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Productivity Changes in Indian Steel Plants: DEA Approach

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**Abstract**

**Purpose -** This study evaluates the technical efficiency and productivity changes in the integrated steel plants in India over a period of five years.
**Design/methodology/approach** - Since this evaluation of integrated steel plants needs consideration of multiple input and output factors, Data Envelopment Analysis (DEA) has been employed including bootstrapping (to account for statistical noise) to evaluate the relative efficiency of the steel manufacturing units. The efficiency and Malmquist productivity indices of a sample of 10 integrated steel plants producing around 55% of the industry's output were determined for the period 2008-13. The results of these changes were further categorized according to the management control, route followed to produce crude steel, size and age of these steel plants, for gaining insights.
**Findings** - The study finds that private sector steel plants with larger capacity and which have adopted the latest and most modern technologies are more efficient and productive over the study period.
**Practical implications** - Public sector steel plants should therefore be provided with more autonomy and delegation of power and should be more agile in responding to market requirements as well as increasing their installed capacities to be competitive in technical efficiency and productivity as well as profitability in the long term to ensure sustainable achievements.
**Originality/values** – Productivity changes over time, both with respect to technological and efficiency changes, for the Indian integrated steel plants producing comparable products using DEA
**Keywords -** Indian Integrated Steel Plant, Data Envelopment Analysis, Bootstrapping, Technical Efficiency, Malmquist Productivity Index, Technological Change
**Paper type** – Research paper



## 1. Introduction

Steel is crucial to the development of any modern economy and is considered to be one of the backbones of human civilization. The level of per capita consumption of steel is treated as an important index of the level of socio-economic development in a country. From only three steel plants, a few electric arc furnace-based plants and a mere one million ton (MT) capacity status at the time of its Independence in 1947, India is now the third largest crude steel producer in the world and the largest producer of sponge iron and it is slated to become the second-largest steel producer (after China) in the world by 2017.

Presently, steel contributes to nearly two per cent of the gross domestic product of India and employs over 600,000 people. Steel production in the country has increased at a compounded annual growth rate of 6.9 per cent over 2008-2015 with the increasing demand by sectors such as infrastructure, real estate and automobiles at home and abroad. Steel plants, however, needs large capital investments to increase production capacities and are very energy intensive requiring large amount of energy inputs, especially in the form of coal and power. Energy cost, therefore, is a major component of the manufacturing cost and ranges between 40-60% in a typical iron and steel plant. The sector also contributes to about 6.2% of the national Green House Gas emissions in India, resulting in environmental issues in coal mining regions as well as around the iron and steel producing plants. The Indian government has therefore instituted an annual competition to identify the best integrated steel plant based on performance in areas such as efficiency of operations, quality, financial performance, energy, customer satisfaction amongst others to ensure that the existing steel plants operate efficiently with minimum/optimum use of the resources and remain competitive both locally and globally. In addition to its motivational value, it also provides an interesting mechanism for participating plants to improve their performance through benchmarking and by following the best practices and learning from each other.

Integrated steel plants in India have been commissioned in last 100+ years under private and public sector undertakings, are of different sizes (installed capacities), and following different production routes to make steel. They follow a complex process involving several stages with multiple inputs and outputs. It will therefore be interesting to study the efficiency and productivity changes in these steel plants over time and also to confirm whether these levels of efficiency and changes are impacted by these factors such as management control, size, age and the route followed. This may give deep insights into the policy options likely to improve the performance of these steel plants by identifying and adopting best practices as well as may give directions to new plants which are being conceived now for adopting best practices to be most efficient.

The literature review, however, indicates that while there are few studies done in the past to evaluate the efficiency of Indian steel plants using Data Envelopment Analysis (DEA), there have been gaps in the way these studies have compared steel plants of different sizes, route followed to produce steel as well as the factors used in these analyses. Comparison of homogeneous units producing comparable products and identification of right input and output factors becomes critical for arriving at a right outcome in the application of data envelopment analysis. Further, while there have been many studies done to analyze the productivity changes over time, both with respect to technological changes as well as efficiency changes for many industries including steel in other countries, there have not been any similar study done for the Indian integrated steel plants.

This gap in the literature has motivated the authors to take up this study with an aim is to gain an understanding of such efforts by examining the overall performance of the steel industry over this period by determining changes in efficiency and productivity of individual integrated steel plants in India between 2008-09 and 2012-13. By grouping these integrated steel plants according to their size, management regime (public or private sector), route followed to make steel and year of incorporation, we aimed to gain some insight into the effects of the changes made before and during this period and hence determine useful policy directions for the future.

We examined the efficiency and productivity of the integrated steel plants for the five-year period using the method of efficiency measurement originally proposed by Farrell (1957), which consists of two components: technical efficiency and scale efficiency to understand their relative performance and identify opportunities for further improvements. These efficiency measurements, however, evaluate the performance of a production unit in reference to best practice in a given year only and do not take into account the improvement in performance with time, including improvement in the efficiency and productivity of the best performers. For comparing performance of steel plants over time, generally referred to as a time series analysis, we measured the productivity changes using the Malmquist Productivity Index (MPI), which accounts for both the shift of best practice and the change in relevant position of the plants along the spectrum of best practice. Observed over multiple time periods; the variations of efficiency of the production units over time can help in making important conclusions.

Remaining of the paper is summarized as follows. Section 2 deals with a literature review on technical efficiency and productivity assessment of plants with specific emphasis on DEA applications at steel plants worldwide. Section 3 gives a brief overview of Indian iron and steel industry, including its output structure and management control, and the methodology used with inputs and outputs considered in this study. Section 4 includes the details about collection of data and methodology used for doing the analysis of these data using DEA. The results of analyzing Indian integrated steel plants are presented in section 5. This section also includes the sensitivity analysis using bootstrapping for understanding the intervals of technical efficiency of the steel plants plant wise as well as over time-periods. The roles of size, production route, management control as well as year of incorporation on their efficiency performance are also discussed here. In section 6, the discussions are presented. Conclusions, major recommendations including impact on society, research limitation and opportunities for future studies have been presented in section 7.

