



PERFORMANCE AND EFFICIENCY OF HIGH-SPEED RAIL SYSTEMS

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1. INTRODUCTION AND POLICY CONTEXT

Since the introduction in Japan in 1964 and in France in 1981, high-speed rail systems have been developed in various countries in Asia and Europe. Governments try to create new dynamics in railway transport to cater for the rising need for high-speed travel demand and railways are revitalized to be able to compete better with other modes of transport. An important focus is on the development of new high-speed networks in order to facilitate growth in mobility and to limit air travel. The building of high-speed rail systems requires substantial investment in infrastructure, railway stations and rolling stock. Efficient use of these capital-intensive assets is needed to justify the investments made. In addition, identification of areas of improvement in production and marketing is important to optimize operational performance and productivity. National governments decide on the development of high-speed rail systems based on the expected future demand for high-speed travel and the social benefits for the country. Long-term performance forecasts for high-speed rail are a basic input for the decision-making process. Ex post, in the operational stage, the assumptions need to be validated based on the actual system performance.

The goal of this paper is to identify the best high-speed rail practices in the world and to clarify the efficiency of the world's major high-speed rail systems currently in operation. This study compares the high-speed rail performance of the world's major high-speed rail systems regarding travel performance, ridership, train fleet and network. Based on the actual performance data and system characteristics, the efficiency of the selected high-speed railway systems is benchmarked using Data Envelopment Analysis (DEA) techniques. Four Asian and four European high-speed rail systems are benchmarked against their peers using the actual system characteristics and performance between 2007 and 2012. This study identifies the most efficient high-speed rail systems and the contributing factors in achieving high performance in production and marketing. High-speed rail system operators can use the results to adjust their strategy in order to improve their performance and process efficiency. Policy makers that are planning for a high-speed rail future may benefit from the experiences in other countries to make better decisions on the investments in infrastructure and rolling stock needed.

The paper is structured as follows. Section 2 gives a review of the development on benchmarking in the railway industry and the applied methods. In section 3 the methodology and the DEA-model, variables and data used in the study are presented to benchmark eight high-speed rail systems across Europe and Asia. Section 4 provides the results for the Malmquist Productivity Index and the efficiency and

effectiveness scores. Finally, section 5 presents the conclusion from the benchmark and discusses the results.

2. BENCHMARKING METHODS AND APPLICATION TO RAILWAYS

Benchmarking is intended to compare products or services with the competition or with organisations that are recognized as leaders in their sector to find best practices and ways to grow. This implies that it doesn't give an answer to how industry leaders themselves can improve. The best practices can be found by comparing individual performances within a selected peer group. The main objective of benchmarking is to measure and compare the realized output of a product or service with the amount of inputs (Hansen et al, 2013). Besides the uni-dimensional Ratio Analysis (RA) or Partial Productivity Measures (PPM) analysis for productivity and efficiency measurement, four multi-dimensional approaches can be identified (see figure 1 for an overview): Total Factor Productivity (TFP), Data Envelopment Analysis (DEA), Least Squares Regression (LSR) and Stochastic Frontier Analysis (SFA) (Coelli et al, 2005, Ozcan, 2008, Merkert et al, 2010). The PPM analysis, where an output variable is viewed in relation to a single input variable is a practical, easy and fast way to of comparing performance. The challenge here is to find meaningful efficiency indicators. In the more practical and technical-managerial studies like the CoMET/Nova metro railway benchmark, the European IMPROVERAIL project and the INFRACOST and LICB studies performed by the UIC to benchmark rail infrastructure companies, Key Performance Indicators were developed for the comparison (Anderson et al, 2003). An application for comparing the performance of eight high-speed railways in Europe and Asia was presented by Doomernik (2013). The main disadvantage is that only one indicator at the time can be evaluated. A multi-PPM analysis, where more ratios are assessed at the same time can easily lead to misinterpretation. The benchmarks established using old analytical schemes based on various multiple ratios created more dilemmas than solutions (Ozcan, 2008). The TFP analysis enables to evaluate multiple inputs and outputs simultaneously resulting in a single index for efficiency that makes it possible to rank the entities under study. DEA, LSR and SFA are more sophisticated tools that can also handle multiple inputs and outputs. All five benchmark methods can be recognized in international (mostly European) railway efficiency and productivity studies. As PPM is the most widely used measure in railways, DEA and SFA have become the most commonly applied methods in rail efficiency analysis in recent years (Merkert, 2010). A selection of recent benchmark studies presented by Hansen et al. (2013) also shows that DEA and SFA have become frequently used since about 2008. The utilization of either DEA or SFA is now one of the most defining elements of the studies, while LSR and TFP have lost importance (Laird et al, 2011). The same report states that no single benchmark can be applied to all railways and

several benchmarking methods should be used concurrently, since particular insight can be gained from each of them.

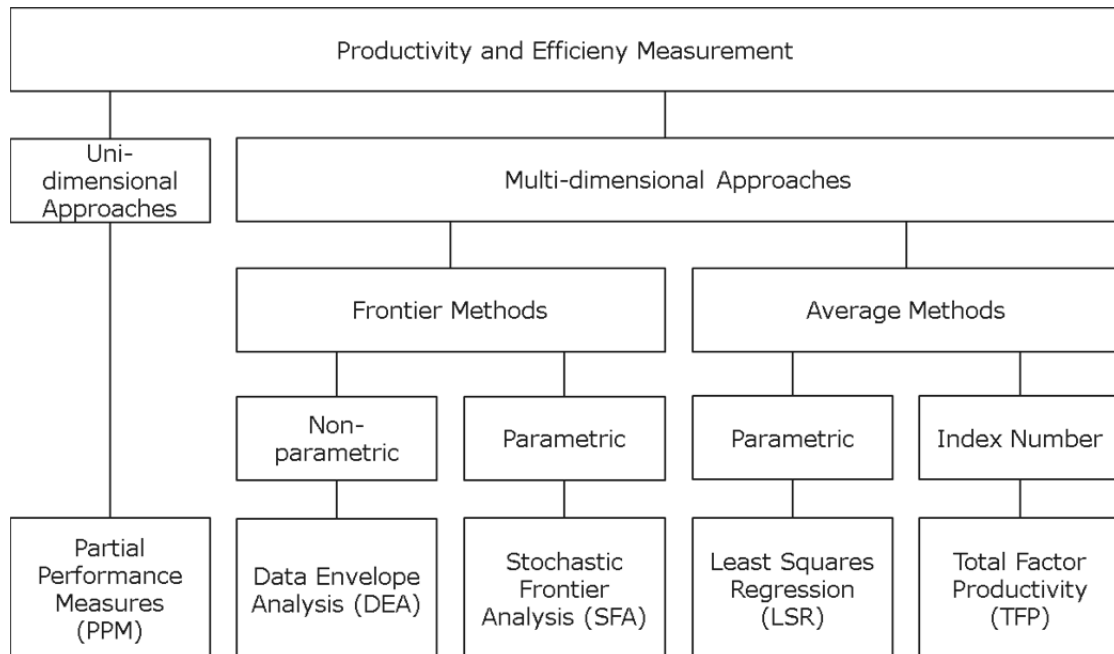


Figure 1: Overview of Productivity and Efficiency Measurement (adopted from Laird et al, 2011)

There have been many studies in the rail sector where DEA is used as a comparison technique. For an overview, see for example Merkert et al. (2010) and Hansen et al. (2013). To our knowledge, there are no benchmark studies for high-speed railway systems using DEA. DEA is however very suitable for the use in the rail sector, due to the highly regulated and quasi-monopolistic industry structure (Coelli & Perelman et al, 2000) and where the formal link between input and output is not clear in the first instance. An important advantage of DEA is that the results are based on a relative comparison and that DEA can work with index numbers, ensuring that no sensitive information is provided to others as often desired by companies (Caldas, 2013). SFA requires a-priori a production function specification and assumptions regarding the distribution of input variables and technical inefficiencies (Karlaftis, 2012). In practice this information is often missing. To by-pass these complications DEA is chosen as the preferred technique for this study.

