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An evaluation of the productivity change in public transport sector using DEA-based model

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A B S T R A C T

This study aims to build a framework for measuring the productivity in the public transport sector through a data envelopment analysis (DEA) technique. This paper extends the Malmquist productivity index (MP1) and Luenberger productivity indicator (I.P1) evaluation with the concept of an input-oriented new slack model (NSM). NSM model measures the efficiency with the effect of slacks and satisfies unit invariance, radial and translation invariance properties. In particular, the purpose of the proposed extension is to obtain the overall productivity change in terms of technical change (Frontier Shift) and technical efficiency change (Catch-up Effect) for Rajasthan State Road Transport Corporation (RSRTC) bus depots from 2008 to 2019. For this purpose, the number of buses, number of employers, fuel consumption and route distance arc are considered input variables, while passenger-kilometres occupied, and vehicle utilisation are output variables. Finally, the result demonstrates that the average total factor productivity (TFP) growth of 46 depots using MPI and LPI over the study period is 1.956% and 1.409%, respectively. This study enables policy-maker and managers to evaluate the input to reach consistent output up to an optimum level and understand the process of improving the productivity level for the bus depots.

1. Introduction

The public transport sector plays an essential role in increasing overall accessibility and making the environment healthier by reducing emissions and oil consumption. Therefore, it helps to reduce road traffic congestion and increases economic growth. The social benefits are to provide educational facilities, health services, employment scope and delivering goods & services. Public road transport is one of the basic requirements for commuting in rural areas at low operating costs. Additionally, it boosts the country's economy, overall productivity and development by reducing transportation costs, parking facility costs, vehicle operating costs and rate of accidents. It contributed approximately 8% to GDP in 2020 (https://bit.ly/3o7Fyjv). Thus, the transport sector is one of the major sources of economic growth. Rajasthan State Road Transport Corporation (RSRTC) was recognized on October 1964 under the Road Transport Corporation Act, 1950. RSRTC is a sustainable provider of intercity public transport in Rajasthan and has 52 small & large bus depots. In addition, the buses are categorized as Ordinary, Express, Deluxe, Volvo Mercedes, AC Sleeper and Volvo LCD. Approximately 0.9 million passengers travel daily (RSRTC, Annual Report; from 2008 to 2018). The road length has increased rapidly over time from 17,339 Km (March 1951) to 2,64,244 Km by March 2019 (https://bit.ly/2Wj6D7S, January 2020). National highway number 8 (NH8) encompasses an overall span of 5,585 Km in Rajasthan and is connected to major cities like Ajmer, Jaipur, Udaipur and Chittorgarh (https://bit.ly/3ESyfSG). Presently, RSRTC bus depots are suffering huge losses due to subsidized fares and some underperforming depots. The overall financial performance of RSRTC appears to be gloomy and it would not be wrong to say that it is heading towards a severe financial crisis. Due to all this, depots exhibit inefficiency and usually provide poor quality service. There is an immediate need to reform the existing and intensive steps need to be taken to address the grievances of the public (Khosravi et al., 2015).

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The pursuit of this research is to determine the efficiency score and total productivity changes of RSRTC bus depots. It would be helpful to the policy-maker in the legislative frameworks for developing suitable management strategies and improving the performance level. Data envelopment analysis (DEA) provides relative efficiency and productivity change of decision-making units (DMUs) over the period with multiple input and output variables. While DEA is one of the most useful techniques, this technique investigates the efficiency based on linear programming. The purpose of the DEA is to identify the best-performing units in a certain area and develop strategies to improve the performance of the DMUs, if it is not recognized as one of them (Liang et al., 2008). Productivity is a salient source of financial growth and competitiveness as basic statistical information for many comparisons and performance assessments. Malmquist productivity index (MPI) is a widely spread approach to measure productivity change, proposed by Caves et al. (1982). An important privilege of this technique is that it can simultaneously provide production technology for multiple inputs and outputs. Färe et al. (1992) further developed the productivity index. MPI is a ratio-based technique that uses the distance functions (Shephard, 2012) to decompose the productivity growth into technical efficiency change (TEC) and technological change (TC) components (Fare et al., 1994; Zofio, 2007). The limitation of MPI is that one has to choose between input or output orientation, corresponding to under one consideration either revenue maximization or cost minimization. Moreover, MPI exaggerates the score of productivity growth and decline. Chambers et al. (1996) introduced a difference-based and arithmetic mean of the directional distance functions (DDF) which is known as the Luenberger productivity index (LPI). LPI evaluates productivity by considering contraction of inputs and expansion of outputs simultaneously (Boussemart et al., 2003). MPI gives approximately twice of LPI score value. This study addresses the potential gap between MPI and LPI using DEA technique. These indices are applied to investigate the productivity level of RSRTC depots for panel data over the period 2008-19.

The goal of this study is to observe and analyse changes in efficiency and productivity changes for 46 out of 52 RSRTC bus depots due to non-availability of data over the period 2008-19. This study emphasizes the utilization of productivity and their time variability by using MPI and LPI with the DEA technique. No such study has been done on the productivity of Rajasthan public transport sector. This paper is decomposed like this; section 2 is summarized study on the productivity of the transport sector using DEA technique. Then, section 3 contains a methodology framework, particularly the basic NSM model. Section 4 describes the MPI model and an empirical discussion that measures the productivity of bus depots in RSRTC, besides policy implications and suggestions are given. The conclusions and future work are presented in the last section.

2. Literature Review

There is a lack of an elaborated study about the public road transport sector in the previous studies, hence increasing the importance of this study. For analysing the efficiency and productivity change of DMUs, DEA and productivity-related models have become prominent. The productivity of the transport sector has received crucial attention in previous literature. In the earlier studies, main concern has been highlighted on financial and economic productivity outcomes in various sectors (Gordon, 1992; Hensher & Daniels, 1995; Örkcü et al., 2016; Cowie, 2018; Du et al., 2018; Tzeremes, 2019; Pastor et al., 2020). Wu et al. (2008) suggested the Malmquist DEA approach for evaluating the productivity of China's transportation over the period 1980-2005. They used the bootstrap method to estimate the confidence interval for technical efficiency. Odeck (2008) used the MPI methodology to assess the productivity of Norwegian bus industry data (1995-2002) for pre mergers (1995-1998) and post mergers (1999-2002) years. Agarwal et al. (2009) examined the productivity of 34 state road transport undertakings (STUs) of India using the DEA-based MPI approach for the period 1989-1990 to 2000-2001. Also, multiple regression analysis is assessed to determine the impact of several background and uncontrollable variables on the productivity of STUs.