## 2. Literature review

Performance evaluation and benchmarking helps business operations/processes to become more productive and efficient with better quality of products and services and is an important continuous improvement tool for staying competitive in the present business environment facing global competition. Single-measure based gap analysis is often used as a fundamental method in performance evaluation and benchmarking. However, it is rare that one single measure can suffice for the purpose of performance evaluation (Farrell, 1957). A business unit's performance is a complex phenomenon requiring more than a single criterion to characterize it. Further, the use of single measures ignores any interactions, substitutions or tradeoffs among various performance measures. Benchmarks can be established but they are somewhat limited as they work with single measurements one at a time. It is difficult to evaluate an organization's performance when there are multiple inputs and outputs to the system. The difficulties are further enhanced when the relationships between the inputs and the outputs are complex and involve unknown tradeoffs.

To evaluate the performance of organizations in the field of Multiple Criteria Decision Making (MCDM), Berger and Humphrey (1997) observed that frontier analysis essentially is a sophisticated way to benchmark the relative performance of production units. To evaluate the performance of the production units, these frontier analyses can use either parametric frontier approaches (most commonly used are Stochastic Frontier Analysis (SFA), Distribution-Free Approach (DFA) and Thick-Free Approach (TFA) or non-parametric frontier approaches (most popular are Data Envelopment Analysis (DEA) and Free Disposal Hull (FDH). While the parametric approaches impose a particular functional form that presupposes the shape of the frontier, the non-parametric approaches impose less structure on the frontier but do not consider random error owing to data problems or other measurement errors.

In the literature, a number of previous studies have used DEA as a tool for MCDM (Chen, 2012). Lampe and Hilgers (2014) mentioned that DEA and SFA being the most important methods to evaluate the efficiency of individual and organizational performance, while SFA is mainly adopted in economic research field, DEA is more recognized as a standard technique in Operations Research. DEA is therefore an actively growing field of operations research and performance measurement and since its inception in 1978, after the seminal paper by Charnes, Cooper and Rhodes, over 5,000 articles, books and dissertations has appeared as per the ISI Web of Science database (Liu et al. 2013). The application fields of DEA are also diverse: from education to banks, health care (hospitals, clinics), prisons, agricultural production, banking, manufacturing, transportation, courts, and to many others (Liu et al, 2013). Among the multifaceted applications, the top-five industries addressed are: banking, health care, agriculture and farm, transportation, and education (these five applications make up 41% of all application-embedded papers). Cook and Seiford (2009) also provided a sketch of some of the major research thrusts in data envelopment analysis (DEA) over three decades.

There is a vast volume of literature on DEA applications to many diverse areas including health sector evaluation (Miller and Adam Jr, 1996), electricity distribution (Amado et al, 2013), luxury hotels efficiency comparison (Min et al, 2008, Dabestani et al, 2016), quality management practices (Lin et al, 2004). Andersen & Petersen (1993) developed a modified version of DEA based upon comparison of efficient DMUs relative to a reference technology spanned by all units. The procedure provides a framework for ranking efficient units and facilitates comparison with rankings based on parametric methods (Liao and Chen, 2002). Researchers have also studied many variants of the application of DEA under different specific situations (Allen & Thanassoulis, 2004, Cheng et al, 2013, Kao, 2014, Lee & Johnson, 2014, Lim & Zhu, 2013, Thanassoulis et al, 1998). Chang and Sun (2009) also applied DEA to enhance assessment capability of FMEA.

**In Asian context too, many studies have been conducted to investigate the efficiency, effectiveness and performance analysis of many industrial and service industries, both in public and private sectors, using data envelopment analysis such as Indian general insurance sector (Mandal and Dastidar, 2014), Indian railway container business (Bhanot and Singh, 2014), logistics firms performance in Singapore and Malyasia (Peng et al, 2015), healthcare services (Caglar, 2016), supply chain process in pharmaceutical business (Kumar et al., 2015), Indian banks (Rachita, 2015), public sector hospitals in India (Sandeep et al., 2015), oil gas and power sector of India (Punita et al., 2016), Indian retailers (Aradhana and Ravi, 2016), Indian software companies (Bimal, 2016), Higher education institutes in India (Sangeeta and Jitesh, 2016), glass firms in India (Mini and Seema, 2016), Indian telecom service providers (Siddhant e al., 2016), knowledge and safety**

**management organizations (Hadi et al., 2017), a rural employment guarantee scheme in India (Sarabjeet et al., 2017) and rail transport service performance for Indian railways (Mohita et al., 2017).**

In the DEA method, efficiency scores of production units are measured relative to an estimated production frontier and nonparametric estimators are based on a finite sample of observed production units. While nonparametric efficiency measures are often criticized for lacking a statistical basis, by focusing on the underlying data generating process, the bootstrap methods are used to analyze the sensitivity of nonparametric efficiency scores to sampling variation. The bootstrap introduced by Efron (1979) is an attractive tool to analyze the sensitivity of measured efficiency scores to sampling variation. Simar & Zelenyuk (2006) proposed some general methodology for bootstrapping in frontier models with real data to illustrate this methodology. Chowdhury et al. (2011) also presented a productivity measure for hospital services on Ontario applying MPI and decomposing it into efficiency change and technological changes with bootstrapping.

In the steel industry also, large number of research studies has been done in the literature to gain an insight of technical efficiency of steel plants world-wide using DEA. Ray and Kim (1995) studied the level of technical and cost efficiencies of American steel plants for the period 1970-1986. Parker & Wu (1998) studied the efficiency of UK's steel plant before and after its privatization (in 1988) and compared its technical efficiency with technical efficiencies of six other major steel producing countries using DEA. Ma, Evans, Fuller and Stewart (2002) studied China's Iron and Steel industry and evaluated the technical efficiency and Malmquist productivity indexes of a sample of 88 enterprises for the period 1989–1997, with the aim of gaining some insights into the policy options likely to achieve this. Hsueh-Liang Wu (2005) studied the aggregated annual data of the 27 steel plants of the Taiwanese steel industry over the sample period (1970-1996) on the quantities of inputs and of outputs, using the Data Envelopment Analysis (DEA). The study not only examined the industry-level technical efficiency across the same period, but also includes the two contextual variables, namely, business cycle and technological progress, into the DEA model to manifest the catching-up effects of the Taiwanese steel industry. Youngchul Shin (2011) analyzed the production efficiencies of 14 Korean steel companies using DEA model during the years 2007-2009. Mahapatra, Mukherjee and Bhar (2014) presented an application of the DEA-AHP model for measuring the organizational efficiency of a steel plant in India during the period FY03-10. Debnath and Sebastian (2014) used data envelopment analysis to evaluate the relative efficiency of the 22 Indian steel manufacturing units with income more than Rs. 50 crores for the year 2007-08.

