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- Infrastructure Development
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CONTENTS

Efficiency Evaluation of Indian Railways Using Data Envelopment Analysis

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ABSTRACT

Indian Railways is a State owned public utility of the Government of India under the Ministry of Railways. Railway network is considered to be arteries of the nation as it is the major carrier of people and material across the country. There is greater need for efficiency evaluation of Indian Railways. The present study is dedicated to analyse the efficiency of Indian Railways for the period 1980-81 to 2018-19. We have used CCR model to find efficient years and reference sets were introduced for every inefficient year and determine the amount of input decrease and output increase to make them efficient. We found that the minimum and maximum efficiency is 0.74 and 1 respectively. During the entire period the technical efficiency ranged between 0.74 to 1 where 0.74 is minimum (in year 2002-03) and 1 is maximum (in 1980-81, 1981-82,1982-83,1988-89, 2011-12, 2012-13,2013-14, 2014-15,2015-16, 2017-18 and 2018-19). The years which forms the CRS frontier are 1980-81, 1981-82, 1982-83, 1988-89, 2011-12, 2012-13, 2013-14, 2014-15,2015-16, 2017-18 and 2018-19. These efficient years set the standard for the inefficient years to improve their performance. Indian railways confirm the existence of efficiency gaps in asset utilization, staff productivity, freight rates, and cost and revenue performance.

JEL Classification: L92,O3, R41

Keywords: Indian Railways, Railway Zones, Efficiency, Productivity, Data Envelopment Analysis

Railway network is considered to be arteries of the nation as it is the major carrier of people and material across the country. The first train steamed off from Bombay to Kalyan on 16th April 1853, made it possible for India to become the first country in Asia have a Rail network. Though the construction of Railways in 1853 onwards by the British attracted the largest single source of foreign investment in the 19th century, the impact of it on industrialization and economic development of India was rather insignificant due to the colonial character of the state. After India attained independence in 1947, major policy initiatives were made to reorient the railways for catalysing the industrial and economic development of the country. Some of the recent studies pointed out that though these policies were successful in developing a strong industrial base in India, the regional inequalities still persist without much change and are showing tendencies to widen further (Das, 1993 and Kurien, 2000).

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The Indian Railways (IR), more than 150 years old, is among one of the largest and oldest railway systems in the world. It has an extensive network, and played an integrating role in the social and economic development of the country. Indian Railways is the fourth largest rail network in the world with a track length of 117,996 km kilometres, 7,172 railway stations, 11,452 locomotives, 70,937 passenger coaches, 277,987 freight wagons. Indian Railways carried 8.26 billion passengers and transported 1.16 billion tonnes of freight in the year ending March 2018. It operates 12500 passenger trains and 7500 freight trains daily. In terms of employment, it is the eighth largest employer in the world, with 1.308 million employees as of March 2017.The Indian railway network carries an average of 23 million passengers a day and over a billion tonnes of freight a year.

Due to variety of reasons, there exist acute bottlenecks in the supply of most of the infrastructure facilities such as road, rail, telecommunication etc., in India. Due to the uniqueness of their service, the problems that confront many infrastructure facilities are quite complex and varied in nature. Therefore, opening up the market to greater international competition in order to provide the required additional infrastructure facilities or invigorate efficiency is not a viable policy proposition in most of these sectors. Again these sectors are often characterized by scale economics, network externalities, long gestation lags in investment and public goods aspects in their output, raising familiar but policy wise difficult problems. There is a need for improvement of efficiency, and for increase in supply (given the current serious shortages) in each infrastructure sector, keeping its special characteristics in view (Bhagwati and Srinivasan, 1993).

LITERATURE REVIEW

In this section, an attempt has been made to review the efficiency and productivity literature along with major studies on Indian Railways. There are only a few studies on analysing productivity and efficiency in the Indian Railways.