Afterward, Choi et al. (2015) used an output-oriented MPI model to look at the average productivity of the five major transportation industries in the United States between 2004 and 2011, including airline, truck, rail, pipeline, and water and pooled transportation. Rodseth (2017) proposed the ratio efficiency measure (REM) and logistics productivity index were evaluated for 24 Norwegian municipalities of urban freight transport between 2008-2012. Yu et al. (2017) analysed the meta-frontier efficiency-change index (MEC), technology-change index (MTC) and technology-gap-change index (TGC) of transport sector in 30 Chinese provinces from 2000 to 2012 by applying the contemporaneous meta-frontier Malmquist-Luenberger carbon emission performance index (CMML) that included the non-radial directional distance functions (DDF). In addition, Odeck (2018) reviewed 11 research papers in which the researcher used several approaches to obtain efficiency and productivity in the transportation sector. Recently, Gulati (2021) used sequential Malmquist-Luenberger productivity index (SMLPI) approach to estimate the unbiased TFP of 8 passenger bus companies that are working in big metropolitan cities over the time 2011-2016. Moreover, Liu et al. (2021) empirically addressed the green productivity growth rate and stability of China's road transportation using DEA, DDF and global Malmquist Luenberger index (GMLI) model.

There are limited studies about the productivity change of the public transport sector globally. This work assists in productivity change in terms of technical changes (TEC) and technological changes (TC) analysis at RSRTC bus depots over the consecutive period for 2008-19. The primary goal of this research is to help policy-maker in formulating effective policies to enhance the overall health and competitiveness of the RSRTC depots. This study would also serve them with the perspective of how to develop satisfactory outcomes for passengers.

3. Data Envelopment Analysis and NSM model Framework

DEA is a non-parametric linear programming-based technique and the objective of DEA is to measure how relatively DMUs are performing efficiently. First time, the DEA was proposed by Charnes et al. (1978). The ratio of total amount of outputs to total amount of inputs, which is motivated by productivity, is the definition of the efficiency of DMU (Ramanathan, 2003). The fundamental DEA model was introduced by Charnes et al. (1978) based on the constant return to scale (CRS) assumption. Whereas, Banker et al. (1984) established a variable return to scale (VRS) assumption based DEA model that incorporates the convexity constraint into the CCR model known as the Banker-Charms-Cooper (BCC) model. These models are the objective oriented to recognise the benchmarking entities and recommend ways to make inefficient DMUs more efficient. An input-oriented model attempts to reduce the input value with the current amount of output value. An output-oriented model, on the other hand, maximizes the output value with the present quantity of the input value. The proposed research is considered as an input-oriented NSM model. This implies that this study focuses on minimizing the input value to get the current quantity of output and convex hull of the existing DMUs used to extend the production frontier. NSM model directly deals with slacks, radial properties, unit and translation invariance.

Assumed there are J DMUs $(j = 1,2,\ldots\ldots o,\ldots,J)$ each of which consumes M inputs to produce N outputs define by x_{mj} $(m = 1,2,\ldots\ldots\ldots,M)$ and y_{nj} $(n = 1,2,\ldots\ldots\ldots,N)$ respectively. Agarwal et al. (2011) computed the overall technical efficiency (OTE) with the exact impact of input slacks on the value of efficiency at o^{th} DMU. Thus, this model considered under variable returns to scale (VRS) convexity assumption (Banker et al. 1984). The mathematical formulation of the input-oriented NSM model is given below as:

$$
\begin{aligned}
&\min \quad \theta_o^* = \theta_o - \frac{1}{M+N}\left[\sum_{m=1}^{M}\frac{s_m^-}{x_{mo}} + \sum_{n=1}^{N}\frac{s_n^+}{y_{no}}\right] \\
&\text{subject to} \\
&\sum_{j=1}^{J}\lambda_{jo}\, y_{nj} - s_n^+ = y_{no} && \forall\ (n = 1,2,\ldots.,N) \\
&\sum_{j=1}^{J}\lambda_{jo}\, x_{mj} + s_m^- = \theta_o x_{mo} && \forall\ (m = 1,2,\ldots.,M) \\
&\sum_{j=1}^{J}\lambda_j = 1 && \forall\ (j = 1,2,\ldots.,J) \\
&\lambda_j \geq 0 \\
&\theta_o \textit{ is unrestricted in sign} \\
&s_m^- \geq 0,\ \ s_n^+ \geq 0
\end{aligned}
\tag{1}
$$

where,

θ_o^* : Total input oriented efficiency of DMU_o

θ_o : Reduction applied to all inputs of o^{th} DMU to improve efficiency

s_n^+ : The amount of shortfall for n^{th} output

s_m^- : The amount of excess resources used for m^{th} input

λ_j : Intensity variables for each DMU

3.1 Definition

The o^{th} DMU satisfies the condition θ_o^* = 1 and all the input and output slacks ($s_n^+,\ s_m^-$) equivalent to zero, only then DMU is called efficient. Otherwise, the DMU is known as inefficient DMU, it can also interpret as if $\theta_o^* \leq 1$ and/or non-zero value of slacks ($s_n^+,\ s_m^- \neq 0$) seek either excess or shortfall the resources and exist inefficiency in the performance of DMU.

4. Technical Background of Malmquist Productivity Index

4.1 Definition

It is assumed that for two time period, denoted as *t* and *t*+1. For period *t*, inputs are using, $x_{mj}^t \in R_+^m$ to produce outputs $y_{nj}^t \in R_+^n$ and the production technology can be received in terms of the input Shepard distance function (SDF) (Shephard, 1953) as:

$$D^t(x_o^t, y_o^t) = \sup\left\{\theta : \frac{x_{mj}^t}{\theta} \in T_o, \theta > 0\right\}, \tag{2}$$

where T_o is the collection of technology for each DMUs with the different input x_{mj}^t and output vectors y_{nj}^t for the period *t*, which is given as:

$$T_o = \min\left\{x_{mj}^t, y_{nj}^t\right) \in R_+^m \times R_+^n : \ \ x_{mj}^t \text{ produces } y_{nj}^t\right\} \tag{3}$$

4.2 Classical Malmquist Productivity Index

First time, Malmquist (1953) proposed this index as in context of consumer theory. After that, the idea of estimation of productivity an index for DMUs at consecutive periods (Caves et al., 1982). Färe et al. (1992) integrated the DEA and MPI to measure the productivity changes. The input-oriented Malmquist productivity index (IMPI) is as follows 4 for time period *t* and *t*+1:

$$IMPI_o^{t,t+1}(x^{t+1},y^{t+1},x^t,y^t) = \left[\frac{D_{o,vrs}^{t}(x_o^t,\ y_o^t)}{D_{o,crs}^{t}(x_o^{t+1},\ y_o^{t+1})} \times \frac{D_{o,crs}^{t+1}(x_o^t,\ y_o^t)}{D_{o,vrs}^{t+1}(x_o^{t+1},\ y_o^{t+1})}\right]^{0.5} \tag{4}$$

