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Belt and Road Initiative and Railway Sector Efficiency—Application of Networked Benchmarking Analysis

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Abstract: In recent years, there has been a lot of attention paid to China's Belt and Road Initiative (BRI), which aims to invest in better connecting China, South-East Asia, Central Asia, the Middle East and Europe. As countries that share the same continent, and are in many cases without proper sea connection (landlocked), the key mode of long-distance transportation is railways. However, numerous countries have different levels of past investments, labor productivity, transportation profile, and culture surrounding railways, and all of this leads to differences in overall efficiency. In this research, we apply well established and widely used data envelopment analysis (DEA) to evaluate the longitudinal efficiency of railway operations. This is the first time such an analysis is completed on the Belt and Road member countries. Efficiency itself hardly improved at all during the examination period, whether in passenger and freight or just freight transports. China itself represents an important benchmark for many countries, as its efficiency is all the time highest possible. In the network benchmarking analysis, it was shown that China, Estonia, Latvia, and Israel are often proposed benchmarks for the others to increase their efficiency in the future. From efficiency development perspective, Chinese railway sector is beneficial and more balanced to be benchmarked as compared to other significantly sized railway countries, like India or Russia.

Keywords: belt and road; railways; efficiency; networks; benchmarking

1. Introduction

In the six years since China first announced its ambitious One Belt and One Road (OBOR) program (or just Belt and Road Initiative, BRI), we have witnessed numerous implementation plans, project proposals, infrastructure project deliveries, and new logistics products being released (like scheduled container trains to different European cities). For example, He [1] introduced a plan to develop a high-speed railway connection from China through Central Asia to Iran, with the potential to attract 60 million people from various different countries to benefit from faster traveling and better freight connectivity. We already know that China is building and developing logistics infrastructure to make the port of Gwadar an important logistics hub in Pakistan [2,3]—this not only concerns the port, but also a significant amount of hinterland infrastructure construction too. This infrastructure will serve increasing trade and transit between Pakistan and China. Similarly, China is constructing a railway connection from its city of Kunming to Vientiane, Laos, which provides the opportunity to continue railway construction down to Bangkok as well as to Kuala Lumpur and Singapore [4]. Railway projects also concern Eastern Europe [5,6], like connecting Budapest (Hungary) with Serbia and a future plan to eventually reach the port of Piraeus in Greece (nowadays in a concession contract to a Chinese company, COSCO) through Macedonia. Direct container trains from China to Eastern, Northern, Central, and Southern Europe have also been implemented in the railway sector—these have been supported financially by the OBOR program, however, their volumes have been significantly increasing [4–8].

It should be noted that one motivation for the OBOR program is to develop Central and North-West parts of China, areas that have been lacking in development compared to other more coastal regions [9]. The OBOR program has its risks, but from an international railway research perspective it is a very interesting long-term project, and we need to know more about the potential positive implications e.g., on efficiency and whether the Chinese railway sector has that much to provide for other OBOR countries. From earlier research, we do know that the Chinese railway system is one of the most efficient in the world [10,11], and is strong in both the passenger and freight sub-segments (the latter has traditionally been stronger in worldwide comparisons). We also know that many former Soviet and Eastern European countries have been struggling with railway sector efficiency. However, it would be of interest to know how this Chinese leadership holds up today: What is its relative performance compared to other OBOR countries? Many OBOR countries have a long tradition of serving transit trains (e.g., Kazakhstan, Mongolia, Russia, Belarus, and Ukraine), and they could have even higher efficiency standards. Is China's performance in the railway sector so exemplary that it would be worthwhile for others to use it as a benchmark and implement projects as such? This research uses data envelopment analysis to answer these two stated research problems [12].

DEA multi-variable efficiency analysis, which uses linear programming to establish frontiers, will give relative efficiency values for different decision making units (DMUs). In this research, DMUs are countries and their respective railway systems. DEA efficiency analysis methodology also enables us to detect the best benchmark alternatives for lower performance countries. To analyze these benchmark alternatives throughout the years, we used network theory and specific programs to gain information from important and central key frontier countries. This is yet another smart application, together with DEA efficiency analysis, contributing to the OBOR area, and to this special issue of *Sustainability*. Until today, no research has applied DEA for railway sector countries in OBOR area, and using network theory to analyze benchmarks is also a new seminal construct. This research thus fills the gaps in the knowledge concerning railway efficiency of OBOR countries, and also develops new analysis methods for benchmarking. Our analysis is based on the most recent statistics from UIC [13] (International Union of Railways, or in French "Union Internationale des Chemins de Fer"), but these were compared to earlier World Bank [14] railway sector database data (to increase research validity).

Railways hold the key to sustainable growth in the future, even in situation that global trade slows down and recessionary forces emerge in countries and communities [15]. For the UK it has been forecast [15] that until 2055, freight and high-speed railway passenger transport will increase substantially (volume growth has been estimated to range from 0–300%). In emerging countries, the growth experienced could be even higher as urbanization continues, e.g., in India and China. High-speed railway (or just faster passenger transport) will also increase the transportation capacity of railways in general, which will enable better customer experience at affordable prices and enable further passenger transportation growth. However, passenger transport has historically not been that profitable (only in some parts of Japan and China), and has typically required public support [16]. In turn, freight transport has been analyzed as producing profits and shareholder value if it predominates to the extreme (lots of freight and not that much passenger transport), as in Canada and the USA [17]. Passenger transport, however, holds significant potential, as there is a lot of work to be done to integrate local urban transport in cities with long-distance transport [18], and this integration is especially fruitful in emerging economies (many of the OBOR program countries are in this category). As Stanton et al. [19] argue, to encourage people to favor rail transports, this transportation mode should be more flexible for customer needs (e.g., instead of selling trips from A to B, it could be sold by time or distance), and digitalization and mobile Internet should be made available to serve versatile needs of passengers.

This research is structured as follows: A literature review concerning the railway sector and OBOR is presented in Section 2. Research methodology, software, and data sources used follow in Section 3. An empirical data analysis of World Bank [14] and UIC [13] data with DEA is presented in Section 4. Network analysis is presented in Section 5. Research is concluded in Section 6, where we also propose new avenues for further study in this area.

2. Railway Research of the Belt and Road Initiative

Currently, China has the world's largest high-speed rail infrastructure, and it is still in its enlargement phase. Inaugurated in 2008 (some trial tracks exist from early 2000), this network has been expanding, and was 25,164 km long at the end of 2017 [20]. Expansion will continue in the forthcoming years, although it is slowing slightly. The success of this massive infrastructure project could be due to passenger transportation numbers (1.75 billion passengers in 2017) and competitiveness of rail among other passenger transportation modes (41% share in 2017; [20]). Li et al. [21] estimated that completed railway projects in China were having indirect economic spillover effects of 14% from total effects. Gao et al. [22] found that the operating efficiency of China's railway enterprises in 2007 was rather high (between 0.8–1.0). Li et al. [23] found that China's railway companies have had significantly higher overall technical efficiency after the reform and introduction of the high-speed railway. The structural reform of the railway industry and the successful popularization of high-speed rail have significantly improved the technical efficiency of the railway industry in China.

In OBOR railway research, high-speed railways have special status, and plans exist to expand these from China using the hinterland to the south, south-west, west, and north-west, eventually reaching Eastern Europe [1,24,25]. It is not only in passenger transport that speed improvements are desired; He [1] also stated that container freight trains should reach a maximum speed of 120 km/h in this same network. Shao et al. [25] built a decision making model for the most potential railway sections to be developed further in OBOR; they were mostly tied to Russia domestically, but also internationally (e.g., from Russia to China, Belarus, Ukraine, Georgia, and Latvia). Other favorable connections to develop further were those starting from China, for example those reaching Russia, India, Myanmar, and Nepal. There were also other railway sections with high potential that originated neither in Russia nor China, like between Afghanistan and Pakistan, Afghanistan and Iran, Belarus and Poland, Iran and Iraq, and Poland and the Czech Republic. However, it should be emphasized that OBOR is not only about future plans, as many high-speed railway projects are already at completion [4,5,25], including Hungary–Serbia, China–Laos, Moscow–Kazan, and China–Mongolia. It is still too early to evaluate the OBOR program's effectiveness and implementation success overall, however, it could be said that it will change the railway system in OBOR countries, and will possibly bring significant efficiency improvements through new management systems and modern technologies being implemented.

