CHAPTER 4. EFFICIENCY AND EFFECTIVENESS MEASUREMENT FOR RAIL TRANSPORT

This chapter measures productive efficiency and service effectiveness for 44 selected railways worldwide over the period of 1995 to 2001. More specifically, the research measures efficiency by adopting input-orientated DEA models and by selecting number of passenger cars per kilometer of lines, number of freight cars per kilometer of lines, and number of employees per kilometer of lines as input factors, and passenger-train-kilometer per kilometer of lines and freight-train-kilometer per kilometer of lines as output variables. Both three-stage DEA method and proposed four-stage DEA method are applied and the results are compared. In addition, this research also measures effectiveness by employing output-orientated DEA models and by choosing passenger-kilometers and ton-kilometers as two output variables and passenger train-kilometers and freight train-kilometers as two input factors. Similar to efficiency measurement, the results measured from three-stage and four-stage DEA method are compared. The remaining of this chapter is organized as follows. The data set is presented in 4.1. 4.2 and 4.3 describe analytical results of efficiency and effectiveness measurement, respectively, including measured by CCR, BCC models and three-stage, four-stage DEA approaches. The concluding remarks are described in 4.4.

4.1 The Data

For measuring the rail technical efficiency, previous studies usually select passenger train-kilometers and freight train-kilometers as two outputs, number of employees, number of cars, and length of lines as input factors (for example, Coelli and Perelman, 2000). There are two reasons, however, this research does not choose length of lines as an input factor. The first one is that, for rail industry, from the perspective of economics, line facility is always attributed to fixed cost due to sunk characteristics; this research attempts to measure the efficiency of the variable input factors usage. The second reason is that, the length of lines varies from 220 to 62,915 kilometers in the samples, since we are looking for a more homogeneous set of DMUs, where comparison makes sense. Therefore, this research measures the technical efficiency and productivity by selecting number of passenger cars per kilometer of lines, number of freight cars per kilometer of lines, and number of employees per kilometer of lines as inputs and passenger-train-kilometer per kilometer of lines and freight-train-kilometer per kilometer of lines as input factors and passenger-train-kilometer per kilometer of lines and freight-train-kilometer per kilometer of lines as output variables. For measuring the service effectiveness and sales force, on the other hand, we choose passenger-kilometers and ton-kilometers as two outputs and utilize passenger train-kilometers and freight train-kilometers as two inputs. For simplicity, we do not account for such external factors as public/private ownership and regulatory differences across the firms.

The data set used in this research is drawn from International Railway Statistics published by the International Union of Railways (UIC). The complete data set contains 50 railways and covers seven years (1995-2001), so there is a total of 350 observations for the panel data. Since DEA method measures the efficiency (effectiveness) of each sample related to efficient (effective) DMUs, the results are affected by the influential observations. Therefore, it is important to detect the outliers from the samples. In this paper, we conduct the boxplot test to identify the potential outliers and remove from the sample. The procedure for detecting outliers is described as follows. Firstly, all possible ratios, including output to input and consumption to output, are computed and then a boxplot is constructed for each ratio. Fifty percent of the sample lies within the box. The median ±3.5×IR represents an extended boxplot, where IR is the inter-quartile range, or the difference between the third quartile and the first quartile. Any DMU with the value of ratio outside the extended boxpolt is considered as an outlier. After the procedure has been preceded, six DMUs are considered as outliers thus been removed from the sample set. The final sample set consists of 44 DMUs over seven years, that is, 308 observations. Table 4-1 summarizes the descriptive statistics of the data including two consumption (passenger-kilometers and ton-kilometers), two outputs (passenger train-kilometers and freight train-kilometers), four inputs (length of lines, number of passenger cars, number of freight cars, and number of employees), two environmental variables (gross national income per capita and population density), and two variables characterizing the railways (percentage of electrified and ratio of passenger train-kilometers to total train-kilometers).

Table 4-1 The descriptive statistics for the observations (44 railways over 7 years)

Year	Statistics	Service consumptions		Service output			Service input			Environmental Variables		Characteristics of railways	
		Pax-km	Ton-km	Pax Train-km	Freight Train-km	Length of lines	Pax cars	Freight cars	Labors	GNI	POP	ELEC (%)	ROP
1995	Max.	319365	252967	695323	240924	62660	34314	467884	1602051	45060	982.2	1.000	0.925
	Min.	104	265	562	858	220	40	162	1265	200	0.4	0.000	0.173
	Mean	22725	21910	89495	33525	8152	4684	43602	93436	13716	42.7	0.377	0.666
	Std.	60476	47782	153275	53945	12219	7419	84453	248375	13427	147.1	0.290	0.163
1996	Max.	341999	273515	693664	245810	62915	34188	269783	1586429	45251	980.2	1.000	0.932
	Min.	119	265	553	832	220	46	170	1253	200	0.4	0.000	0.168
	Mean	23227	21291	90142	32651	9025	4324	34060	90441	13846	41.6	0.355	0.670
	Std.	63312	48053	154794	53379	14414	7205	59071	245024	13317	145.1	0.283	0.164
1997	Max.	357013	277567	697635	249528	62725	34648	261482	1583614	45388	982.2	1.000	0.930
	Min.	120	331	856	891	220	52	170	1235	210	0.4	0.000	0.232
	Mean	23369	21137	90587	32735	8095	4233	32409	87757	13605	41.9	0.385	0.670
	Std.	64735	48277	155648	52881	11994	7137	56226	243334	13220	147.3	0.286	0.166
1998	Max.	379897	284249	698160	250465	62495	28729	443527	1578802	45098	982.2	1.000	0.964
	Min.	135	314	1112	934	220	50	170	1212	220	0.4	0.000	0.220
	Mean	23477	21071	91746	31942	8071	4047	39356	85401	13826	42.7	0.391	0.666
	Std.	67072	48904	159405	52189	11946	6596	79304	242089	13317	147.1	0.288	0.166
1999	Max.	403884	284270	726938	246185	62810	35656	243540	1578000	43630	999.0	1.000	0.939
	Min.	136	326	679	1068	220	47	165	1241	220	0.4	0.000	0.182
	Mean	24326	20530	93400	31486	8054	4290	31818	83607	13533	43.2	0.395	0.669
	Std.	70141	48634	164154	52651	11927	7347	54737	241654	13062	149.6	0.289	0.174
2000	Max.	430666	305201	739800	260594	62759	36621	235346	1577192	41860	1015.9	1.000	0.941
	Min.	74	326	752	1095	220	52	165	1241	210	0.4	0.000	0.180
	Mean	25103	21927	94115	32578	7974	4222	30728	82263	13627	43.7	0.399	0.660
	Std.	73649	52446	166611	55562	11753	7469	51990	241380	13052	152.1	0.288	0.184
2001	Max.	457022	312371	697781	260218	62759	36476	233993	1545300	39840	1032.4	1.000	0.949
	Min.	75	334	752	1034	220	45	175	1450	210	0.4	0.000	0.156

Year	Statistics	Service consumptions		Service output			Service input			Environmental Variables		Characteristics of railways	
		Pax-km	Ton-km	Pax Train-km	Freight Train-km	Length of lines	Pax cars	Freight cars	Labors	GNI	POP	ELEC (%)	ROP
	Mean	25739	22034	92989	31644	7884	4205	26899	80013	13246	44.2	0.405	0.664
	Std.	77099	53489	162547	53275	11662	7424	47935	236541	12617	154.6	0.289	0.191
Panel	Max.	457022	312371	739800	260594	62915	36621	467884	1602051	45060	1032.4	1.000	0.964
	Min.	74	265	553	832	220	40	162	1212	200	0.4	0.000	0.156
	Mean	23995	21414	91782	32366	8179	4286	34124	86131	13604	43.0	0.387	0.666
	Std.	67626	49216	158003	52901	12190	7165	62917	240308	13085	147.9	0.285	0.171

Note: GNI denotes per capita gross national income (US dollar) and POP denotes population (in million persons) of the country to which the railway belongs. ELEC represents the percentages of lines being electrified. ROP is defined as the ratio of passenger train-kilometers to total train-kilometers.

In addition to outlier detecting, another important procedure is the isotonicty testing. The isotonicty relations are assumed for DEA, which means that an increase in any input should not result in a decrease in any output (see for example, Golany and Roll, 1989). Consequently, the correlation coefficients between any input and any output should be positive. The isotonicty test results are indicated in Table 4-2, from the table, we see that all correlation coefficients are positive. Some coefficients are relative high, for example, correlation between passenger-train-kilometer to length of lines, while some are relative low, for instance, freight-train-kilometer to passenger-kilometer. This is because using freight cars cannot produce passenger service. Same results can be found in the relation between service outputs and consumptions, the correlation coefficient between passenger-train-km and passenger-km are high, but relative low between freight-train-km. This is because freight service output cannot be consumed by passengers.

Table 4-2 the correlation coefficients between input and output, output and consumption

Efficiency measurement					Effectiveness measurement		
Input/output	Line	Labor	Pcars	Fcars	Output/consum.	P-tr-km	F-tr-km
P-tr-km	0.7595	0.6955	0.8918	0.4548	Pass-km	0.8557	0.4586
F-tr-km	0.9595	0.7937	0.4936	0.8419	Ton-km	0.5050	0.8226

4.2 Efficiency Measurements

4.2.1 Measured by CCR and BCC models

To measure the efficiency, this research solves both CCR and BCC models by employing GAMS computer program. The estimated results for the two models are indicated in Table 4-3 and 4-4, respectively. From the tables, we note that, in general, low efficiency scores are found in the rail industry with only a few exceptions. The average efficiencies are 0.565 and 0.653, based on CCR and BCC model, respectively. This partly reflects that most railways have been facing a decline situation. In addition, the results indicate that BCC efficiencies are greater than or equal to those estimated from CCR model. This result explains that the BCC approach forms a convex hull of intersecting planes; which envelop the data points more tightly than the CCR conical hull. Therefore, technical efficiency scores provided by BCC model are greater than or equal to those obtained from CCR model.