Rao (1975) was the first study on productivity in Indian Railways during the period 1951-72. He analyzed the productivity of Indian Railways using the conventional Solow index of productivity. They have used two alternative measures of output- the "monetary" and physical indicators. The former was Gross Value Added at constant prices. The Gross Value Added is defined as the sum of wages and surplus and then it is deflated by composite index of freight and fare charges. As far as this measure is concerned in terms of regulated nature of the industry the results are biased. The physical output was measured as aggregate output obtained by assigning weights in the ratio of 2:3 to passenger and freight services. Labour input was measured as the number of persons employed. Capital measure was obtained by deflating additions to book values by wholesale price index of Transport Machinery. Capital was adjusted for capital utilization rates. This adjustment would automatically eliminate one of the factors affecting productivity. Further, the measure of capacity utilization itself was based on reliable data. It was shown that the contribution of "technical change" to output was about 30 percent. The growth rate of productivity was about 0.9 per cent per year during 1951-74. It was also pointed out that capital-saving technical progress took place in Indian Railways. This was based on the fact that output-labour ratio increased at a faster rate than capital-labour ratio.

Varma (1988) estimated cost function both at aggregate and sub-aggregate levels covering a twenty-seven year span, 1951-52 through 1978-79. Specifically, temporal analysis of incremental and unit cost of passenger and freight output was attempted. Diagnostic analysis of incremental cost was carried out in terms of changes in capacity utilization, magnitude and composition of output, traction technology and factors explaining variations in fuel, repair and maintenance costs.

Sailaja (1998) conducted the first comprehensive study of Indian Railways at all India level paying careful attention to the issue of proper measurement of the input and output variables. This study analysed the data for Indian Railways during 1950-51 to 1985-86. This study specifies a multi-product production function and its dual cost function. Total differentiation of the cost function leads to an index of productivity. It is approximated by the Tornquist Index of productivity, which uses revenue shares as weights for output growth rates and cost shares as weights for input growth rates. Total Factor productivity growth in Indian Railways was quite low (2.5per cent per annum) compared to that in the American and Canadian Railways. Analysis of the cost structure of the railways indicates that technical change led to cost savings of about 1.5 per cent per year for the period 1950-51 to 1985-86. The nature of technical change was labour saving and intermediate saving but capital using. The estimated substitution elasticities indicate that labour and capital were substitutes, labour and intermediate inputs were complements and capital and intermediates were substitutes. Her study also concluded that the average annual growth rates of passenger output and freight output stood at 4.69per cent and 5.23per cent respectively. Jha and Singh (1992) have studied the pattern of technical efficiency in eight zones of Indian Railways over the period 1966-67 to 1988-89. Separate cost functions have been constructed for the passenger and freight output.

The cost function study by Sharma (1995) on Indian railways made an attempt for the first time to estimate returns to scale, returns to density and analysis at the disaggregate level of Indian Railways across nine zones. He estimated total factor productivity of the nine zones over the period from 1983-84 to 1992-93. The effect of operating characteristics and technological change was built into the cost function model by adding variable relating to route kilometres, BG ratio and time trend. The system consisting of the trans-log cost function and the cost share equations were estimated.

Sharma (1995) found a well behaved cost function for the zonal railways. The model had a good fit with an adjusted R^2 of 0.9725. The assumptions of homogeneity, homotheticity, constant returns to scale and absence of technical change were rejected by the data. The estimated elasticities indicate that capital and labour are substitutes of each other. Energy and labour are also substitutes while capital and energy substitution is statistically insignificant. Sharma (1995) also found that the 'unigauge programme' is not a cost saving exercise per se. The TFP index for the period 1983-93 for all zones combined dropped to 128.9 in 1992-93 from 131.3 in 1991-92. This decline has been observed for all the zones except Eastern Railways and South Central railways. This situation is the result of a fall in aggregated output in the last year while the input did not decline. The major source of output growth on Indian Railway for the period 1992-93 was the total factor productivity, which accounted for 74 per cent of the output growth". Capital contributed 22 per cent; labour and energy contributions were just 2 per cent each. All the Zonal railways exhibit strongly increasing returns to scale (1.73-1.76) and density (3.44). These figures are high and are indicative of low flexibility of costs in Indian Railways as a government run service department. On privately run railway systems in USA the studies have found only mildly increasing returns to scale.

Methodology

The CCR Model

Given the data, we measure the efficiency of each DMU once and hence need n optimizations, one for each DMU_j to be evaluated. Let the DMU_j to be evaluated on any trial be designated as DMU_o where o ranges over 1, 2,..., n. The following fractional programming problem can be solved to obtain the values for input and output weights as variables.

$$\text{Max } \square = \frac{\sum_{r=1}^{s} u_r.y_{ro}}{\sum_{i=1}^{m} v_i.x_{io}} \quad \text{.......(1)}$$

$$\text{subject to} \quad \frac{\sum_{r=1}^{s} u_r.y_{rj}}{\sum_{i=1}^{m} v_i.x_{ij}} \leq 1, j = 1,2, \ldots, n \quad \text{........(2)}$$

$$\text{And } u_r, v_i \geq 0 \quad \text{........ (3)}$$

Here, for each DMU the ratio of virtual output to virtual input should not exceed 1.