Data Envelopment Analysis (DEA) is a non-parametric technique to compare performance between entities, normally indicated as Decision Making Units (DMU's), that allows multiple inputs and outputs. It is possible to increase the efficiency by lowering the input or increasing the output, keeping the inputs unchanged (Caldas, 2013). Besides this distinction between input and output orientation, in DEA a difference can be made regarding the returns to scale. The Constant Returns to Scale (CRS) assumption implies that all DMU's operate at an optimal scale, while

Variable Returns to Scale (VRS) divide the CRS-efficiency score into Technical Efficiency (TE) and Scale Efficiency (SE). Figure 2 shows that the inefficiency of DMU F is partly due to technical inefficiency and partly due to scale inefficiency (Struyf, 2013).

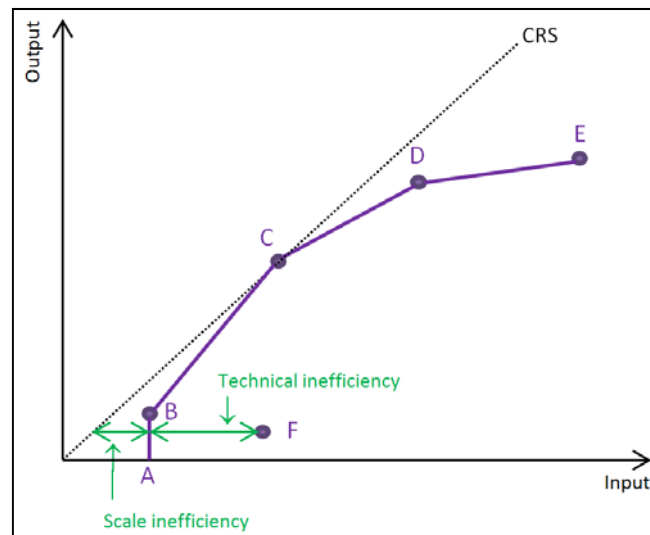


Figure 2: Technical and Scale (in)efficiency (Struyf, 2013)

The difference between CRS and VRS is that in the VRS model an additional condition on the weights is introduced. This is because the CRS model does not work properly if there is more than one optimal solution. When economies-of-scale are not changed by an increase in efficiency, CRS can be applied. If this is not the case, a VRS model is needed.

An interesting feature of DEA is that, by using the Malmquist Productivity Index (MPI), it can also capture the dynamics in efficiency. This index tells us how much the ratio of aggregate output to aggregate input has changed between any two time periods (Färe and Grosskopf, 2000). This is a commonly applied approach to assessing dynamic efficiency in a DEA environment, assuming constant-return-to-scale (CRS) technology. An important feature of the DEA Malmquist Index is that it can decompose the overall efficiency into two mutually exclusive components, one measuring Efficiency Change (EC) and the other measuring Technical Change (TC).

Traditional DEA (TDEA) models are based on a “black box” approach with multiple inputs and outputs. The actual transformation process is generally not modelled explicitly. TDEA reveals rather than imposes the structure of the transformation process. Network DEA (NDEA) models allow to identify components inside the box and to evaluate organizational performance and its component performance (Färe and Grosskopf 2000). This is done by splitting the model into two or more stages where an output feeds a subsequent stage. This approach can be applied to railways

to assess besides the overall technical effectiveness, the technical efficiency and service effectiveness separately (Lan and Lin, 2006, Yu, 2008). By plotting these results for all DMU's in a performance matrix as illustrated in figure 3, best practices can be found and strategies can be proposed to improve the position of underperformers (Ozcan, 2008, Lan and Lin, 2006).

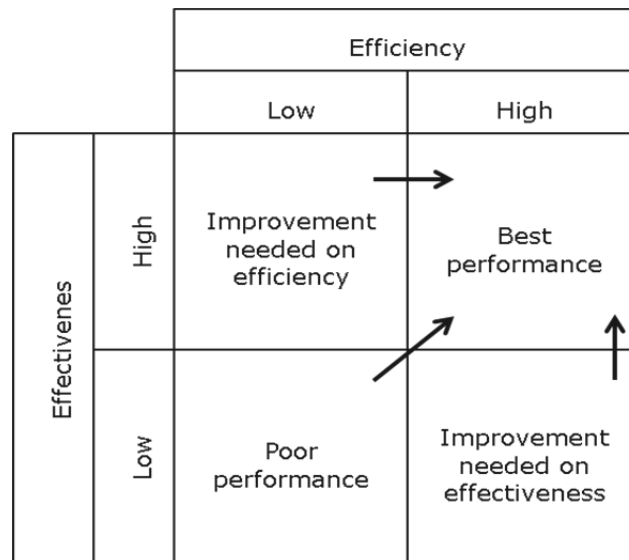


Figure 3: Performance matrix (Ozcan, 2008)

Performance can be defined as an appropriate combination of efficiency and effectiveness. An organization can be efficient, but not effective; it can also be effective and not efficient (Ozcan, 2008). Efficiency, the ratio between output and input, is a key performance parameter indicating if assets are properly used. Effectiveness indicates if the inputs are properly used to produce the best possible outcome. Besides the evaluation of performance on both dimensions, the correlation between efficiency and effectiveness can be studied as well to answer the question whether efficient organisations are also effective or not. Karlaftis and Tsamboulas found that efficiency is generally negatively related to effectiveness in their research on 15 European transit systems for a ten year time period (1990-2000). This implies that increasing efficiency may result in decreased effectiveness (2012).

3. METHODOLOGY AND NETWORK DEA MODEL

A railway system can be modelled as a Multiple-Input Multiple Output (MIMO) system for efficiency, productivity and costs analyses (Cantos et al 2010, Mizutani and Uranishi 2012). A system approach with N inputs and M outputs is the basis for our DEA study. In the current study, NDEA is chosen for the high-speed rail systems' performance and efficiency assessment. As DEA can be considered a "black box" approach, we introduce a two-stage Network DEA (NDEA) model to evaluate the overall technical effectiveness, the technical efficiency of the production process and service effectiveness of the consumption process simultaneously in a single model

as proposed by Lin and Lan (2006) and Yu (2008). PPM gives the possibility to clarify in more detail the differences in ranking and efficiency results. As the results of the PPM analysis have already been reported earlier (Doomernik, 2013), we will focus in this paper on the DEA approach to compare efficiency.