The literature review, however, indicates that while there are few studies done in the past to evaluate the efficiency of Indian steel plants using DEA, there have been gaps in the way these studies have compared steel plants of different sizes, route followed to produce steel as well as the factors used in these analyses. Comparison of homogeneous units producing comparable products and identification of right input and output factors becomes critical for arriving at a right outcome in the application of data envelopment analysis. Further, while there have been many studies done to analyze the productivity changes over time, both with respect to technological changes as well as efficiency changes for many industries including steel, there have not been any similar study done for the Indian integrated steel plants. The authors also did not find any similar study done for the steel plants where bootstrapping has been used to analyze the sensitivity of efficiency scores relative to the sampling variations of the estimated frontier. These gaps in the literature have motivated the authors to take up this study.

## 3. India's integrated steel plants and their efficiency & productivity change analysis

While world crude steel production marginally increased by 0.8% with 1628 million tons in 2016 as compared to 1615 million tons in 2015, India was amongst very few countries where the production in 2016 increased by around 7.4% over 2015. Over the years, India has also improved its ranking in the world and presently, it is now the third largest producer of crude steel (after China and Japan) with a production of around 96 million tons in 2016**.** India's share of world population is 17.5%; its share in global crude steel production is only 5.5%. However, it is a matter of satisfaction that India's per capita consumption is increasing at a faster rate than world average. India, however, has miles to go before it attains the world average and the same situation interpreted differently implies that the growth potential of the Indian steel Industry is quite high.

The steel industry is the foundation industry of any economy, especially in the developing countries whose material intensity is likely to increase significantly in the future, for infrastructure development and growth in the manufacturing sector. India certainly is one such economy which is poised to grow significantly over the next decade and a competitive and efficient domestic steel industry is a pre-requisite for India to succeed in its industrial vision for “Make in India”. The Government of India aims to triple the steel capacity to 300 million tons by 2025. In order to ensure that such capacity is viable to set up and value creating for the stakeholders, it is important to ensure that steel plants focus on operational and commercial excellence across all its operations and also leverage its asset footprint to drive customer centricity with their differentiated product portfolio and world-class quality of products and services to overcome the market challenges.

Since steel plants are quite capital intensive units, initially most of the steel plants in India were commissioned under the public sector controlled by Government of India. However, later with the liberalization of Indian economy since 1991, private sector companies were also allowed to invest in commissioning new plants or add capacity in the existing plants. **The performance of the steel plants is dependent on various factors such as size of the plant, the route followed for making crude steel, technology used in the plant as well as type of management control (public or private) amongst others.** Crude steel in India is made through three different routes – Oxygen furnace route, Electric arc furnace route and Induction furnace route. During 2013, the proportions of these were 44 % through oxygen furnace route, 23 % through electric arc furnace route and rest 33 % through induction furnace route.

**To compare the performance of steel plants, units considered for any study should be homogeneous, to the extent possible, with respect to their capacity, route used to make steel and also type of steel being produced.** Accordingly, with both public and private sector steel plants working together in India, this study has been undertaken to compare the technical efficiency and productivity of **integrated steel plants starting operation from iron ore in one location, having minimum production capacity of one million ton (MT) of crude/cast steel capacity per year, producing finished steel to national or international specifications and having completed operation for at least two years**. A list of such integrated steel plants with details on their year of incorporation, management control, routes of crude steel made, installed capacity and actual production of crude steel has been shown in Table 1. These 10 integrated steel plants covers more than 80% of the crude steel produced **through oxygen furnace route and electric arc furnace route in India, performance of which can be compared, as these can be considered as homogeneous units.**

**Insert Table 1: Integrated steel plants in India (with >1 MT/year capacity at one location)**

## 4. Data collection

Based on the literature review, we decided to use data envelopment analysis as a tool to examine the technical efficiency and productivity of steel plants, in view of factors such as consideration of multiple inputs and outputs, non-parametric study and the difficulty in assigning specific weightages to input and output factors to maintain objectivity. Both the performance evaluation features of DEA, for a period in terms of technical efficiency and performance changes over time in terms of MPI, was used to get insight on the performance of Indian steel plants.

The data considered in the present analysis were sourced from the annual assessment conducted by Ministry of Steel Government of India for the recognition of best integrated steel plants in India for the period 2008-09 to 2012-13. Data were taken for the 10 integrated steel plants participated in this assessment, which cover more than 80% of the crude steel produced in India through the oxygen furnace and electric arc furnace routes.

The output variables which we selected for use in the analysis was (i) Gross margin as a percentage of turnover, representing the financial performance of the plant and (ii) customer satisfaction index representing the quality and customer related performance of the plants. **Gross Margin has been defined as profit before interest and depreciation related to iron and steel products only. Turnover is for iron & steel products, including by-products arising out of the process of manufacture of iron & steel products. Customer satisfaction index was assessed through a survey of the customers of different plants by an independent market research agency. The sample survey covered around 600 responses across various customer segments. The survey was by means of a detailed questionnaire covering various process areas like price, timely delivery, technical specifications, availability, commercial terms, stock yard facilities, billing and accounts process, behavior of personnel, attending to the customer complaints, after sales service, pre sales contact, packaging etc. The responses were mapped on a five point scale and based on the weightage to the different process areas accorded by the respondents, an overall customer satisfaction index (in %) was arrived at for consideration as an output in this analysis.**

