**Appendix**

**Table A.1**

Global technical environmental efficiency results for 128 DMUs.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Dalian Port | Yingkou Port | Qingdao Port | Rizhao Port | Yantai Port | Tianjin Port | Tangshan Port | Qinhuangdao Port |
| 2005 | 0.3488 | 0.0850 | 0.0855 | 0.0896 | 1.0000 | 0.1128 | 0.3274 | 0.0395 |
| 2006 | 0.3062 | 0.0468 | 0.1750 | 0.0873 | 0.9098 | 0.1060 | 0.4515 | 0.0589 |
| 2007 | 0.3108 | 0.0439 | 0.2198 | 0.1439 | 0.5057 | 0.1023 | 1.0000 | 0.1226 |
| 2008 | 0.3101 | 0.0397 | 0.2627 | 0.1485 | 0.6438 | 0.0321 | 0.5758 | 0.0982 |
| 2009 | 0.3301 | 0.0526 | 0.1089 | 0.1342 | 0.5507 | 0.0587 | 1.0000 | 1.0000 |
| 2010 | 0.3640 | 0.0476 | 0.2297 | 0.1747 | 1.0000 | 0.0700 | 1.0000 | 0.3980 |
| 2011 | 0.4111 | 0.0524 | 0.4189 | 0.2617 | 0.7613 | 0.0783 | 1.0000 | 1.0000 |
| 2012 | 0.3685 | 0.0552 | 0.6334 | 0.3973 | 0.6916 | 0.0922 | 0.8184 | 1.0000 |
| 2013 | 0.4007 | 0.0615 | 1.0000 | 1.0000 | 0.7254 | 0.1114 | 1.0000 | 1.0000 |
| 2014 | 0.3980 | 0.0683 | 1.0000 | 1.0000 | 0.5983 | 0.1178 | 0.6780 | 0.1487 |
| 2015 | 0.3717 | 0.0576 | 0.5800 | 0.6270 | 0.5629 | 0.1569 | 0.5978 | 0.1121 |
| 2016 | 0.3704 | 0.0498 | 0.7573 | 0.4403 | 0.5635 | 0.2089 | 0.5787 | 0.1312 |
| 2017 | 0.3732 | 0.0148 | 0.2288 | 0.1651 | 0.4004 | 0.2661 | 0.0454 | 0.0663 |
| 2018 | 0.4241 | 0.0115 | 0.2848 | 0.3685 | 0.4140 | 0.2518 | 1.0000 | 0.4550 |
| 2019 | 0.3507 | 0.0286 | 0.4931 | 0.2285 | 0.3583 | 0.2821 | 0.6788 | 0.0678 |
| 2020 | 0.4140 | 1.0000 | 1.0000 | 0.0230 | 0.3164 | 0.0241 | 0.7299 | 0.2823 |