3.1 Input and output variables

To provide high-speed train services in a country, two major physical assets are needed: i) a high-speed rail network and ii) a fleet of high-speed trains. For this study, we only consider the network and the rolling stock assets, being the two major production factors for railway performance. Railway stations for access and egress of passengers are left out of the equation as in most cases they are not a performance limiting factor. Difficulties with defining meaningful parameters is another reason not to take stations into account as not only the number, but also the size, location and accessibility by other modes of transport are normative parameters.

Besides physical assets, an operational model and timetable to run the trains on the network is required to deliver the rail services. Operational expenditures and staff on board and at the railway stations are also production factors, but we do not take these into account in this study, mainly due to the fact that only limited data is available on operational costs and staffing levels in high-speed rail.

Appropriate infrastructure and rolling stock are needed for supplying high-speed train services. The total length of high-speed lines in the network and the number of available high-speed trains and their seating capacity are key parameters for the high-speed rail system performance. The final output performance can be expressed in terms of travel volume and is defined as the product of yearly number of passengers and the average travel distance per passenger. Ridership and train or seat kilometres produced by the fleet are additional output variables indicating the railway's performance.

The high-speed rail MIMO system is detailed in figure 4 with two asset-related input parameters ($N=2$) for the infrastructure and rolling stock and two output parameters ($M=2$) for the transport and travel performance.

The overall process is split into two subsequent stages to assess the efficiency of the production and consumption process separately. These stages are linked by the fleet performance being an output of the production process and an input for the consumption process. The production process uses network length and fleet capacity to produce train-km's, who are in turn input for the consumption process delivering ridership and travel performance as outputs. By plotting the results for all DMU's regarding production efficiency, service effectiveness and system efficiency in a

performance matrix (figure 3), best practices can be found and strategies can be proposed to improve the position of underperformers.

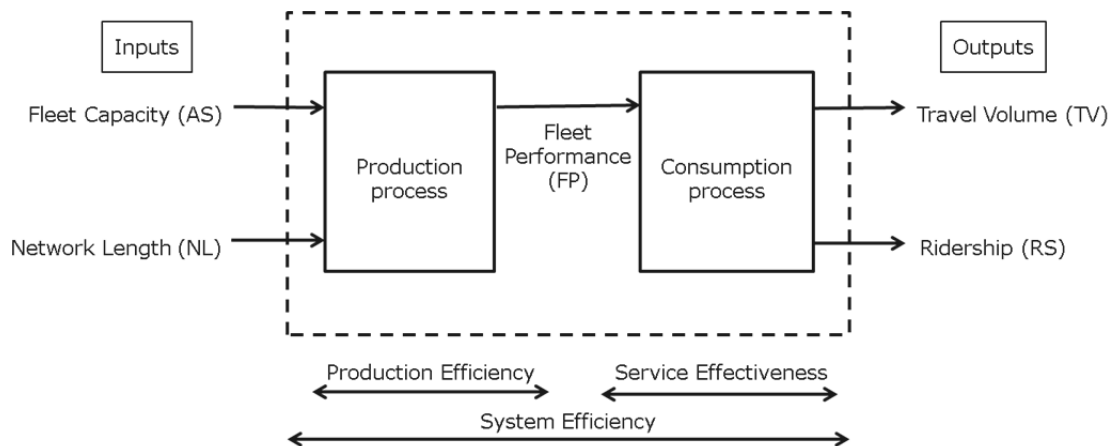


Figure 4: A two-stage multiple-input multiple-output NDEA model of a high-speed railway system

The efficiency and effectiveness scores and Malmquist productivity indices are calculated for the overall process and the two separate stages. Merkert et al use an input orientation because "it assumes that rail firms have higher influence on the inputs, since output volumes are substantially influenced by macro-economic factors and often pre-determined by long-term contracts and exogenously controlled public transport service level requirements" (Merkert et al., 2010). For this NDEA analysis model the output orientation is applied for the overall model and the individual stages. Regarding stage 1, improving the fleet performance has a preference over decreasing the infrastructure or fleet capacity. In practice taking out of operation and disinvestments in high-speed lines and rolling stock are very unusual to improve technical efficiency. For the effectiveness (stage 2) it is easier on the short term to influence ridership and travel performance by proper marketing and sales activities than to change the timetable. The calculated VRS efficiency is split into Technical Efficiency and Scale Efficiency scores. The Malmquist Productivity Index is decomposed to identify the Efficiency Change and Technical Change factor from the CRS results over the 2007 to 2012 time period. All efficiency and effectiveness scores and Malmquist Productivity Indices are calculated by using DEAP (Data Envelopment Analysis Program) software written by Tim Coelli (2001).

3.2 Selected high-speed rail networks

To find best practices in production and marketing in the worlds' largest high-speed rail systems, eight networks are identified, four of which can be found in Asia (Japan, Taiwan, China, Korea) and four in Europe (France, Germany, Spain, Italy). The selection was made on the basis of actual travel volume over the selected time frame. The study not only compares the individual peers, but also explores the

differences between two regions, Europe and Asia. From the resulting performance matrices, strategies are proposed to improve the overall efficiency.

3.3 System characteristics and performance data

Table 1 shows the descriptive statistics of the input and output variables used in the study with their associated values from the data collected for the eight high-speed railway systems for 2007 till 2012 (in total 48 observations). The complete dataset can be found in appendix 1. For all countries, the figures are derived from UIC data, statistical handbooks and annual reports. To fill in information gaps, additional data is used from several other sources. For China, data from the World Bank (Bullock et al 2012) and the CRH timetable is used with estimations on travel performance made by the author and input from the universities of Beijing and Shanghai, as data on China's high-speed rail programme is not made publicly available.

Table 1: Descriptive statistics of inputs and outputs (N = 48)

Variable		NL	FS	AS	FPT	FPS	RS	TV
		Network Length	Fleet Size	Available Seats	Fleet Performance	Fleet Performance	Ridership	Travel Volume
Indicator		Total route-km	Number of trains	Number of available seats (thousands)	Yearly train-km of fleet (millions)	Yearly seat-km of fleet (billions)	Yearly number of passengers (millions)	Yearly passenger-km (billions)
Unit		km	-	-	km	km	-	km
Europe (N=4)	mean	1391	243	105.9	95.1	42.1	60.0	24.1
	SD	91	26	12.1	10.3	4.8	7.5	3.5
	min	562	97	37.5	45.4	13.4	11.4	8.5
	max	2056	475	216.4	182.6	83.2	115.5	54.0
Asia (N=4)	mean	2885	449	278.4	177.5	111.3	222.6	65.3
	SD	433	63	38.4	25.4	15.7	32.4	9.5
	min	330	30	29.7	7.9	7.8	15.6	3.5
	max	6405	632	455.4	300.0	216.2	485.5	144.6