A lot of media attention has been received by the OBOR container freight trains operating between Europe and China, enabled by the single land mass of the continent. This connection has mainly been operating between Poland/Germany and China [4–7]. Connectivity also exists to Spain, UK, Finland, and Hungary, to name a few. Current volume at maximum is one or two hundred thousand Twenty-foot Equivalent Unit (TEU) containers (p.a.). This is actually at the same levels as the Trans-Siberian Railway (TSR) was in the early 1980′s for Japanese containerized cargo reaching the Middle East and Europe, as well as what Finland achieved together with Russia, South Korea, Japan, and China in 2004 [26,27]. A troublesome part of the equation in this connection is the cost level—it has historically always been financially supported, in one way or another. In the Soviet and Russian TSR booms connected to Japan and Finland, prices of international transit were so competitive that it simply became financially attractive to use. As Russian railways' tariff lists were corrected in 2005, the entire volume disappeared from the Finnish connection in matter of months. Currently, China is financially subsidizing these container trains to Europe [7]—this practice has enabled freight volume growth and taken cargo away from air freight (leading to much less pollution), but it is an open question whether container trains will be sustainable if governmental support is not so significant in the future. However, the cargo being transported from China to Europe is interesting and highly value added—electronics of such well-known companies as Hewlett Packard, Samsung, and Foxconn [4,28]. These originate from new manufacturing locations in China, which are now increasingly in the mid and western parts of the country. This is one part of the Made in China 2025 program [29]. In addition, the direct railway linkage between China's bigger cities is new and improved, saving more than 1000 km in railway distance as compared to TSR times and enabling much faster connectivity [8]. Earlier land bridge operations used to travel through the entire TSR, and were eventually shipped to final location using the sea ports Vladivostok or Nakhodka. A lot of investments have been needed to achieve functional direct railway access to China, not only at the border-crossing station Khorgas [1], but in the entirety of Kazakhstan [30], and the railway section of north-west China [31]. He [1] sees the two changes of gauge, which take place between China and Kazakhstan and Belarus and Poland, as the main constraint for land bridge container trains,. This consumes time and incurs additional costs.

Another avenue in OBOR railway research of is the buildup of railway–sea port infrastructure. Chinese companies own now numerous concession contracts to sea ports, like those of Greece (Piraeus), Sri Lanka (Hambantota), and Pakistan (Gwadar). These all require railway and pipeline infrastructure in order to be able to handle significant volumes. Railway will also give an opportunity to enlarge the hinterland area of sea ports—this is planned, e.g., to Piraeus sea port (Greece), where future hinterland is trying to reach Eastern Europe, and eventually Germany [5,6]. Similar, but even larger-scale OBOR investments are planned to be made in Pakistan, worth 46 billion USD [2,32]. Again, these will shape the railway sector and possibly increase efficiency in OBOR countries.

3. Research Methodology and Data Sources Used

The efficiency measurement models used in this study are both input oriented, where in the World Bank [14] data-based passenger and freight output model there are five inputs included (all inputs of Figure 1) and two outputs (passenger-km and freight ton-km), while in the two freight output model (freight tons and ton/km) the number of inputs is four (not including passenger coaches). Figure 1 illustrates further the variables and models used for the first dataset of this study. In these models, the number of locomotives is the total sum of different power use engines (electric, diesel, and in some cases steam). Passenger coaches and freight wagon amounts are taken separately for the passenger and freight output models, while in the two freight output model, passenger coaches were excluded. Staff and railway network route length are separate input factors as well. The World Bank [14] database reports performance in country level, and, typically, only includes governmental operator's data, however, in some cases the number might also include private operators (like in the data from the USA). The World Bank [14] database is already a bit outdated, with its coverage ending in 2005 and 2006 (from the latter year there is limited data availability).

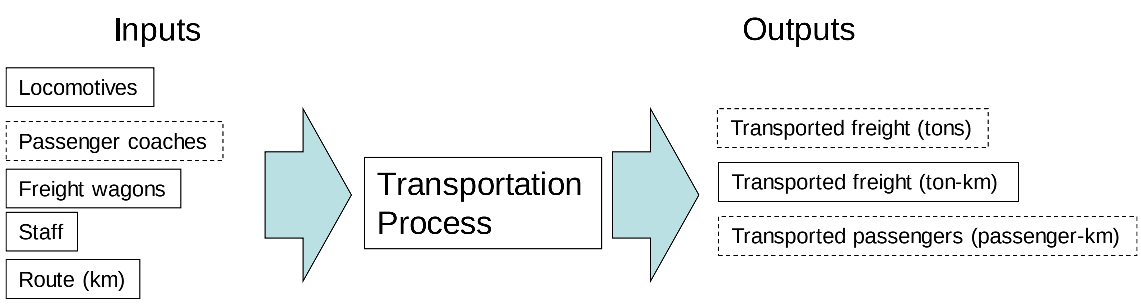

Figure 1. Models used in this study for World Bank data (dashed lines indicate that variable is used only in one model, while continuous lines indicate use in both efficiency measurement models).

For UIC, data-based DEA efficiency measurement models are similar to the above, with the only change in the measurement of number of locomotives. In UIC (Figure 2), locomotives are divided into two different classes, that of diesel and electric based traction (due to the lack of DMUs to be analyzed in 2012–2016, in the passenger-freight model locomotive amount was summed together as frontier could not be analyzed otherwise). Other measures were the same as in the previous models. Thus, the passenger and freight output models (passenger-km and freight ton-km) include all six inputs of Figure 2, while the two freight output model (freight tons and ton-km) excludes passenger coaches as input. UIC [13] reports data on a country level, but it is not necessarily limited only to governmentally-owned operators, as in some cases major private sector representatives are also included. However, in general, the UIC [13] reports only governmentally owned companies, as these companies originally established this entire organization. UIC data is annual, as is World Bank data, but it extends to 2016.

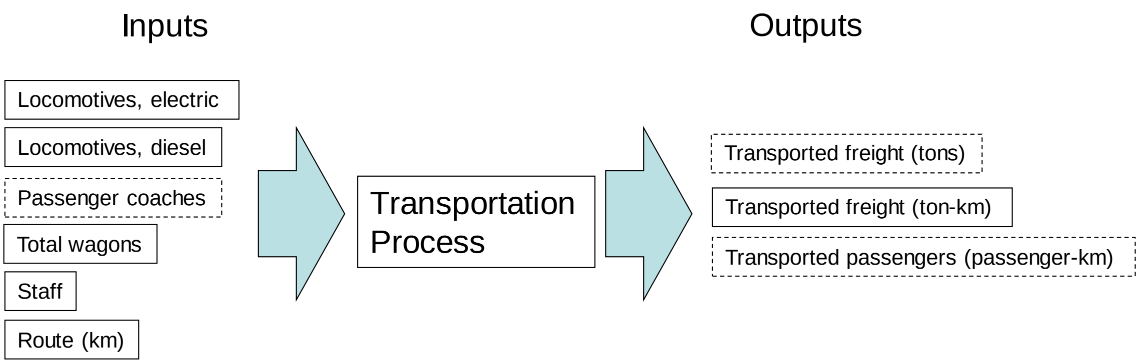

Figure 2. Models used in this study for UIC data (dashed lines indicate that variable is used only in one model, while continuous lines indicate use in both efficiency measurement models).

Inputs and outputs used in this research work were selected based on seminal DEA efficiency examinations of railways in different countries. For example, Oum and Yu [33] used as output passenger-km and freight ton-km, as did Cantos et al. [34] and Savolainen and Hilmola later [35]. In the freight model, the two outputs used were the as Hilmola [36] and Hilmola [10], however, in these works, freight DEA models had one output at a time. According to our knowledge, there does not exist a single journal level publication using all three outputs of this study at the same time. Inputs used in this research work were the same as in the earlier mentioned studies, however, energy consumption was not taken into account. In general, railway DEA models are rather concentrated on the input side on capital invested and human input, while passengers and freight are typically used as outputs. For example, railway stations were analyzed in the UK by different railway network infrastructure investments and staff count, and train stops and passengers handled were used as outputs [37]. Only in the railway network scheduling DEA model [38] were time based output indicators used.