Thus, the geometrically decomposition of productivity changes into two different components, i.e., the Malmquist technical efficiency change (MTEC) and technical change (MTC) for the period *t* (first year) and period *t*+1 (second year) (Fare et al., 1994). The IMPI can also be defined as:

$$= \frac{D_{o,vrs}^{t+1}(x_o^{t+1},\ y_o^{t+1})}{D_{o,vrs}^{t}(x_o^t,\ y_o^t)} \left[\frac{D_{o,crs}^{t}(x_o^{t+1},\ y_o^{t+1})}{D_{o,vrs}^{t+1}(x_o^{t+1},\ y_o^{t+1})} \times \frac{D_{o,vrs}^{t}(x_o^t,\ y_o^t)}{D_{o,crs}^{t+1}(x_o^t,\ y_o^t)}\right]^{\mathbf{0.5}} \tag{5}$$

$$= MTEC_o(x^{t+1},y^{t+1},x^t,y^t) \times MTC_o(x^{t+1},y^{t+1},x^t,y^t)$$

where $D^t(x^t,y^t)$ is defined as the input distance function for period *t*, which is given by M number of inputs vectors ($x \in$ R) to produce N number of output vectors ($y \in$ R). The total productivity progresses if $IMPI^{t,t+1}(x^t,y^t)$ greater than 1, the value of $IMPI^{t,t+1}(x^t,y^t)$ less than 1 implies TFP decline and $IMPI^{t,t+1}(x^t,y^t)$ equals to 1 means constant (no change) in TFP for the period *t* to *t*+1. Currently, the first component of equation 5 is interpreted as the change in efficiency from period *t* to period *t*+1; this element is known as efficiency change or catch-up impact. The second component, known as the change in technology, depicts the transition from the old to the new frontier in technology between period *t* and *t*+1. Technology change (TC) and technical efficiency change (TEC) >1(<1, 1) denote growth (decline, no change) over the period, respectively. DEA-MPI can be applied on both constant return to scale (CRS), variable return to scale (VRS) assumption to obtain pure efficiency change (PEC), scale efficiency change (SEC) as mentioned in Eqs. (7-8).

$$IMPI_o^{t,t+1}(x^{t+1},y^{t+1},x^t,y^t) = \frac{D_{o,vrs}^{t+1}(x_o^{t+1},\ y_o^{t+1})}{D_{o,vrs}^{t}(x_o^t,\ y_o^t)} \times \left[\frac{D_{o,crs}^{t+1}(x_o^{t+1},\ y_o^{t+1})}{D_{o,crs}^{t}(x_o^t,\ y_o^t)} \times \frac{D_{o,vrs}^{t}(x_o^t,\ y_o^t)}{D_{o,vrs}^{t+1}(x_o^{t+1},\ y_o^{t+1})}\right]$$

$$\times \left[\frac{D_{o,crs}^{t}(x_o^t,\ y_o^t)}{D_{o,crs}^{t}(x_o^{t+1},\ y_o^{t+1})} \times \frac{D_{o,crs}^{t+1}(x_o^t,\ y_o^t)}{D_{o,crs}^{t+1}(x_o^{t+1},\ y_o^{t+1})}\right]^{0.5} \tag{6}$$

$$= [PTEC_{\boldsymbol{o}}(x^{t+1},y^{t+1},x^t,y^t) \times SEC_{\boldsymbol{o}}(x^{t+1},y^{t+1},x^t,y^t) \times TC_{\boldsymbol{o}}(x^{t+1},y^{t+1},x^t,y^t)]$$

Although, as shown in equation 6, this index consists of three components. PEC and SEC were measured in the first and second components, respectively, while TC was measured in the third expression. The PEC and SEC components are decomposition of TEC index. PEC is defined as below:

$$PEC_o^{t,t+1}(x^{t+1},y^{t+1},x^t,y^t) = \frac{D_{o,vrs}^{t+1}(x_o^{t+1},\ y_o^{t+1})}{D_{o,vrs}^{t}(x_o^t,\ y_o^t)} \tag{7}$$

$$SEC_o^{t,t+1}(x^{t+1},y^{t+1},x^t,y^t) = \left[\frac{D_{o,crs}^{t+1}(x_o^{t+1},\ y_o^{t+1})}{D_{o,crs}^{t}(x_o^t,\ y_o^t)} \times \frac{D_{o,vrs}^{t}(x_o^t,\ y_o^t)}{D_{o,vrs}^{t+1}(x_o^{t+1},\ y_o^{t+1})}\right] \tag{8}$$

Intuitively, this model is computing the input-oriented NSM-MPI based on the model 6 for calculating the productivity changes over the consecutive period. x_{mo}^t is m^{th} input and y_{no}^t is n^{th} output of o^{th} DMU for the time period t. Now, $D_o^t(x_o^t,\ y_o^t)$ and θ_o^* represents the OTE score indicating the inputs reduction required to produce the given output level. The following Eqs. (9-12) present a summary of the new index model.

$$\begin{array}{ll}
D_{o,crs}^t(x_o^t,\ y_o^t) = \theta_o - \dfrac{1}{M+N}\left[\displaystyle\sum_{m=1}^{M}\frac{s_m^-}{x_{mo}^t} + \sum_{n=1}^{N}\frac{s_n^+}{y_{no}^t}\right] & \\
\text{subject to} & \\
\sum_{j=1}^{J}\lambda_{jo}\, y_{nj}^t - s_n^+ = y_{no}^t & \forall\ (n = 1,2,\dots.,N) \\
\sum_{j=1}^{J}\lambda_{jo}\, x_{mj}^t + s_m^- = \theta_o x_{mo}^t & \forall\ (m = 1,2,\dots.,M) \\
\lambda_j \ge 0 & \forall\ (j = 1,2,\dots.,J) \\
\theta_o\ \textit{is unrestricted in sign} & \\
s_m^- \ge 0,\ \ s_n^+ \ge 0 &
\end{array} \tag{9}$$