And, the optimal objective value $\square^*$ is at most 1.

CCR Efficiency

1. DMUo is CCR-efficient if $\square^* = 1$ and there exists at least one optimal (v^*, u^*), with $v^* > 0$ and $u^* > 0$.

2. Otherwise, DMUo is CCR-inefficient.

The above model can be converted into linear programming problem using Charnes-Cooper (1962) transformation:

$$\text{Max } \square_{CCR} = \sum_{r=1}^{s} u_r.y_{ro}$$

$$\text{subject to} \sum_{i=1}^{m} v_i.x_{io} = 1$$

$$\sum_{r=1}^{t} u_r.y_{rj} - \sum_{i=1}^{m} v_i.x_{ij} \leq 0, j = 1,2, \ldots, n$$

$$u_r \geq 0, r = 1,2, \ldots, s$$

$$v_i \geq 0, i = 1,2, \ldots, m$$

.......(4)

This model is known as Charnes Cooper Rhodes multiplier model.

Data Source

The objective of this study is to analyse the efficiency of Indian Railways for the period 1980-81 to 2018-19. Thus, the railway efficiency is calculated in each year and the efficiency performance of railways are considered as an independent DMU. The data has been sourced from various published sources. The proposed study intends to utilize relevant data available in the

- "Annual Statistical Statements of Indian Railways, Ministry of Railways, Government of India, New Delhi", Various issues.
- "Indian Railways Year Book, Ministry of Railways, Government of India, New Delhi", Various issues.
- "Annual Report and Accounts of Indian Railways, Ministry of Railways, Government of India, New Delhi", Various issues.
- "National Accounts Statistics of the CSO for the Indian economy.
- Economic Survey Reports
- Indian Statistical Abstracts
- Statistical Abstracts published by Directorate of Economics and Statistics

The used inputs and outputs were selected based on the research limitations and availability of information which are as under:

INPUT VARIABLES

- Number of Rolling Stock
- Energy: Fuel
- Capital: Total track-kilometres
- Labour: Total number of employed persons

OUTPUT VARIABLES

- Total number of passengers carried in thousands
- Total freight carried tonnes in thousands

RESULTS

The table below exhibits the CCR score along with reference set details for each year, respectively. In table 1, the results show that within 39 years, only 11 years(in 1980-81, 1981-82,1982-83,1988-89, 2011-12, 2012-13,2013-14, 2014-15,2015-16, 2017-18 and 2018-19) were found to be efficient years. Although technical efficiency of Indian Railways within eleven years has been equal to "1", of course, it does not mean that it is perfect "100 per cent". It only indicates that Indian Railways has used its inputs better than the other years. In table 1, the average technical efficiency score is 89 per cent for Indian Railways during the entire period. It indicates that Indian Railways are 11 per cent inefficiently operating, and there is a scope of 11 per cent improvement in output given the inputs during the entire period. Alternatively, this shows that Indian Railways can attain the given level of output using only about 89 per cent of the existing level of inputs.

During the entire period the technical efficiency ranged between 0.74 to 1 where 0.74 is minimum (in year 2002-03) and 1 is maximum (in 1980-81, 1981-82,1982-83,1988-89, 2011-12, 2012-13,2013-14, 2014-15,2015-16, 2017-18 and 2018-19). The years which forms the CRS frontier are 1980-81, 1981-82,1982-83,1988-89, 2011-12, 2012-13,2013-14, 2014-15,2015-16, 2017-18 and 2018-19. These efficient years set the standard for the inefficient years to improve their performance. Table 1 shows the reference sets for inefficient units during the entire study period. For instance, the year 1983-84 achieves the efficiency score of 0.95. It is the reference set for two efficient years, namely 1882-83, 1988-89 and 2011-12 with peer weights 0.92, 0.057 and 0.09, respectively. Also for the other inefficient years we can get similar results.