As with all databases, the World Bank [14] railway data and UIC [13] include errors and inconsistencies. These were taken out during the research process by examining all variables through big spreadsheets, where evolution of these variables was easy to follow. In some cases, countries were excluded from a particular year, e.g., if railway route length changed (dropped) to one tenth in one year to increase back to original in few years' time. In some cases, freight volumes that increased by a factor of ten or more in one year were also excluded. However, it should be emphasized that these exclusions were not in high numbers, and only concerned a few countries. Countries were not necessarily included in all years of efficiency examination, as data was not available in every year for all needed measures. In some cases, missing data was taken from ministry webpages, if they were available (e.g., route length or freight volumes). Within Russian gauge standard (1520 mm) using countries (e.g., Reference [39]) there is some bias in wagon amounts, as railway reforms in these countries have separated ownership of wagons (both publicly and privately owned) and traction units (typically publicly owned). Therefore, wagon amounts of governmental railway operators of Russia, Belarus, Estonia, Latvia, or Lithuania, etc. do not reflect fully reality. However, we decided to use UIC [13] data, as there does not exist another trustworthy alternative.

A troublesome part of using two output variable DEA models is the possible correlation between outputs (and inputs). This following analysis is not free from this limitation (see Lin's [40] critique of Reference [41]). Tables 1 and 2 illustrate that, in general, all variables (inputs and outputs) are positively correlated with each other—if the amount of route (km) increases in a national railway system, then this will typically lead to a higher amount of staff, locomotives, wagons, and different kinds of outputs. Correlations of Tables 1 and 2 were also statistically tested, and, in general, they were highly statistically significant and positively related to each other. This is a rather typical finding from a service system, which cannot hold inventories and hedge market uncertainties.

Table 1. Coefficients between input and output variables used in World Bank data DEA models (n = 151).

	Route {I}	*Locomotives {I}*	*Staff {I}*	*F_wagon {I}*	*F_Tons {O}*	*F_Tonkms {O}*	*Passkms {O}*
Route {I}	1.000						
Locomotives {I}	0.927	1.000					
Staff {I}	0.921	0.944	1.000				
F_wagon {I}	0.918	0.982	0.908	1.000			
F_Tons {O}	0.823	0.956	0.909	0.951	1.000		
F_Tonkms {O}	0.812	0.925	0.872	0.939	0.978	1.000	
Passkms {O}	0.917	0.878	0.951	0.831	0.827	0.778	1.000

Table 2. Coefficients between input and output variables used in UIC data DEA models (n = 316).

	Tracks (km) {I}	*Dlocos {I}*	*Elocos {I}*	*Wagons {I}*	*Staff {I}*	*Freight (tn) {O}*	*Freight (tkm) {O}*	*Pass (pkm) {O}*
Tracks (km) {I}	1.000							
Dlocos {I}	0.955	1.000						
Elocos {I}	0.906	0.911	1.000					
Wagons {I}	0.912	0.933	0.868	1.000				
Staff {I}	0.965	0.932	0.876	0.918	1.000			
Freight (tn) {O}	0.901	0.946	0.905	0.951	0.928	1.000		
Freight (tkm) {O}	0.840	0.922	0.928	0.880	0.860	0.962	1.000	
Pass (pkm) {O}	0.888	0.777	0.756	0.760	0.912	0.782	0.679	1.000

Due to the high correlation between outputs, it was tested with UIC data models (years 2000–2016, n = 356; more observations than in Table 2, as passenger km data was missing in overall sample), how the two factor freight model performed as compared to single factor efficiency models of tons and ton-km. These single factor DEA models were not used in this research, but they were built for the purpose of verifying and justifying the usage of two factor DEA models. Correlations between efficiency levels of the two factor freight model (used in this research) and ton and ton-km models were high and positive (to the level of 0.91–0.92). These are, of course, highly statistically significant. Therefore, undesired bias in the measurement in the following analysis should be low or nonexistent.

In the following, all efficiency calculations were completed on an annual basis for two different datasets. This corresponds to six efficiency calculations for World Bank [14] data models. In total, 12 calculations were completed, as this concerns two different models. In the case of UIC [13], the analysis process consisted of 17 separate efficiency calculations, and in two models, 34 calculations were then completed. As UIC [13] has more recent data, and tries to incorporate different actors in railways in different countries (due to restructuring, deregulation, and competition taken place), its data and results were more valid for OBOR countries' efficiency analysis in the following. However, to ensure that UIC [13] analyses were correct, it was vital to have the World Bank [14] data models as a comparison point. All computations were completed with EMS software (v.1.3.0), which is rather commonly used freeware for efficiency frontier analysis. All efficiency evaluations in the following are based on assumption of a "constant return on scale" (CCR), and they are input oriented (as amount of inputs exceeds outputs). Another alternative for CCR models could have been "variable return on scale" efficiency analysis, which could have given better results for smaller countries. However, as can noted from the following, smaller countries were already able to perform well with the CCR efficiency frontier.

In total, Chinese OBOR program members include 65 countries from different geographical locations. ((1) China, including Mongolia in East Asia and 12 ASEAN countries (Singapore, Malaysia, Indonesia, Myanmar, Thailand, Laos, Cambodia, Vietnam, Brunei, and the Philippines), (2) Eighteen countries in Western Asia (Jordan, Lebanon, Israel, Palestine, Saudi Arabia, Yemen, Oman, the United Arab Emirates, Qatar, Kuwait, Bahrain, Greece, Cyprus, and Egypt on the Sinai Peninsula), (3) Eight South Asian countries (India, Pakistan, Bangladesh, Afghanistan, Sri Lanka, Maldives, Nepal, and Bhutan), (4) Five Central Asian countries (Kazakhstan, Uzbekistan, Turkmenistan, Tajikistan, and Kyrgyzstan), (5) Seven CIS countries (Russia, Ukraine, Belarus, Georgia, Azerbaijan, Armenia, and Moldova), and (6) Sixteen Central and Eastern European States (Poland, Lithuania, Estonia, Latvia, Czech Republic, Slovakia, Hungary, Slovenia, Croatia, Bosnia-Herzegovina, Montenegro, Serbia, Albania, Romania, Bulgaria and Macedonia). In the following analysis we could not include these all, as some countries do not have a functional railway system at all (e.g., Lebanon, Cyprus, Maldives, Bhutan, Kuwait, Bahrain, United Arab Emirates, Qatar, or the Sinai Peninsula), while in others, data availability was challenging (as there was not complete data available for DEA models or data was inaccurate). In the following analyses, we have evaluated 35 countries in each model. This is not full coverage by any means, but it gives a perspective of the OBOR region's level of efficiency and its development. Many smaller and underdeveloped countries do not provide data at all, but it could be assumed that their efficiencies are low.

4. Efficiency Analysis of Belt and Road Countries' Railway Sector

4.1. DEA Efficiency Analysis with World Bank Data (2000–2005)

Regarding the joint model of passenger and freight transports, both large and small countries showed high performance (see Table 3). China and India, large countries at the frontier, constantly showed 100% efficiency. Russia, Kazakhstan, Iran, and Thailand also showed 100% efficiency when their data was available for analysis. Smaller countries Estonia, Latvia, and Israel also made frontier performance. Mongolian performance was also exceptional at the end of observation period, and was rather close to efficiency frontier performance.

Poor performance (below 20% from the efficiency frontier) in the passenger and freight transport model was present in three East European countries (Bosnia-Herzegovina, Albania, and Macedonia) as well as in Armenia and Syria. The observations of these countries are limited, but available data does not provide support for improvement over the years.

What is striking in the analysis is the presentation of East European countries in the performance of 50% and below. This includes also one of the largest railway sector countries in Europe, that of Poland. What is worrying in this group of countries is the development of efficiency over a six year period—it was typically declining, but in some cases, at best, somehow sustaining. It should be noted that Turkey and Vietnam also showed declining efficiency in this period. However, performance development of these lower performance countries was similar to entire sample—the average performance was around 60% for early years, but dropped to 54% in the end of the evaluation period.

For the two factor freight model, results differed a bit from earlier model (Table 4). Typically, Asian countries of the Belt and Road performed lower on freight side (also concluded in general from Asia in Marchetti and Wanke [42]). However, China was consistently at the efficiency frontier. Russia and Kazakhstan also had exceptional performance. From smaller countries, Estonia, Latvia, Iran (experienced significant decline in the last observation year), Israel (some drop in the last observation year), and Jordan made 100% performance as well. Mongolia showed exceptional performance, but did not make it to the frontier. Belarus also performed well, however, in the last observation year this weakened a bit.

Table 3. Efficiency results of model (ascending order), where outputs are passenger km and freight ton-km (World Bank data).