In the same way, we can obtain the OTE score for o^{th} DMU in the time period *t*+1, $D_o^{t+1}(x_o^{t+1},\ y_o^{t+1})$ by using the inputs and outputs in period *t*+1 instead of *t*,

$$D^{t+1}_{o,crs}(x^{t+1}_o,\ y^{t+1}_o) = \theta_o - \frac{1}{M+N}\left[\sum_{m=1}^{M}\frac{s^-_m}{x^{t+1}_{mo}} + \sum_{n=1}^{N}\frac{s^+_n}{y^{t+1}_{no}}\right]$$

subject to

$$\begin{aligned}
&\textstyle\sum_{j=1}^{J}\lambda_{jo}\,y^{t+1}_{nj} - s^+_n = y^{t+1}_{no} && \forall\ (n = 1,2,\ldots,N)\\
&\textstyle\sum_{j=1}^{J}\lambda_{jo}\,x^{t+1}_{mj} + s^-_m = \theta_o x^{t+1}_{mo} && \forall\ (m = 1,2,\ldots,M)\\
&\lambda_j \geq 0 && \forall\ (j = 1,2,\ldots,J)\\
&\theta_o\ \textit{is unrestricted in sign}\\
&s^-_m \geq 0,\ \ s^+_n \geq 0
\end{aligned} \tag{10}$$

where, $D^{t+1}_o(x^{t+1}_o,\ y^{t+1}_o)$ is the OTE for the first mixed period *t* and *t*+1 obtained by solving,

$$D^{t}_{o,crs}(x^{t+1}_o,\ y^{t+1}_o) = \theta_o - \frac{1}{M+N}\left[\sum_{m=1}^{M}\frac{s^-_m}{x^{t+1}_{mo}} + \sum_{n=1}^{N}\frac{s^+_n}{y^{t+1}_{no}}\right]$$

subject to

$$\begin{aligned}
&\textstyle\sum_{j=1}^{J}\lambda_{jo}\,y^{t}_{nj} - s^+_n = y^{t+1}_{no} && \forall\ (n = 1,2,\ldots,N)\\
&\textstyle\sum_{j=1}^{J}\lambda_{jo}\,x^{t}_{mj} + s^-_m = \theta_o x^{t+1}_{mo} && \forall\ (m = 1,2,\ldots,M)\\
&\lambda_j \geq 0 && \forall\ (j = 1,2,\ldots,J)\\
&\theta_o\ \textit{is unrestricted in sign}\\
&s^-_m \geq 0,\ \ s^+_n \geq 0
\end{aligned} \tag{11}$$

where, $D^{t+1}_o(x^{t}_o,\ y^{t}_o)$ is second mixed period OTE as shown below,

$$D^{t+1}_{o,crs}(x^{t}_o,\ y^{t}_o) = \theta_o - \frac{1}{M+N}\left[\sum_{m=1}^{M}\frac{s^-_m}{x^{t}_{mo}} + \sum_{n=1}^{N}\frac{s^+_n}{y^{t}_{no}}\right]$$

subject to

$$\begin{aligned}
&\textstyle\sum_{j=1}^{J}\lambda_{jo}\,y^{t+1}_{nj} - s^+_n = y^{t}_{no} && \forall\ (n = 1,2,\ldots,N)\\
&\textstyle\sum_{j=1}^{J}\lambda_{jo}\,x^{t+1}_{mj} + s^-_m = \theta_o x^{t}_{mo} && \forall\ (m = 1,2,\ldots,M)\\
&\lambda_j \geq 0 && \forall\ (j = 1,2,\ldots,J)\\
&\theta_o\ \textit{is unrestricted in sign}\\
&s^-_m \geq 0,\ \ s^+_n \geq 0
\end{aligned} \tag{12}$$

From the DDF, the traditional Luenberger productivity indicator (LPI) is able to define a measure of productivity change over the period of time (Jradi et al. 2019). LPI represents the shortage distance function that takes into consideration both input reductions and output progress (Chambers et al. 1996; Chambers, 2002), as follows equation 13:

$$LPI^{t,t+1}_o(x^{t+1},y^{t+1},x^t,y^t) = \frac{1}{2}\left[\left(D^t_o(x^t_o,\ y^t_o) - D^t_o(x^{t+1}_o,\ y^{t+1}_o)\right) + \left(D^{t+1}_o(x^t_o,\ y^t_o) - D^{t+1}_o(x^{t+1}_o,\ y^{t+1}_o)\right)\right] \tag{13}$$

The LPI index, on the contrary, is an arithmetic mean of the DDF indices for *t* and *t*+1 period. Similarly, LPI can be separated into two parts:

$$\begin{aligned}
LPI^{t,t+1}_o&(x^{t+1},y^{t+1},x^t,y^t)\\
&= \left(D^t_o(x^t_o,\ y^t_o) - D^{t+1}_o(x^{t+1}_o,\ y^{t+1}_o)\right)\\
&+ \frac{\mathbf{1}}{\mathbf{2}}\left[\left(D^{t+1}_o(x^{t+1}_o,\ y^{t+1}_o) - D^t_o(x^{t+1}_o,\ y^{t+1}_o)\right) + \left(D^{t+1}_o(x^t_o,\ y^t_o) - D^t_o(x^t_o,\ y^t_o)\right)\right]
\end{aligned} \tag{14}$$

The Luenberger technological change (LTC) and technical efficiency change (LTEC) components of the LPI index. This decomposition was motivated by the Malmquist productivity index, which is defined by:

$$LTC^{t,t+1}_o(x^{t+1},y^{t+1},x^t,y^t) = \left(D^t_o(x^t_o,\ y^t_o) - D^{t+1}_o(x^{t+1}_o,\ y^{t+1}_o)\right) \tag{15}$$

$$LTEC_o^{t,t+1}(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{\mathbf{1}}{\mathbf{2}}\left[\left(D_o^{t+1}(x_o^{t+1},\ y_o^{t+1}) - D_o^t(x_o^{t+1},\ y_o^{t+1})\right) + \left(D_o^{t+1}(x_o^t,\ y_o^t) - D_o^t(x_o^t,\ y_o^t)\right)\right] \tag{16}$$

Thus, a positive growth of LPI is indicated by a value greater than 0. Since negative growth is indicated by value of LPI less than 0 and LPI equal to 0 means unchanged in productivity.

4.3 Data, Inputs and Outputs Selection

Improving the performance and delivering the effective service of the transport sector is a vital goal of this proposed study. Many studies have been done in the transport sector using the non-parametric model for efficiency and productivity evaluation, but no one study has been implemented in Rajasthan public transport sector. In addition, the research was hampered by a lack of datapoints for a few years. This study used secondary data from the annual report of RSRTC depots in Rajasthan. Data is taken for 2008-2019 depending on 46 RSRTC depots located in 33 districts of Rajasthan. Furthermore, due to paucity of datapoints for a few years included in the evaluation phase of this study, Jaisalmer, Karauli, Partapgarh, Rajasamand, Sawaimodhopur and Shapur were not included. The following section first described four inputs and two outputs that contribute to the evaluation of efficiency in the transport sector identified from the literature survey (Markovits-Somogyi, 2011; Agarwal et al., 2011; Hanumappa et al., 2015). Specifically, the number of buses (I_1), the number of employees (I_2), fuel consumption (I_3) and routes distance (I_4) are inputs. The outputs are the passenger-kilometer occupied (O_1) and vehicle utilization (O_2). Thus, Table 1 represents the summary of statistics of all the variables for 46 depots from 2008 to 2019.