The results denoted above are based both on the assumptions of constant returns to scale (CRS) and variable returns to scale (VRS). To investigate which returns to scale is more appropriate to rail systems, Banker (1996) proposed the following method. Assume that θ is half-normally distributed, the research evaluates the statistic $T_{HN}=\sum_{j=1}^{N}(\theta_j^C-1)^2/\sum_{j=1}^{N}(\theta_j^B-1)^2$, where θ_j^C and θ_j^B are CCR and BCC efficiencies, respectively. If T_{HN} is greater than $F_{critical}\ (N, N)$, then reject the null hypothesis of CRS. Firstly, we test for normality by applying the kurtosis method (Thode, 2002), $b_2=m_4/(m_2)^2$, where b_2 is coefficient of kurtosis, m_4 and m_2 are the fourth and second moments, respectively. Since b_2 is 2.308, for two-sided 0.05 test, $2.20<2.308<4.16$, we cannot reject the null hypothesis of normality. That is, the efficiency scores follow half-normal distribution. Then we test for CRS, since T_{HN} (=76.7032/58.5708=1.3095) is greater than $F\ (308,308)$=1.2876, thus reject the null hypothesis of CRS. That is, VRS is prevailing for the rail industry. In the following analysis, therefore, only the measurements based on BCC model are discussed.

Table 4-3 the efficiency measurement for 44 railways (CCR)

No	Country	Railways	1995	1996	1997	1998	1999	2000	2001	mean	stdev
1	Austria	*ÖBB*	0.528	0.558	0.581	0.662	0.677	0.697	0.840	0.649	0.106
2	Belgium	*SNCB/NMBS*	0.418	0.432	0.442	0.413	0.418	0.411	0.435	0.424	0.012
3	Denmark	*DSB*	0.617	0.613	0.812	0.990	0.987	1.000	1.000	0.860	0.180
4	Finland	*VR*	0.632	0.641	0.678	0.691	0.682	0.677	0.671	0.667	0.022
5	France	*SNCF*	0.448	0.735	0.769	0.529	0.551	0.562	0.817	0.630	0.141
6	Germany	*DB AG*	0.660	0.688	0.667	0.709	0.674	0.674	0.692	0.681	0.017
7	Greece	*CH*	0.315	0.336	0.355	0.915	0.542	0.418	0.442	0.475	0.209
8	Ireland	*CIE*	0.767	0.791	0.766	0.800	0.794	0.557	0.711	0.741	0.086
9	Italy	*FS SpA*	0.357	0.381	0.402	0.394	0.380	0.390	0.399	0.386	0.015
10	Luxembourg	*CFL*	0.275	0.741	0.731	0.748	0.780	0.735	0.700	0.673	0.177
11	Netherlands	*NS N.V.*	0.994	0.799	0.908	0.879	0.926	0.964	1.000	0.924	0.071
12	Portugal	*CP*	0.539	0.518	0.656	0.692	0.769	0.824	0.688	0.669	0.112
13	Spain	*RENFE*	0.572	0.616	0.675	0.650	0.667	0.663	0.761	0.658	0.058
14	Sweden	*SJ AB*	0.956	1.000	1.000	0.945	0.980	1.000	0.989	0.981	0.023
15	Norway	*NSB BA*	0.720	0.858	0.882	0.995	0.874	0.970	0.855	0.879	0.090
16	Switzerland	*BLS*	0.896	0.779	0.917	1.000	1.000	1.000	1.000	0.942	0.084
17	Switzerland	*CFF/SBB/FFS*	0.473	0.543	0.565	0.873	0.556	0.586	0.719	0.616	0.135
18	Bulgaria	*BDZ*	0.319	0.301	0.304	0.281	0.282	0.251	0.301	0.291	0.022
19	Croatia	*HZ*	0.378	0.438	0.444	0.430	0.490	0.525	0.481	0.455	0.048
20	Czech Rep	*CD*	0.375	0.391	0.361	0.345	0.348	0.386	0.406	0.373	0.023
21	Estonia	*EVR*	0.229	0.230	0.363	0.404	0.602	0.642	0.589	0.437	0.176
22	Hungary	*GYSEV/RÖEE*	0.900	1.000	1.000	0.752	0.869	0.831	0.873	0.889	0.089
23	Hungary	*MÁV Rt.*	0.366	0.384	0.426	0.425	0.451	0.435	0.467	0.422	0.036
24	Latvia	*LDZ*	0.266	0.346	0.423	0.396	0.712	0.820	0.538	0.500	0.202
25	Lithuania	*LG*	0.359	0.408	0.418	0.415	0.396	0.422	0.383	0.400	0.023
26	Poland	*PKP*	0.438	0.384	0.396	0.420	0.432	0.433	0.398	0.414	0.022
27	Romania	*CFR*	0.415	0.295	0.285	0.257	0.152	0.216	0.227	0.264	0.082
28	Slovak	*ZSR*	0.369	0.349	0.371	0.356	0.360	0.356	0.440	0.372	0.031
29	Slovenia	*SZ*	0.549	0.550	0.577	0.590	0.610	0.621	0.609	0.587	0.029
30	Moldova	*CFM (E)*	0.174	0.167	0.141	0.131	0.100	0.093	0.108	0.131	0.032
31	Ukraine	*UZ*	0.265	0.308	0.359	0.363	0.372	0.395	0.345	0.344	0.044
32	Turkey	*TCDD*	0.435	0.458	0.489	0.466	0.456	0.531	0.437	0.467	0.033
33	Israel	*IsR*	0.571	0.659	0.567	0.444	0.445	0.532	0.674	0.556	0.092
34	Morocco	*ONCFM*	0.269	0.354	0.346	0.407	0.413	0.409	0.500	0.385	0.072
35	Syria	*CFS*	0.355	0.312	0.335	0.307	0.302	0.346	0.343	0.329	0.021
36	Mozambique	*CFM*	0.196	0.268	0.234	0.208	0.233	0.285	0.286	0.244	0.036
37	Tanzania	*TRC*	0.813	0.765	0.966	0.987	0.810	0.898	0.984	0.889	0.093
38	Azerbaijan	*AZ*	0.132	0.145	0.157	0.163	0.178	0.191	0.210	0.168	0.027
39	Korea	*KNR*	0.581	0.735	0.731	0.692	0.819	0.792	0.673	0.718	0.079
40	Japan	*JR*	0.740	0.953	0.973	0.811	0.994	0.984	1.000	0.922	0.103
41	India	*IR*	0.276	0.318	0.327	0.347	0.337	0.355	0.356	0.331	0.028
42	Taiwan	*TRA*	0.637	0.635	0.651	0.677	0.690	0.731	0.777	0.685	0.053
43	Turkmenistan	*TRK*	0.493	0.415	0.513	0.435	0.456	0.470	0.447	0.461	0.034
44	Australia	*QR*	0.934	0.889	0.967	0.960	0.983	0.992	1.000	0.961	0.039
Mean			0.500	0.534	0.567	0.576	0.581	0.593	0.604	0.565	0.071

Table 4-4 the efficiency measurement for 44 railways (BCC model)