Historically, the largest high-speed rail systems can be found in Japan, France, Germany and Spain. These countries have mature networks built gradually over decades. Heavy investments in high-speed rail over the last decade gave China the position of operating the largest high-speed rail network and fleet in the world since 2010. Train densities on the European high-speed network (ratio of FPT and NL from table 1) are about 10% higher than in Asia. In operational models where high-speed trains run on conventional tracks as well, train densities will be higher than in services where only high-speed tracks are used (Doomernik, 2013). From 2011 on, China is leader in ridership and travel volume and shows the fastest growth. Smaller networks can be found in Taiwan and Korea. Although France and China had a comparable fleet size in 2010, China's fleet capacity (number of available seats) is larger as their train sets can carry more passengers. This is typical for the Asian train sets (Doomernik, 2013). In Asia the average number of seats per train (ratio AS/FS from table 1) is 620 compared to 436 for Europe. Due to such high-capacity trains, Asia produces 170% more travel volume and 164% more seat kilometres than

Europe with only 86% more train kilometres. Large differences can also be seen regarding the average travel distance (ratio TV/RS from table 1). In Asia travellers take shorter trips (293 km) than in Europe (402 km). Seat occupancy (ratio of TV and FPS from table 1) is comparable for Europe (57%) and Asia (59%).

4. EMPIRICAL RESULTS

4.1 Malmquist Productivity Index

The results from the Malmquist Productivity Index and its decomposition in Efficiency Change and Technical Change are listed in Table 2 and graphically displayed in figure 2 for the eight high-speed rail systems. When the values of the Malmquist index and its components are more than 1 in an output-oriented evaluation, they indicate progress (Ozcan and Ozgen, 2004).

Table 2: Malmquist Productivity Index

	2008-2007	2009-2008	2010-2009	2011-2010	2012-2011	mean	2012-2007
Malmquist Productivity Index (MPI)							
France	1.011	0.967	0.984	0.998	0.974	0.986	0.940
Germany	1.063	0.972	1.058	0.987	1.064	1.028	1.141
Italy	0.931	1.250	1.003	1.001	1.070	1.046	1.188
Spain	0.965	1.028	0.963	0.786	1.036	0.951	0.778
Mean Europe	0.991	1.048	1.001	0.938	1.035	1.002	0.998
Japan	0.965	0.922	1.015	1.019	0.998	0.983	0.969
Korea	1.012	0.953	1.075	1.056	1.054	1.029	1.184
China	1.252	0.663	0.832	1.201	1.200	0.999	0.878
Taiwan	1.917	1.052	1.116	1.103	1.066	1.215	2.573
Mean Asia	1.237	0.885	1.003	1.093	1.077	1.053	1.269
Mean Europe + Asia	1.108	0.963	1.002	1.012	1.056	1.027	1.125
Efficiency Change (EC)							
France	1.000	1.000	1.000	0.954	0.916	0.973	0.874
Germany	1.063	0.957	1.049	0.928	0.961	0.990	0.951
Italy	0.912	1.255	1.003	0.942	0.920	0.999	0.995
Spain	0.928	1.070	0.984	0.746	0.891	0.917	0.649
Mean Europe	0.974	1.065	1.009	0.888	0.922	0.969	0.856
Japan	0.998	0.945	1.023	1.037	0.949	0.990	0.949
Korea	1.062	0.904	1.107	1.000	1.000	1.012	1.062
China	1.000	1.000	0.840	1.115	1.067	1.000	1.000
Taiwan	1.920	1.000	1.000	1.000	1.000	1.139	1.920
Mean Asia	1.194	0.961	0.988	1.037	1.003	1.034	1.179
Mean Europe + Asia	1.079	1.012	0.998	0.960	0.961	1.001	1.005
Technical Change (TC)							
France	1.011	0.967	0.984	1.045	1.063	1.013	1.075
Germany	1.000	1.016	1.008	1.063	1.107	1.038	1.199
Italy	1.020	0.996	1.000	1.063	1.163	1.047	1.195
Spain	1.040	0.960	0.979	1.054	1.163	1.037	1.199
Mean Europe	1.018	0.984	0.993	1.056	1.123	1.034	1.166
Japan	0.967	0.976	0.993	0.983	1.052	0.994	1.021
Korea	0.953	1.055	0.971	1.056	1.054	1.017	1.114
China	1.252	0.663	0.990	1.077	1.125	0.999	0.878
Taiwan	0.998	1.052	1.116	1.103	1.066	1.066	1.340
Mean Asia	1.036	0.921	1.016	1.054	1.074	1.019	1.076
Mean Europe + Asia	1.027	0.952	1.004	1.055	1.098	1.026	1.120