Table 1

Statistics Summary of RSRTC Depots for the Period 2008-19

		Inputs				Outputs	
Years		**Number of Buses**	**Number of Employees**	**Fuel Consumption (1000 KL)**	**Routes Distance**	**Passenger Kilometers Occupied (Lakh Km)**	**Vehicle Utilization**
2008-09	Mean	88.48	372.61	25.01	11151.6	4.36	394.83
	Max	134	624	42.79	19529	9.61	572
	Min	45	160	11.61	3151	1.86	277
	Std Dev	23.84	129.67	7.62	3504.77	1.51	50.36
2009-10	Mean	88.22	368.09	25.56	11169.1	4.52	399
	Max	135	696	44.59	20489	8.95	578
	Min	45	156	11.81	3979	1.86	280
	Std Dev	23.82	127.66	7.75	3746.12	1.55	49.58
2010-11	Mean	90.35	376.87	25.57	11074	4.67	395.8
	Max	143	918	48.96	21800	9.94	586
	Min	43	150	11.79	3713	2.01	272
	Std Dev	26.34	150.18	8.19	3930.38	1.58	50.9
2011-12	Mean	91.41	395.57	26.48	12236	4.7	403.46
	Max	142	815	50.84	30810	9.79	607
	Min	43	165	12.4	3506	2.11	267
	Std Dev	25.49	141.88	8.57	4843.67	1.54	52.01
2012-13	Mean	88.63	367.54	25.97	10172.7	4.5	394.93
	Max	145	744	49.09	20243	9.79	614
	Min	44	147	12.25	3490	2.14	259
	Std Dev	24.63	134.77	8.86	3365.72	1.62	52.66
2013-14	Mean	88.63	405.04	25.5	10351	4.59	393.8
	Max	145	836	54.05	18535	10.49	614
	Min	44	176	11.58	3301	1.96	246
	Std Dev	24.63	142.89	9.56	3369.77	1.71	53.32
2014-15	Mean	90.26	390.48	26	10234.7	4.66	394.96
	Max	154	826	53.72	18552	10.28	615
	Min	49	172	12.81	3530	2.08	287
	Std Dev	25.25	133.8	8.91	3103.05	1.64	50.67
2015-16	Mean	86.65	365.91	24.53	9911.37	4.54	401.63
	Max	153	776	50.09	17782	9.55	650
	Min	47	176	12.25	3189	2.19	337
	Std Dev	25	122.89	8.52	3014.77	1.54	50.55
2016-17	Mean	83.11	339.5	23.81	9234.76	4.2	391.72
	Max	147	709	48.57	17368	8.89	608
	Min	50	148	11.33	2703	1.98	323
	Std	22	115.4	8.34	3153.92	1.4	46.65
2017-18	Mean	81.28	315.35	25.1	10065.3	4.45	387.33
	Max	141	692	49.32	17794	9.17	596
	Min	45	144	10.86	4338	2.16	306
	Std Dev	22.13	112.56	8.04	2804.66	1.36	46.25
2018-19	Mean	74.5	290.98	22.47	9543.28	4.19	391.93
	Max	140	665	45.75	16769	9.02	586
	Min	41	123	9.86	4586	1.97	311
	Std Dev	22.05	108.18	7.41	2682.35	1.34	45.38

Input parameters comprised

(I_1) The number of buses which is indicative of capital input.

(I_2) The number of employees which is indicative of labor input.

(I_3) Fuel consumption which is indicative of energy input and is calculated as,

Total Fuel Consumption (1000 Kl) = (Description of Km)/ (Average diesel consumption) (12)

(I_4) The route distance which is described as total Km travelled by passenger.

Output parameter comprised

(O_1) Passenger Km occupied is the cumulative distance traveled by each passenger which is defined as below:

Passenger Km occupied (Lakh Km) = Average no. of Buses × Description of Km × Load Factor (13)

(O_2) Vehicle Utilization is the total kilometers travelled by a bus per day per hour.

4.4 Empirical Results and Discussion

Initially, operational technical efficiency (OTE) is computed using the input-oriented NSM DEA model. The best and worst depots are investigated based on efficiency value across all the depots. Those results are given in Table 2. In addition, the extended analysis applying the NSM model along with IMPI and LPI to determine the productivity changes of 46 depots is refined and deteriorated over the period 2008-2019, in the following subsection.

4.4.1 NSM Results

Table 2 summarizes the efficiency values of 46 depots during the period of 2008-09 to 2018-19 utilizing the NSM DEA model.

Table 2
Efficiency Values of NSM-VRS

Depots	Years										
	208-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	Mean
Abu Road	0.855	0.76	0.858	0.885	0.933	0.981	1	1	1	1	1	0.934
Ajaymeru	0.691	0.699	0.812	0.853	0.838	0.845	0.831	0.83	0.792	0.833	0.768	0.799
Ajmer	0.828	0.805	0.884	0.866	0.875	0.851	0.885	0.862	0.855	0.862	0.758	0.848
Alwar	0.711	0.705	0.905	0.87	0.829	0.805	0.829	0.853	0.866	0.901	0.827	0.827
Anoopgarh	0.869	0.865	0.919	0.954	1	1	0.995	0.916	0.869	1	0.956	0.94
Banswara	0.854	0.873	0.886	0.956	0.954	0.915	0.859	0.884	0.879	0.839	0.86	0.887
Baran	0.798	0.89	0.908	0.91	0.942	0.869	0.843	0.874	0.873	0.887	0.846	0.877
Barmer	0.935	0.904	0.958	1	1	0.947	0.976	1	1	1	1	0.975
Beawar	0.709	0.736	0.836	0.835	0.848	0.897	0.949	0.877	0.925	0.987	1	0.873
Bharatpur	0.758	0.768	0.777	0.821	0.893	0.848	0.877	0.854	0.849	0.866	0.801	0.828
Bhilwara	0.739	0.784	0.912	0.888	0.891	0.92	0.935	0.914	0.965	1	0.931	0.898
Bikaner	0.782	0.705	0.9	0.914	0.824	0.85	0.902	0.872	0.86	0.914	0.86	0.853
Bundi	0.761	0.78	0.791	0.841	0.905	0.841	0.892	0.882	0.858	0.808	0.812	0.834
Chittorgarh	0.669	0.665	0.779	0.801	0.8	0.752	0.774	0.778	0.805	0.861	0.748	0.766
Churu	0.971	0.903	0.919	0.923	1	1	1	0.966	0.917	0.987	0.953	0.958
Dausa	0.7	0.736	0.758	0.795	0.854	0.78	0.834	0.864	0.869	0.951	0.894	0.821
Deluxe	1	1	1	1	1	1	1	1	1	1	1	1
Dhaulpur	0.757	0.788	0.794	0.918	0.925	0.861	0.884	0.861	0.865	0.858	0.856	0.852
Didwana	0.946	0.918	0.843	0.82	0.943	0.903	0.928	0.963	0.907	0.958	0.917	0.913
Dungarpur	0.732	0.722	0.858	0.916	0.851	0.837	0.89	0.863	0.811	0.749	0.727	0.814
Falna	1	1	1	1	1	1	1	1	1	1	1	1
Ganganagar	0.738	0.761	0.945	0.997	0.97	1	0.949	0.942	0.904	0.927	0.902	0.912
Hanumangarh	0.789	0.758	0.898	0.996	1	1	0.944	0.971	0.914	0.888	0.854	0.91
Hindaun	0.776	0.763	0.778	0.843	0.865	0.855	0.885	0.901	0.897	0.881	0.856	0.845
Jaipur	0.841	1	1	1	1	1	1	1	1	1	1	0.986
Jalore	0.932	0.892	0.991	0.868	0.859	0.839	0.889	0.872	1	0.858	0.9	0.9
Jhalawar	0.671	0.713	0.768	0.744	0.825	0.729	0.728	0.746	0.763	0.767	0.773	0.748
Jhunjhunu	0.827	0.973	0.989	1	0.882	0.894	0.887	0.909	0.819	0.939	0.879	0.909
Jodhpur	0.673	0.665	0.869	0.932	0.887	0.814	0.859	0.869	1	0.97	0.89	0.857
Khetri	0.955	0.847	0.874	0.866	0.918	0.907	0.834	0.865	0.795	0.915	0.985	0.887
Kota	0.694	0.708	0.839	0.865	0.808	0.79	0.823	0.811	0.993	0.796	0.776	0.809
Kotputli	1	1	1	1	1	1	1	1	0.887	1	1	0.99
Lohagarh	0.79	0.796	0.84	0.932	0.914	0.838	0.846	0.864	0.858	0.826	0.819	0.848
Matsyanagar	0.824	0.876	0.963	0.99	1	1	1	1	1	1	1	0.968