No	Country	Railways	1995	1996	1997	1998	1999	2000	2001	mean	stdev
1	Austria	*ÖBB*	0.740	0.732	0.784	0.929	0.950	1.000	1.000	0.876	0.120
2	Belgium	*SNCB/NMBS*	0.499	0.508	0.497	0.525	0.519	0.517	0.508	0.510	0.011
3	Denmark	*DSB*	0.619	0.616	0.819	0.987	1.000	1.000	1.000	0.863	0.180
4	Finland	*VR*	0.635	0.648	0.675	0.689	0.685	0.686	0.692	0.673	0.022
5	France	*SNCF*	0.497	0.775	0.813	0.605	0.630	0.679	0.857	0.694	0.128
6	Germany	*DB AG*	0.769	0.804	0.806	0.859	0.914	1.000	0.952	0.872	0.086
7	Greece	*CH*	0.385	0.406	0.444	1.000	0.672	0.593	0.622	0.589	0.213
8	Ireland	*CIE*	0.830	0.852	0.827	0.868	0.862	0.797	0.786	0.832	0.032
9	Italy	*FS SpA*	0.427	0.449	0.476	0.457	0.408	0.414	0.425	0.437	0.025
10	Luxembourg	*CFL*	1.000	0.681	0.600	0.629	0.673	0.643	0.623	0.693	0.138
11	Netherlands	*NS N.V.*	1.000	0.892	0.973	0.993	0.944	1.000	1.000	0.972	0.041
12	Portugal	*CP*	0.555	0.543	0.663	0.696	0.787	0.829	0.705	0.682	0.107
13	Spain	*RENFE*	0.579	0.625	0.677	0.655	0.673	0.673	0.764	0.664	0.057
14	Sweden	*SJ AB*	1.000	1.000	1.000	0.955	0.980	1.000	1.000	0.991	0.017
15	Norway	*NSB BA*	0.769	0.929	0.953	1.000	1.000	1.000	1.000	0.950	0.085
16	Switzerland	*BLS*	0.932	0.837	0.941	1.000	1.000	1.000	1.000	0.958	0.062
17	Switzerland	*CFF/SBB/FFS*	0.722	0.779	0.803	1.000	0.927	1.000	1.000	0.890	0.120
18	Bulgaria	*BDZ*	0.297	0.284	0.289	0.256	0.265	0.248	0.311	0.279	0.023
19	Croatia	*HZ*	0.387	0.423	0.391	0.450	0.488	0.497	0.470	0.444	0.044
20	Czech Rep	*CD*	0.450	0.450	0.407	0.375	0.355	0.393	0.433	0.409	0.037
21	Estonia	*EVR*	0.227	0.227	0.410	0.515	0.861	1.000	0.897	0.591	0.326
22	Hungary	*GYSEV/RÖEE*	0.931	1.000	1.000	0.796	1.000	0.928	1.000	0.951	0.076
23	Hungary	*MÁV Rt.*	0.352	0.381	0.428	0.431	0.458	0.453	0.478	0.426	0.045
24	Latvia	*LDZ*	0.267	0.356	0.451	0.427	0.645	0.819	0.576	0.506	0.188
25	Lithuania	*LG*	0.302	0.391	0.438	0.411	0.393	0.471	0.521	0.418	0.069
26	Poland	*PKP*	0.493	0.451	0.468	0.455	0.446	0.427	0.439	0.454	0.022
27	Romania	*CFR*	0.325	0.237	0.238	0.235	0.172	0.226	0.228	0.237	0.045
28	Slovak	*ZSR*	0.539	0.499	0.539	0.487	0.437	0.460	0.545	0.501	0.043
29	Slovenia	*SZ*	0.826	0.744	0.833	0.886	0.936	0.933	0.861	0.860	0.067
30	Moldova	*CFM (E)*	0.173	0.179	0.168	0.162	0.157	0.152	0.154	0.164	0.010
31	Ukraine	*UZ*	0.307	0.377	0.327	0.313	0.314	0.362	0.331	0.333	0.026
32	Turkey	*TCDD*	0.473	0.500	0.514	0.516	0.518	0.536	0.542	0.514	0.023
33	Israel	*IsR*	0.622	0.703	0.682	0.668	0.623	0.636	0.737	0.667	0.044
34	Morocco	*ONCFM*	0.291	0.366	0.369	0.421	0.417	0.428	0.505	0.400	0.066
35	Syria	*CFS*	0.362	0.326	0.341	0.314	0.308	0.354	0.351	0.337	0.021
36	Mozambique	*CFM*	0.716	0.922	0.724	0.743	0.793	0.827	0.824	0.793	0.073
37	Tanzania	*TRC*	0.981	1.000	1.000	1.000	1.000	1.000	1.000	0.997	0.007
38	Azerbaijan	*AZ*	0.143	0.145	0.153	0.151	0.173	0.166	0.192	0.160	0.018
39	Korea	*KNR*	0.761	0.855	0.861	0.806	0.989	0.957	0.988	0.888	0.091
40	Japan	*JR*	0.762	0.987	1.000	0.814	1.000	0.984	1.000	0.935	0.102
41	India	*IR*	0.274	0.321	0.332	0.338	0.340	0.368	0.368	0.334	0.032
42	Taiwan	*TRA*	1.000	0.969	0.925	0.912	0.904	1.000	1.000	0.959	0.044
43	Turkmenistan	*TRK*	0.446	0.367	0.454	0.427	0.422	0.442	0.430	0.427	0.029
44	Australia	*QR*	1.000	0.986	0.993	1.000	1.000	1.000	1.000	0.997	0.005
Mean			0.583	0.603	0.625	0.640	0.660	0.679	0.684	0.639	0.069

4.2.2 Sensitivity analysis

As mentioned in 3.1.1.3, many researchers criticize the robustness of DEA since the measured results may be sensitive to the possible data errors. Based on BCC measurement described in 4.2.1, there are 49 efficient DMUs. To analyze whether these 49 efficient DMUs are sensitive or not, this research thus employs Seiford and Zue's sensitivity analysis model; which was described in 3.1.1.3. The results are indicated in Table 4-5. Note that some efficient DMUs are sensitive while some efficient DMUs are relative robust. For instance, the efficient DMU 149 (CFF, 98), DMU 281 (CFF, 2001) and DMU 306 (TRA, 2001) are rather robust (stable) because their sensitivity indexes are relative large (higher than 15%), suggesting that they are not sensitive to possible data error. By contrast, the efficient DMU 44(QR, 95), DMU 125 (TRC, 97), DMU 176 (QR, 98), DMU 179 (DSB, 99), DMU 191 (NSB, 99), DMU 220 (QR, 99), DMU 257 (TRC, 2000), DMU 264 (QR, 2000), DMU 278 (SJ, 2001), DMU 279 (NSB, 2001) and DMU 286 (GYSEV, 2001) are very sensitive to possible data error because they have relatively small sensitivity indexes (less than 1%).

Table 4-5 The results of sensitivity analysis for BCC efficiency measurement.

Firm	g_k	g_{-k}	Firm	g_k	g_{-k}	Firm	g_k	g_{-k}
DMU10	4.18%	4.02%	DMU176	0.14%	0.14%	DMU242	4.52%	4.33%
DMU11	6.71%	6.28%	DMU179	0.90%	0.89%	DMU257	0.54%	0.54%
DMU14	4.59%	4.39%	DMU191	0.89%	0.88%	DMU264	0.49%	0.49%
DMU42	8.15%	7.53%	DMU192	6.53%	6.13%	DMU265	8.56%	7.89%
DMU44	0.99%	0.98%	DMU198	6.51%	6.12%	DMU267	11.93%	10.66%
DMU58	8.10%	7.50%	DMU213	5.83%	5.51%	DMU275	5.71%	5.40%
DMU66	2.52%	2.45%	DMU216	10.11%	9.18%	DMU278	0.27%	0.27%
DMU81	2.61%	2.54%	DMU220	0.01%	0.01%	DMU279	0.84%	0.83%
DMU102	5.48%	5.20%	DMU221	5.40%	5.13%	DMU280	3.52%	3.40%
DMU110	1.82%	1.79%	DMU223	6.10%	5.75%	DMU281	15.81%	13.65%
DMU125	0.06%	0.06%	DMU226	2.70%	2.63%	DMU286	0.92%	0.91%
DMU128	1.67%	1.64%	DMU231	2.25%	2.20%	DMU301	2.65%	2.58%
DMU139	5.34%	5.07%	DMU234	3.86%	3.72%	DMU304	12.20%	10.87%
DMU147	3.19%	3.09%	DMU235	4.82%	4.60%	DMU306	15.50%	13.42%
DMU148	2.16%	2.11%	DMU236	4.37%	4.19%	DMU308	3.14%	3.05%
DMU149	16.03%	13.82%	DMU237	2.37%	2.32%			
DMU169	7.13%	6.65%	DMU241	4.23%	4.06%			

Note: g_k denotes the percentages increase in all inputs for the DMU_k, and g_{-k} denotes the percentages decrease in all inputs for the remaining DMUs.

4.2.3 Measured by 3-stage DEA procedure

One shortcoming is that the CCR and BCC models do not take environmental factors and statistical errors into account. To incorporate environmental factors and statistical noises into the efficiency measurement model, this research thus adopts Fried's *et al.* (2002) three-stage model. Since the BCC efficiency scores and slacks (including radial and non-radial) have been estimated, and the factors influencing efficiency have been identified, we thus regress the amount of slacks on the potential environmental factors by using stochastic cost frontier model. Following Fried's *et al.* (2002), this research opts for the estimation of three separate SFA regressions. The dependent variables in the SFA regression models are the total slacks, that is the sum of radial slack and non-radial slack, calculated from the BCC model. The estimated results of SFA model are indicated in Table 4-6, from which we see that most parameters are significant except ROP to input 2 (slack of passenger cars) and Line to input 3 (slack of freight cars). It should also be noted that negative coefficient, for example, coefficient of ELEC, means greater percentage of electrified lines will leads to lower input slacks, and thus higher efficiency.

Table 4-6 estimated results of SFA model.

Parameters	Input 1(Labor)		Input 2 (Pcars)		Input 3 (Fcars)	
	coefficient	t-ratio	coefficient	t-ratio	coefficient	t-ratio
Constant	1.457	10.472*	0.731	5.867*	-1.217	-5.272*
ln(ELEC)	-0.327	-4.561*	-0.255	-3.873*	-0.462	-4.741*
ln(ROP)	-2.546	-5.551*	-0.106	-0.344	-3.200	-5.760*
ln(Line/1000)	0.195	6.156*	0.060	1.191*	0.055	1.215
σ^2	15.639	2.450*	9.397	3.662*	14.621	1.140
γ	0.996	413.306*	0.997	555.945*	0.989	112.241*
μ	-7.893	-1.974*	-6.121	-2.886*	-6.445	-0.745
Log likelihood function	-329.029		-259.455		-355.538	
LR one-sided test	98.370		106.256		61.975	

Note: t-values in parentheses, asterisks (*) represent significance at the 0.05 levels. Also note that $\sigma^2 = \sigma_u^2 + \sigma_v^2, \gamma = \sigma_u^2 / \sigma^2$

Thus, the stochastic slack functions for labor, passenger cars, freight cars become:

$$Slack_{Labor} = -1.475 - 0.327ELEC - 2.546ROP + 0.159Line/1000 + v_i + u_i$$

$$Slack_{Pcars} = -0.731 - 0.255ELEC - 0.106ROP + 0.060Line/1000 + v_i + u_i$$

$$Slack_{Fcars} = -1.217 - 0.462ELEC - 3.200ROP + 0.055Line/1000 + v_i + u_i$$

Once parameters of SFA model have been estimated, the input data were adjusted by applying model (3-35). It should be noted, when adjusting input data, in contrast to Fried *et al.* (2002), who accomplished by using the Jondrow's *et al.* (1982) methodology, this research adopts another point estimator proposed by Battese and Coelli (1988). The reason has been described in previous chapter. After adjusting the input data, the efficiency thus been re-estimated by applying BCC DEA model, the results are indicated in Table 4-7.