Since energy is one of the crucial inputs in iron and steel production, we considered specific energy consumption in terms of energy consumed per ton of crude steel produced as a separate inputs factor in the analyses. **The overall specific energy consumption (in terms of Giga Calories per ton of crude steel) is calculated based on World Steel Association (WSA) norms, and includes aggregate primary energy input based on the heat content of different types of fuels namely coal, oil, electricity etc.** The other inputs factors considered for this analyses include labour productivity, blast furnace productivity and steel furnace productivity. **Labour productivity has been calculated in terms of man-year required per ton of crude steel production. Pig iron, HBI (Hot Briquetted Iron) or DRI (Direct Reduced iron) produced for sale is given credit with an equivalent factor of 50% and manpower is reckoned in terms of works strength. Works manpower is calculated after excluding non-works departments like administration, marketing, finance, township, construction units, mines etc. but including production services like production planning and control etc.**

**Blast furnace is the heart of any steel plant and the most critical set of capital equipment, which converts iron-ore/agglomerates into the liquid pig iron (called hot metal). The next critical set of equipment are steel furnaces which converts the hot metal produced in the previous stage into steel as per the chemical composition specified by the end customers. Therefore, the productivity of blast furnaces and the steel furnaces were considered as the inputs factors in this analysis. The blast furnace productivity is evaluated as blast furnace working volume cubic meter-days required to produce one ton of the hot metal. Working volume of a blast furnace is the volume of the furnace between center line of the tuyers and normal stock line/big bell in the open position. Available days are calculated as the difference of available calendar days and duration of capital repairs. Available calendar days have been taken at 360 days so as to account for planned/ scheduled monthly shutdowns in a year. Any shutdown due to technical problems, market conditions or raw material constraints is not considered for calculation of capital repairs. Steel furnace productivity is evaluated as time taken to produce one heat in the steel furnace based on the available hours of the steel furnace and number of heats produced during the yea**r.

While there are number of factors which can be considered as inputs and outputs for this analysis, in DEA, the number of inputs and outputs factors for consideration depends on number of samples (steel plants) for having a reasonable level of discrimination amongst units. A suggested "rule of thumb" used in many similar studies is that the number of samples should be greater than the multiplication of number of inputs and outputs for an effective discrimination between efficient and inefficient DMUS. Accordingly, since our study involves 10 integrated steel plants, only the above 4 input factors and 2 outputs factors were considered in this analysis and data for all 10 steel plants for the study period were collected. Table 2 shows a statistical summary of these steel plants along with the inputs and outputs considered in this analysis.

**Insert Table 2: Statistical summary of the steel plants considered in the analysis (2013)**

## 5. Analysis and Results

In this section, the results obtained employing DEA methodology used for the efficiency and productivity change measurement with the data collected explained in section 4 is reported. Composition of the production frontier for each of the 5 years is given and explained in section 5.1. In section 5.2, the results on the overall technical efficiency, pure technical efficiency and scale efficiency during this period based on DEA Constant Return to Scale (CRS) and Variable Return to Scale (VRS) models is presented. In order to take into account for statistical noise in the estimate of efficiency measures, the interval of technical efficiency measures using bootstrapping method has been presented in section 5.3. This part of the analysis, however, only provides the performance of each plant in any given year measured against the production frontier (best practice) in that year. Section 5.4 gives the changes in productivity of the steel plants over this period using MPI, which also captures the changes over time aspect of the performance of the steel plants by incorporating the shift in the production frontier over time. In order to further study the reasons behind these changes in technical efficiency and productivity, the plants in the study were then grouped according to their main attributes namely management control (public vs. private), size and age of the plant, as well as route followed in steel making (Oxygen furnace vs. Electric and furnace) and the results are then presented in Section 5.5.

### 5.1 Production frontier

The production frontier for each year for the period 2008-09 to 2012-13 is constructed under the variable return to scale (VRS) model with output orientation system to identify the best practice of that year. As per this model, an efficiency score of 1 is given to the steel plants which are on the frontier, meaning an efficient plant, in any year. The composition of the production frontiers over this period along with the efficiency scores of each of the plants being studied is shown in Table 3.

**Insert Table 3: Composition of the production frontier for variable return to scale**

Out of the total 10 steel plants under study, 7 plants came on the production frontier at least once during 2008-13. Plants F, G, and I were on the frontier for every year. All these three plants are in the private sector. ***This implies that management control (whether it is a public or private sector plant with management control in the hands of government of India or with supposedly professional management under a private sector enterprises) is a factor impacting the performance of Indian integrated steel plants.*** While Plant F and G follow oxygen furnace route for steel making, Plant I follows the electric furnace route. Further, while both Plant F and G are larger steel plants in size (around 10 million tons/year capacity), Plant I is a medium-sized plant (with a capacity of around 3 million tons/year). With respect to the age of these 3 plants, while both Plant G and I are comparably newer plants, with the ages of 21 and 16 years respectively, Plant F is the first and still the foremost steel plant in India which is operating for 100+ years in India. In spite of being the oldest plant of the country, Plant F has been growing and/or updating & modernizing its processes/technology in tune with the world's best available processes/technologies at regular intervals and today it is one of the most modern steel plant globally.

Standard DEA methodology gives the relative efficiency of the production units and does not provide a ranking amongst all efficient units. Andersen and Petersen (1993) developed an analogous model which also provides the ranking amongst the efficient units. This model compares the evaluating unit with a linear combination of all other sample units excluding the unit itself. The score reflects the radial distance from the unit under evaluation to the production frontier estimated with the unit excluded from the sample. Table 4 shows the ranking of the 10 integrated steel plants for each of the period 2008-09 to 2012-13 based on this model.

**Insert Table 4: Ranking of Indian integrated steel plants during 2008-13**

It can be seen from this ranking analysis that for all these 5 years, ***while the private sector steel plants were always in top 5 places, the public sector plants were always ranked last 5, confirming the above findings that private sector steel plants are more efficient than public sector steel plants.***

**5.2. Technical and scale efficiencies**

The technical efficiency, pure technical efficiency and scale efficiency of steel plants for the period 2008-13 were calculated using the output oriented model with the CRS & VRS assumptions using DEA frontier software. Fig. 1 shows the overall mean efficiency of the steel plants for each of these years obtained by comparing each plant with the best practice (production frontier) in that particular year. The coefficient of variation (the standard deviation as percentage of the sample mean) is also shown, as an indication of the variation in technical efficiency between the steel plants.