**Table A.2**

Local pure technical environmental efficiency results for 128 DMUs.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Dalian Port | Yingkou Port | Qingdao Port | Rizhao Port | Yantai Port | Tianjin Port | Tangshan Port | Qinhuangdao Port |
| 2005 | 0.3599 | 0.9999 | 0.1240 | 0.1701 | 1.0000 | 0.1236 | 1.0000 | 0.0468 |
| 2006 | 0.3111 | 0.0681 | 0.2539 | 0.1608 | 1.0000 | 0.1188 | 1.0000 | 0.0654 |
| 2007 | 0.3120 | 0.0562 | 0.3072 | 0.2145 | 0.5718 | 0.1310 | 1.0000 | 0.1348 |
| 2008 | 0.3110 | 0.0474 | 0.3230 | 0.2247 | 0.6791 | 0.0511 | 0.7592 | 0.1106 |
| 2009 | 0.3310 | 0.0629 | 0.1144 | 0.1673 | 0.6098 | 0.0953 | 1.0000 | 1.0000 |
| 2010 | 0.3859 | 0.0517 | 0.2547 | 0.2081 | 1.0000 | 0.1279 | 1.0000 | 0.4458 |
| 2011 | 0.6175 | 0.0529 | 0.4866 | 0.3072 | 0.7723 | 0.1568 | 1.0000 | 1.0000 |
| 2012 | 0.3866 | 0.0585 | 0.7039 | 0.4240 | 0.6961 | 0.1948 | 0.9043 | 1.0000 |
| 2013 | 0.4494 | 0.0666 | 1.0000 | 1.0000 | 0.7279 | 0.2438 | 1.0000 | 1.0000 |
| 2014 | 0.4518 | 0.0768 | 1.0000 | 1.0000 | 0.6001 | 0.2918 | 0.6983 | 0.1502 |
| 2015 | 0.4065 | 0.0664 | 0.6425 | 0.6486 | 0.5693 | 0.3360 | 0.6105 | 0.1149 |
| 2016 | 0.4099 | 0.0586 | 0.8762 | 0.4969 | 0.5652 | 0.3889 | 0.6002 | 0.1385 |
| 2017 | 0.4374 | 0.0187 | 0.8476 | 0.1753 | 0.4117 | 0.3958 | 0.0638 | 0.0677 |
| 2018 | 1.0000 | 0.0149 | 0.8567 | 1.0000 | 0.4357 | 0.3891 | 1.0000 | 1.0000 |
| 2019 | 0.5208 | 0.0297 | 0.7741 | 0.4126 | 0.3660 | 0.3916 | 0.7917 | 0.0685 |
| 2020 | 0.4153 | 1.0000 | 1.0000 | 1.0000 | 0.3165 | 0.0717 | 1.0000 | 0.4037 |

**Table A.3**

Scale environmental efficiency results for 128 DMUs.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Dalian Port | Yingkou Port | Qingdao Port | Rizhao Port | Yantai Port | Tianjin Port | Tangshan Port | Qinhuangdao Port |
| 2005 | 0.9692 | 0.0850 | 0.6895 | 0.5267 | 1.0000 | 0.9126 | 0.3274 | 0.8440 |
| 2006 | 0.9842 | 0.6872 | 0.6892 | 0.5429 | 0.9098 | 0.8923 | 0.4515 | 0.9006 |
| 2007 | 0.9962 | 0.7811 | 0.7155 | 0.6709 | 0.8844 | 0.7809 | 1.0000 | 0.9095 |
| 2008 | 0.9971 | 0.8376 | 0.8133 | 0.6609 | 0.9480 | 0.6282 | 0.7584 | 0.8879 |
| 2009 | 0.9973 | 0.8362 | 0.9519 | 0.8022 | 0.9031 | 0.6159 | 1.0000 | 1.0000 |
| 2010 | 0.9432 | 0.9207 | 0.9018 | 0.8395 | 1.0000 | 0.5473 | 1.0000 | 0.8928 |
| 2011 | 0.6657 | 0.9905 | 0.8609 | 0.8519 | 0.9858 | 0.4994 | 1.0000 | 1.0000 |
| 2012 | 0.9532 | 0.9436 | 0.8998 | 0.9370 | 0.9935 | 0.4733 | 0.9050 | 1.0000 |
| 2013 | 0.8916 | 0.9234 | 1.0000 | 1.0000 | 0.9966 | 0.4569 | 1.0000 | 1.0000 |
| 2014 | 0.8809 | 0.8893 | 1.0000 | 1.0000 | 0.9970 | 0.4037 | 0.9709 | 0.9900 |
| 2015 | 0.9144 | 0.8675 | 0.9027 | 0.9667 | 0.9888 | 0.4670 | 0.9792 | 0.9756 |
| 2016 | 0.9036 | 0.8498 | 0.8643 | 0.8861 | 0.9970 | 0.5372 | 0.9642 | 0.9473 |
| 2017 | 0.8532 | 0.7914 | 0.2699 | 0.9418 | 0.9726 | 0.6723 | 0.7116 | 0.9793 |
| 2018 | 0.4241 | 0.7718 | 0.3324 | 0.3685 | 0.9502 | 0.6471 | 1.0000 | 0.4550 |
| 2019 | 0.6734 | 0.9630 | 0.6370 | 0.5538 | 0.9790 | 0.7204 | 0.8574 | 0.9898 |
| 2020 | 0.9969 | 1.0000 | 1.0000 | 0.0230 | 0.9997 | 0.3361 | 0.7299 | 0.6993 |