Table 4-7 the efficiency measurement for 44 railways (3-stage)

No	Country	Railways	1995	1996	1997	1998	1999	2000	2001	mean	stdev
1	Austria	*ÖBB*	0.951	0.932	0.938	0.961	0.965	0.969	0.958	0.953	0.014
2	Belgium	*SNCB/NMBS*	0.927	0.987	0.962	0.965	1.000	0.850	0.964	0.951	0.050
3	Denmark	*DSB*	0.962	0.959	1.000	0.947	0.937	0.938	1.000	0.963	0.027
4	Finland	*VR*	0.935	0.932	0.923	0.940	0.921	0.924	0.924	0.929	0.007
5	France	*SNCF*	0.983	0.937	0.921	0.938	1.000	0.917	0.893	0.941	0.038
6	Germany	*DB AG*	0.908	0.931	0.968	0.989	0.927	0.872	0.947	0.934	0.039
7	Greece	*CH*	0.909	0.956	0.912	0.767	0.890	0.919	0.911	0.895	0.060
8	Ireland	*CIE*	0.836	0.855	0.846	0.859	0.862	0.880	0.879	0.860	0.016
9	Italy	*FS SpA*	1.000	0.965	0.940	0.955	1.000	0.977	0.964	0.971	0.023
10	Luxembourg	*CFL*	1.000	0.903	0.949	0.989	0.996	0.909	0.925	0.953	0.042
11	Netherlands	*NS N.V.*	0.991	1.000	1.000	1.000	1.000	0.984	0.997	0.996	0.006
12	Portugal	*CP*	0.893	0.907	0.964	0.977	0.943	0.934	0.931	0.936	0.030
13	Spain	*RENFE*	1.000	0.987	0.968	0.973	0.969	0.971	0.950	0.974	0.016
14	Sweden	*SJ AB*	0.937	0.933	0.891	0.901	0.929	0.930	0.921	0.920	0.017
15	Norway	*NSB BA*	0.894	0.888	0.886	0.881	0.889	0.889	0.855	0.883	0.013
16	Switzerland	*BLS*	0.940	0.986	0.967	0.964	0.971	0.953	0.990	0.967	0.017
17	Switzerland	*CFF/SBB/FFS*	1.000	0.990	0.986	1.000	0.952	0.956	1.000	0.983	0.021
18	Bulgaria	*BDZ*	0.908	0.891	1.000	0.905	0.921	0.911	0.949	0.926	0.037
19	Croatia	*HZ*	0.953	0.914	0.866	0.850	0.937	0.951	0.956	0.918	0.044
20	Czech Rep	*CD*	0.888	1.000	1.000	0.909	0.897	0.879	0.908	0.926	0.052
21	Estonia	*EVR*	0.981	1.000	1.000	0.907	0.838	0.809	0.886	0.917	0.078
22	Hungary	*GYSEV/RÖEE*	0.919	0.773	0.775	0.836	0.805	0.752	0.783	0.806	0.056
23	Hungary	*MÁV Rt.*	0.971	0.981	0.901	0.883	0.960	0.949	0.943	0.941	0.036
24	Latvia	*LDZ*	0.912	1.000	0.876	0.911	0.932	0.843	0.902	0.911	0.049
25	Lithuania	*LG*	0.922	1.000	0.980	0.920	0.940	0.894	0.835	0.927	0.055
26	Poland	*PKP*	0.903	0.941	0.916	0.923	0.921	0.921	0.888	0.916	0.017
27	Romania	*CFR*	0.783	0.848	0.859	0.924	1.000	0.958	0.922	0.899	0.074
28	Slovak	*ZSR*	0.933	0.893	0.949	0.950	0.985	0.850	0.909	0.924	0.044
29	Slovenia	*SZ*	0.907	0.927	0.897	0.872	0.855	0.852	0.883	0.885	0.027
30	Moldova	*CFM (E)*	0.844	0.896	0.910	0.855	0.892	0.922	0.921	0.892	0.031
31	Ukraine	*UZ*	0.881	0.964	0.845	0.836	0.828	0.869	0.878	0.871	0.046
32	Turkey	*TCDD*	0.882	0.867	0.861	0.859	0.859	0.926	0.953	0.887	0.038
33	Israel	*IsR*	0.930	0.909	0.915	0.919	0.936	0.937	0.910	0.922	0.012
34	Morocco	*ONCFM*	0.988	0.919	1.000	0.953	0.959	0.949	0.905	0.953	0.034
35	Syria	*CFS*	0.976	0.911	0.905	0.926	0.932	0.968	0.976	0.942	0.031
36	Mozambique	*CFM*	0.882	0.867	0.892	0.883	0.871	0.865	0.865	0.875	0.011
37	Tanzania	*TRC*	0.815	0.806	0.825	0.816	0.815	0.821	0.821	0.817	0.006
38	Azerbaijan	*AZ*	0.861	0.870	0.854	0.866	0.927	0.889	0.857	0.875	0.026
39	Korea	*KNR*	1.000	1.000	0.998	0.995	0.993	0.983	0.882	0.979	0.043
40	Japan	*JR*	0.985	0.953	0.950	0.972	0.990	0.978	0.970	0.971	0.015
41	India	*IR*	0.909	0.961	0.957	0.851	0.942	0.941	0.940	0.929	0.038
42	Taiwan	*TRA*	1.000	0.987	1.000	1.000	1.000	1.000	1.000	0.998	0.005
43	Turkmenistan	*TRK*	0.938	0.984	0.987	0.906	0.905	0.899	1.000	0.945	0.044
44	Australia	*QR*	0.867	0.872	0.873	0.874	0.874	0.874	0.877	0.873	0.003
Mean			0.927	0.931	0.928	0.916	0.929	0.913	0.921	0.924	0.007

4.2.4 Measured by 4-stage procedure

As mentioned in previous chapter, although we re-estimate efficiency by substituting adjusted data, however, there is no guarantee that such measurement can always completely eliminate the slacks. One can see from table 4-8, although the amounts of slacks are decreased, there still exist some slacks in all input variables. To incorporate slacks into the measurement, this research thus employs the Slack-adjusted DEA model (3-36) with exception of calculation method of slacks. The results are documented in Table 4-9. Comparing the results measured from three-stage with those from adjusted-data DEA model, 52 DMUs remain unchanged in efficiency scores, since they do not have non-radial slacks. It is worthy to note that, the average efficiency decreased when we adopt SA-DEA model. On average, efficiency scores estimated from SA-DEA model are slightly less than those from data-adjusted DEA model. In other words, the efficiency scores may be overestimate if the slacks are neglected.

Table 4-8 the results of input slack analysis

	Estimated by BCC model						Estimated by using adjusted data.					
	Employee		Pcars		Fcars		Employee		Pcars		Fcars	
	Ra.	Non-ra	Ra.	Non-ra	Ra.	Non-ra	Ra.	Non-ra	Ra.	Non-ra	Ra.	Non-ra
No.	260	96	260	11	260	141	275	44	275	67	275	20
TS	1182	161.5	65.1	16.6	726	141.3	327.8	159.5	41.5	8.1	262.8	18.9
AS	3.839	0.524	0.211	0.054	2.357	0.459	1.064	0.518	0.135	0.026	0.853	0.061

Note: No., TS, AS, stand for number of DMUs with slacks, total slacks, average slacks (defined as total slacks / 308), respectively, Ra and Non-ra stand for radial and non-radial slacks, respectively.

4.2.5 Comparison

The analytical results reveal that different model will lead to different result. Table 4-10 shows the distribution frequencies of estimated results based on CCR, BCC models and 3-stage, 4-stage DEA approaches. On average, the efficiency estimated by 3-stage DEA procedure is the highest, while CCR efficiency is the lowest. It should be noted that the efficiencies based on CCR and BCC model are somewhat lower than those from 3-stage and 4-stage DEA approaches, because they do not take the environmental factors, managerial inefficiency and statistical noises into account. In other words, the conventional CCR and BCC models attribute all deviation from frontier to inefficiency.

Table 4-9 the efficiency measurement for 44 railways (4-stage)