**Insert Fig. 1: Overall technical efficiency of steel plants during 2008-13**

It can be seen from this figure that that mean overall technical efficiency of the steel plants in India has been between 84.4% to 96.9% over the period 2008-13. The highest overall technical efficiency mean score of 96.9% was in the year 2008-09 (in this year 7 out of 10 plants had an efficiency of 1 and were on the production frontier), which gradually decreased over years to 84.4 % in 2011-12 (with 3 plants having efficiency of 1 and on the production frontier). It has however improved in the year 2012-13 to 91.3 % with 4 plants on production frontier with efficiency score as one. It can also be seen from the figure that ***as the mean efficiency score is reducing, the coefficient of variation tends to increase,*** since DEA gives relative efficiency of the steel plants. During the year 2012-13, the technical efficiency of the individual plants was converging as shown by the reduced coefficient of variation. This indicates that the ***overall performance of the steel plants was moving towards best practice over the period***, although there was still room for improvement.

The overall technical efficiency, pure technical efficiency and scale efficiency of Indian integrated steel plants during this period is shown in Fig. 2. This score was obtained by running the data envelopment analysis model both with the CRS and VRS assumptions and looking at differences in these scores. The ratio of technical efficiency scores with these CRS and VRS assumptions gives the measurement of the scale efficiency. Since the technical efficiency scores with CRS and VRS assumptions are different for each of the years under study***, it confirms that there exists an economies of scale in the Indian steel plants.*** The effect of scale efficiencies were more prominent during the year 2010-11 and 2011-12 and accordingly the overall mean technical efficiency of Indian steel plants were the lowest during this period in the five-year period under study.

**Insert Fig. 2: Technical and scale efficiencies of steel plants during 2008-13**

**5.3 Sensitivity analysis using bootstrapping of technical efficiency estimates**

One of the criticisms against DEA is that it implicitly assumes that all distance between an observation and the efficient boundary reflects inefficiency. However, the distance of an observation from the efficient boundary reflects inefficiency as well as noise (due to measurement errors). In DEA we can use bootstrapping to correct DEA efficiencies for bias and to estimate confidence intervals for them, recognizing that our data is subject to random noise. We assume that the probability distribution of observed DEA efficiencies mimics the true but unknown parent population of DEA efficiencies. We drew with replacement a sample from the observed DEA efficiencies and conducted bootstrapping on technical efficiencies of the steel plants over the period 2008-13 with N=1000 at 95% confidence level and calculated the bias and confidence intervals of the mean technical efficiencies of the steel plants. Since we used 5-years panel data on the performance of the steel plants, the hypotheses was tested among individual plant means (where the average is taken over all time periods) and time means (where the average is taken over all plants) of efficiency measures as suggested by Atkinson & Wilson (1995). A graphical representation of the technical efficiencies of the steel plants showing the mean, lower and upper bounds at 95% confidence interval with a sample size of 1000, plant-wise as well as year-wise over the 5-

year period is depicted in Fig. 3 & Fig. 4 respectively. It can be seen from the graphs that as concluded earlier, even the seeing the intervals, the technical efficiency of the private sector steel plants are generally much better than the public sector steel plants. Further, it can be seen that the range of technical efficiency (between lower and upper bounds) is always less in the cases of public sector steel plants as compared to private sector steel plants (except Plant G, which has the least range amongst all plants). Fig. 4 also shows that during the period 2011-13, the range of technical efficiency is higher as compared to previous years, which may be due to increasing gaps between the performance of private and public sector steel plants.

**Insert Fig. 3: Plant-wise technical efficiency intervals using bootstrapping**

**Insert Fig. 4: Year-wise technical efficiency intervals using bootstrapping**

### 5.4 Productivity change

In the earlier analysis to get technical efficiencies and scale efficiencies of the steel plants, the efficient frontier for each year is derived from the best practice of that year. It is, therefore, ignores shifts in the frontier over time and, no matter how the efficient frontier changes, the plants on the frontier will have the same efficiency score of one. Therefore, plants that have not improved their technology or management practices will suffer a reduction in technical efficiency as they are overtaken by plants that have made improvements. Thus, technical efficiency scores are more useful for making across-group comparisons rather than for identifying changes with time. As indicated earlier, the changes in productivity during a period can be measured using MPI, as this considers both the frontier shift as well as the efficiency of plants relative to the best practices.

The MPI and its various components e.g. the Overall Efficiency Change (EFFCH) and the Technological Change (TECHCH) were calculated for each steel plant in each year of the data set. The analysis normally produces % changes in productivity and its components from year to year. Fig. 5 shows the cumulative changes in MPI and its components for India's integrated steel plants with 2008-09 set us as the reference year.

**Insert Fig. 5: Changes in the MPI and its components during 2008-13**

While the values more than 1 indicates the progress in MPI, EFFCH and TECHCH from the period 1 to period 2, the values less than shows the regress during the time periods. It can be seen that **TECHCH *increased by around 16% in 2010-11,*** indicating a shift of the production frontier on the outward (better) side. It dropped back to about 1.0% in 2011-12 as the remaining plants of the industry caught up. The index then further dropped to around 0.9 in 2012-13 showing a regress in the frontier technology. These changes in the technology frontiers were partly balanced by a drop in the EFFCH by around 10% in 2010-11 indicating an increase in the distance between the average performance of the sample and the best practice. However, during 2012-13, the drop in the TECHCH by around 10% was again balanced by the increase in EFFCH by around 9 % showing a convergence of the performance of all steel plants towards best practice. ***The trend of these indices over 5-year period also indicate that the progress or regress in the technology change is getting mostly balanced by the corresponding regress or progress in the efficiency change indices and the overall result in terms of MPI has remained around 1 during this period***, with about 3 % drop in the MPI of the Indian integrated steel plants in 2012-13 as compared to 2008-09.

To understand the reasons responsible for the changes in the efficiency of the Indian integrated steel plants over this time period of 2008-13, we also decomposed EFFCH into its components of technical efficiency change index (TEEFCH) and scale efficiency change index (SECH). Fig. 6 shows the trend for these changes on an overall basis for all the steel plants with 2008-09 as the reference period (with an index of 1).