**Table A.4**

Annual average environmental efficiency of 8 ports during the study period.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Global technical  environmental efficiency | Local pure technical  environmental efficiency | Scale  environmental efficiency |
| 2005 | 0.2611 | 0.4780 | 0.6693 |
| 2006 | 0.2677 | 0.3723 | 0.7572 |
| 2007 | 0.3061 | 0.3409 | 0.8423 |
| 2008 | 0.2638 | 0.3133 | 0.8164 |
| 2009 | 0.4044 | 0.4226 | 0.8883 |
| 2010 | 0.4105 | 0.4343 | 0.8807 |
| 2011 | 0.4980 | 0.5492 | 0.8568 |
| 2012 | 0.5071 | 0.5460 | 0.8882 |
| 2013 | 0.6624 | 0.6860 | 0.9086 |
| 2014 | 0.5011 | 0.5336 | 0.8915 |
| 2015 | 0.3833 | 0.4243 | 0.8827 |
| 2016 | 0.3875 | 0.4418 | 0.8687 |
| 2017 | 0.1950 | 0.3022 | 0.7740 |
| 2018 | 0.4012 | 0.7120 | 0.6186 |
| 2019 | 0.3110 | 0.4194 | 0.7967 |
| 2020 | 0.4737 | 0.6509 | 0.7231 |

**Table A.5**

Global technical efficiency results for 128 DMUs (without CO2 emissions).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Dalian Port | Yingkou Port | Qingdao Port | Rizhao Port | Yantai Port | Tianjin Port | Tangshan Port | Qinhuangdao Port |
| 2005 | 0.2906 | 0.0440 | 0.0463 | 0.0475 | 0.4432 | 0.0652 | 0.0425 | 0.0195 |
| 2006 | 0.2799 | 0.0242 | 0.1047 | 0.0469 | 0.5004 | 0.0605 | 0.0924 | 0.0299 |
| 2007 | 0.3054 | 0.0227 | 0.1390 | 0.0815 | 0.3664 | 0.0579 | 0.1922 | 0.0654 |
| 2008 | 0.3276 | 0.0204 | 0.1640 | 0.0829 | 0.4131 | 0.0166 | 0.2327 | 0.0517 |
| 2009 | 0.3452 | 0.0274 | 0.0605 | 0.0738 | 0.3719 | 0.0315 | 0.7214 | 1.0000 |
| 2010 | 0.3919 | 0.0247 | 0.1391 | 0.0999 | 1.0000 | 0.0383 | 0.4487 | 0.2092 |
| 2011 | 0.4602 | 0.0273 | 0.2641 | 0.1488 | 0.6373 | 0.0433 | 1.0000 | 1.0000 |
| 2012 | 0.4128 | 0.0289 | 0.4200 | 0.2420 | 0.5774 | 0.0517 | 0.5994 | 0.3927 |
| 2013 | 0.4205 | 0.0322 | 1.0000 | 0.2967 | 0.6639 | 0.0632 | 1.0000 | 1.0000 |
| 2014 | 0.4070 | 0.0359 | 1.0000 | 1.0000 | 0.4321 | 0.0674 | 0.5343 | 0.0791 |
| 2015 | 0.3743 | 0.0301 | 0.4330 | 0.4805 | 0.4312 | 0.0946 | 0.4567 | 0.0592 |
| 2016 | 0.3633 | 0.0259 | 0.6497 | 0.2883 | 0.4161 | 0.1355 | 0.4719 | 0.0660 |
| 2017 | 0.3781 | 0.0075 | 0.1333 | 0.0917 | 0.3000 | 0.1865 | 0.0234 | 0.0326 |
| 2018 | 0.5150 | 0.0058 | 0.1734 | 0.2393 | 0.3254 | 0.1716 | 1.0000 | 0.1882 |
| 2019 | 0.4401 | 0.0146 | 0.3619 | 0.1366 | 0.3039 | 0.2009 | 0.6944 | 0.0302 |
| 2020 | 0.4183 | 0.0030 | 1.0000 | 0.0117 | 0.2454 | 0.0123 | 0.8150 | 0.0949 |

