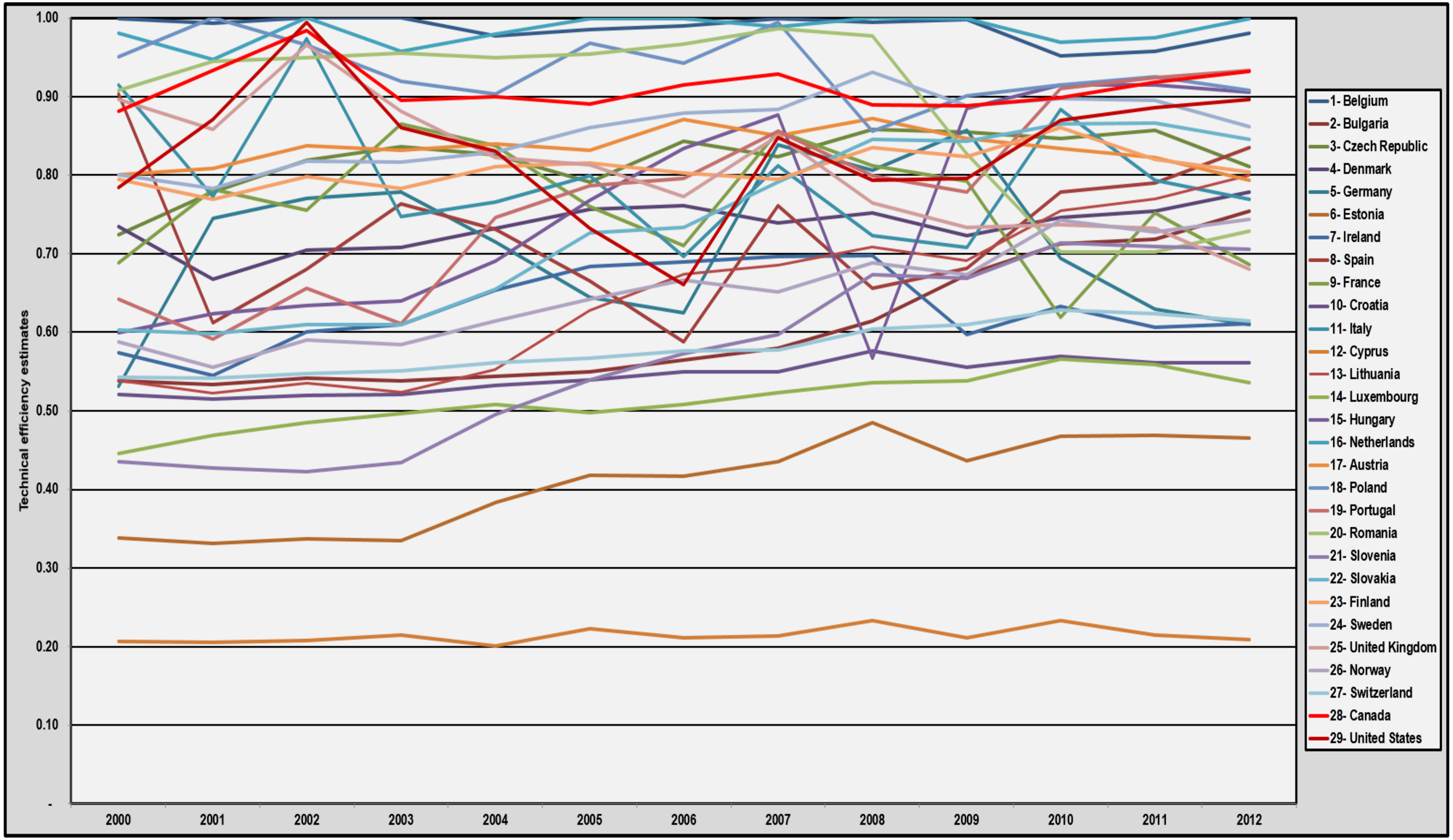
Table 6: SFA results for road network ton-km efficiency, 2000-2012

	Coefficient	Standard-error	t-ratio
Beta 0 (tonnage by kilometer)	4,65E+00	3,13E-02	1,49E+02
Beta 1 (motorway length)	1,75E-05	6,20E-06	2,83E+00
Beta 2 (other road length)	-2,18E-07	1,08E-07	-2,02E+00
Beta 3 (lorries)	1,01E-07	4,25E-08	2,39E+00
Beta 4 (employment)	7,06E-07	3,90E-07	1,81E+00
Beta 5 (motor vehicle movements)	-5,59E-08	6,53E-07	-8,56E-02
Sigma-squared	7,51E-02	1,29E-02	5,81E+00
Gamma	8,97E-01	4,12E-01	2,18E+01