Table 2
Efficiency Values of NSM-VRS (Continued)

Depots	Years										
	208-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	Mean
Nagore	0.855	0.839	0.838	0.92	0.893	0.922	0.875	0.893	0.888	0.926	0.886	0.885
Pali	0.984	0.982	0.957	0.994	1	0.947	0.987	0.998	1	1	0.974	0.984
Phalaudi	1	1	1	1	1	1	1	1	0.985	1	1	0.999
Sardaarshahar	0.915	0.847	0.873	0.911	0.9	0.958	0.918	0.897	0.916	0.909	0.946	0.908
Sikar	0.697	0.669	0.828	0.888	0.831	0.82	0.875	0.915	1	1	0.941	0.86
Sirohi	0.895	0.963	0.953	0.986	0.957	0.999	0.968	0.974	1	1	0.982	0.971
Srimadhopur	0.861	0.809	0.781	0.835	0.943	0.816	0.791	0.768	0.737	0.79	0.811	0.813
Tijara	1	1	1	1	1	1	1	0.997	0.955	1	1	0.996
Tonk	0.814	0.808	0.871	0.885	0.866	0.843	0.841	0.838	1	0.853	0.826	0.859
Udaipur	0.644	0.625	0.8	0.81	0.848	0.737	0.834	0.802	1	0.791	0.858	0.795
Vaishalinagar	0.703	0.688	0.763	0.768	0.679	0.781	0.821	0.813	0.833	0.839	0.81	0.773
Vidhyadharnagar	0.918	0.69	0.984	0.988	1	0.963	0.936	1	1	0	1	0.948
Mean	0.823	0.819	0.885	0.908	0.912	0.895	0.904	0.903	0.911	0.914	0.895	0.888

If the efficiency score is 1 then DMU is referred to as efficient otherwise inefficient (<1). It is noticed that half of the number of depots during the study period are relatively less than the average of efficiency scores (0.888). Looking at the efficiency scores, it is observed that Deluxe and Falna were the most efficient ($\theta_o^* = 1$) depots in the whole study period. Remaining depots are inefficient for at least one year under the study period. On the other hand, Jhalawar has the lowest average inefficient (0.748) depot during the entire period. Jaipur is not efficient only for the year 2008-09. Similarly, Kotputh and Phalaudi are not efficient only for 2010-17. All the depots are performing best in the year 2017-18 as the highest average efficiency value is 91.597%. The average minimum efficiency value in the year 2012-13 is 78.612%. The next subsections describe the IMPI, LPI, MITEC, MTC, LTEC and LTC values during the study period by table and figures.

4.4.2 IMPI and LPI Results

As mentioned earlier IMPI is a combination of MTEC and MTC. These two components are individually enumerated and then analyzed. Furthermore, the changes in MTEC can be decomposed into two main components PEC and SEC. Figure 1 represents the annual average values of total factor productivity (TFP) using IMPI and LP1 applied to measure the productivity changes with on input-oriented NSM-VRS model for all depots on the study period.

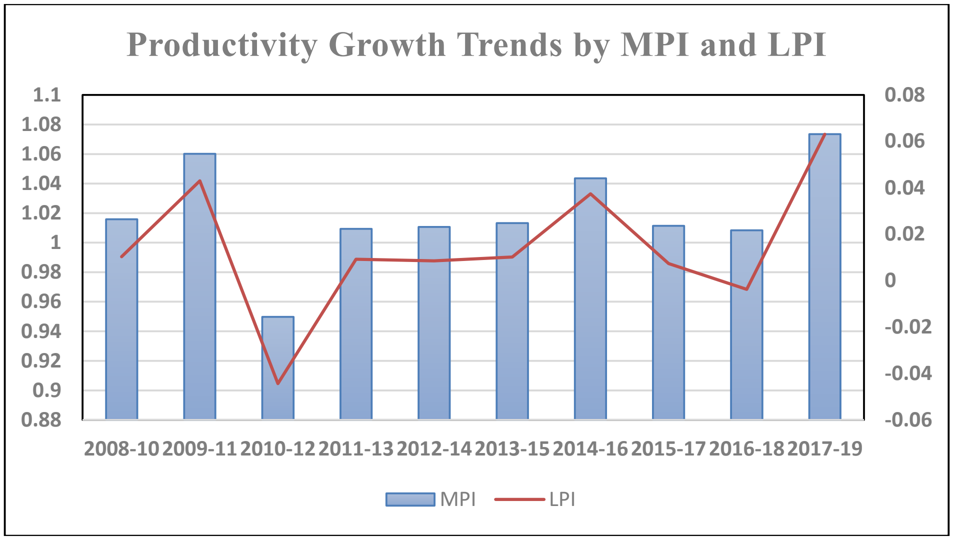

Fig. 1. Trends of IMPI and LPI Values for Depots Over the Period 2008-19

The analysis of IMPI and decomposition of components for RSRTC bus depots is discussed to better understand. The positive average IMPI growth is 1.957% depotwise while MTEC has progressed by 1.289% and MTC has declined by -0.772% throughout the period. This growth is due mainly to a positive value of MTEC and not because of MTC. Similarly, LPI gained about 1.41% whereas LTEC increased by 3.383% and LTC declined by -0.564% for each depot. This progressed mainly due to LTEC, while LTC is most of the time negative. The highest average IMPI progress value is 7.343% in 2017-19 and decreases in TFP is -5.022% in 2010-12. Moreover, the highest average IMPI value is 5.898% for Beawar whereas Tijara has the lowest average IMPI value -0.0261% over the entire period. Further, the highest average TFP value of LPI increases by 6.306% in 2017-19 and decreases by -4.432% in 2010-12. It is noted that Beawar depot has the highest average LPI value