**Table A.6**

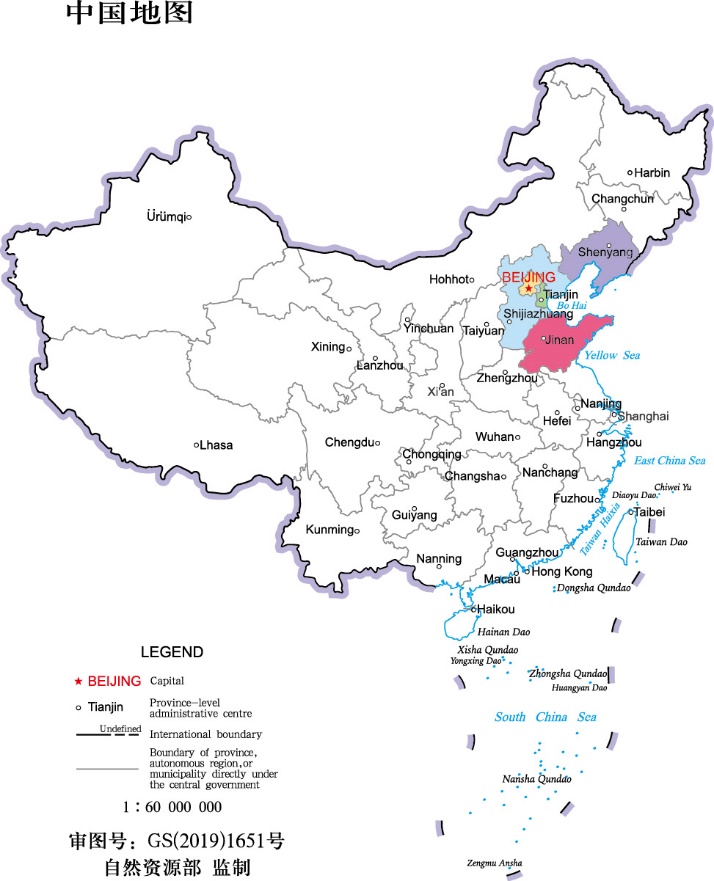
Local pure technical efficiency results for 128 DMUs (without CO2 emissions).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Dalian Port | Yingkou Port | Qingdao Port | Rizhao Port | Yantai Port | Tianjin Port | Tangshan Port | Qinhuangdao Port |
| 2005 | 0.3309 | 0.9974 | 0.0697 | 0.1017 | 0.9998 | 0.0738 | 0.9983 | 0.0239 |
| 2006 | 0.3261 | 0.0360 | 0.1665 | 0.0946 | 0.8284 | 0.0722 | 0.9986 | 0.0344 |
| 2007 | 0.3562 | 0.0295 | 0.2166 | 0.1339 | 0.4253 | 0.0818 | 0.7364 | 0.0739 |
| 2008 | 0.3678 | 0.0247 | 0.2133 | 0.1296 | 0.4683 | 0.0275 | 0.5211 | 0.0590 |
| 2009 | 0.3882 | 0.0331 | 0.0640 | 0.0948 | 0.4033 | 0.0550 | 1.0000 | 1.0000 |
| 2010 | 0.4378 | 0.0269 | 0.1578 | 0.1230 | 1.0000 | 0.0802 | 0.9996 | 0.2921 |
| 2011 | 0.6721 | 0.0275 | 0.3216 | 0.1810 | 0.6826 | 0.1037 | 1.0000 | 1.0000 |
| 2012 | 0.4668 | 0.0307 | 0.4915 | 0.2620 | 0.5970 | 0.1371 | 0.8148 | 0.9994 |
| 2013 | 0.5225 | 0.0352 | 1.0000 | 0.9873 | 0.6730 | 0.1811 | 1.0000 | 1.0000 |
| 2014 | 0.5240 | 0.0410 | 1.0000 | 1.0000 | 0.4348 | 0.2280 | 0.5398 | 0.0827 |
| 2015 | 0.4831 | 0.0352 | 0.4940 | 0.5075 | 0.4325 | 0.3125 | 0.4602 | 0.0621 |
| 2016 | 0.4853 | 0.0310 | 0.7075 | 0.3447 | 0.4188 | 0.4290 | 0.4730 | 0.0762 |
| 2017 | 0.5342 | 0.0095 | 0.3948 | 0.1008 | 0.3313 | 0.4049 | 0.0332 | 0.0354 |
| 2018 | 1.0000 | 0.0075 | 0.5171 | 0.9999 | 0.3917 | 0.3790 | 1.0000 | 0.2445 |
| 2019 | 0.6028 | 0.0152 | 0.7364 | 0.3219 | 0.3223 | 0.3888 | 0.7794 | 0.0357 |
| 2020 | 0.4246 | 0.0035 | 1.0000 | 0.9982 | 0.2867 | 0.0393 | 1.0000 | 0.1293 |