Notes: mu is restricted to be zero; eta is restricted to be zero; log-likelihood function = 0.30665854E+03; LR test of the one-sided error = 0.79575347E+03

The number of number of iterations was 10, the number of cross-sections was 29, the total number of time periods was 13, leading to a total number of observations of 377. The results show that important variables for the efficiency of road freight transport (ton-km) are difficult to distinguish in such a long time series (low coefficients). From the respective inputs, employment appears to be most important, followed by motorway length and lorries. Other road length and motor vehicle movements appear to influence efficiency negatively. The results might be influenced by the large fluctuations caused by the financial crisis of 2007-2008 and its carry over effects into 2009 and 2010 although this might be solved in further research by lengthening the data period.

Figure 1: Yearly road tonnage by kilometer efficiency SFA with 29 countries, 2000 – 2012*



*Latvia, Turkey, Iceland and Former Yugoslavia were removed because of a lack of data.

The efficiency models per year for ton-km ranging from 2000 to 2012 result in the above Figure 1. Several conclusions can be drawn based on this figure. First, the overall differences in road freight transport network efficiency (roughly between 50%-99%) have remained the same although fluctuations over the years for the individual countries can be considerable. Secondly, efficient countries in general remain efficient over the years. Especially Canada and the USA are efficient over the years, but Belgium and the Netherlands are even more efficient and also Poland do show high efficiencies over the years. Both Canada and United States perform quite efficient and this might be partly caused by the two countries sharing a similar road transportation industry. The U.S. Interstate highway network and Canada's highway system both have the same minimal width and basic configuration so 53 feet trucks can circulate on the continental network without requiring any special permit. Tonnage by kilometer is proportionally equivalent with both, only at a ratio of 1 to 10 considering Canada has only a tenth of the U.S. population. This suggests that individual country policy should aim for good connections between physical, legal, and operational networks. Belgium and the Netherlands are countries that might be expected to be efficient as both have a large port and strong transport links to and from the hinterland. Overall, the figure shows that inefficient countries have remained inefficient over the years. This calls for further detailed research into the freight transport policies of these countries of the last decades.

5.3 Rail Stochastic Frontier Analysis

In the Stochastic Frontier Analysis applied to the rail freight transport sector, rail data have been collected and used to build the SFA model and to compare the respective country efficiencies. Europe has been split into the individual countries to obtain a sufficient number of countries for the analysis. The following inputs have been used for the rail freight transport efficiency: rail track length km (total), the number of locomotives, the number of wagons, the number of enterprises, and the employment. Ton-km has been used as output. Table 7 depicts that the top 5 consists of Latvia, Canada, Lithuania, Austria and Sweden. Latvia and Lithuania are very small countries and might have a limited rail network relative to large freight flows to neighboring countries. Furthermore, they are linked to the Russian railway system which has a different gauge when compared to Europe. Canada’s rail infrastructure is concentrated in the South and has good connections to the USA. The freight strength of Canadian railroads is the shipments of grain, coal, oil, potash etc. to West Coast ports, especially Vancouver, where 2km+ long trains are deployed. There are also a lot of Double-Stack (DS) container trains going to Vancouver and Prince Rupert. Also Sweden’s rail infrastructure is concentrated in the Southern part of the country. Austria is a country dedicated to rail freight transport and also its main rail carrier is known for its efficient operations (Wiegmans and Donders, 2007).

Table 7. Rail freight transport efficiency ranking, 2000-2012

Rail transport technical efficiency estimates, 2000 - 2012					
Ranking	Country	Efficiency (Ton)	Ranking	Country	Efficiency (Tonkm)
1	Germany	0,978	1	Latvia	0,991
2	Canada	0,972	2	Canada	0,990
3	Poland	0,864	3	Lithuania	0,979
4	Austria	0,763	4	Austria	0,978
5	United Kingdom	0,760	5	Sweden	0,970
6	Czech Republic	0,740	6	Switzerland	0,937
7	Switzerland	0,679	7	Poland	0,896
8	France	0,670	8	Estonia	0,870
9	Estonia	0,668	9	Slovakia	0,850
10	Italy	0,660	10	Czech Republic	0,831
11	Sweden	0,652	11	Finland	0,830
12	Belgium	0,647	12	Italy	0,786
13	Latvia	0,641	13	Turkey	0,780
14	Lithuania	0,619	14	Romania	0,768
15	Romania	0,603	15	Belgium	0,749
16	Slovakia	0,600	16	Germany	0,706
17	Hungary	0,568	17	Netherlands	0,694
18	Finland	0,563	18	Spain	0,689
-	Mean	0,541	19	Hungary	0,688
19	Netherlands	0,526	-	Mean	0,688
20	Norway	0,454	20	United Kingdom	0,679
21	Spain	0,422	21	France	0,640
22	Turkey	0,405	22	Bulgaria	0,585
23	Bulgaria	0,394	23	United States	0,583
24	Slovenia	0,388	24	Slovenia	0,571
25	Croatia	0,350	25	Norway	0,532
26	Luxembourg	0,333	26	Croatia	0,512
27	Portugal	0,309	27	Portugal	0,486
28	Denmark	0,285	28	Denmark	0,485
29	United States	0,284	29	Greece	0,268
30	Greece	0,195	30	Former Yugoslav	0,262
31	Former Yugoslav	0,186	31	Luxembourg	0,246
32	Ireland	0,126	32	Ireland	0,172