Country	2000	2001	2002	2003	2004	2005	Average
Bosnia-Herzegovina					0.058		0.058
Armenia	0.067						0.067
Albania					0.077	0.071	0.074
Macedonia		0.163	0.106	0.108	0.105	0.107	0.118
Syria	0.177	0.188					0.182
Azerbaijan					0.185	0.241	0.213
Bulgaria	0.305	0.256	0.199	0.191	0.181	0.169	0.217
Georgia	0.257	0.253	0.264		0.194	0.257	0.245
Croatia	0.264	0.228	0.303	0.315	0.199	0.200	0.251
Czech Republic	0.340	0.330	0.262	0.239	0.224	0.209	0.267
Slovakia	0.343	0.357	0.286	0.270	0.220	0.374	0.308
Romania	0.379	0.355	0.273	0.271	0.270		0.310
Hungary	0.350	0.505	0.329	0.322	0.323	0.298	0.355
Vietnam	0.406		0.360			0.354	0.373
Poland	0.511	0.405	0.369	0.382	0.323	0.288	0.379
Slovenia		0.447	0.406	0.466	0.320	0.265	0.381
Greece			0.444	0.533	0.400	0.418	0.449
Uzbekistan			0.381			0.536	0.458
Turkey	0.520	0.567	0.490	0.560	0.470	0.393	0.500
Lithuania	0.519	0.602	0.588		0.596	0.531	0.567
Saudi Arabia	0.658	0.623	0.428	0.521	0.627	0.607	0.577
Malaysia	0.654	0.663		0.721	0.659	0.510	0.641
Belarus				0.714	0.635	0.618	0.656
Ukraine	0.740	0.822	0.728		0.653	0.460	0.681
Mongolia			0.776			0.942	0.859
Latvia	0.914	1.000	1.000	1.000	0.734	0.966	0.936
Pakistan	0.982	0.923	0.971	0.996	0.963	0.848	0.947
Iran	0.865	1.000	1.000	1.000	1.000	1.000	0.978
China	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Estonia	1.000	1.000	1.000	1.000	1.000	1.000	1.000
India	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Israel	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Kazakhstan			1.000		1.000	1.000	1.000
Russia					1.000		1.000
Thailand	1.000			1.000			1.000
Average	0.594	0.595	0.576	0.619	0.531	0.540	
n	24	23	26	22	29	29	

In the group of poor performance countries, there exists again a number of East European countries, namely Albania, Greece, Macedonia, Bulgaria, and Romania. Apart from Romania, these countries did not show any improvement in efficiency, and were actually in general weakening. Performance was also weak in Armenia, Pakistan, and Syria.

Below 50% efficiency performance (average across the period) was present in high number of countries—this just illustrates the difficult position railways occupy in the hinterland transportation market. Again, numerous East European countries made this list, and the situations of Poland, Hungary, Croatia, and Czech Republic did not improve during the observation period. Positive development was detected only from Slovakia. Other Belt and Road countries in troublesome situations in the freight model were Vietnam, Malaysia, Thailand, Turkey, Georgia, and Saudi Arabia. Performance trajectory in these countries in some cases sustained current performance, but in Turkey, Malaysia, and Vietnam it was declining. Overall, the entire sample did not show significant improvements during the six year observation period—average performance stayed somewhat above 40%.

Table 4. Efficiency results of model (ascending order), where outputs are freight tons and freight ton-km (World Bank data).

Country	2000	2001	2002	2003	2004	2005	Average
Armenia	0.061						0.061
Albania				0.078	0.079	0.036	0.064
Pakistan	0.071	0.081	0.083	0.079	0.071	0.073	0.076
Greece		0.116	0.090	0.118	0.134	0.069	0.105
Macedonia		0.176	0.166	0.194		0.149	0.171
Bulgaria	0.146	0.190	0.183	0.208	0.213	0.129	0.178
Syria	0.179	0.200					0.190
Romania	0.168	0.160	0.139	0.247	0.251		0.193
Vietnam	0.233		0.241			0.173	0.216
Malaysia	0.255	0.276		0.236	0.233	0.120	0.224
Thailand	0.221			0.254			0.238
Turkey	0.290	0.271	0.247	0.267	0.271	0.169	0.252
Georgia	0.256	0.253	0.264		0.350	0.279	0.280
Poland	0.286	0.242	0.302	0.329	0.368	0.185	0.285
Hungary	0.261	0.300	0.318	0.317	0.388	0.193	0.296
Saudi Arabia	0.298	0.266	0.271	0.305	0.413	0.238	0.299
Bosnia-Herzegovina					0.341	0.257	0.299
Czech Republic	0.234	0.297	0.327	0.410	0.383	0.171	0.304
Croatia	0.323	0.419	0.391	0.417	0.306	0.143	0.333
Slovakia	0.367	0.363	0.356	0.518	0.500	0.568	0.445
Slovenia		0.388	0.482	0.640	0.677	0.302	0.498
India	0.463	0.489	0.501	0.542	0.533	0.517	0.508
Uzbekistan			0.411			0.623	0.517
Ukraine	0.620	0.665	0.623		0.693	0.499	0.620
Lithuania	0.519	0.582	0.633		0.940	0.601	0.655
Iran	0.523	0.638	1.000	1.000	1.000	0.447	0.768
Jordan		0.564	1.000				0.782
Belarus				0.866	0.863	0.705	0.811
Mongolia			0.932			0.953	0.942
Israel	1.000	1.000	1.000	1.000	1.000	0.858	0.976
Latvia	0.914	1.000	1.000	1.000	1.000	1.000	0.986
China	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Estonia	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Kazakhstan			1.000		1.000	1.000	1.000
Russia					1.000		1.000
Average	0.404	0.437	0.517	0.479	0.556	0.430	
n	24	25	27	23	27	29	

4.2. DEA Efficiency Analysis with UIC Data (2000–2016)

Results of UIC [13] data concerning the passenger and freight factor model are similar to the earlier World Bank [14] data model. China and India were, of course, consistently at the efficiency frontier (Table 5). Iran was also exceptional with its frontier performance. Russia, Kazakhstan, and Thailand made the frontier as well, when data was available. Smaller countries Estonia, Latvia, and Israel made the 100% efficiency frontier too. Mongolia and Malaysia followed their earlier good performance, and reached 100% efficiency many times during the years.

The efficiency evaluation also contains some surprising improvements: Vietnam, Bangladesh, Lithuania, and Saudi Arabia improved their performance over the years, and reached the efficiency frontier. Another lower performance country, Syria, showed high performance in the last data availability year (2008).

Countries with very poor performance (below 20%) were not so numerous. Bosnia-Herzegovina, Iraq, Albania, and Serbia were in this group of countries. These countries' performance did not improve over the years, and in some cases, comparative performance worsened.

Table 5. Efficiency results of model (ascending order), where outputs are passenger-km and freight ton-km (UIC data).