Table 1. Efficiency and Reference Sets

DMU	Technical Efficiency	Reference Sets		
1980-81	1.00	1980-81=1		
1981-82	1.00	1981-82=1		
1982-83	1.00	1982-83=1		
1983-84	0.95	1982-83=0.92	1988-89=0.057	2011-12=0.09
1984-85	0.96	1982-83=0.828	1988-89=0.136	2011-12=0.013
1985-86	0.92	2011-12=0.063	1882-83=0.608	1980-81=0.280
1986-87	0.90	2012-13=0.006	2011-12=0.103	1980-81=0.816
1987-88	0.96	1982-83-0.611	1988-89=0.280	2011-12=0.066
1988-89	1.00	1988-89=1		
1989-90	0.97	1982-83=0.199	1988-89=0.746	2011-12=0.057
1990-91	0.92	1982-83=0.236	1988-89=0.676	2011-12=0.084
1991-92	0.90	1982-83=0.337	1988-89=0.532	2011-12=0.128
1992-93	0.87	1982-83=0.133	1988-89=0.723	2011-12=0.143
1993-94	0.87	1988-89=0.769	2011-12=0.186	
1994-95	0.84	2011-12=0.238	1988-89=0.672	
1995-96	0.79	2011-12=0.286	1988-89=0.605	
1996-97	0.75	2011-12=0.322	1988-89=0.556	
1997-98	0.76	2011-12=0.376	1988-89=0.495	
1998-99	0.76	2011-12=0.399	1988-89=0.452	
1999-2000	0.75	2011-12=0.471	1988-89=0.208	1982-83=0.128
2000-01	0.75	2012-13=0.321	2011-12=0.200	1980-81=0.239
2001-02	0.77	2012-13=0.246	2011-12=0.312	1980-81=0.207
2002-03	0.74	2012-13=0.440	2011-12=0.167	1980-81=0.167
2003-04	0.75	2012-13=0.334	2011-12=0.308	1980-81=0.178
2004-05	0.74	2012-13=0.377	2011-12=0.317	1980-81=0.133
2005-06	0.78	2012-13=0.275	2011-12=0.445	1980-81=0.088
2006-07	0.82	2012-13=0.252	2011-12=0.504	1980-81=0.052
2007-08	0.86	2013-14=0.786	1980-81=0.015	
2008-09	0.89	2013-14=0.824	1980-81=0.012	
2009-10	0.98	1988-89=0.005	2011-12=0.917	
2010-11	0.98	1988-89=0.003	2011-12=0.458	
2011-12	1.00	2011-12=1		
2012-13	1.00	2012-13=1		

2013-14	1.00	2013-14=1		
2014-15	1.00	2014-15=1		
2015-16	1.00	2014-15=0.703	2013-14=0.298	
2016-17	0.98	2013-14=0.497	1980-81=0.17	2017-18=0.508
2017-18	1.00	2017-18=1		
2018-19	1.00	2018-2019=1		
Mean	0.89			

Data Envelopment Analysis also generates input and output slacks. In the output-oriented model, slacks are mostly observed in output. The availability can see the extent of the inefficiency inherent in any inefficient years of slacks as they provide more information about it. The size of inefficiency can be judged by the number of input slacks and output slacks in inefficient years. Slacks show the scope of improvement that is available to inefficient years of Indian Railways by eliminating excess input utilization or by augmenting output production. Table 2 provides the year wise output slacks under overall technical efficiency. In Table 2, empirical results show that 11 Pareto efficient years do not have any slack in output as they are producing optimum output. In case of passenger-kilometre, 10 years out of 39 years observed slacks with the maximum amount of slack found is 56284.028 kilometre (in 1993-94) followed by 43908.687 kilometre (in 1994-95). Thus, in 29 years, we do not have any slack in passenger-kilometre. This indicates that most of the inefficient years have not produced optimally using given resources and technology.