5.05% and Tonk has declined -0.638% of productivity for the entire study period. All indices were calculated using the "MATLAB" software. The following sub-subsections describe two components of productivity. Moreover, all average values of productivity indices shown in Table 3.

Table 3
Productivity Performance Values of NSM MPI and LPI

Depots	MPI	LPI	MTEC	LTEC	MTC	LTC	MSEC	MPEC
Abu Road	1.035	0.034	1.025	0.031	1.014	0.036	1.004	1.021
Ajaymeru	1.108	0.013	1.015	0.043	1.005	-0.016	1.001	1.019
Ajmer	1.183	0.001	0.993	0.025	1.01	-0.023	1.011	0.986
Alwar	1.019	0.012	1.02	0.085	1.001	-0.061	1.007	1.014
Anoopgarh	1.018	0.015	1.01	0.029	1.01	0.002	1.005	1.011
Banswara	1.007	0.005	1.002	0.016	1.005	-0.007	0.985	1.015
Baran	1.006	0.004	1.004	0.011	1.003	-0.004	0.997	1.01
Barmer	1.023	0.022	1.009	0.025	1.014	0.018	1.014	1.003
Beawar	1.059	0.051	1.036	0.063	1.023	0.038	1.013	1.025
Bharatpur	1.014	0.011	1.009	0.019	1.007	0.003	1.006	1.002
Bhilwara	1.036	0.03	1.028	0.051	1.009	0.008	1	1.025
Bikaner	1.018	0.013	1.018	0.064	1.006	-0.038	1.001	1.006
Bundi	1.013	0.009	1.007	0.016	1.007	0.002	1.012	0.995
Chittorgarh	1.024	0.016	1.016	0.044	1.01	-0.011	1.009	1.01
Churu	1.008	0.007	1.002	0.014	1.008	0.001	0.998	1.002
Dausa	1.034	0.028	1.027	0.037	1.009	0.018	1.015	1.014
Deluxe	1.007	0.003	1	-0.034	1.007	0.04	0.991	1
Dhaulpur	1.018	0.014	1.017	0.026	1.004	0.003	1.001	1.011
Didwana	1.012	0.009	1.004	0.012	1.009	0.007	1.006	0.998
Dungarpur	1.011	0.006	1.007	0.018	1.006	-0.005	1.013	0.994
Falna	1.02	0.018	1	-0.008	1.02	0.044	1	1
Ganganagar	1.032	0.025	1.023	0.088	1.012	-0.039	0.988	1.033
Hanumangarh	1.017	0.013	1.011	0.091	1.01	-0.065	0.985	1.023
Hindaun	1.014	0.012	1.013	0.03	1.002	-0.006	1.006	1.006
Jaipur	1.016	0.011	1.019	0.129	0.998	-0.107	0.982	1.019
Jalore	1.019	0.012	1.008	0.024	1.012	0.001	1.011	0.996
Jhalawar	1.023	0.015	1.017	0.025	1.007	0.006	0.999	1.017
Jhunjhunu	1.018	0.012	1.009	0.045	1.01	-0.022	0.995	1.01
Jodhpur	1.032	0.022	1.037	0.061	1	-0.017	1.006	1.026
Khetri	1.02	0.015	1.008	0.022	1.012	0.007	0.982	1.025
Kota	1.015	-0.003	1.015	0	0.996	-0.006	1.013	1.007
Kotputli	1.023	0.021	1.001	-0.015	1.021	0.056	1.003	1.001
Lohagarh	1.012	0.008	1.007	0.023	1.006	-0.006	1.002	1.005
Matsyanagar	1.026	0.019	1.019	-0.005	1.007	0.044	1.002	1.019
Nagore	1.012	0.01	1.005	0.018	1.009	0.001	0.984	1.015
Pali	1.008	0.006	0.999	0.004	1.01	0.008	1.013	0.99
Phalaudi	1.015	0.014	1	0.001	1.015	0.027	0.996	1
Sardaarshahar	1.018	0.015	1.009	0.034	1.009	-0.003	0.99	1.018
Sikar	1.023	0.017	1.036	0.14	0.991	-0.105	0.999	1.023
Sirohi	1.017	0.015	1.01	0.011	1.008	0.018	0.994	1.016
Srimadhopur	1.036	0.031	1.018	0.026	1.018	0.036	0.993	1.024
Tijara	1	-0.004	1	-0.034	0.999	0.027	0.999	1
Tonk	1.007	-0.006	1.006	-0.026	0.998	0.014	1	1.007
Udaipur	1.034	0.012	1.041	0.077	0.992	-0.052	1.024	1.016
Vaishalinagar	1.018	0.013	1.018	0.089	1.001	-0.064	1.008	1.008
Vidhyadharnagar	1.04	0.022	1.016	0.111	1.024	-0.066	0.997	1.022
Mean	1.025	0.014	1.013	0.034	1.008	-0.006	1.001	1.011

Note: * MPI Index (>1) indicates a productivity progress, (<1) indicates a decline of productivity and (=1) indicates no change of productivity.
* LPI Index (>0) indicates a productivity progress, (<0) indicates a decline of productivity and (=0) indicates no change of productivity.

4.4.3 MTEC & LTEC Results

The technical efficiency change (TEC) shows the gap in two frontiers for 2008 and 2019. Usually, the change in productivity using proper technology and efficient utilization of inputs of the depot can be related to the performance of the technical experience throughout the study period for reforming the management of depot services. MTEC and LTEC consist of the change in efficiency of all depots between 2008-2019. Often, MTEC is an important attribute for accumulated TFP progress. The geometric mean of MTEC is 1.29% per year 2008-19. The highest average of MTEC in 2009-11 is 9.094%. In 2017-19, the minimum average MTEC value is 0.978% which means that the average MTEC value of depots decreased (2.2%) during the period. Of these, Udaipur experienced the greatest growth in MTEC 4.088% between 2008 and 2019. Technical efficiency of Deluxe and Falna neither increased nor decreased (MTEC= 1), indicating that they are on the efficiency frontier. There are eight depots (Abu Road, Beawar, Bhilwara, Dausa, Ganganagar, Jodhpur, Sikar and Udaipur) progress (20-40) % in the MTEC, whereas Ajmer and Pali showed the decline in average MTEC by 0.6% and 0.12% over the period 2008-19.