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average
Bosnia-Herzegovina	0.031	0.034	0.041	0.072	0.114	0.340	0.101	0.107	0.236	0.107	0.121	0.100	0.127	0.154	0.253	0.121	0.071	0.125
Iraq		0.223	0.255			0.055			0.063									0.149
Albania				0.276		0.105	0.159	0.090										0.157
Serbia				0.176	0.131	0.172	0.148	0.167	0.303	0.142	0.166	0.119	0.106	0.122	0.167			0.160
Bulgaria	0.310	0.227	0.201	0.317	0.206	0.198	0.184	0.166	0.213	0.125	0.129	0.171	0.297	0.313	0.207	0.107	0.102	0.204
Romania	0.386	0.248	0.189	0.345		0.254	0.272	0.236	0.214	0.155	0.165	0.163	0.148	0.157	0.186	0.157	0.255	0.215
Slovakia	0.251	0.225	0.198	0.387	0.177	0.234	0.202	0.202	0.305	0.179	0.214	0.165	0.189	0.206	0.245	0.187	0.199	0.221
Croatia	0.187	0.208	0.209	0.287	0.214	0.245	0.266	0.296	0.337	0.298	0.277	0.216	0.219	0.197	0.226	0.170	0.157	0.236
Montenegro					0.239													0.239
Czech Republic	0.294	0.232	0.208	0.335	0.231	0.233	0.276	0.272	0.294	0.245	0.253	0.223	0.283	0.311	0.246		0.250	0.261
Kyrgyzstan		0.209			0.370				0.497	0.275		0.224						0.315
Poland	0.375	0.312	0.311	0.492	0.361	0.338	0.348	0.343	0.364	0.281	0.313	0.274	0.335	0.340	0.325			0.341
Hungary	0.430	0.362	0.397		0.435	0.341	0.335	0.265	0.390									0.369
Syria		0.247		0.461	0.314	0.214			1.000									0.447
Slovenia	0.320	0.335	0.361	0.515	0.442	0.461	0.372	0.436	0.733	0.555		0.499	0.488	0.609	0.702	0.524	0.514	0.492
Moldova	0.616	0.441	0.474	0.686	0.685			0.576	0.544	0.340		0.190						0.506
Jordan			0.413	1.000	0.024	0.395			0.756									0.518
Ukraine	0.537	0.532			0.556							0.587						0.553
Belarus				1.000	1.000	0.940	0.829	0.651	1.000	0.905	0.760	0.751	0.514	0.564	0.893	0.407	0.429	0.760
Saudi Arabia	0.930	0.670		0.756		0.852	0.725	0.724	1.000									0.808
Lithuania	0.605	0.588	0.647	0.639	0.622	0.584	0.596	0.787	1.000	0.991	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.827
Bangladesh								0.664	1.000									0.832
Vietnam		0.837	0.668					0.808	1.000	1.000								0.863
Mongolia		1.000	1.000						1.000	0.875								0.969
Iran	1.000	0.927	1.000	1.000		1.000			1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.995
Malaysia	1.000	0.951	1.000	1.000	1.000	0.993	1.000	1.000		1.000	1.000	1.000						0.995
China	1.000	1.000	1.000		1.000		1.000	1.000				1.000	1.000	1.000				1.000
Estonia	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000										1.000
India		1.000				1.000	1.000	1.000	1.000	1.000	1.000	1.000			1.000	1.000	1.000	1.000
Israel		1.000	1.000			1.000	1.000	1.000										1.000
Kazakhstan		1.000	1.000							1.000	1.000	1.000						1.000
Latvia	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000										1.000
Pakistan	1.000	1.000	1.000	1.000														1.000
Russian Federation					1.000											1.000	1.000	1.000
Thailand								1.000										1.000
Average	0.593	0.586	0.590	0.607	0.506	0.520	0.541	0.574	0.620	0.551	0.528	0.510	0.439	0.459	0.496	0.516	0.498	
N	19	27	23	21	22	23	20	24	23	19	14	19	13	13	13	11	12	

If the group of countries showing below 50% performance (on average) were examined in detail, it could be concluded that this group includes many East European countries. As concluded in the earlier analysis, in this longer observation period, these countries hardly improved their relative efficiency performance at all (apart from Slovenia). Together, all analyzed countries on average did not show any improvement in average efficiency; In fact, some declining trajectory could be detected.

The two factor freight model gives similar results as earlier—in general, Asian countries of the BRI were not that high performing. China, of course, made frontier in all years when data was available (Table 6). In the earlier analysis, India was not particularly strong in freight, however, in this most recent data, its performance improved gradually, and occasionally reached frontier performance. Russia and Kazakhstan made the frontier, when their data was available. From smaller countries, Estonia, Latvia, Lithuania (gradual improvement to the frontier during the years), and Israel made the frontier too.

In the freight model, Belarus, Slovenia, and Jordan occasionally showed very high performance, but this was not consistent throughout the years. The situation was the same in Mongolia, where performance in some early years was exceptionally good, but declined in the latter observation years.

A higher number of countries than in passenger and freight model were classed as low performing countries (with an average performance below 20%). Three of these countries were from Eastern Europe (Albania, Serbia, and Romania). Positively, these countries were not declining within their comparative performance to the others, and, actually, Romania substantially improved over the years. Other lowly performing countries were Bangladesh, Iraq, Pakistan, Thailand, Malaysia, and Syria. None of these improved during the observation period.

There were a number of countries with average performance, below 50%. The biggest group in this category was former East European countries, as well as Saudi Arabia and Vietnam. Many of these countries sustained their comparative efficiency performance or even improved it. Improvements were made by smaller numbers of countries in the last years of analysis. However, performance improved consistently for the overall sample too, which encourages development in the freight sector.

DEA is a multivariable and non-parametric method, but sometimes it is fruitful to analyze research results further with key partial productivities. One such method used outputs of this research divided by railway network size (track km). As the passenger and freight model was elaborated with such an analysis and a scatter gram was formed, further understanding could be built on the results. Figure 3 illustrates this. It can be clearly identified that India had exceptional passenger transport partial productivity with regard to track length. However, its performance on freight was low. In Figure 3, performance can be seen to consistently improve, and the last observation years are consistently further to the right. Opposite to this is Russia, which has extremely high freight partial productivity to track length, but lower passenger transport partial productivity (however, still good in comparison to most of the countries analyzed). Russia's performance also improved from early 2000's. Lastly, Figure 3 shows China to be exceptional, doing well in both regards, partial productivity of freight and passengers, as evaluated relative to railway network size. China's performance was also, annually, typically moving higher. These three major countries were in a class of their own, and only Kazakhstan came somewhat close to Russian performance.

In freight analysis using scatter grams and partial productivities of ton and ton-km to railway network size (tracks), it becomes clear once again why some countries performed so much better than the others (Figure 4). Russia had an extremely high performance of ton-km per railway network size, however, its tons per network size was lower (but not low compared to others). The opposite direction, where ton per track was high and ton-km per track low, was represented by the countries of the Baltic States and Israel. Again, China was between these two extremes, where the country had balanced partial productivity in both measures. Ton and ton-km partial productivities increased annually, followed from some distance by Kazakhstan.

Table 6. Efficiency results of model (ascending order), where outputs are freight tons and freight ton-km (UIC data).

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Average
Bangladesh						0.031		0.038	0.045									0.038
Albania				0.041	0.041	0.036	0.040	0.051	0.049	0.072								0.047
Iraq		0.101	0.124		0.150	0.054			0.014									0.089
Pakistan	0.085	0.101	0.113	0.089	0.098		0.117									0.114		0.103
Thailand								0.167										0.167
Malaysia	0.161	0.185	0.215	0.177	0.151	0.124	0.167	0.166	0.169	0.178	0.172	0.198						0.172
Serbia				0.195	0.155	0.170	0.181	0.260	0.239	0.157	0.173	0.151	0.126	0.162	0.176			0.179
Romania	0.147	0.146	0.121	0.251	0.175	0.146	0.134	0.190	0.187	0.120	0.113	0.131	0.123	0.186	0.206	0.223	0.503	0.182
Syria		0.174		0.174	0.124	0.123		0.271	0.231									0.183
Bulgaria	0.176	0.163	0.228	0.254	0.189	0.180	0.172	0.240	0.226	0.127	0.146	0.263	0.233	0.263	0.194	0.264	0.218	0.208
Croatia	0.116	0.166	0.224	0.255	0.190	0.211	0.226	0.377	0.346	0.232	0.220	0.204	0.206	0.242	0.242	0.243	0.239	0.232
Montenegro					0.158	0.166	0.229	0.365	0.362	0.281								0.260
Czech Republic	0.232	0.232	0.237	0.257	0.185	0.168	0.179	0.278	0.306	0.266	0.240	0.238	0.245	0.319	0.312	0.363	0.387	0.261
Vietnam		0.234	0.176					0.277	0.300	0.343								0.266
Hungary	0.235	0.233	0.305		0.237	0.213	0.260	0.336	0.332									0.269
Poland	0.286	0.256	0.330	0.329	0.250	0.251	0.218	0.296	0.266	0.197	0.231	0.312	0.242	0.307	0.298			0.271
Slovakia	0.340	0.339	0.338	0.359	0.270	0.249	0.261	0.327	0.349	0.238	0.241	0.263	0.266	0.311	0.307	0.331	0.394	0.305
Saudi Arabia	0.328	0.258		0.176		0.267	0.277	0.441	0.475									0.317
Moldova	0.272	0.364	0.371	0.455	0.421		0.425	0.479	0.514	0.185		0.115	0.105	0.149				0.321
Bosnia-Herzegovina	0.170	0.193	0.233	0.275	0.597	0.798	0.349	0.460	0.536	0.453	0.442	0.565	0.581	0.616	0.624	0.652	0.719	0.486
Kyrgyzstan		0.265			0.477				0.895	0.695		0.692						0.605
Iran	0.449	0.402	0.509	0.475		0.449	0.501	0.647	0.606	0.498	0.523	0.582	0.837	1.000	1.000	1.000	1.000	0.655
Jordan		0.329	0.424	1.000	0.602	0.493		0.809	0.643	0.944								0.655
Slovenia	0.420	0.443	0.652	0.790	0.545	0.528	0.540	0.815	0.799	0.530		0.546	0.579	0.767	0.825	0.816	0.957	0.659
Ukraine	0.685	0.691			0.737							0.623						0.684
Lithuania	0.493	0.434	0.676	0.739	0.608	0.569	0.580	0.797	0.867	0.629	0.675	0.781	0.868	1.000	1.000	1.000	1.000	0.748
Belarus				0.830	0.736	0.884	0.721	0.686	0.806	0.768	0.771	0.677	0.676	0.669	0.770	0.689	0.792	0.748
India		0.528				0.929	0.619	0.643	1.000	1.000	1.000	0.716			1.000	0.835	0.872	0.831
Mongolia		0.928	0.967						0.885	0.719								0.875
Israel		1.000	0.904			0.819	0.784	1.000										0.902
Latvia	0.969	0.994	1.000	0.982	1.000	1.000	0.955	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.994
Kazakhstan	0.991	0.995	1.000							1.000	1.000	1.000						0.998
China	1.000	1.000	1.000		1.000		1.000	1.000				1.000	1.000	1.000				1.000
Estonia	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000					1.000
Russian Federation					1.000											1.000	1.000	1.000
Average	0.428	0.434	0.485	0.433	0.427	0.394	0.414	0.479	0.480	0.485	0.497	0.527	0.506	0.533	0.568	0.609	0.698	
n	20	28	23	21	26	25	24	28	28	24	16	21	16	15	14	14	13	