No	Country	Railways	1995	1996	1997	1998	1999	2000	2001	mean	stdev
1	Austria	*ÖBB*	0.824	0.879	0.885	0.778	0.782	0.775	0.823	0.821	0.047
2	Belgium	*SNCB/NMBS*	0.927	0.987	0.962	0.965	1.000	0.850	0.964	0.951	0.050
3	Denmark	*DSB*	0.945	0.926	1.000	0.928	0.881	0.901	1.000	0.940	0.046
4	Finland	*VR*	0.885	0.879	0.877	0.888	0.883	0.884	0.881	0.882	0.004
5	France	*SNCF*	0.977	0.920	0.902	0.915	1.000	0.885	0.842	0.920	0.054
6	Germany	*DB AG*	0.908	0.924	0.923	0.939	0.817	0.772	0.781	0.866	0.073
7	Greece	*CH*	0.743	0.773	0.715	0.595	0.691	0.719	0.718	0.708	0.056
8	Ireland	*CIE*	0.788	0.770	0.758	0.770	0.776	0.739	0.788	0.770	0.017
9	Italy	*FS SpA*	1.000	0.965	0.940	0.955	1.000	0.968	0.954	0.969	0.023
10	Luxembourg	*CFL*	1.000	0.903	0.862	0.916	0.863	0.782	0.800	0.875	0.074
11	Netherlands	*NS N.V.*	0.969	1.000	1.000	1.000	1.000	0.931	0.950	0.979	0.029
12	Portugal	*CP*	0.838	0.839	0.946	0.967	0.894	0.901	0.889	0.896	0.049
13	Spain	*RENFE*	1.000	0.964	0.963	0.971	0.965	0.961	0.938	0.966	0.018
14	Sweden	*SJ AB*	0.904	0.931	0.891	0.901	0.908	0.910	0.901	0.906	0.012
15	Norway	*NSB BA*	0.820	0.825	0.821	0.814	0.786	0.796	0.751	0.802	0.027
16	Switzerland	*BLS*	0.840	0.851	0.849	0.926	0.944	0.874	0.881	0.881	0.040
17	Switzerland	*CFF/SBB/FFS*	1.000	0.986	0.980	1.000	0.843	0.790	1.000	0.943	0.088
18	Bulgaria	*BDZ*	0.847	0.853	1.000	0.870	0.868	0.889	0.939	0.895	0.055
19	Croatia	*HZ*	0.846	0.809	0.767	0.770	0.830	0.885	0.876	0.826	0.047
20	Czech Rep	*CD*	0.812	1.000	1.000	0.861	0.873	0.879	0.908	0.905	0.071
21	Estonia	*EVR*	0.971	1.000	1.000	0.816	0.682	0.409	0.699	0.797	0.218
22	Hungary	*GYSEV/RÖEE*	0.884	0.645	0.633	0.747	0.592	0.581	0.616	0.671	0.108
23	Hungary	*MÁV Rt.*	0.897	0.925	0.814	0.787	0.883	0.872	0.867	0.864	0.048
24	Latvia	*LDZ*	0.912	1.000	0.819	0.882	0.924	0.795	0.846	0.883	0.070
25	Lithuania	*LG*	0.922	1.000	0.921	0.902	0.926	0.836	0.664	0.882	0.107
26	Poland	*PKP*	0.849	0.875	0.824	0.885	0.909	0.921	0.811	0.868	0.042
27	Romania	*CFR*	0.721	0.812	0.815	0.797	1.000	0.941	0.903	0.855	0.096
28	Slovak	*ZSR*	0.770	0.691	0.811	0.819	0.914	0.697	0.816	0.788	0.078
29	Slovenia	*SZ*	0.745	0.849	0.751	0.698	0.609	0.639	0.742	0.719	0.080
30	Moldova	*CFM (E)*	0.708	0.733	0.743	0.700	0.752	0.777	0.786	0.743	0.032
31	Ukraine	*UZ*	0.645	0.875	0.717	0.724	0.725	0.746	0.737	0.738	0.069
32	Turkey	*TCDD*	0.864	0.850	0.856	0.837	0.830	0.917	0.860	0.859	0.028
33	Israel	*IsR*	0.890	0.873	0.858	0.842	0.822	0.839	0.825	0.850	0.025
34	Morocco	*ONCFM*	0.962	0.830	0.948	0.909	0.926	0.906	0.870	0.907	0.045
35	Syria	*CFS*	0.943	0.851	0.851	0.876	0.882	0.938	0.947	0.898	0.043
36	Mozambique	*CFM*	0.708	0.669	0.730	0.714	0.707	0.707	0.707	0.706	0.018
37	Tanzania	*TRC*	0.635	0.604	0.722	0.675	0.632	0.690	0.703	0.666	0.043
38	Azerbaijan	*AZ*	0.499	0.670	0.659	0.714	0.797	0.782	0.763	0.698	0.103
39	Korea	*KNR*	1.000	1.000	0.983	0.995	0.912	0.968	0.874	0.962	0.049
40	Japan	*JR*	0.973	0.858	0.853	0.972	0.790	0.815	0.820	0.869	0.075
41	India	*IR*	0.640	0.700	0.694	0.603	0.689	0.682	0.687	0.671	0.036
42	Taiwan	*TRA*	1.000	0.987	1.000	1.000	1.000	1.000	1.000	0.998	0.005
43	Turkmenistan	*TRK*	0.920	0.961	0.984	0.854	0.881	0.827	1.000	0.918	0.067
44	Australia	*QR*	0.804	0.811	0.830	0.832	0.838	0.837	0.847	0.829	0.015
Mean			0.858	0.865	0.860	0.848	0.846	0.823	0.840	0.849	0.054

Table 4-10 Distribution frequencies of estimated results based on CCR, BCC, 3-stage, and 4-stage efficiency measurement

Range	CCR	BCC	3-stage	4-stage
Less than 0.2	15	15	0	0
0.200~0.299	22	16	0	0
0.300~0.399	58	37	0	0
0.400~0.499	52	53	0	2
0.500~0.599	29	22	0	3
0.600~0.699	40	33	0	27
0.700~0.799	29	23	6	59
0.800~0.899	22	28	91	64
0.900~0.999	27	32	178	80
1	14	49	33	32
Max.	1.000	1.000	1.000	1.000
Min.	0.093	0.143	0.752	0.409
Mean	0.565	0.639	0.923	0.849
Std. Dev.	0.245	0.269	0.054	0.109

Furthermore, comparing the results measured from 4-stage with those from 3-stage DEA procedure, 52 DMUs remain unchanged in efficiency measurement. It is worthy to note that, the average efficiency decreased when we adopt SA-DEA model. On average, efficiency scores estimated from four-stage DEA model are slightly less than those from three-stage DEA model (0.849 vs. 0.924). Then we conclude that, the efficiency scores may be overestimate if the residual slacks are neglected.

4.3 Effectiveness Measurements

4.3.1 Measured by CCR and BCC model

As aforementioned in previous chapter, due to the transport service is non-storable, therefore, measuring service effectiveness is not a trivial task. This research evaluates the effectiveness for 44 selected railways by adopting output-oriented CCR and BCC model and by using GAMS computer program. The results are indicated in Table 4-12 (for CCR model) and 4-13 (for BCC model). It is need to note that, average effectiveness for 44 railways over 7 years are 0.446 and 0.497, based on CCR and BCC model, respectively. Comparing Table 4-12 with Table 4-13, one can see that, the BCC approach forms a convex hull of intersecting planes which envelop the data point more tightly than the CCR conical hull and thus provides effectiveness scores which are greater than or equal to those estimated using the CCR model.

4.3.2 Sensitivity analysis

Similar to efficiency measurement, to analyze whether the 18 effective DMUs are sensitive or not, this research thus employs Seiford and Zue's sensitivity analysis model; which was described in 3.1.1.3. The empirical results are indicated in Table 4-11. From the table one can see that some effective DMUs are sensitive while some are relative stable. For instance, the effective DMU 36 (CFM, 95), DMU 66 (GYSEV, 96), DMU 81 (TRC, 96) and DMU 227(CH, 2000) are rather robust because their sensitivity indexes are rather large (higher than 15%), implying that they are not sensitive to possible data error. By contrast, the effective DMU 84 (JR, 96), DMU 251 (UZ, 2000) and DMU 295 (UZ, 2001) are very sensitive to possible data error because they have relatively small sensitivity indexes (less than 1%). Note that DMU 81 (TRC, 96) is the most robust (stable) in effectiveness analysis because its sensitivity indexes are the largest. In other words, it is not sensitive to possible data error. By contrast, the effective DMU 84 (JR, 96) and DMU 251 (UZ, 2000) are sensitive to possible data error because they have relatively small sensitivity indexes.

Table 4-11 The results of sensitivity analysis for BCC effectiveness measurement.

Firm	h_k	h_{-k}	Firm	h_k	h_{-k}	Firm	h_k	h_{-k}
DMU11	1.18%	1.20%	DMU80	7.45%	8.05%	DMU251	0.20%	0.20%
DMU31	2.16%	2.21%	DMU81	17.39%	21.05%	DMU260	1.43%	1.45%
DMU36	16.61%	19.92%	DMU84	0.10%	0.10%	DMU285	7.48%	8.08%
DMU37	2.26%	2.31%	DMU110	8.11%	8.82%	DMU295	0.81%	0.82%
DMU44	1.19%	1.21%	DMU227	15.80%	18.76%	DMU305	3.63%	3.76%
DMU66	16.13%	19.23%	DMU250	10.58%	11.83%	DMU308	5.92%	6.29%

Note: h_k denotes the percentages decrease in all outputs for the DMU_k, and h_{-k} denotes the percentages increase in all outputs for the remaining DMUs

Table 4-12 Service effectiveness (CCR model)