*Iceland was removed because of a lack of data.

The SFA analysis for the rail network gives the following MLE results (Table 8, ton-km).

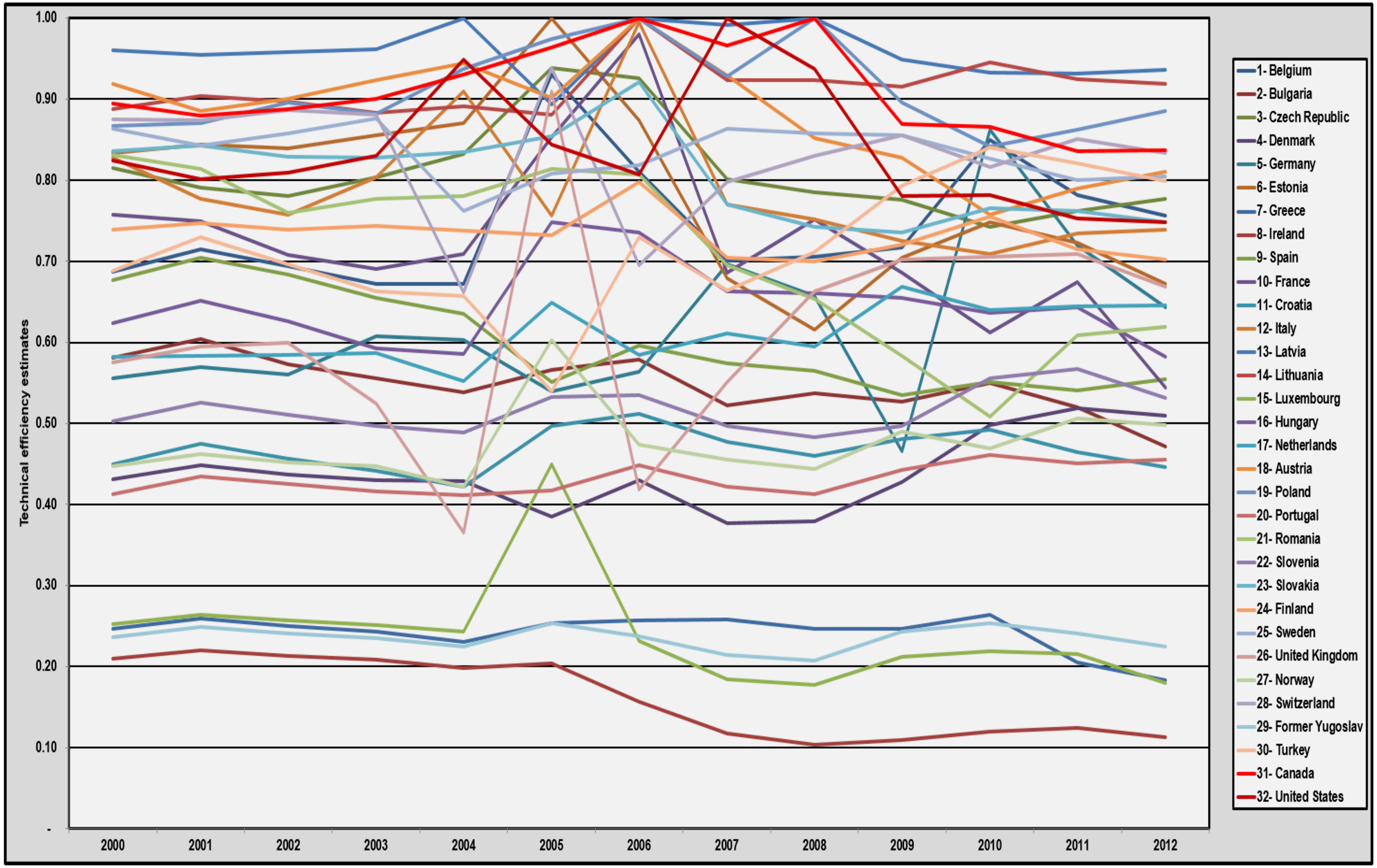
Table 8: SFA results for rail network tonnage by kilometer efficiency, 2000-2012