**Insert Fig. 6: Efficiency change of steel plants and its components during 2008-13**

***The TEEFCH and SECH change during the initial periods of 2009-10 and 2010-11 in the negative direction is presumably due to the prevalent economic scenario during this period and steel plants in India were also affected by this global economic slow-down.*** However, even in this ***down-period, some of the steel plants were still able to perform better due to their inherent strength of technology as well as their higher levels of customer centricity and relationships***, other plants could not do the same. This may be the reason of the larger distance of most plants from the best practice frontier and hence the lower efficiency changes during this period. The efficiency change indices however is showing a positive trend during the periods 2011-12 and 2012-13 with both the technical efficiency change and scale efficiency change indices going up resulting into increase in the overall efficiency change index.

## 5.5 Factors affecting steel plant performance

Literature review on the performance of Indian integrated steel plants suggests that there are many factors which impact the performance of the steel plants, the most important being them being their management control (public sector enterprise or a private sector enterprise), routes followed to produce crude steel (oxygen furnace route or electric arc furnace route), size (capacity) and age (based on year of incorporation) of the plants. Since we have considered only the integrated steel plants with capacity more than 1 million tons/year at a single location in our sample of analysis, all other factors are generally the same for these plants such as level of production technology, product structure (all plants producing carbon steels as long and flat products, customer requirements etc. We investigated the effects of these by dividing the sample of steel plants into appropriate groups and analyzing the changes in the technical efficiency and productivity over the period for each group.

### 5.5.1 Management control (Public sector vs. Private sector)

The integrated steel plants in India were divided into two groups based on the management and administrative control being exercised namely public sector steel plants, which are directly under the supervision of the Indian Government (Ministry of Steel) and private sector plants, which are managed and controlled by the independent boards under the public limited companies.

**Insert Fig. 7a: Technical efficiency of Indian steel plants with management control**

Fig. 7a and 7b show the changes in technical efficiency and MPI (with 2008-09 taken as reference year) reference over time for these two groups. ***The technical efficiency of the private sector steel plants is consistently more than the plants in the public sector during all the 5 years. This is mainly because of greater autonomy in their management and operations and having a higher level of flexibility in meeting market demands.*** Furthermore, the private sector enterprises may have greater incentive to operate their units more efficiently, because they get resources directly from the market and hence tend to operating accordingly to the profit maximization rule with faster return on capital employed to its shareholders.

**Insert Fig. 7b: MPI of steel plants with management control**

However, the story for the changes in the productivity of the steel plants (with reference to the year 2008-09) as depicted in Fig. 7b indicates that the ***Malmquist Productivity Index for both the public as well as private sector steel plants move together almost at same pace during the year 2009-10 to 2011-12.*** However, the same for the year 2012-13 shows a different trend for public and private sector steel plants – public sector plants continue to move downwards showing regress whereas private sector steel plants showing upward trend indicating progress. ***This may be mainly due to the time lag in the steel industry with the private sector plants being the leader in technological changes followed than by the public sector plants.***

### 5.5.2 Route followed to produce crude steel (Oxygen vs. Electric arc furnace)

The steel plants were next divided into 2 groups based on the route followed by the plants to produce crude steel. Out of the 10 integrated steel plants under analysis, 7 of them follow the oxygen furnace route where the remaining 3 follows the electric arc furnace route to produce crude steel as per customer requirements. Fig. 8 shows that t***he technical efficiency of the steel plants following the electric arc furnace route is higher than those following the oxygen furnace route***. This conclusion may generally be contrary to the general belief that the electric arc furnace route of steel making consumes more energy as compared to the oxygen furnace route, which has been considered as a separate input factor in this analysis. This may primarily be due to the reason that all the 3 steel plants using electric arc furnace route are in the private sector and t***his factor is more predominant in deciding the efficiency of the plant as compared to the route followed for steel production.***

**Insert Fig. 8: Technical efficiency of steel plants with route followed**

### 5.5.3 Age of the steel plants

The Indian integrated steel plants were next divided into groups according to the age of the plants based on the year of incorporation. For this analysis, the Indian integrated steel plants were divided into 2 groups – plants commissioned before 1990 (6 plants) and after 1990 (4 plants). Fig. 9 shows the changes in the technical efficiency of the steel plants during the year 2008-13 as per this grouping. ***The steel plants commissioned after 1990s, which are more modern plants with the latest technologies exhibit better technical efficiency, as expected, compared to the relatively older steel plants.***

**Insert Fig. 9: Technical efficiency of steel plants with age (year of commissioning)**

### 5.5.4 Size (capacity) of the steel plants

The Indian integrated steel plants were finally divided into 2 groups according to their size (plant production capacity). The grouping was done based on plants having capacity up to 5 million tons/year (medium-sized) and more than 5 million tons/year (large-sized). Accordingly, there were 8 plants under the first group and only 2 plants in the second group. Both the plants in group 2 (Plant F and G), which have installed capacity of around 10 million tons/year, are in the private sector and follow oxygen furnace route for steel making. Plant F is the oldest steel plant in India (commissioned in 1911), Plant G is one of the newer plant commissioned after 1990s. But both these plants have been on the production frontier for all the 5 years under analysis and have been efficient. Therefore, it can be concluded that ***technical efficiency of the Indian steel plants which are larger in size (> 5 MTPA) is higher than the steel plants which are comparatively medium sized.***

## 6. Discussions

In this study, the technical efficiency and the productivity changes in the Indian integrated steel plants during the year 2008-13 were analyzed by using DEA model. The data for 10 integrated steel plants, which covers around 80% of the steel made in India through the oxygen furnace and electric arc furnace routes, included 4 inputs (namely Specific energy consumption, Blast furnace productivity, steel furnace productivity and labour productivity) and 2 outputs (namely gross margin as % of turnover and customer satisfaction index), which were used in this analysis. The CCR and BCC efficiency of the plants based on an output-orientation DEA model were calculated for the evaluation of relative efficiencies of India's integrated steel plants. Sensitivity analysis of the technical efficiency of the steel plants was also carried out using bootstrapping at 95% confidence interval with a sample size of 1000. Malmquist productivity index (MPI) of these plants was also calculated to get the insight on changes in their productivity over a period of 5 years.