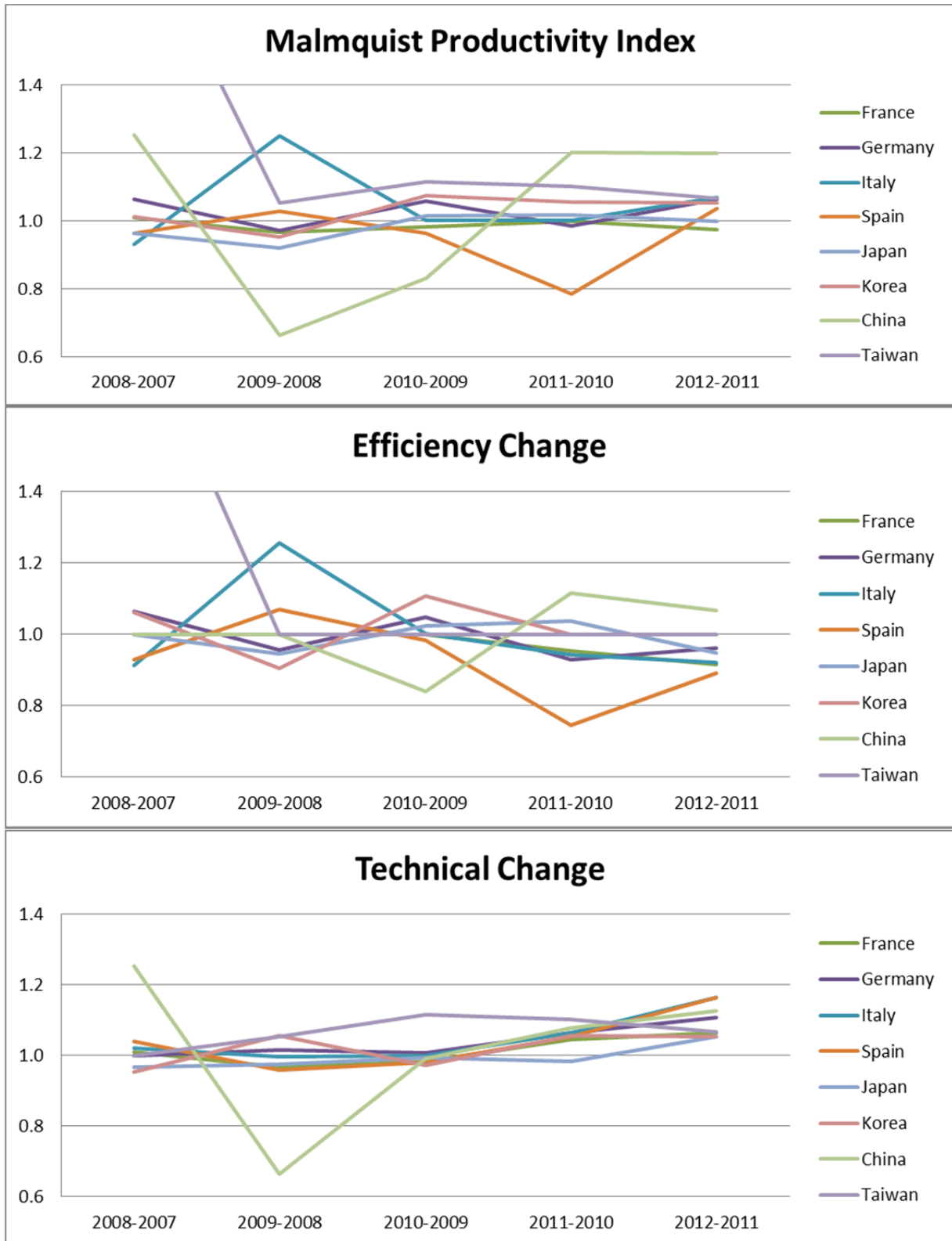


Figure 5: Malmquist Productivity Index and decomposition in Efficiency and Technical Change

The MPI reflects a productivity improvement for the whole peer group of 12.5% over the five-year period from 2007 till 2012. This is caused by technical change rather than improvement of efficiency.

In contrast with Europe, where the MPI was stable and close to 1 from 2007 to 2012, Asia achieved a productivity growth of 26.9% over the same time period. Europe didn't show any productivity improvement because, despite the 16.6% technical change, efficiency dropped with 14.4%. In Asia both technical efficiency improvements (+17.9%) and technology change (+7.6%) contributed to the overall productivity growth.

Looking at the individual HSR networks in Europe and Asia, the evolution of the Malmquist index is fairly stable over the years for Germany, Japan, Korea and France. Germany, Italy, Korea and Taiwan show an above-average MPI-value between 2007 and 2012. The high productivity improvement in Taiwan is remarkable (+157%). Taiwan is the only DMU that has achieved a productivity index above unity in every successive year. This is in fact from the start, as the Taiwan high-speed rail services were inaugurated in January 2007 and services were gradually increased. This also explains the high 2008-2007 MPI. Underperformers are the networks in Spain and China, but for different reasons. Efficiency in of the Spanish HSR-network dropped with 34.1% in five years' time, but this is partly compensated with a technical improvement of 19.9%. China achieved to keep up efficiency, but shows a decreasing technical change of 12.2%. A lot of variation can be seen in the China technical change index, making progress over the last couple of years. In this case we have to realise that China only started their high-speed operations in 2008 and is still growing fast. The network is not fully mature yet and CRH (the Chinese national high-speed railway operator) is still optimising their operations.

In general, productivity improvement for the peer group comes from technical change, rather than from efficiency change, which is declining year-on-year. Only Taiwan was able to maintain efficiency in five successive years.

4.2 Production efficiency and service effectiveness

The results from the DEA analysis are presented in Appendix 2. From the descriptive statistics (table 3) can be seen that Asian high-speed rail systems are fully efficient in the VRS-model. Scale efficiency is comparable for both Asian and European systems. The CRS and VRS models show that Asia outperforms Europe regarding production efficiency and service effectiveness.

Table 3: Descriptive statistics of efficiency of eight high-speed railways in Europe and Asia 2007 - 2012

Region	2007 -2012	Production efficiency			Service effectiveness			System Efficiency		
		CRS TE	VRS TE	SE	CRS TE	VRS TE	SE	CRS TE	VRS TE	SE
Europe (N=4)	mean	0.795	0.896	0.889	0.792	0.842	0.944	0.791	0.821	0.963
	SD	0.020	0.024	0.009	0.032	0.035	0.011	0.028	0.028	0.007
	min	0.542	0.591	0.796	0.504	0.522	0.783	0.555	0.579	0.856
Asia (N=4)	mean	0.936	0.985	0.949	0.877	0.977	0.897	0.958	1.000	0.958
	SD	0.025	0.011	0.021	0.027	0.012	0.025	0.020	0.000	0.020
	min	0.545	0.773	0.545	0.608	0.776	0.608	0.521	1.000	0.521

CRS TE = Technical Efficiency from CRS DEA VRS TE = Technical Efficiency from VRS DEA SE = Scale Efficiency

The efficiency scores as displayed in Appendix 2 for the production and marketing process are reflected in performance matrices in figure 6 (comparison between networks) and 7 (development in time) for the years 2007-2012. Overall efficient DMU's are coloured green and inefficient ones orange (overall efficiency between 0.75 and 1.00) or red (overall efficiency between 0.50 and 0.75).

The Asian DMU's and France are the best performers in the peer group. In all years Italy appears to be the worst performer and Germany and Spain are in the middle of the spectrum. Except for 2007, when the high-speed rail service was started, Taiwan was overall efficient and efficient in production. Year-on-year Taiwan has improved their marketing efficiency compared to others. This is in line with the MPI results shown earlier. Although the efficiency of the production process varies over the years China was able to be fully efficient in their marketing process. The results from the Malmquist index shows that technical change has been lagging behind. This indicates that improvements could be achieved in optimising the technical production process. For Korea the opposite is the case: an efficient production process, but variation in the marketing efficiency. In Japan we see a dip in 2008 and 2009 in their marketing performance. The last three years they have an efficient production and are improving their marketing performance, but are outperformed by Korea and Taiwan. This ranking can also be recognised by the MPI results. The evolution of the production and marketing efficiency in Italy and Germany shows the same pattern: a steady reduction in production efficiency and improving marketing performance after a light shortfall. Italy is performing a bit better in production, but this cannot compensate for their marketing inefficiency. Spain and France show fluctuating results. Their marketing is better than their production performance. France is improving and Spain is losing on production efficiency over the last years.