**Table A.7**

Scale efficiency results for 128 DMUs (without CO2 emissions).

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Dalian Port | Yingkou Port | Qingdao Port | Rizhao Port | Yantai Port | Tianjin Port | Tangshan Port | Qinhuangdao Port |
| 2005 | 0.8782 | 0.0441 | 0.6643 | 0.4671 | 0.4433 | 0.8835 | 0.0426 | 0.8159 |
| 2006 | 0.8583 | 0.6722 | 0.6288 | 0.4958 | 0.6041 | 0.8380 | 0.0925 | 0.8692 |
| 2007 | 0.8574 | 0.7695 | 0.6417 | 0.6087 | 0.8615 | 0.7078 | 0.2610 | 0.8850 |
| 2008 | 0.8907 | 0.8259 | 0.7689 | 0.6397 | 0.8821 | 0.6036 | 0.4466 | 0.8763 |
| 2009 | 0.8892 | 0.8278 | 0.9453 | 0.7785 | 0.9221 | 0.5727 | 0.7214 | 1.0000 |
| 2010 | 0.8952 | 0.9182 | 0.8815 | 0.8122 | 1.0000 | 0.4776 | 0.4489 | 0.7162 |
| 2011 | 0.6847 | 0.9927 | 0.8212 | 0.8221 | 0.9336 | 0.4176 | 1.0000 | 1.0000 |
| 2012 | 0.8843 | 0.9414 | 0.8545 | 0.9237 | 0.9672 | 0.3771 | 0.7356 | 0.3929 |
| 2013 | 0.8048 | 0.9148 | 1.0000 | 0.3005 | 0.9865 | 0.3490 | 1.0000 | 1.0000 |
| 2014 | 0.7767 | 0.8756 | 1.0000 | 1.0000 | 0.9938 | 0.2956 | 0.9898 | 0.9565 |
| 2015 | 0.7748 | 0.8551 | 0.8765 | 0.9468 | 0.9970 | 0.3027 | 0.9924 | 0.9533 |
| 2016 | 0.7486 | 0.8355 | 0.9183 | 0.8364 | 0.9936 | 0.3159 | 0.9977 | 0.8661 |
| 2017 | 0.7078 | 0.7895 | 0.3376 | 0.9097 | 0.9055 | 0.4606 | 0.7048 | 0.9209 |
| 2018 | 0.5150 | 0.7733 | 0.3353 | 0.2393 | 0.8307 | 0.4528 | 1.0000 | 0.7697 |
| 2019 | 0.7301 | 0.9605 | 0.4914 | 0.4244 | 0.9429 | 0.5167 | 0.8909 | 0.8459 |
| 2020 | 0.9852 | 0.8571 | 1.0000 | 0.0117 | 0.8559 | 0.3130 | 0.8150 | 0.7340 |



**Fig. A.1.** Geographical location of ports around the Bohai Sea.

Note: Based on the standard map GS(2019)1651 of the standard map service website of the Ministry of Natural Resources of the People’s Republic of China, and the base map boundary has not been modified. The ports around the Bohai Sea are located in the areas marked in color in the figure.

**Formula A.1**

The following formulas are used to estimate the efficiency of a DMU excluding undesirable outputs. In this model, . If ,the efficiency value of the DMU in the SBM model is 1, and a DMU is deemed to be efficient.