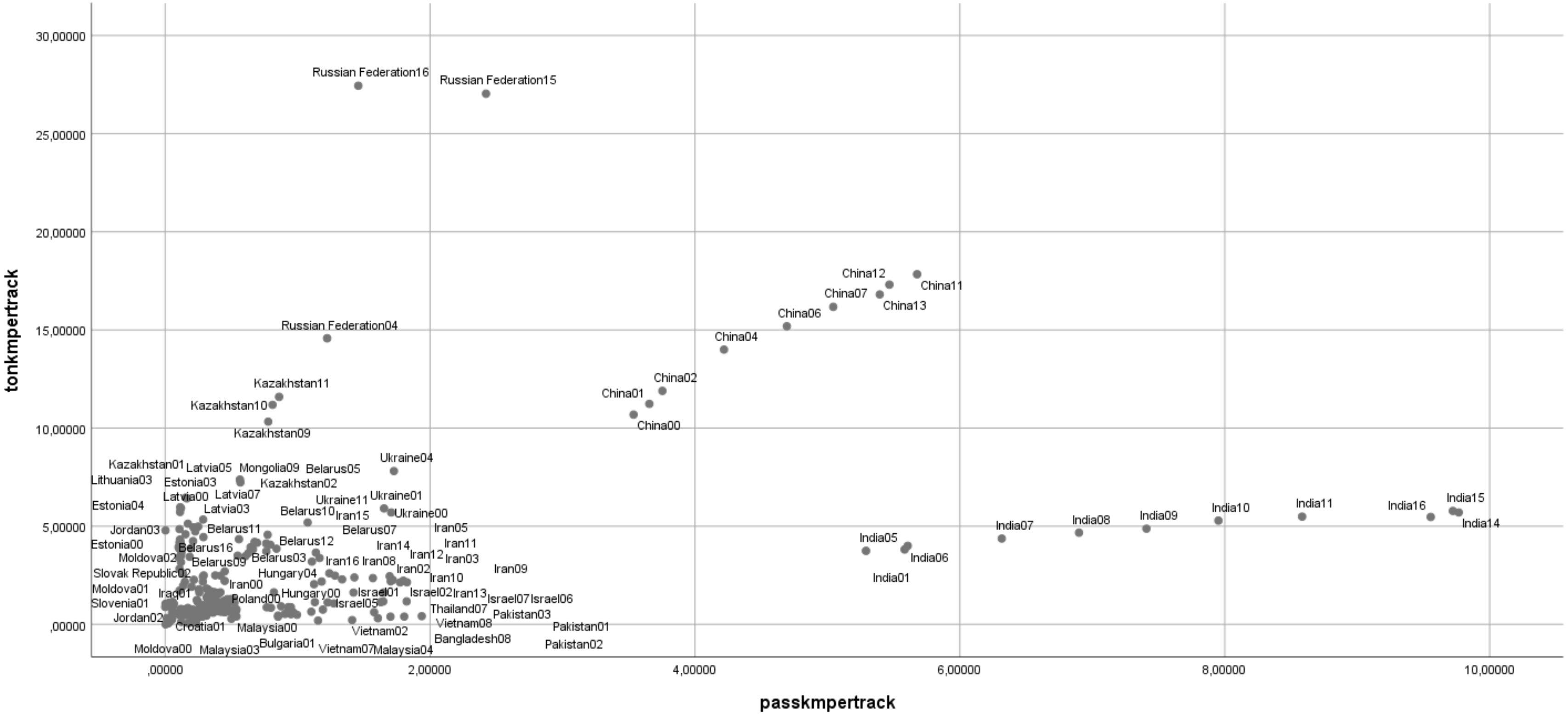

Figure 3. Graph from partial productivities of ton/km per track length and pass/km per track length (name of country and year of observation close to dot).

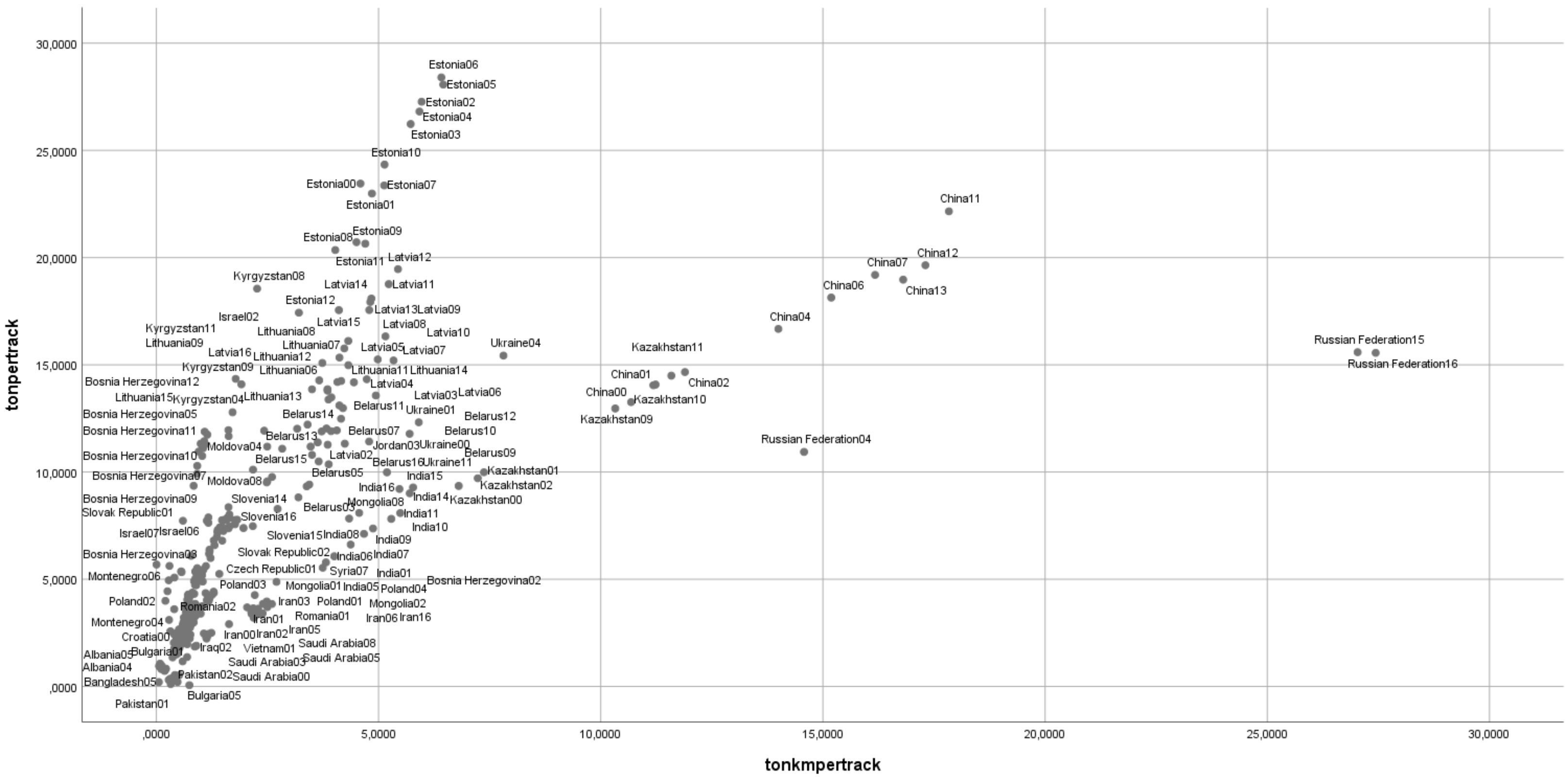

Figure 4. Graph from partial productivities of ton per track length and ton-km per track length (name of country and year of observation close to dot).