No	Country	Railways	1995	1996	1997	1998	1999	2000	2001	mean	stdev
1	Austria	*ÖBB*	0.208	0.228	0.203	0.185	0.176	0.186	0.202	0.199	0.016
2	Belgium	*SNCB/NMBS*	0.314	0.318	0.292	0.307	0.286	0.291	0.317	0.303	0.014
3	Denmark	*DSB*	0.272	0.278	0.304	0.338	0.376	0.401	0.757	0.390	0.169
4	Finland	*VR*	0.310	0.302	0.311	0.303	0.302	0.308	0.304	0.306	0.004
5	France	*SNCF*	0.246	0.281	0.254	0.264	0.266	0.277	0.285	0.267	0.014
6	Germany	*DB AG*	0.212	0.220	0.246	0.252	0.246	0.235	0.258	0.238	0.017
7	Greece	*CH*	0.318	0.354	0.381	0.420	0.433	0.495	0.471	0.410	0.063
8	Ireland	*CIE*	0.160	0.155	0.169	0.174	0.178	0.218	0.182	0.177	0.021
9	Italy	*FS SpA*	0.349	0.346	0.334	0.329	0.362	0.371	0.400	0.356	0.024
10	Luxembourg	*CFL*	0.233	0.238	0.307	0.300	0.301	0.305	0.294	0.283	0.032
11	Netherlands	*NS N.V.*	0.991	0.632	0.624	0.711	0.697	0.728	0.735	0.731	0.123
12	Portugal	*CP*	0.300	0.301	0.262	0.236	0.279	0.241	0.269	0.270	0.026
13	Spain	*RENFE*	0.227	0.245	0.230	0.254	0.245	0.256	0.279	0.248	0.018
14	Sweden	*SJ AB*	0.256	0.254	0.231	0.235	0.238	0.240	0.232	0.241	0.010
15	Norway	*NSB BA*	0.193	0.184	0.178	0.178	0.225	0.200	0.208	0.195	0.017
16	Switzerland	*BLS*	0.254	0.309	0.246	0.219	0.247	0.226	0.308	0.258	0.036
17	Switzerland	*CFF/SBB/FFS*	0.252	0.239	0.262	0.274	0.284	0.285	0.262	0.265	0.017
18	Bulgaria	*BDZ*	0.681	0.306	0.325	0.357	0.316	0.303	0.240	0.361	0.145
19	Croatia	*HZ*	0.226	0.213	0.193	0.188	0.186	0.212	0.194	0.202	0.015
20	Czech Rep	*CD*	0.234	0.238	0.236	0.221	0.219	0.228	0.247	0.232	0.010
21	Estonia	*EVR*	0.622	0.667	0.728	0.802	0.961	0.907	1.000	0.812	0.148
22	Hungary	*GYSEV/RÖEE*	0.187	0.215	0.299	0.285	0.274	0.235	0.190	0.241	0.046
23	Hungary	*MÁV Rt.*	0.256	0.279	0.276	0.283	0.283	0.296	0.315	0.284	0.018
24	Latvia	*LDZ*	0.712	0.776	0.813	0.808	0.832	0.875	0.922	0.820	0.068
25	Lithuania	*LG*	0.572	0.612	0.654	0.654	0.654	0.694	0.696	0.648	0.044
26	Poland	*PKP*	0.326	0.324	0.321	0.315	0.318	0.324	0.281	0.315	0.016
27	Romania	*CFR*	0.375	0.392	0.345	0.342	0.333	0.344	0.334	0.352	0.023
28	Slovak	*ZSR*	0.288	0.266	0.264	0.270	0.254	0.277	0.274	0.270	0.011
29	Slovenia	*SZ*	0.199	0.186	0.186	0.186	0.180	0.182	0.197	0.188	0.007
30	Moldova	*CFM (E)*	0.659	0.667	0.702	0.806	0.584	0.711	0.718	0.692	0.068
31	Ukraine	*UZ*	0.954	0.984	0.945	0.976	0.982	1.000	1.000	0.977	0.021
32	Turkey	*TCDD*	0.315	0.306	0.318	0.315	0.316	0.320	0.331	0.317	0.008
33	Israel	*IsR*	0.431	0.422	0.385	0.397	0.433	0.476	0.471	0.431	0.034
34	Morocco	*ONCFM*	0.572	0.609	0.631	0.647	0.596	0.623	0.647	0.618	0.027
35	Syria	*CFS*	0.254	0.310	0.345	0.456	0.519	0.461	0.545	0.413	0.110
36	Mozambique	*CFM*	0.679	0.708	0.517	0.332	0.308	0.222	0.224	0.427	0.207
37	Tanzania	*TRC*	1.000	1.000	0.381	0.252	0.722	0.600	0.724	0.669	0.285
38	Azerbaijan	*AZ*	0.394	0.365	0.458	0.544	0.621	0.604	0.578	0.509	0.103
39	Korea	*KNR*	0.546	0.561	0.563	0.561	0.514	0.511	0.548	0.543	0.022
40	Japan	*JR*	0.966	0.995	0.978	0.974	0.979	1.000	0.989	0.983	0.012
41	India	*IR*	0.827	0.871	0.880	0.908	0.948	0.959	1.000	0.913	0.059
42	Taiwan	*TRA*	0.452	0.448	0.463	0.490	0.513	0.517	0.508	0.484	0.030
43	Turkmenistan	*TRK*	0.880	0.852	0.842	0.913	0.856	0.937	0.852	0.876	0.036
44	Australia	*QR*	1.000	0.863	0.816	0.858	0.868	0.906	1.000	0.902	0.072
Mean			0.448	0.439	0.425	0.435	0.448	0.454	0.472	0.446	0.052

Table 4-13 Service effectiveness (BCC model)

No	Country	Railways	1995	1996	1997	1998	1999	2000	2001	mean	stdev
1	Austria	*ÖBB*	0.210	0.230	0.204	0.186	0.177	0.187	0.203	0.200	0.018
2	Belgium	*SNCB/NMBS*	0.319	0.322	0.297	0.311	0.290	0.295	0.322	0.308	0.014
3	Denmark	*DSB*	0.284	0.291	0.319	0.354	0.395	0.422	0.848	0.416	0.197
4	Finland	*VR*	0.317	0.310	0.318	0.309	0.308	0.315	0.310	0.312	0.004
5	France	*SNCF*	0.246	0.281	0.254	0.264	0.266	0.277	0.285	0.268	0.014
6	Germany	*DB AG*	0.247	0.250	0.279	0.287	0.265	0.269	0.279	0.268	0.015
7	Greece	*CH*	0.462	0.511	0.565	0.738	0.764	1.000	0.798	0.691	0.189
8	Ireland	*CIE*	0.189	0.182	0.199	0.205	0.209	0.275	0.214	0.210	0.031
9	Italy	*FS SpA*	0.350	0.347	0.335	0.329	0.363	0.373	0.402	0.357	0.025
10	Luxembourg	*CFL*	0.312	0.319	0.553	0.491	0.456	0.448	0.417	0.428	0.088
11	Netherlands	*NS N.V.*	1.000	0.656	0.645	0.737	0.724	0.756	0.764	0.755	0.118
12	Portugal	*CP*	0.317	0.316	0.272	0.245	0.292	0.251	0.281	0.282	0.029
13	Spain	*RENFE*	0.228	0.247	0.231	0.256	0.247	0.258	0.281	0.250	0.018
14	Sweden	*SJ AB*	0.257	0.256	0.233	0.237	0.239	0.241	0.233	0.242	0.010
15	Norway	*NSB BA*	0.200	0.190	0.185	0.184	0.235	0.208	0.217	0.203	0.019
16	Switzerland	*BLS*	0.452	0.972	0.413	0.328	0.434	0.355	0.462	0.488	0.219
17	Switzerland	*CFF/SBB/FFS*	0.254	0.241	0.265	0.277	0.287	0.287	0.264	0.268	0.017
18	Bulgaria	*BDZ*	0.692	0.313	0.332	0.368	0.326	0.312	0.246	0.370	0.147
19	Croatia	*HZ*	0.242	0.228	0.205	0.199	0.198	0.226	0.205	0.215	0.017
20	Czech Rep	*CD*	0.234	0.239	0.237	0.222	0.220	0.229	0.248	0.233	0.010
21	Estonia	*EVR*	0.714	0.758	0.796	0.856	0.996	0.927	1.000	0.864	0.114
22	Hungary	*GYSEV/RÖEE*	0.701	1.000	1.000	0.753	0.636	0.454	0.424	0.710	0.232
23	Hungary	*MÁV Rt.*	0.260	0.283	0.280	0.288	0.287	0.301	0.320	0.288	0.019
24	Latvia	*LDZ*	0.744	0.798	0.827	0.822	0.850	0.882	0.922	0.835	0.058
25	Lithuania	*LG*	0.609	0.637	0.672	0.674	0.675	0.706	0.714	0.670	0.037
26	Poland	*PKP*	0.351	0.349	0.345	0.326	0.318	0.324	0.281	0.328	0.024
27	Romania	*CFR*	0.377	0.395	0.348	0.344	0.336	0.347	0.337	0.355	0.022
28	Slovak	*ZSR*	0.292	0.271	0.267	0.273	0.258	0.281	0.277	0.274	0.011
29	Slovenia	*SZ*	0.208	0.196	0.195	0.195	0.188	0.192	0.208	0.197	0.008
30	Moldova	*CFM (E)*	0.772	0.794	0.877	0.997	0.932	1.000	0.970	0.906	0.094
31	Ukraine	*UZ*	1.000	0.985	0.945	0.976	0.982	1.000	1.000	0.984	0.020
32	Turkey	*TCDD*	0.318	0.310	0.319	0.321	0.325	0.320	0.338	0.322	0.009
33	Israel	*IsR*	0.655	0.650	0.617	0.634	0.573	0.639	0.640	0.630	0.028
34	Morocco	*ONCFM*	0.644	0.677	0.705	0.709	0.666	0.681	0.709	0.684	0.025
35	Syria	*CFS*	0.288	0.322	0.347	0.470	0.542	0.471	0.546	0.427	0.106
36	Mozambique	*CFM*	1.000	1.000	0.618	0.575	0.532	0.284	0.286	0.614	0.295
37	Tanzania	*TRC*	1.000	1.000	0.390	0.252	0.724	0.608	0.728	0.672	0.283
38	Azerbaijan	*AZ*	0.442	0.405	0.510	0.585	0.654	0.628	0.590	0.545	0.095
39	Korea	*KNR*	0.557	0.573	0.574	0.573	0.524	0.521	0.559	0.554	0.023
40	Japan	*JR*	0.975	1.000	0.985	0.980	0.980	1.000	0.991	0.987	0.010
41	India	*IR*	0.863	0.920	0.924	0.935	0.948	0.977	1.000	0.938	0.044
42	Taiwan	*TRA*	0.473	0.470	0.491	0.523	0.553	0.561	0.564	0.519	0.041
43	Turkmenistan	*TRK*	0.902	0.916	0.881	0.923	0.885	0.970	0.879	0.908	0.032
44	Australia	*QR*	1.000	0.866	0.817	0.861	0.872	0.906	1.000	0.903	0.071
Mean			0.499	0.506	0.479	0.486	0.498	0.499	0.513	0.497	0.066

4.3.3 Measured by 3-stage procedure

Following Fried's *et al.* (2002), this research opts for the estimation of two separate SFA regressions. The dependent variables in the SFA regression models are the total slacks, that is the sum of radial slack and non-radial slack, calculated from the BCC model. The estimated results of SFA model are indicated in Table 4-14. From the Table 4-14, the evidence shows that all of parameters are significant. It should be noted that negative coefficient, for example, coefficient of PD, means greater population density will leads to lower amount of slacks, and thus higher effectiveness. On the other hand, positive sign in coefficients of GNI indicates that higher income per capita will generate higher amount of slacks in service consumption thus lower service effectiveness. This is partly because, in general, higher income per capita usually leads higher ownership of private car thus lower ridership of public transportation. This seems consistent with the underlying transportation theory.