	Coefficient	Standard-error	t-ratio
Beta 0 (tonnage by kilometer)	4,03E+00	9,32E-01	4,32E+00
Beta 1 (rail track length)	1,78E-05	1,60E-05	1,12E+00
Beta 2 (number of locomotives)	2,64E-05	5,96E-05	4,43E-01
Beta 3 (number of wagons)	-2,27E-06	6,23E-06	-3,64E-01
Beta 4 (enterprises)	6,95E-04	5,80E-03	1,20E-01
Beta 5 (employment)	1,20E-06	1,15E-05	1,05E-01
Sigma-squared	1,82E-01	9,99E-01	1,82E-01
Gamma	8,73E-01	3,61E-01	2,42E+00

Notes: mu is restricted to be zero; eta is restricted to be zero; log-likelihood function = 0.20182509E+03; LR test of the one-sided error = 0.92342364E+03

The number of iterations was 7, the number of cross-sections was 32, the total number of time periods was 13, leading to a total number of observations of 416. Important variables for the ton-km efficiency are difficult to see as the coefficients for the time period are quite low. When the years are compared individually then the employment, the number of enterprises and the rail track length come forward as important variables influencing efficiency. The efficiency of the rail freight transport networks of the respective countries shows a wider efficiency range (when compared with road) in performance per country. In general, from Figure 2 it can be seen that good performers over the years keep on performing well (and bad performers in general stay bad performers). Overall, the changes in efficiency in rail freight transport are much larger when compared with road transport. In ton-km efficiency, Latvia, Lithuania, Poland, Canada, and Switzerland can be found at the top. The position of the small countries Latvia and Lithuania might be explained by their close connections with Russia. In the Figure, Canada performs slightly better than the United States for a couple of reasons. First, Canada assembles the longest train convoys in the world by using two locomotives. Since most rail freight moves on the Quebec-Windsor corridor and between the ports of Halifax/Montreal and Vancouver, the mainline of the network is bound to be used extensively with double-stack train convoys to achieve economies of scale. Furthermore, considering the modeling, the number of enterprises is an important variable. Canada only has three class 1 rail companies (CN, CP and the American company CSX). For three railway companies to dominate the Canadian market does make it far more efficient in modeling terms than for its American counterpart with its numerous railway companies (BNSF, CSX, Norfolk Southern, etc.). For policy making this might suggest to not enable too much competition in rail freight transport as this reduces the possibilities for realization of scale economies. This is remarkable given the general-hold belief that liberalization leads to more efficiency. This can be further specified into liberalization leading to more efficient transport companies, but to less efficient freight transport systems. Also, Canada has undertaken a massive railway network restructuring since 2010 where a lot of "inefficient" railway segments were either shut down or relegated as short lines. Trucking is now filling the gap between more remote markets and the mainlines. In the U.S., most major railways converge to Chicago where trains are reassembled and then set for their final destination. This is more of a traditional hub and spoke network and it leads to more "wasted" kilometers in the U.S. than in Canada simply because of the different network configuration. In Europe, many relatively smaller companies exist in the rail freight sector, not leading to efficiency. For policy-making in rail freight this might suggest that encouraging cross-border mergers and acquisitions leading to larger rail freight companies might be desirable. In addition, several hub-and-spoke systems exist all trying to deliver to the economic core regions in the center of Europe. Switzerland is in the core of Europe and has a clear rail freight policy and its high efficiency score underlines that the policy is working. At the bottom of Figure 2 small countries such as Ireland, Greece and Luxembourg are found. In Figure 2, also different periods can be distinguished. First, after 2003 the burst of the dotcom bubble caused serious fluctuations in the volumes and thus also the efficiencies of the respective countries. Secondly, the financial crisis of 2007-2008 caused serious fluctuations in transported rail freight volumes and thus also in efficiencies. The periods before 2003 and after 2010 show quite stable developments in efficiency scores of the countries. For policy-making this suggests that – on the short-term – large efficiency fluctuations should not deserve too much attention from policy-makers. Countries should develop steady goals for the long-term and not get too overenthusiastic of high efficiencies or too depressed from low efficiencies. Connect the inputs and output to the long term goals of rail freight and then check if adaptation is needed.