***The overall technical efficiency of India's integrated steel plants during the period 2008-13 was 91 %.*** During the year 2008-09, the mean technical efficiency was 97% (with 7 out of 10 steel plants on the production frontier). The overall efficiency gradually decreased over next 3 years to a level of 84 % during 2011-12 (with 3 plants on the production frontier). The efficiency however improved to a level of 91% during the year 2012-13, with the technical efficiency of all the plants converged with a move toward best practice (as evident by the reduced coefficient of variation). While ***this level of overall technical efficiency of Indian integrated steel plants looks quite good as compared to the same for the Chinese steel plants*** (it was 63% as studied by Ma et. al, 2002 for the period 1989-97), this comparison may not be valid as the sample size and category of steel plants considered in these studies were different. Ma et. al (2002) included 88 enterprises of sizes varying from 0.1 to 8.3 million tons per year producing varying products (pig iron, crude steel as well as finished steel), we have included integrated steel plants of sizes more than 1 million tons/year and producing finished steel only. Our study has also confirmed that the efficiency of the steel plants depends on the size, and therefore ***wide variation in the size of the steel plants considered in the sample will result into lower overall technical efficiency and may not be a valid comparison of relative efficiencies.***

It was also observed that CRS efficiency and VRS efficiency scores are different for all steel plants except 3 plants (namely Plant F, G and I – the CRS efficiency was 1 for these plants in each period) over this period of 2008-13. ***This confirms that economies of scale exist in Indian integrated steel plants.*** The same conclusion was also arrived at by Ma et al (2002) while studying Chinese steel plants during the period 1989-1997.

The MPI of plants for the period 2008-13 was measured and was decomposed into efficiency and technological changes. The efficiency change is then further broken-down into scale efficiency and technical efficiency changes. It has been found that the Indian integrated steel plants has MPI both under 1 (showing regress) and above 1 (showing progress) and have experienced a decrease in productivity by 3% during the period 2008-13. This decrease in productivity can be decomposed into a 10 % decrease of technological change with a corresponding 9 % of technical efficiency change. This is primarily due to the prevailing economic condition in India during this period of 2008-13. Similar studies done at the Chinese steel plants in 2002 had observed that the productivity of the industry improved steadily with an average annual rate of 3 % over the whole period. The study at the Chinese steel plants was for the period 1989-1997, during which the Chinese economy was growing at a fast pace with corresponding growth in the demand for steel in the country.

In frontier analysis, the technology regress is an empirical issue and involves changes in the management practices, institutional or production technologies. This may be due to the overall economic and industrial scenario in the country during this period and does not mean that the production techniques once known and used by the plants have been discarded and not being used now. Further, it is generally believed that the technology change index and the efficiency change index are positively related, whereas in our study ***they moved in opposite directions in all these time periods. Similar results were obtained by Ma et al. (2002) in their study of the productivity changes in Chinese Iron and Steel industry for the period 1989-97. There is a time lag between the actions of the efficient*** (plant on the frontier - named by Ma et al. as Innovators) and other plants (followers) due to the capital intensive nature of the steel industry taking long time to commission new technologies. When the best practice plant makes any further technological changes, the resultant outward shift of the frontier leave the followers (inefficient plants) further behind i.e. their technical efficiency falls when the technology progress is made by the best practice plants. However, when the technological progress by the innovators reaches a temporary limit, the other plants try to catch up with the horizontal deployment of similar technologies/practices in their plants too. Thus, the distance between the best practice frontier and their performance will be reduced with the increase in the technical efficiency of the follower plants. In the Indian integrated steel plant scenario, some of the plants namely plants in the private sector took the lead in making few technological advances in their processes, which were later followed by most other plants explaining the above shifts in the technological and efficiency changes. However, it may be mentioned here that ***this catch-up by the inefficient plants to deploy the best practices for overall improvement in the productivity of the steel plants in the country is not happening at the right pace and this may be the reason behind a small reduction in the Malmquist productivity index in 2012-13 as compared to the reference year of 2008-09***.

**In addition to the above, we also investigated the effect of factors such as management control, route followed to produce crude steel, size (capacity) and age of these plants, which impact the performance of the steel plants. The study finds that Indian *private sector steel plants with larger capacity (production***

***capacity of 5 million tons per year and more) and which have adopted the latest and most modern technologies (plants which have been commissioned post 1990) are more efficient and productive over the study period*. These findings were also similar to the findings of the Chinese steel plants (Ma et. al, 2002) in which large enterprises under the supervision of central government were found more efficient and productive compared to the medium and small local enterprises under the supervision of provincial governments.**

**7. Conclusions**

**Steel is crucial to the development of any modern economy and is considered to be the backbone of human civilization. The level of per capita consumption of steel is treated as an important index of the level of socio-economic development and living standards of the people in any country. All major industrial economies are characterized by the existence of a strong steel industry and the growth of many of these economies has been largely shaped by the strength of their steel industries in their initial stages of development. India's economic growth is contingent upon the growth of the Indian steel industry. India today occupies a central position on the global steel map, with the establishment of new state-of-the-art steel mills, acquisition of global scale capacities by players, continuous modernization and up gradation of older plants, improving energy efficiency and backward integration into global raw material sources. With the Indian economy poised for its next wave of growth under the reforms being unleashed in the last few years, there is tremendous opportunity for the Indian steel industry to prosper and grow exponentially.**

We used Data Envelopment analysis to evaluate the relative efficiency and productivity of Indian integrated steel plants to gain an understanding of its present status and identify and adopt best practices, which would give directions to new plants being conceived now to be most efficient and productive. We gained from the use of DEA MPI change technique to understand that detailed insight can be obtained by decomposing the MPI into its individual components. This technique is helpful to researchers who wish to gain insights about the efficiency performances of top firms. In addition to evaluating CCR efficiency, VRS efficiency gives additional insight about the scale efficiency impact on the performance and indicates opportunities for further improvement. Moreover, by analyzing the different components of MPI, critical insights about firm's performance can be captured and implications of various MPI components can also be revealed to get a clearer picture about the changes in firm's performance. This helps in making the firm aware about its opportunities for improvement to initiate appropriate countermeasures.