5. Using Network Analysis to Reveal Benchmarking Relationships

In DEA efficiency analysis, it is typically standard service for software to propose benchmarked decision making units (DMU) that are at frontier, and remind some lower performing DMUs (for more, see Lim et al., [43]). In this research work, DMUs are countries. For the World Bank data-based passenger and freight two factor models, China, Estonia, India, and Israel were at the frontier all the time (in all evaluated years). Kazakhstan, Russia, and Thailand were at frontier when their data was available for analysis. Benchmarking lists are provided from each efficiency evaluation completed, so, in World Bank data, benchmarking information was available from six years. Lists are difficult to use for long-term evaluation to see what DMUs are most important for further efficiency improvements. A mix of passenger and freight might change, as well as used inputs. It is also possible that a particular country might be benchmarked in some years (at efficiency frontier), while in others it fell below the highest standard, and had some other countries to learn from—as examples in the passenger and freight model, Iran (below frontier in 2000) and Latvia (below frontier in 2001, 2004, and 2005). As the number of countries in this study was high, and it used a longitudinal analysis approach, only option for proper benchmarking analysis was to use network analysis software. In the following, all networks were built with software Pajek (64 bit, 5.06a), which is well established in this field, e.g., References [44,45]. Network analysis arranges connections based on stated linkages (in this paper, proposed benchmarking relationships), and the most important DMUs (countries) are at the center of the network (with the most proposed benchmarking relationships). In the following analysis we used the Kamada-Kawai (free) algorithm to arrange networks to reveal central key countries. Network figures might have high similarities with each other, but it should be remembered that railway is critical infrastructure invested in over the long term, and operations and efficiency do not change that greatly during shorter periods of time.

As is shown in Figure 5 (passengers and freight model), China and Estonia were central and key benchmarked DMUs during the entire period of 2000–2005 (they had the most links to other countries). In addition, Israel was rather central in the entire network. Thailand is also close to central regions in Figure 5, as is Iran. However, India has its own group of countries for which it acts as a benchmark, and it is located in Figure 5 in the right part of the network. Kazakhstan and Russia are on their own group of countries, in the left side of the network. Latvia is a bit further away from the center, and it is closer to the left side of the network.

In the two factor freight model of World Bank data, there were fewer countries consistently at the efficiency frontier. Basically, only China and Estonia were able to achieve this. Kazakhstan and Russia were at the frontier, if data was available. Latvia and Israel were at frontier in most of the years recorded, but in one year out of six, they were not. Therefore, it is not surprising to find out from Figure 6 that China and Estonia were the two most benchmarked countries. Latvia is a bit away from these two, and Israel is even further up in the network. Kazakhstan and Russia have connections to other countries, but these are in the down-middle and down-right positions.

In the UIC data efficiency analysis model of passengers and freight, there were higher number of countries at the frontier (China, Estonia, India, Israel, Kazakhstan, Latvia, Pakistan, Russia, and Thailand), however, all of these countries had data availability issues. Iran was also close to this group of countries, as it was out of frontier only in one year, and it had actually highest frequency of 100% efficiency from all countries (13 years). Interestingly, this longitudinal approach did not provide clear answers as to which countries should be benchmarked—actually, only Estonia fell in the center region of the network, and possibly Israel and Kazakhstan (Figure 7). In turn, countries are clustered to different sub-groups in Figure 7, where China and India are benchmarks to Eastern European countries located in the right side of the network. Russia and Pakistan are also positioned rather close to this. Iran is in the middle of this sub-group. Another sub-group is located in left side of network. Latvia typically acts as benchmark for these countries.

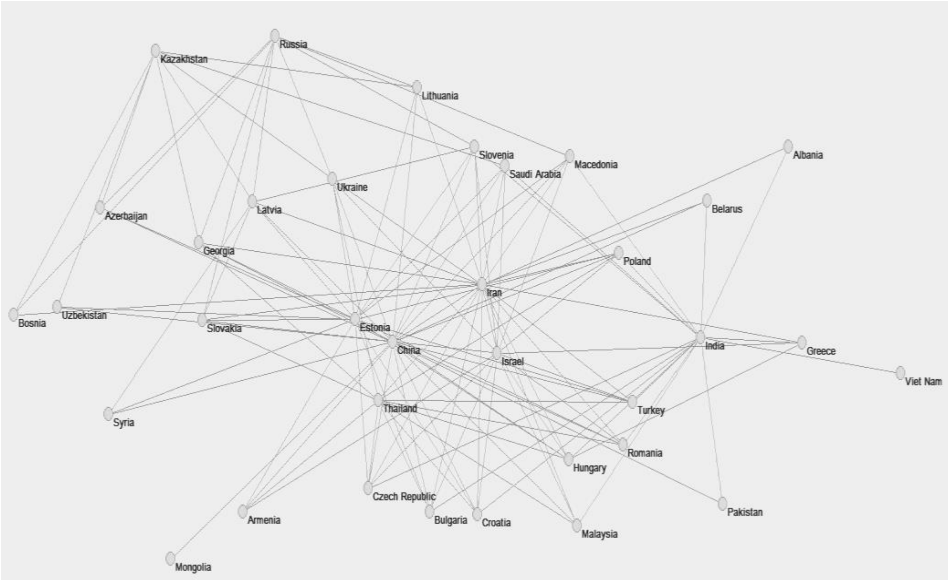

Figure 5. Relationships as a network between railway countries based on World Bank data in passenger km and freight ton-km model (contains 321 benchmarking relationships).

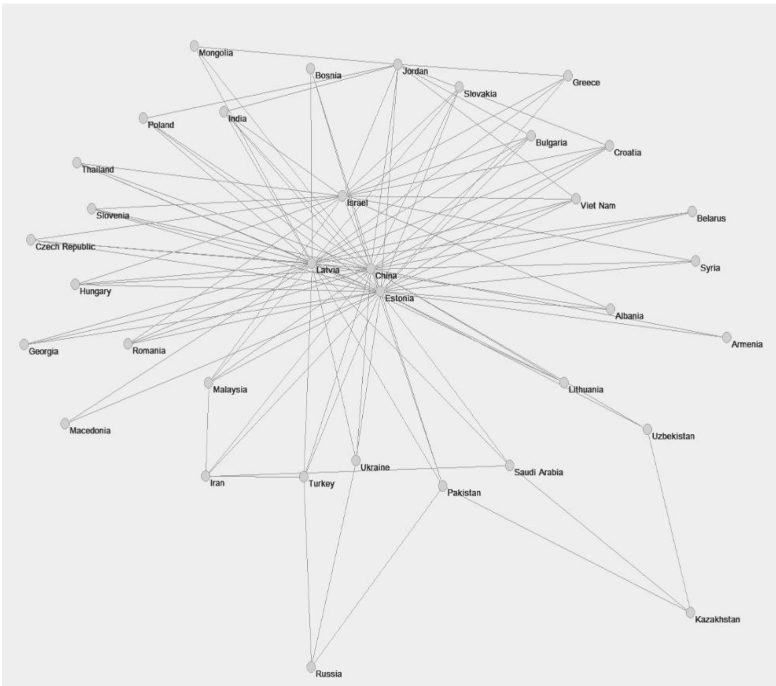

Figure 6. Relationships as a network between railway countries based on World Bank data in freight tons and freight ton-km model (contains 274 benchmarking relationships).