Figure 2: Yearly rail tonnage by kilometer efficiency SFA with 32 countries 2000 – 2012*



*Iceland was removed because of a lack of data.

6. Conclusions, discussion and policy implications

The focus of this paper has been on the efficiency of road and rail freight transport networks in different geographical contexts. The main research problem has been analyzing these efficiencies and derive governance suggestions from the results. In the paper, the networks are compared, theory on optimization, efficiency and methods is discussed, a database has been constructed and the efficiencies of the respective countries are compared.

The initial networks of the three regions under analysis differ considerably: the network of Canada is mainly North-South oriented, the network of the USA is East-West oriented, while the European network is oriented from the borders to the core of Europe and this should be taken into account when analyzing efficiencies and formulating policies. This means that policies that work in the U.S. and Canada are no guarantee that these policies will also work in Europe or vice versa. For example, policies encouraging double-stacked long container trains working in North-America will not be transferrable to Europe. When comparing the road freight transport networks of Canada, Europe and the USA, several similarities and differences come to the fore. First, the three countries are similar with regard to truck driver shortages, truck taxing and congestion. The countries differ in their approach towards sustainability and efficiency. The environmental pressure on trucking seems to be higher in Europe (although this might differ among member states), while the efficiency of trucking in Canada and the USA seems much higher due to the larger trucks that are allowed to operate. For railways, the main differences are: distances, traction, wagon capacity, flow type, and prioritization. The main similarity is that for all countries rail freight transport is the second important freight transport mode after trucking.

The benchmarking results for road indicate that Europe uses its infrastructure quite efficiently in terms of ton and ton-km per km infrastructure. In terms of the efficiency of the companies using the infrastructure (ton/lorry, ton per employee) the United States are more efficient than Europe and Canada. Overall, for rail it can be concluded that the United States do possess quite an efficient system. In terms of policy-making, Europe might consider which aspects of the efficiency of companies it might want to implement in which way in the European rail freight system. Efficiency of rail freight companies might be encouraged, however, efficiency of the rail freight system should be treated differently.

In the SFA road model for the whole period (2000-2012), it shows that Poland, the Netherlands, the UK, Germany, Italy and Canada are efficient (all above 95%) in ton-kms. Also the USA is quite efficienct in ton-km. Overall the efficiency analyses show that many countries are already quite efficient (the overall efficiency is quite high with a mean of 0.75 (ton-km)). Main determinants of the efficiency in ton are difficult to determine given the low coefficients of most variables in a long time period. This connects well with the balancing relationship between investing in infrastructure and economic growth that follows from or induces these investments. Infrastructure length negatively impacting efficiency is probably because the larger a country is and the lower its population density is, the more infrastructure it needs and the less it is efficient.

The efficiency of the rail freight transport networks of the respective countries shows much more difference in performance per country over the years. Also rail efficiency depicts that in general good performers over the years keep on performing well (and bad performers in general stay bad performers). Latvia, Lithuania, Switzerland, Canada and Poland perform well in rail ton-km. Although the USA is not in the top 5, its performance is quite good over the years. In Europe, overall, liberalization of rail freight transport does not show to have much impact in the sense that marked improvements in efficiency for individual countries can be observed. Also in rail freight efficiency it shows that efficiency levels can be improved and that differences between countries are considerable.

From the analysis, several implications for managerial practice can be derived. In road freight transport, all three case study areas are worthwhile to operate in. In Europe, however, several individual member states do show low efficiencies (for rail or road) suggesting that these countries might be relatively more difficult to operate in. The causes do not follow from the efficiency analysis but could be regulation or infrastructure related, but this needs more research. On the other hand, these member states might show potential for improvement and thus be interesting to transportation businesses if they show potential in terms of businesses and customers. The focus on sustainability in Europe on the one hand might be regarded as a negative influence on business performance as regulation will add additional limitations to transport operations. On the other hand, it could be seen as a chance and if sustainable business models are developed these might be 'exported' to the USA and Canada. Rail freight transport in the USA and Canada offers a level playing field for all transportation businesses. In Europe, rail freight efficiency shows quite some room for improvement. In Europe, deregulation has not worked out very well so far (because of limited interoperability of transport infrastructures across borders, Witte et al., 2012) and might prevent transportation businesses to start operations.

Suggestions for further research can take different directions. First, it would be interesting to also build models for IWW. Furthermore, IWW and short sea shipping need to be integrated (in terms of data) so as to make them comparable. Secondly, there might be opportunities for a combined model that integrates the different freight transport modes. This might reveal that countries with only two transport modes (rail and road) are more efficient than countries with three or four modes (such as Europe).

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