Table 4-14 SFA result for output slacks

Parameters	Pax-km		Ton-km	
	coefficient	t-ratio	coefficient	t-ratio
Constant	-5.092	-6.854*	-2.745	-5.593*
ln(PD)	-2.183	-3.409*	-0.258	-5.383*
ln(GNI)	0.605	14.461*	0.297	8.551*
ln(Line)	1.076	15.688*	1.315	26.333*
σ^2	10.390	5.729*	10.559	2.685*
γ	0.987	275.729*	0.987	251.639*
μ	-6.404	-3.935*	-6.456	-1.799*
Log likelihood function	-410.812		-403.307	
LR one-sided test	129.93		101.97	

Note: t-values in parentheses, asterisks (*) represent significance at the 0.05 levels. Also note that

$$\sigma^2 = \sigma_u^2 + \sigma_v^2, \gamma = \sigma_u^2 / \sigma^2$$

Hence, the stochastic slack frontier functions become

$Slack_{Paxkms} = -7.951 + 1.288\ln(Line) - 0.54(POP) + 0.505\ln(GNI) + v_i + u_i$, and

$Slack_{Tonkms} = -1.373 + 1.046\ln(Line) - 0.073\ln(POP) + 0.265\ln(GNI) + v_i + u_i$.

Once the stochastic slack frontier functions have been estimated, one needs to adjust the consumption data by using the equation (3-35), and re-measure effectiveness by using BCC model. This is so-call Fried's *et al.* (2002) three-stage DEA procedure. The Table 4-15 indicates the results measured by three-stage DEA method. It should be note that average effectiveness for 44 railways over 7 years is 0.923, which is considerably higher than those measured based on CCR and BCC models. The main reason is that three-stage DEA procedure incorporates environmental factors and statistical noises into the analytical model.

Table 4-15 Service effectiveness (3-stage)

No	Country	Railways	1995	1996	1997	1998	1999	2000	2001	mean	stdev
1	Austria	*ÖBB*	0.882	0.876	0.873	0.872	0.872	0.874	0.879	0.876	0.004
2	Belgium	*SNCB/NMBS*	0.946	0.946	0.942	0.945	0.941	0.942	0.945	0.944	0.002
3	Denmark	*DSB*	0.944	0.944	0.949	0.952	0.954	0.962	0.990	0.957	0.016
4	Finland	*VR*	0.877	0.876	0.878	0.876	0.876	0.877	0.879	0.877	0.001
5	France	*SNCF*	0.421	0.450	0.429	0.439	0.448	0.507	0.523	0.460	0.039
6	Germany	*DB AG*	0.247	0.271	0.353	0.367	0.368	0.396	0.428	0.347	0.065
7	Greece	*CH*	0.976	0.979	0.981	0.961	0.918	1.000	0.992	0.972	0.027
8	Ireland	*CIE*	0.954	0.953	0.954	0.955	0.840	0.957	0.953	0.938	0.043
9	Italy	*FS SpA*	0.797	0.795	0.791	0.790	0.800	0.804	0.818	0.799	0.010
10	Luxembourg	*CFL*	0.988	0.966	0.951	0.961	0.961	0.978	0.994	0.971	0.016
11	Netherlands	*NS N.V.*	1.000	0.977	0.976	0.982	0.981	0.984	0.985	0.984	0.008
12	Portugal	*CP*	0.966	0.967	0.965	0.965	0.967	0.965	0.967	0.966	0.001
13	Spain	*RENFE*	0.835	0.838	0.835	0.840	0.839	0.841	0.849	0.840	0.005
14	Sweden	*SJ AB*	0.773	0.771	0.750	0.756	0.760	0.764	0.770	0.764	0.008
15	Norway	*NSB BA*	0.887	0.885	0.883	0.884	0.886	0.881	0.882	0.884	0.002
16	Switzerland	*BLS*	0.967	0.990	0.961	0.955	0.957	0.955	0.973	0.965	0.013
17	Switzerland	*CFF/SBB/FFS*	0.926	0.923	0.928	0.930	0.933	0.932	0.931	0.929	0.004
18	Bulgaria	*BDZ*	0.987	0.976	0.977	0.978	0.975	0.973	0.970	0.977	0.006
19	Croatia	*HZ*	0.976	0.970	0.969	0.969	0.969	0.970	0.970	0.970	0.003
20	Czech Rep	*CD*	0.881	0.882	0.882	0.880	0.881	0.881	0.882	0.881	0.001
21	Estonia	*EVR*	0.996	0.996	0.997	0.998	1.000	0.999	1.000	0.998	0.002
22	Hungary	*GYSEV/RÖEE*	0.979	1.000	1.000	0.969	0.978	0.989	0.999	0.988	0.013
23	Hungary	*MÁV Rt.*	0.921	0.923	0.923	0.922	0.922	0.922	0.927	0.923	0.002
24	Latvia	*LDZ*	0.991	0.993	0.994	0.994	0.995	0.996	0.997	0.994	0.002
25	Lithuania	*LG*	0.990	0.991	0.992	0.992	0.992	0.993	0.996	0.992	0.002
26	Poland	*PKP*	0.780	0.789	0.601	0.781	0.794	0.797	0.812	0.765	0.073
27	Romania	*CFR*	0.941	0.942	0.937	0.937	0.936	0.935	0.933	0.937	0.003
28	Slovak	*ZSR*	0.964	0.962	0.962	0.962	0.962	0.963	0.963	0.962	0.001
29	Slovenia	*SZ*	0.983	0.982	0.982	0.970	0.982	0.982	0.982	0.980	0.005
30	Moldova	*CFM (E)*	0.995	0.988	0.994	1.000	0.981	1.000	0.997	0.994	0.007
31	Ukraine	*UZ*	1.000	0.991	0.991	0.996	0.997	1.000	1.000	0.996	0.004
32	Turkey	*TCDD*	0.956	0.955	0.956	0.956	0.958	0.960	0.961	0.957	0.002
33	Israel	*IsR*	0.993	0.988	0.986	0.987	0.982	0.962	0.985	0.983	0.010
34	Morocco	*ONCFM*	0.992	0.993	0.991	0.994	0.992	0.992	0.977	0.990	0.006
35	Syria	*CFS*	0.917	0.971	0.954	0.996	0.996	0.995	0.957	0.969	0.030
36	Mozambique	*CFM*	1.000	1.000	0.923	0.982	0.989	0.988	0.925	0.972	0.034
37	Tanzania	*TRC*	1.000	1.000	0.955	0.963	0.994	0.974	0.981	0.981	0.018
38	Azerbaijan	*AZ*	0.987	0.992	0.994	0.995	0.996	0.995	0.995	0.993	0.003
39	Korea	*KNR*	0.985	0.985	0.985	0.985	0.984	0.983	0.984	0.984	0.001
40	Japan	*JR*	0.988	1.000	0.993	0.990	0.991	1.000	0.995	0.994	0.005
41	India	*IR*	0.976	0.984	0.985	0.988	0.992	0.995	1.000	0.989	0.008
42	Taiwan	*TRA*	0.992	0.992	0.992	0.992	0.993	0.992	0.993	0.992	0.000
43	Turkmenistan	*TRK*	0.996	0.995	0.996	0.997	0.997	0.998	0.978	0.994	0.007
44	Australia	*QR*	1.000	0.972	0.962	0.971	0.973	0.981	1.000	0.980	0.015
	Mean		0.922	0.923	0.915	0.922	0.920	0.928	0.930	0.923	0.012

4.3.4 Measured by 4-stage procedure

As mentioned earlier, when re-estimate effectiveness by substituting adjusted data, there is no guarantee that such measurement can always completely eliminate the slacks. Table 4-16 indicates the estimated slacks based on BCC model and 3-stage DEA method. As one can see from table 4-16, although both the number of DMUs with slacks and the amount of consumption slacks are decreased, there still exist some slacks in passenger-km and ton-km. In order to incorporate the residual into the effectiveness measurement model, this research thus employs the 4-stage DEA method to estimate the effectiveness of railways; the results are documented in Table 4-17. Comparing the measured results with 3-stage DEA procedure, the average effectiveness is slight decreased since the 4-stage procedure takes the residual slacks into account. In other words, the effectiveness scores may be overestimate if the residual slacks are neglected.