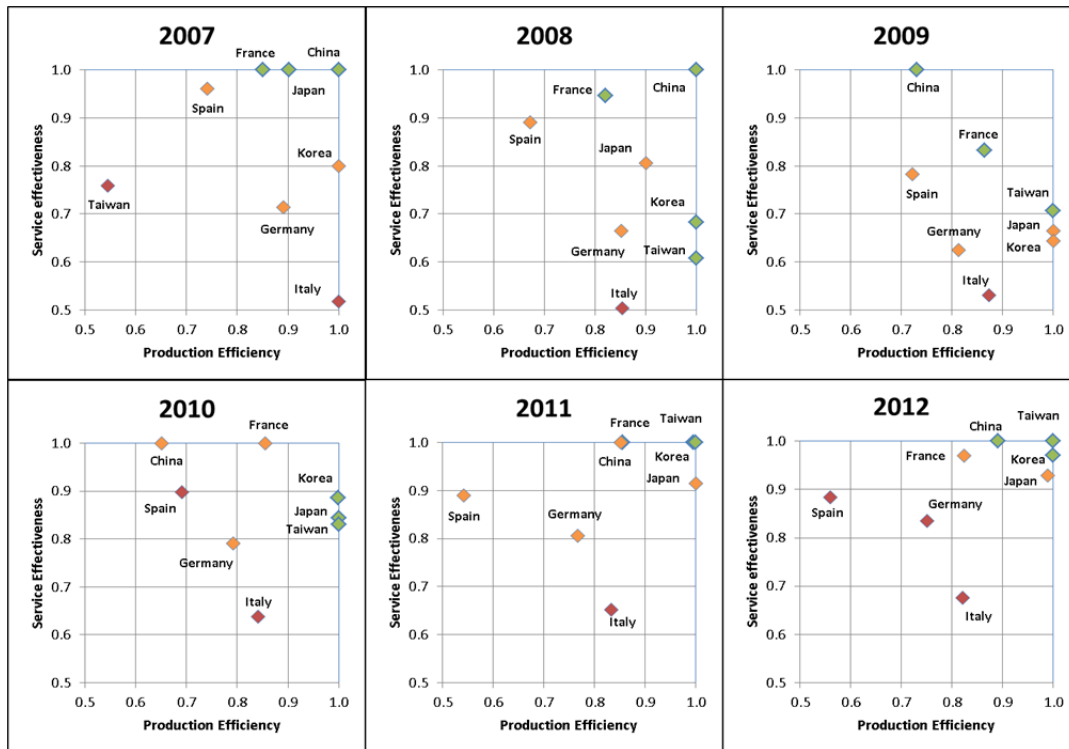


Figure 6: Performance of four European and four Asian high-speed rail networks (2007 – 2012).

Efficient systems are not necessarily effective and vice versa (Ozcan, 2008). In this context, an important question is raised by Karlaftis (2010): “How are efficiency and effectiveness ratings related?” Karlaftis states that “For all systems and years, the ratings on one performance attribute (efficiency) are – generally- negatively related to the ratings on the other attribute (effectiveness).” (Karlaftis, 2010). The correlation coefficients between production efficiency and service effectiveness for all high-speed rail systems in the peer group over the years 2007 to 2012 are presented in table 4 for the CRS and VRS model (in total 48 observations from 8 countries and over 6 years). The results indeed show a negative correlation which implies that increased production efficiency tends to come with decreased service effectiveness. For Europe this effect is much stronger than for Asia where a 10% increase in production efficiency comes with a 7% loss in service effectiveness.

Table 4: Correlation coefficients between Production Efficiency and Service Effectiveness

Region	Service Effectiveness	
	CRS Model	VRS Model
Europe + Asia	-0,091	-0,179
Europe	-0,657	-0,661
Asia	-0,170	-0,128

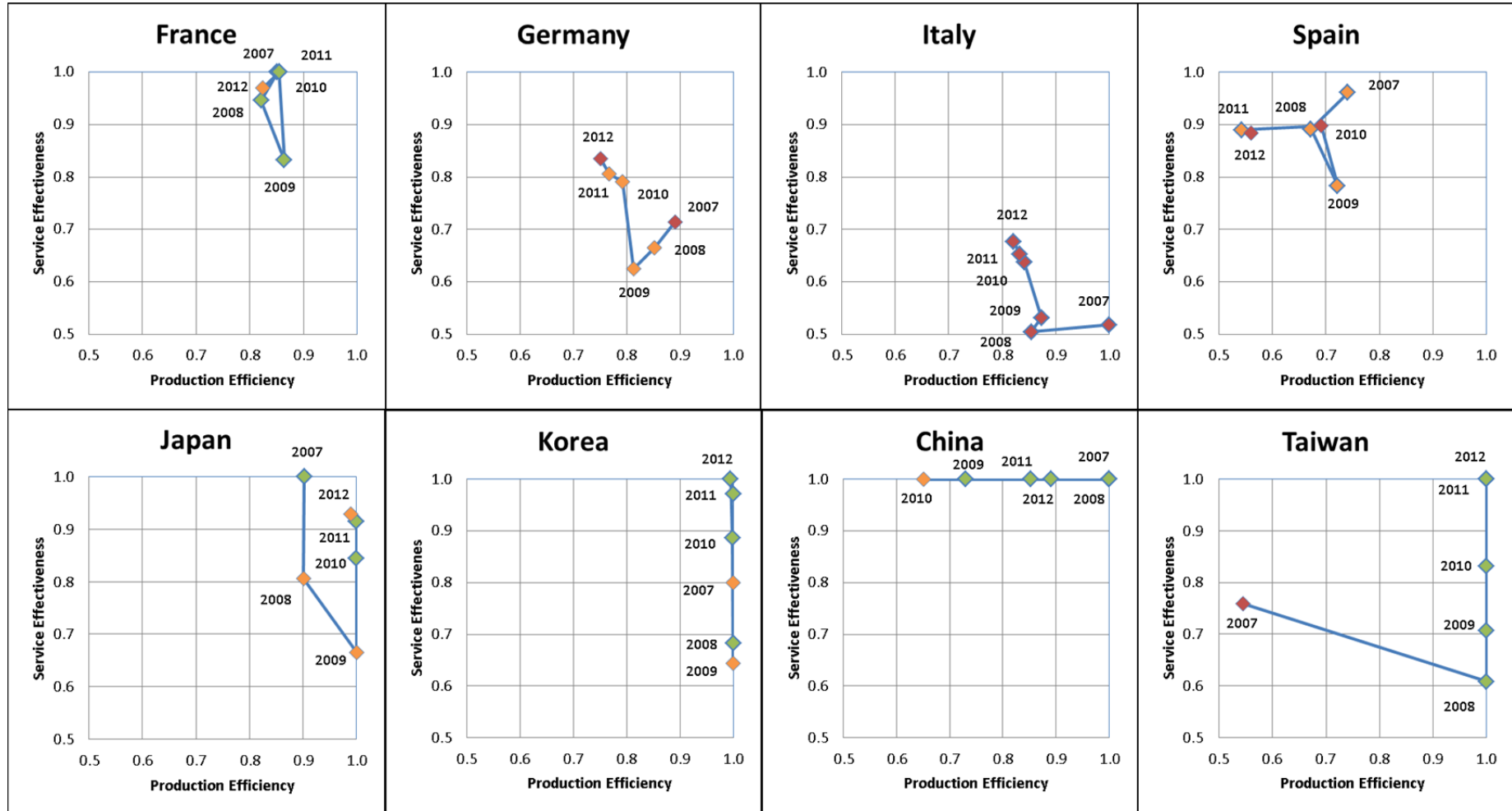




Figure 7: Efficiency development of four European and four Asian high-speed rail networks between 2007 and 2012.