Table 2.Input and Output Slacks

DMU	Passenger Km	Total Freight Tonnes	Total Track Km	No. of Employees	Rolling Stock	Fuel
1980-81	0	0	0	0	0	0
1981-82	0	0	0	0	0	0
1982-83	0	0	0	0	0	0
1983-84	0	0	0	0	0	0
1984-85	0	0	2186.149	54792.211	0	0
1985-86	0	0	3895.695	567453.7	0	0
1986-87	0	0	5514.539	1467527.2	0	0
1987-88	0	0	3398.179	108350.52	0	0
1988-89	0	0	0	0	0	0
1989-90	10066.783	0	0	0	0	0
1990-91	0	0	478.717	69507.913	0	0
1991-92	0	0	344.945	87279.622	0	0
1992-93	23556.555	0	0	73444.198	0	0
1993-94	56284.028	0	2606.938	131899.88	0	0
1994-95	43908.687	0	5860.975	199417.78	0	0
1995-96	25033.37	0	7615.275	228502.28	0	0
1996-97	4756.607	0	8518.626	258411.69	0	0
1997-98	21459.086	0	8565.857	281918.92	0	0
1998-99	6459.302	0	10511.75	322529.85	0	0
1999-00	0	0	13007.65	420964.24	0	0
2000-01	0	0	17056.18	863268.1	0	0
2001-02	0	0	16728.25	781583.74	0	0
2002-03	0	0	15564.8	677888.52	0	0
2003-04	0	0	12957.14	603381.05	0	0
2004-05	0	0	12050.92	517714.31	0	0
2005-06	0	0	13149.77	471157.16	0	0
2006-07	0	0	13794.09	402187.86	0	0
2007-08	0	10338.916	13336.12	345696.08	0	0
2008-09	0	7757.245	11943.96	286408.52	0	0
2009-10	38077.908	0	4345.908	155800.86	0	0
2010-11	1829.052	0	861.121	72256.01	0	0

2011-12	0	0	0	0	0	0
2012-13	0	0	0	0	0	0
2013-14	0	0	0	0	0	0
2014-15	0	0	0	0	0	0
2015-16	0	21082.049	1424.771	0	0	0
2016-17	0	55274.014	0	0	12375.83	0
2017-18	0	0	0	0	0	0
2018-2019	0	0	0	0	0	0
Mean	5934.138	2421.852	5296.697	244103.77	317.329	317.329

CONCLUSION

In this study we have performed an analysis of efficiency of Indian Railways from 1980-1981 to 2018-19. We have found that within 39 years, only 11 years(in 1980-81, 1981-82,1982-83,1988-89, 2011-12, 2012-13,2013-14, 2014-15,2015-16, 2017-18 and 2018-19) were found to be efficient years. Although technical efficiency of Indian Railways within eleven years has been equal to "1", of course, it does not mean that it is perfect "100 per cent". It only indicates that Indian Railways has used its inputs better than the other years. The average technical efficiency score is 89 per cent for Indian Railways during the entire period. It indicates that Indian Railways are 11 per cent inefficiently operating, and there is a scope of 11 per cent improvement in output given the inputs during the entire period. Alternatively, this shows that Indian Railways can attain the given level of output using only about 89 per cent of the existing level of inputs. During the entire period the technical efficiency ranged between 0.74 to 1 where 0.74 is minimum (in year 2002-03) and 1 is maximum (in 1980-81, 1981-82,1982-83,1988-89, 2011-12, 2012-13,2013-14, 2014-15,2015-16, 2017-18 and 2018-19). The years which forms the CRS frontier are 1980-81, 1981-82, 1982-83,1988-89, 2011-12, 2012-13,2013-14, 2014-15,2015-16, 2017-18 and 2018-19. These efficient years set the standard for the inefficient years to improve their performance. We have also found the reference sets for inefficient units during the entire study period. For instance, the year 1983-84 achieves the efficiency score of 0.95. It is the reference set for two efficient years, namely 1882-83, 1988-89 and 2011-12 with peer weights 0.92, 0.057 and 0.09, respectively.

The empirical results show that 11 Pareto efficient years do not have any slack in output as they are producing optimum output. In case of passenger-kilometre, 10 years out of 39 years observed slacks with the maximum amount of slack found is 56284.028 kilometre (in 1993-94) followed by 43908.687 kilometre (in 1994-95). Thus, in 29 years, we do not have any slack in passenger-kilometre. This indicates that most of the inefficient years have not produced optimally using given resources and technology.

Indian railways confirm the existence of efficiency gaps in asset utilization, staff productivity, freight rates, and cost and revenue performance. It raises several research questions on the profitability of Indian Railways, its productive efficiency and technical efficiency. There is an abundant amount of research work has been done so far on the efficiency of railways at the international level. Still, there is inadequate research work on the efficiency of zones in Indian Railways over a period of time. Zonal level productivity estimations help the policymakers to focus on areas that need immediate attention in improving the overall performance of Indian Railways.

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