For the UIC data model concerning two freight outputs, frontier countries were far fewer. China and Estonia had longer periods of consistently showing frontier efficiency, however, Russia was also at the frontier, but only in a limited number of years. Kazakhstan and Latvia were at the frontier nearly all the time, but dropped just slightly below in some years. Lithuania, Iran, India, and Israel were occasionally at frontier. In the network diagram of Figure 8, Estonia and Latvia can be detected to be central countries. Kazakhstan and China are close to center, but still clearly nearer to their respective benchmarking countries. Russia is in left-top corner of network diagram, acting as a benchmark for only a small number of countries. Interestingly, India is close to China in Figure 8 as well. Iran and Israel are both far away from the central and important positions in which they would act as a benchmark to others.

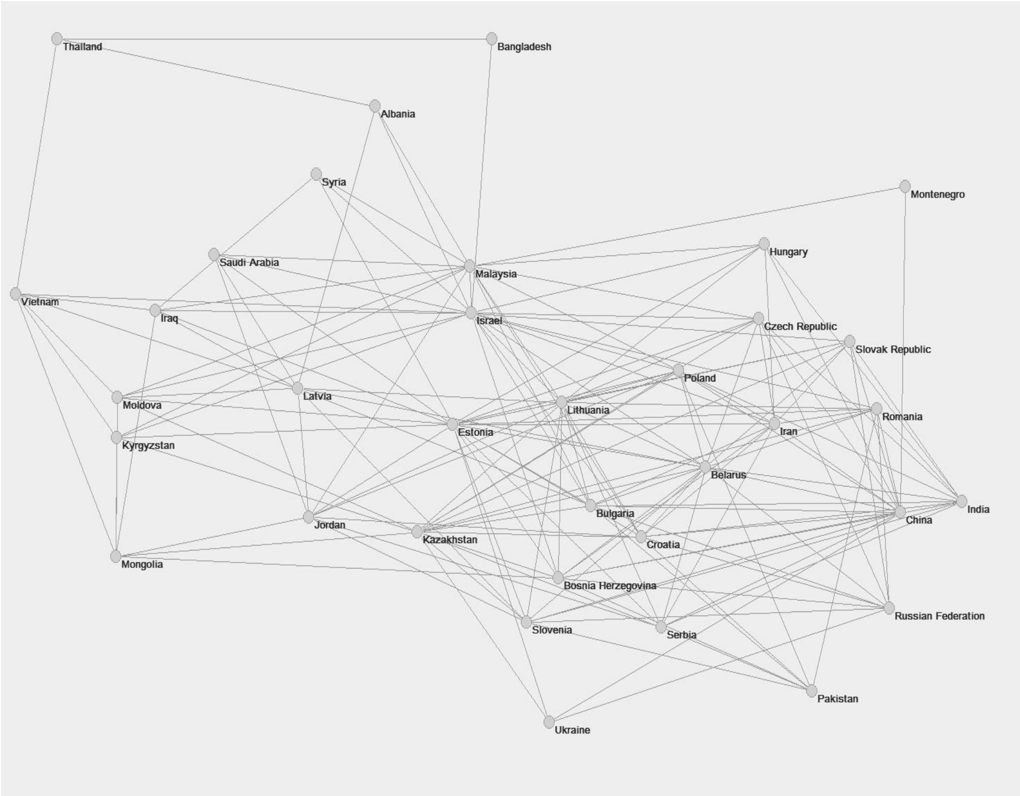

Figure 7. Relationships as a network between railway countries based on UIC data in passenger km and freight ton-km model (contains 527 benchmarking relationships).

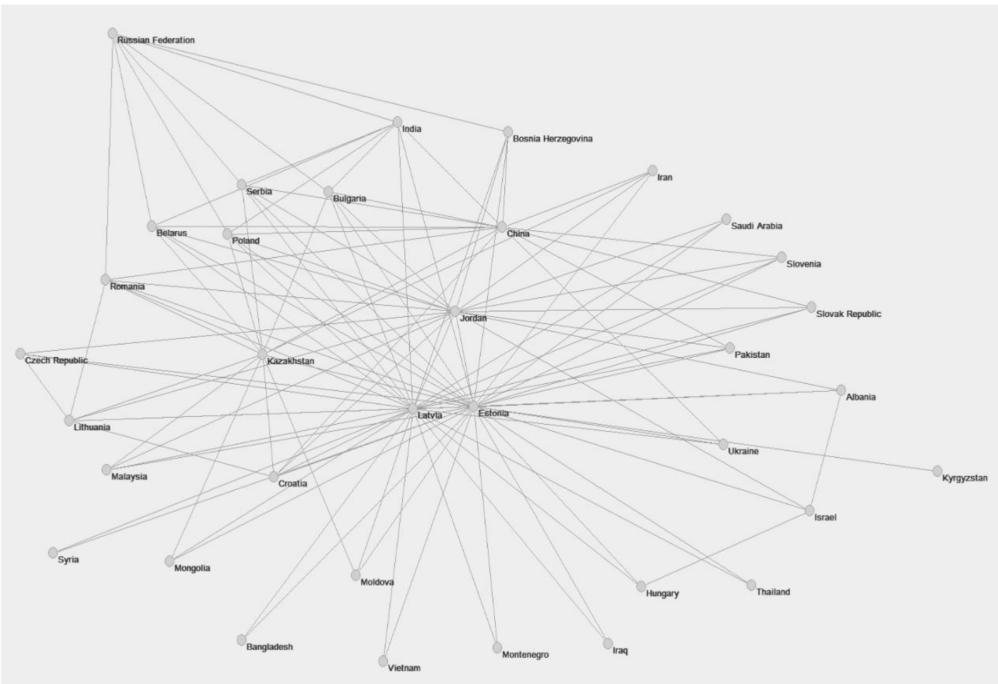

Figure 8. Relationships as a network between railway countries based on UIC data in freight tons and freight ton-km model (contains 456 benchmarking relationships).

6. Conclusions

It was shown in this research that numerous smaller and medium sized countries in OBOR program area have troublesome efficiency levels in railway operations. Typically, former East European countries have low efficiency, but this does not concern Baltic States (similar to findings in Marchetti and Wanke,) [42]. This latter group of countries in the north has solid performance in efficiency terms, based on significant freight flows in this study period (most often transit) and a sea port centric logistics value added service system. Another typical situation is that Asian and Middle East countries perform poorly in a freight model. They might perform well when passengers are included, but logistics flows (cargo) at railways are few and inefficient. It is surprising that many of the low efficiency countries are part of OBOR investment activities—for example, Greece and Hungary, which both have a low rail freight efficiency. Poland handles many Chinese container trains currently, but again has inefficiencies in its railway system. Pakistan was indicated to have a very low efficiency by freight models, but this ought to change as Gwadar-centric supply chain infrastructure investments are completed. The study also found that many Asian countries are low in freight efficiency, which should improve with OBOR investments, as more land-based freight trade could be carried on between Asian countries.

Regarding China's railway sector efficiency as compared to other OBOR countries, we cannot find any reason why it could not act as a benchmark and supply technology to other countries. China's performance was solid in both of the models used in this study, and it has been consistently at the frontier. Some other smaller countries were able to achieve same situation (e.g., Estonia, Latvia, and Israel), but they have very small railway networks, typically with sea port centric logistics systems which are served mostly by railways (often in bulk cargo classes). Based on the network analysis of this study, it seems that China's railway sector is the best benchmark for Eastern Europe. This is an interesting finding, as they already share same technical rail features (e.g., same gauge width, 1435 mm). In the study, we see that some Russian gauge standard countries (1520 mm) could use Russia or Kazakhstan as a benchmark (this was a rather typical connection in the network analysis). This only highlights the importance of co-operation in the OBOR program area—there is a very low probability that gauge width differences will disappear in the future. Many Asian countries are still using a narrow gauge width standard (1050 mm). These require their own specific solutions as well.

As further research in this area, it would be interesting to continue with passenger transport efficiency models of OBOR countries. In this research, we used only passenger and freight, as well as a two factor freight model. However, passenger transports should be thoroughly analyzed from the program area to identify weaknesses and strengths. This could also concern high-speed railway lines (or connections), and comparing how different routes perform with each other. Low emission high-speed transport is the key for the future, and consumers are keen to have fast travel options. This will also attract significant investments in the long-term. Therefore, it is vital to understand the dynamics of this sub-sector further, and identify which regions and countries of the OBOR could implement state of the art railway systems to what extent (and which should be satisfied with lower performing technology). Passenger transport investments are troublesome, as they typically require public sector support even during the usage phase [16]. Additionally, increasingly these investments requires information technology implementations to reach and serve public, and enable smart cities and villages to develop further [46,47].

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