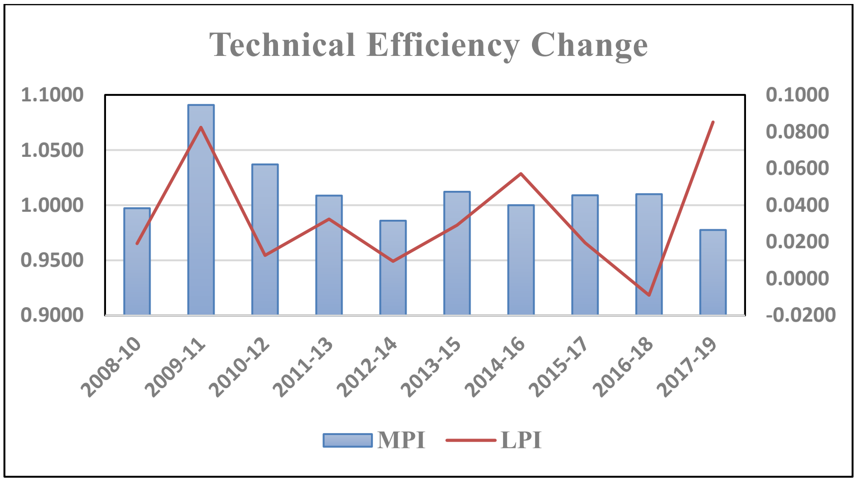

Fig. 2. Malmquist and Luenberger Technical Efficiency Change in 2008-19

Fig. 2 shows that the MTEC and LTEC values for 46 depots over the study period. The LTEC results show that the average efficiency growth over the entire period is 3.38%. The highest average LTEC value in 2017-19 is 8.525%, while -0.892% decreases the average LTEC in 2016-18. Similarly in 2008-19, 7 bus depots offered declining LTEC values over the study period and deluxe had the highest drop in LTEC -3.441%. LTEC observed almost positive value over the period for 39 depots. As per the result, each RSRTC bus depot is growing at different rates of LTEC.

4.4.4 MTC & LTC Indexes

TC calculates the impact of change (shift) in the bus depot of productivity growth range, which helps in explaining the impact of technological change on productivity and the use of production functions. Fig. 3 presents the MTC and LTC values for 46 depots over the study period. On the contrary, the maximum average MTC score of bus depots in 2017-19 is 9.835%, while in the year 2010-12 there is a decline of -8.38%. Jaipur, Kota, Sikar, Tijara, Tonk and Udaipur depots showed a decline in average MTC with value -0.245%, -0.359%, -0.859%, -0.074%, -0.245% and -0.781%, respectively over the study period. Jhunjhunu shows a decrease in MTC for the years 2008-10, 2009-11 and 2010-12 while increasing for the other study periods.

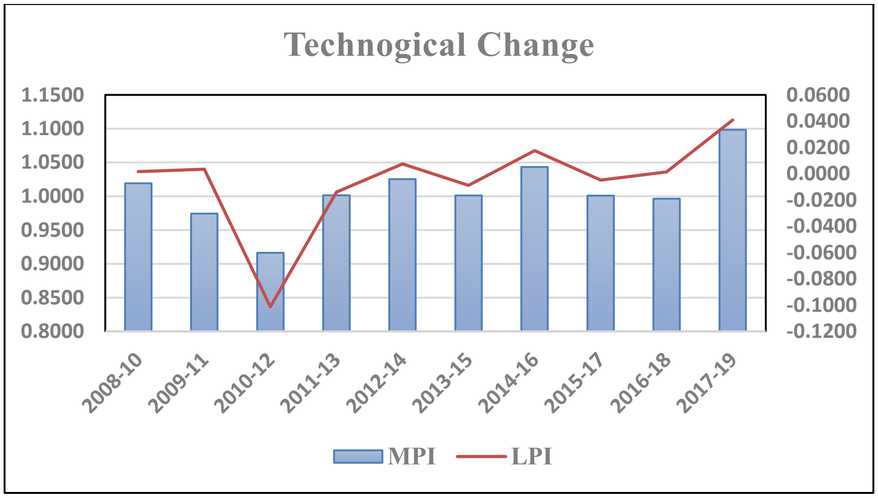

Fig. 3. Malmquist and Luenberger Technological Change in 2008-19

In 2008-10, 2009-11, 2012-14, 2014-16, 2016-18 and 2017-19 average LTC were increasing by 0.15%, 0.35%, 0.75%, 1.75%, 0.14% and 4.08% for all depots, respectively. During the period 2010-12, the maximum average decline in LTC was -10.135%. Further, Kotputli progressed in the average LTC by 5.593% and Jaipur regressed in the average LTC by -10.54% between 2008-19. Twenty-one depots showed a decline in average LTC growth from 2008-10 to 2017-19.

5. Concluding Remarks

Various DEA models have been implemented in the transport sector to obtain productivity. Nevertheless, this study proposed a new productivity index with input-oriented new slack DEA Model (NSM) to measure the overall productivity growth using MPI and LPI. Further, total productivity change is evaluated into two parts: technical Change (Frontier Shift) and technical efficiency change (Catch-up Effect). This study expands the TFP change using NSM DEA model and this model satisfies the radial properties, unit invariance and translation invariance. This study compared the IMPI and LPI trends for 46 RSRTC depots over the period 2008-19. As mentioned above, IMPI overestimates productivity as compared to LPI. The results highlight that the average productivity progressed IMPI and LPI by 1.957% and 1.41%, respectively. It confirms that IMPI overestimated the TFP value as compared to LPI. The approximation techniques of IMPI were tested using LPI and found to be less accurate than the prior study. It is considered to set a benchmark for these 46 depots so this study develops the concept of self-productivity for the depots of RSRTC over the years 2008 and 2019 using IMPI and LPI. With regard to policy-makers in the legislative frameworks, our results suggest the financial development for appropriate management strategies and performance level.

6. Future Scope

As an extension of this study, DEA measures the efficiency of a DMU with its favourable weights. It means that many DMUs lead to efficiency, causing the DMU to fail to be more distinguished. To address this shortcoming the cross-productivity method can extend in the neural cross-productivity model with the most favourable weights of input and output both in a single model with NSM DEA model.

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