Table 4-16 the results of consumption slack analysis

	Estimated by using raw data				Estimated by using adjusted data.			
	Passenger-km		Ton-km		Passenger-km		Ton-km	
	Radial.	Non-rad.	Radial.	Non-rad.	Radial.	Non-rad.	Radial.	Non-rad.
No.	290	57	290	19	288	45	288	13
TS	6,608,582	638,475	7,011,008	68,274	2,711,095	392,360	2,855,532	2,911
AS	21,456	2,073	22,763	222	8,802	1,273	9,271	9.5

Note: No., TS, AS, stands for number of DMUs with slacks, total slacks, average slacks (defined as total slacks / 308), respectively.

Table 4-17 Service effectiveness (4-stage)

No	Country	Railways	1995	1996	1997	1998	1999	2000	2001	mean	stdev
1	Austria	*ÖBB*	0.882	0.876	0.873	0.872	0.872	0.874	0.879	0.875	0.004
2	Belgium	*SNCB/NMBS*	0.946	0.946	0.942	0.945	0.941	0.942	0.945	0.944	0.002
3	Denmark	*DSB*	0.944	0.944	0.949	0.952	0.954	0.962	0.968	0.953	0.009
4	Finland	*VR*	0.877	0.876	0.878	0.876	0.876	0.877	0.879	0.877	0.001
5	France	*SNCF*	0.421	0.441	0.428	0.439	0.448	0.505	0.523	0.458	0.040
6	Germany	*DB AG*	0.223	0.246	0.313	0.322	0.328	0.343	0.382	0.308	0.055
7	Greece	*CH*	0.976	0.977	0.981	0.960	0.917	1.000	0.992	0.972	0.027
8	Ireland	*CIE*	0.954	0.953	0.954	0.956	0.840	0.957	0.953	0.938	0.043
9	Italy	*FS SpA*	0.797	0.795	0.791	0.790	0.800	0.804	0.818	0.799	0.010
10	Luxembourg	*CFL*	0.988	0.965	0.950	0.960	0.960	0.977	0.993	0.970	0.016
11	Netherlands	*NS N.V.*	1.000	0.955	0.956	0.955	0.954	0.954	0.959	0.962	0.017
12	Portugal	*CP*	0.966	0.967	0.966	0.965	0.967	0.965	0.967	0.966	0.001
13	Spain	*RENFE*	0.835	0.838	0.835	0.840	0.839	0.841	0.849	0.840	0.005
14	Sweden	*SJ AB*	0.773	0.771	0.750	0.756	0.760	0.764	0.770	0.763	0.009
15	Norway	*NSB BA*	0.887	0.885	0.883	0.884	0.886	0.881	0.882	0.884	0.002
16	Switzerland	*BLS*	0.967	0.989	0.961	0.955	0.957	0.955	0.973	0.965	0.012
17	Switzerland	*CFF/SBB/FFS*	0.926	0.923	0.928	0.930	0.933	0.932	0.931	0.929	0.004
18	Bulgaria	*BDZ*	0.985	0.976	0.977	0.978	0.975	0.973	0.970	0.976	0.005
19	Croatia	*HZ*	0.976	0.970	0.969	0.969	0.969	0.970	0.970	0.970	0.003
20	Czech Rep	*CD*	0.881	0.882	0.882	0.880	0.881	0.881	0.882	0.881	0.001
21	Estonia	*EVR*	0.996	0.997	0.997	0.998	1.000	0.999	1.000	0.998	0.002
22	Hungary	*GYSEV/RÖEE*	0.979	1.000	1.000	0.968	0.978	0.989	0.999	0.988	0.013
23	Hungary	*MÁV Rt.*	0.921	0.923	0.923	0.922	0.922	0.922	0.927	0.923	0.002
24	Latvia	*LDZ*	0.991	0.993	0.993	0.993	0.995	0.996	0.997	0.994	0.002
25	Lithuania	*LG*	0.989	0.991	0.991	0.991	0.992	0.993	0.996	0.992	0.002
26	Poland	*PKP*	0.778	0.771	0.531	0.777	0.794	0.797	0.812	0.751	0.098
27	Romania	*CFR*	0.941	0.942	0.937	0.937	0.936	0.935	0.933	0.937	0.003
28	Slovak	*ZSR*	0.964	0.962	0.962	0.962	0.961	0.962	0.962	0.962	0.001
29	Slovenia	*SZ*	0.983	0.982	0.982	0.969	0.982	0.982	0.982	0.980	0.005
30	Moldova	*CFM (E)*	0.995	0.988	0.994	1.000	0.981	1.000	0.997	0.994	0.007
31	Ukraine	*UZ*	1.000	0.991	0.991	0.996	0.997	1.000	1.000	0.996	0.004
32	Turkey	*TCDD*	0.956	0.955	0.956	0.956	0.958	0.960	0.961	0.957	0.002
33	Israel	*IsR*	0.993	0.988	0.986	0.987	0.982	0.962	0.985	0.983	0.010
34	Morocco	*ONCFM*	0.992	0.993	0.992	0.993	0.992	0.992	0.977	0.990	0.006
35	Syria	*CFS*	0.917	0.971	0.954	0.975	0.973	0.957	0.938	0.955	0.021
36	Mozambique	*CFM*	1.000	1.000	0.923	0.983	0.989	0.988	0.925	0.973	0.034
37	Tanzania	*TRC*	1.000	1.000	0.952	0.963	0.988	0.960	0.947	0.973	0.023
38	Azerbaijan	*AZ*	0.987	0.992	0.994	0.994	0.994	0.995	0.995	0.993	0.003
39	Korea	*KNR*	0.985	0.982	0.978	0.978	0.975	0.980	0.976	0.979	0.004
40	Japan	*JR*	0.790	1.000	0.990	0.960	0.919	1.000	0.957	0.945	0.074
41	India	*IR*	0.785	0.807	0.817	0.927	0.986	0.934	1.000	0.894	0.089
42	Taiwan	*TRA*	0.992	0.991	0.990	0.989	0.989	0.989	0.977	0.988	0.005
43	Turkmenistan	*TRK*	0.996	0.995	0.996	0.997	0.997	0.999	0.978	0.994	0.007
44	Australia	*QR*	1.000	0.972	0.962	0.971	0.973	0.981	1.000	0.980	0.015
	Mean		0.912	0.917	0.908	0.917	0.916	0.923	0.925	0.917	0.016

4.3.5 Comparison.

Once again, the analytical results reveal that different model will lead to different result. Table 4-18 shows the distribution frequencies of estimated results based on CCR, BCC models, and 3-stage, 4-stage DEA approaches. On average, the efficiency estimated by 3-stage DEA procedure is the highest, while CCR efficiency is the lowest. It should be noted that the effectiveness scores based on BCC model are somewhat lower than those based on 3-stage and 4-stage DEA procedures, because BCC model does not take the environmental effects, managerial ineffectiveness and statistical noises into account.

Table 4-18 Distribution frequencies of estimated results based on CCR, BCC, 3-stage, and 4-stage effectiveness measurement

Range	CCR	BCC	3-stage	4-stage
Less than 0.2	26	16	0	0
0.200~0.299	95	89	2	2
0.300~0.399	66	56	4	5
0.400~0.499	18	20	6	5
0.500~0.599	19	22	2	3
0.600~0.699	23	23	1	0
0.700~0.799	13	23	16	18
0.800~0.899	18	15	40	42
0.900~0.999	21	26	217	213
1	9	18	20	20
Max.	1.000	1.000	1.000	1.000
Min.	0.155	0.177	0.247	0.223
Mean	0.446	0.497	0.923	0.917
Std. Dev.	0.254	0.271	0.130	0.135

Furthermore, comparing the results measured from four-stage procedure with those from three-stage procedure, 199 DMUs remain unchanged in effectiveness measurement. It is worthy to note that, in general, the average effectiveness score decreased when the four-stage procedure is adopted. Thus this research concludes that the effectiveness scores may be overestimate if the residual slacks are neglected.

4.4 Concluding Remarks

This chapter measures the technical efficiency and service effectiveness for some selected 44 railways in the world over the period of 1995 to 2001. There are some conclusions can be draw based on the analytical results. The first one is that efficiency and effectiveness scores estimated from conventional DEA models (CCR and BCC) are relative low. From Table 4-3, 4-4, 4-12, and 4-13, one can easily note that, in general, low efficiency and effectiveness scores are found in the rail industry with only few exceptions. The average efficiency is 0.565 and 0.639, while average effectiveness is 0.446 and 0.497, based on CCR and BCC model, respectively. This partly reflects that most railways have been facing a decline situation in market share.

The second one is that efficiency and effectiveness scores estimated from three-stage data-adjusted model are no less than those from BCC models. The results of three-stage DEA indicate that the efficiency and effectiveness scores estimated from adjusted data are considerably greater than those estimated from unadjusted data (0.924 vs. 0.639 and 0.923 vs. 0.497, respectively). However, the standard deviations of both efficiency and effectiveness between firms decrease, and the number of efficient (and effective) railways increased after data adjusted. The results seem more reasonable since both the environment impacts and the statistical noise terms are taken into account.

The third one is that factors affecting efficiency and effectiveness are identified. This research found that line density, ratio of passenger service, and percentage of electrified lines are the environmental factors significantly influencing the technical efficiency scores and thus affecting the amount of input slacks. Meanwhile, the length of lines, population density, and gross national income per capita are the factors significantly affecting the service effectiveness scores and thus influencing the amount of consumption slacks.

The last one is that, as mentioned earlier, when re-estimate efficiency and effectiveness by substituting adjusted data, there is no guarantee that such measurement can always completely eliminate the slacks. From table 4-8 and 4-16, although slacks are decreased, both input and output slacks are still existed. This research thus employs the four-stage DEA procedure to efficiency and effectiveness measurement. The results conclude that efficiency and effectiveness scores estimated from four-stage model slightly decrease in comparison with three-stage procedure. Because of the former procedure takes slacks into account.