5. SUMMARY AND CONCLUSIONS

In their search to optimise the utilisation of high-speed rail systems governments and railway companies may benefit from good practices in the rest of the world. Benchmarking of these systems in operation may give guidance to best practices in this sector to learn from. This study was initiated as to our knowledge no objective comparison of high-speed rail systems is available. Based on the current knowledge and experience in benchmarking, Network Data Envelopment Analysis (NDEA) in combination with the Malmquist Productivity Index was chosen for the benchmark. For this purpose, a performance matrix is presented to investigate the production efficiency and service effectiveness of the high-speed railways under study. The peer group consisted of the eight largest networks in the world (four in Europe and four in Asia) and revealed significant differences between Asia and Europe. Also within these regions remarkable differences can be found.

5.1 Results

Between 2007 and 2012, Asia achieved a productivity growth of 26.9%. Europe didn't show any productivity improvement because, despite the 16.6% technical change, efficiency dropped with 14.4%. In Asia both technical efficiency improvements (+17.9%) and technology change (+7.6%) contributed to the overall productivity growth.

Germany, Italy, Korea and Japan show an above-average MPI-value between 2007 and 2012. The high productivity improvement in Taiwan is remarkable (+157%). Taiwan is the only DMU that has achieved a productivity index above unity in every successive year.

Underperformers are the networks in Spain and China, but for different reasons. Efficiency in of the Spanish HSR-network dropped with 34.1% in five years' time, but this is partly compensated with a technical improvement of 19.9%. China achieved to keep up efficiency, but shows a decreasing technical change of 12.2%.

The DEA model shows that Asian high-speed rail systems are fully efficient in the VRS model and Asia outperforms Europe regarding production efficiency and service effectiveness. The Asian DMU's and France are the best performers in the peer group. In all years Italy appears to be the worst performer and Germany and Spain are in the middle of the spectrum.

The results show a negative correlation between production efficiency and service effectiveness. For Europe, this effect is much stronger than for Asia where a 10% increase in production efficiency comes with a 7% loss in service effectiveness.

5.2 Methodology

The study shows that high-speed railways can be represented as a MIMO-system with two input and two output variables for benchmark purposes. Meaningful comparisons can be made on the basis of the overall efficiency and the efficiency of the production and marketing process.

A Network DEA-model has proven to be very useful to analyse the differences in performance among the peer group. It gives a better view if performance differences come from the production or marketing and sales process. The performance matrices reveal typical patterns regarding production efficiency and service effectiveness. The conclusions from the Malmquist index are in line with the resulting performance matrices from the DEA-model.

In the NDEA model the number of variables is rather limited. Including extra variables will lead to a better representation and better understanding of the actual situation. For the input one could include for example labour (number of train drivers and train assistants) and operational costs. Besides trainkm's to describe the fleet performance, punctuality could also be an important intermediate variable. Client satisfaction could be added as an extra output variable. To what extent extra variables can be included depends on data availability. The model could be refined by considering shared inputs and adding environmental variables as suggested by Yu (Yu, 2008).

In the analysis coherent national networks are assumed. In Japan, the national network consists of four sub-networks though, operated by JR East, JR Central, JR West and JR Kyushu. The analysis could be detailed to take not the country, but the individual operators as DMU's.

The peer group consists of eight networks which show considerable differences in operational models. The four basic operational models that can be recognised in various countries are the exclusive model where only HS-trains run on HS-track (Japan, Taiwan), the mixed high speed model where HS-trains run on conventional track as well (France, China), the mixed conventional model where also conventional trains can access the HS-network (Spain) and the fully mixed model where both high-speed and conventional trains can run on high-speed and conventional tracks (Germany) (Rus et al. 2009). Although theoretically it would be better to take different operational models into account, the peer group is too limited to split it into sub-groups.

ACKNOWLEDGEMENTS

I would like to thank Tom Duffhues from the Technical University Twente in the Netherlands and Els Struyf from Antwerp University in Belgium for identifying the proper DEA software tools, Geraint Roberts for being so kind to share his results from his Master Thesis at the Starthclyde University in the UK, Adrian Ng from Lloyd's Register Rail in Hong Kong, Mr. Wu from Beijing University, Liehui Wang from East China Normal University and Rang Zong

from Shanghai University for helping to find the right data on the CRH operation in China.

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APPENDIX 1: INPUT AND OUTPUT VARIABLES AND VALUES

Variable		NL	FS	AS	FPT	FPS	RS	TV
		Network Length	Fleet Size	Available Seats	Fleet Performance	Fleet Performance	Ridership	Travel Volume
Indicator		Total route-km	Number of trains	Number of available seats (thousands)	Yearly train-km of fleet (millions)	Yearly seat-km of fleet (billions)	Yearly number of passengers (millions)	Yearly passenger-km (billions)
Unit		km	-	-	km	km	-	km
2007	France	1540	406	181.2	162.9	72.7	105.4	48.0
2007	Germany	1285	254	113.0	109.2	48.6	70.5	21.9
2007	Italy	562	97	56.6	46.8	27.3	23.4	9.2
2007	Spain	1272	136	37.5	48.7	13.4	11.4	8.5
2007	Japan	2452	354	340.5	135.2	134.5	315.8	82.8
2007	Korea	330	46	43.0	21.4	20.0	36.7	9.9
2007	China	405	113	70.8	40.0	25.0	86.5	13.0
2007	Taiwan	345	30	29.7	7.9	7.8	15.6	3.5
2008	France	1872	422	189.4	171.0	76.8	115.5	52.2
2008	Germany	1285	254	113.0	109.8	48.8	74.7	23.3
2008	Italy	562	109	61.8	45.4	25.7	23.9	9.3
2008	Spain	1511	162	48.0	55.3	16.4	22.1	10.5
2008	Japan	2452	363	357.0	138.0	141.2	310.3	81.7
2008	Korea	330	46	43.0	21.8	20.4	37.4	10.0
2008	China	405	191	128.0	53.0	35.5	127.4	25.5
2008	Taiwan	345	30	29.7	15.3	15.1	30.6	6.6
2009	France	1872	435	196.1	173.8	78.3	114.4	51.9
2009	Germany	1285	254	113.0	102.1	45.4	73.2	22.6
2009	Italy	744	108	61.3	47.0	26.7	33.4	11.3
2009	Spain	1599	162	48.0	58.4	17.3	23.1	10.8
2009	Japan	2452	367	363.7	138.3	143.5	288.9	76.0
2009	Korea	330	52	45.2	22.0	19.1	36.8	9.8
2009	China	1409	279	186.3	87.0	58.1	179.6	46.3
2009	Taiwan	345	30	29.7	15.0	14.8	32.3	6.9
2010	France	1872	450	203.7	172.2	78.0	112.6	52.8
2010	Germany	1285	254	113.0	102.3	45.5	77.8	23.9
2010	Italy	923	110	62.2	47.7	27.0	34.0	11.5
2010	Spain	1604	162	48.0	57.6	17.1	22.2	10.4
2010	Japan	2452	375	368.6	134.3	139.2	292.1	77.4
2010	Korea	330	61	48.5	23.3	18.5	40.8	10.8
2010	China	3408	466	306.9	182.0	100.1	290.5	65.2
2010	Taiwan	345	30	29.7	15.5	15.3	36.9	7.5
2011	France	1896	463	209.9	179.3	81.3	114.2	54.0
2011	Germany	1285	246	111.6	99.9	45.3	76.1	23.3
2011	Italy	923	110	62.2	48.7	27.6	37.4	11.5
2011	Spain	2056	203	61.7	58.6	17.8	22.8	10.5
2011	Japan	2534	386	370.4	142.7	142.8	307.0	81.4
2011	Korea	412	65	49.9	27.7	21.3	49.6	13.4
2011	China	4584	551	383.4	250.0	173.9	440.0	98.1
2011	Taiwan	345	30	29.7	16.0	15.8	41.6	8.1
2012	France	1896	475	216.4	182.6	83.2	114.2	54.0
2012	Germany	1285	246	111.6	97.9	44.4	76.6	24.8
2012	Italy	923	110	62.2	48.1	27.2	39.8	12.3
2012	Spain	2056	193	59.0	57.6	17.6	22.3	10.4
2012	Japan	2664	365	352.1	145.7	145.1	321.6	86.0
2012	Korea	412	65	49.9	29.6	22.7	52.4	14.1
2012	China	6405	632	455.4	300.0	216.2	485.5	144.6
2012	Taiwan	345	30	29.7	16.0	15.8	44.5	8.6

Note: Data for China based on estimations by the author.

APPENDIX 2: DEA EFFICIENCY AND EFFECTIVENESS RESULTS

Year	Network	Production Efficiency			Service Effectiveness			System Efficiency		
		CRS TE	VRS TE	SE	CRS TE	VRS TE	SE	CRS TE	VRS TE	SE
2007	France	0.851	0.978	0.870	1.000	1.000	1.000	1.000	1.000	1.000
2007	Germany	0.891	1.000	0.891	0.714	0.724	0.986	0.773	0.784	0.985
2007	Italy	1.000	1.000	1.000	0.518	0.536	0.968	0.626	0.674	0.929
2007	Spain	0.741	0.896	0.827	0.961	1.000	0.961	0.856	1.000	0.856
2007	Japan	0.902	1.000	0.902	1.000	1.000	1.000	1.000	1.000	1.000
2007	Korea	1.000	1.000	1.000	0.800	0.848	0.944	0.942	1.000	0.942
2007	China	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2007	Taiwan	0.545	1.000	0.545	0.759	1.000	0.759	0.521	1.000	0.521
2007	Mean	0.866	0.984	0.879	0.844	0.888	0.952	0.840	0.932	0.904
2008	France	0.821	0.988	0.831	0.946	1.000	0.946	1.000	1.000	1.000
2008	Germany	0.852	1.000	0.852	0.665	0.683	0.973	0.821	0.836	0.983
2008	Italy	0.854	0.920	0.929	0.504	0.522	0.964	0.571	0.599	0.952
2008	Spain	0.672	0.729	0.922	0.891	1.000	0.891	0.794	0.888	0.894
2008	Japan	0.901	1.000	0.901	0.806	1.000	0.806	0.998	1.000	0.998
2008	Korea	1.000	1.000	1.000	0.682	0.776	0.880	1.000	1.000	1.000
2008	China	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2008	Taiwan	1.000	1.000	1.000	0.608	1.000	0.608	1.000	1.000	1.000
2008	Mean	0.888	0.955	0.929	0.763	0.873	0.884	0.898	0.915	0.978
2009	France	0.864	0.992	0.871	0.832	0.973	0.855	1.000	1.000	1.000
2009	Germany	0.813	0.968	0.840	0.625	0.641	0.974	0.786	0.790	0.995
2009	Italy	0.873	0.989	0.883	0.531	0.595	0.892	0.716	0.731	0.980
2009	Spain	0.722	0.791	0.913	0.783	1.000	0.783	0.850	0.910	0.933
2009	Japan	1.000	1.000	1.000	0.665	1.000	0.665	0.943	1.000	0.943
2009	Korea	1.000	1.000	1.000	0.644	0.872	0.739	0.904	1.000	0.904
2009	China	0.730	0.773	0.944	1.000	1.000	1.000	1.000	1.000	1.000
2009	Taiwan	1.000	1.000	1.000	0.706	1.000	0.706	1.000	1.000	1.000
2009	Mean	0.875	0.939	0.931	0.723	0.885	0.827	0.900	0.929	0.969
2010	France	0.855	0.988	0.865	1.000	1.000	1.000	0.954	1.000	0.954
2010	Germany	0.792	0.994	0.796	0.791	0.810	0.977	0.765	0.801	0.955
2010	Italy	0.841	0.993	0.848	0.638	0.676	0.944	0.677	0.696	0.973
2010	Spain	0.691	0.777	0.889	0.898	1.000	0.898	0.623	0.640	0.973
2010	Japan	1.000	1.000	1.000	0.844	1.000	0.844	1.000	1.000	1.000
2010	Korea	0.999	1.000	0.999	0.886	1.000	0.886	1.000	1.000	1.000
2010	China	0.651	0.858	0.758	1.000	1.000	1.000	0.937	1.000	0.937
2010	Taiwan	1.000	1.000	1.000	0.831	1.000	0.831	1.000	1.000	1.000
2010	Mean	0.854	0.951	0.894	0.861	0.936	0.923	0.898	0.930	0.967
2011	France	0.855	0.921	0.928	1.000	1.000	1.000	1.000	1.000	1.000
2011	Germany	0.767	0.873	0.878	0.806	0.825	0.977	0.824	0.871	0.946
2011	Italy	0.833	0.909	0.916	0.652	0.654	0.998	0.718	0.720	0.998
2011	Spain	0.542	0.591	0.917	0.890	1.000	0.890	0.836	0.847	0.986
2011	Japan	1.000	1.000	1.000	0.915	0.977	0.937	0.965	1.000	0.965
2011	Korea	0.995	1.000	0.995	1.000	1.000	1.000	1.000	1.000	1.000
2011	China	0.852	1.000	0.852	1.000	1.000	1.000	0.840	1.000	0.840
2011	Taiwan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2011	Mean	0.855	0.912	0.936	0.908	0.932	0.975	0.870	0.892	0.974
2012	France	0.824	0.897	0.919	0.970	0.984	0.987	0.874	0.956	0.914
2012	Germany	0.751	0.852	0.881	0.835	0.863	0.968	0.735	0.740	0.994
2012	Italy	0.821	0.874	0.939	0.676	0.718	0.942	0.622	0.647	0.962
2012	Spain	0.560	0.595	0.942	0.884	1.000	0.884	0.555	0.579	0.959
2012	Japan	0.989	1.000	0.989	0.929	0.977	0.950	0.949	1.000	0.949
2012	Korea	1.000	1.000	1.000	0.971	1.000	0.971	1.000	1.000	1.000
2012	China	0.891	1.000	0.891	1.000	1.000	1.000	1.000	1.000	1.000
2012	Taiwan	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2012	Mean	0.854	0.902	0.945	0.908	0.943	0.963	0.842	0.865	0.972

CRS TE = Technical Efficiency from CRS DEA

VRS TE = Technical Efficiency from VRS DEA

SE = Scale Efficiency = CRS TE/VRS TE