To further increase the efficiency and productivity of the Indian integrated steel plants and hence reduce the inputs of energy and other resources to raise the outputs, we suggest the following policy implications drawn from this study:

(a) More reforms should be carried out in the public sector steel plants, which are controlled by the Government of India because of their strategic importance to the economy. The management of these plants should be provided with more autonomy and delegation of power to initiate improvement actions based on the best practices identified through this analysis to compete with the levels of efficiency achieved the private sector steel plants.

(b) While some of the private sector steel plants have been continuously growing in size over time by adding capacities and/or through de-bottlenecking the plant to increase their production capacities, the public sector steel plants have been slower in adopting the same. While most of these plants are also adding capacities now, there is always a bigger-time gap between the public and private steel plants. Therefore, it is necessary that public sector steel plants should also be more agile in responding to market requirements.

(c) According to the international standards, the minimum size of the integrated iron and steel plants for efficient steel making is around 3 million tons/year. In our analysis, it has been seen that 2 of the public sector steel plants which have installed capacities around 2 million tons/year only, have always been the most inefficient plants as compared to other plants. Management of these plants should hasten-up the process of increasing their installed capacities so that they also start operating in the efficient zone as per the international standards.

(d) India is likely to become the second largest crude steel manufacturer in the world after China. In the next five years, the demand of finished steel in the domestic market may grow at the rate of over 10% annually, on an average, as compared to 8% annual growth achieved during the period 1991-92 to 2010-11. To meet this growing demand, large number of memorandum of understandings have been finalized with different Indian states for an installed capacity of around 500 million tons by 2020 involving an investment of around Rs. 10 lakh crores. It is therefore necessary that the new plants which are being conceived should adopt the latest and most modern technologies and are of optimum size to be most efficient. They should also be given to operate with complete autonomy and delegation of power in line with the private sector steel plants to be competitive.

(**e) Impact on society: The model developed here can be applied to diverse evaluation conditions thus leading to better utilization of scarce resources and capacities. The study finds that Indian *private sector steel plants with larger capacity (production capacity of 5 million tons per year and more) and which have adopted the latest and most modern technologies (plants which have been commissioned post 1990) are more efficient and productive over the study period*. The findings can be useful for policymakers, steel plant planners and administrators in designing a system based on various criteria that can help improve the overall efficiency and productivity of integrated steel plants and decide about benchmarking and funding strategies.**

### 7.1 Research limitations and opportunities for future study

This study has few limitations that should be addressed and some of these can also be the directions for future research. In DEA studies, the choice and the number of inputs and outputs, and the DMUs determine how good of a discrimination exists between efficient and inefficient units. Since there are only 10 integrated steel plants in India, the sample size was 10 only for the purpose of homogeneity. This restricted the consideration of only 4 input and 2 output factors only for good discrimination power amongst efficient and inefficient units, although there are other factors, which could also have been considered.

Another limitation of this study is that since DEA is an extreme point technique, errors in measurement of factor values can cause significant problems as DEA efficiencies are very sensitive to even small errors, making sensitivity analysis an important component of post-DEA procedure. While we have used data in our analysis which were collected and reported to Ministry of Steel, Government of India (based on uniform guidelines and formulae used across all steel plants), any noises such as measurement error in any data can cause misleading results.

The valid model developed in this study to compare the performance of steel plants can help future researchers to undertake similar studies in other industries especially in process industries. An avenue for further investigation is to examine the use of other variants of DEA model to get more insights.

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| SN | Plant | Sector | Route | Crude Steel (MT/year) | |
|---|---|---|---|---|---|
| | | | | Capacity | Production (FY14) |
| 1 | Plant A | Public | Oxygen furnace | 3.925 | 5.136 |
| 2 | Plant B | Public | Oxygen furnace | 4.360 | 3.776 |
| 3 | Plant C | Public | Oxygen furnace | 1.900 | 2.291 |
| 4 | Plant D | Public | Oxygen furnace | 1.800 | 2.019 |
| 5 | Plant E | Public | Oxygen furnace | 2.910 | 3.202 |
| 6 | Plant F | Private | Oxygen furnace | 9.700 | 9.153 |
| 7 | Plant G | Private | Oxygen furnace | 10.000 | 9.257 |
| 8 | Plant H | Private | Electric arc furnace | 3.300 | 2.971 |
| 9 | Plant I | Private | Electric arc furnace | 3.250 | 2.835 |
| 10 | Plant J | Private | Electric arc furnace | 4.600 | 3.245 |

**Table 1: Integrated steel plants in India (with >1 MT/year capacity at one location)**

| Variables | Mean | Maximum | Minimum | Standard Deviation |
|---|---|---|---|---|
| Age of plants (years) | 44 | 104 | 16 | 26.65 |
| Crude steel capacity (Million tons/year) | 4.57 | 10.00 | 1.80 | 2.93 |
| Crude steel production (Million tons/year) | 4.39 | 9.26 | 2.11 | 2.68 |
| Specific energy consumption (Gcal/tcs) | 6.72 | 7.51 | 6.00 | 0.38 |
| BF Productivity (Tons/Cu.Mts./Day) | 1.87 | 2.77 | 1.24 | 0.47 |
| Steel furnace productivity (No. of heats) | 7450.60 | 11446.00 | 4144.00 | 2482.97 |
| Labour productivity (Tons/person/year) | 552.70 | 1368.00 | 197.00 | 371.45 |
| Gross margin (as % of turnover) | 15.81 | 31.80 | 6.28 | 8.72 |
| Customer satisfaction index (%) | 81.06 | 87.40 | 76.60 | 3.62 |

**Table 2: Statistical summary of the steel plants considered in the analysis (2013)**

| SN | Plant | 2008-09 | 2009-10 | 2010-11 | 2011-12 | 2012-13 | Frequency @ |
|---|---|---|---|---|---|---|---|
| 1 | Plant A | * | | | | | 1 |
| 2 | Plant B | | | | | | - |
| 3 | Plant C | | | | | | - |
| 4 | Plant D | | | | | | - |
| 5 | Plant E | * | | | | | 1 |
| 6 | Plant F | * | * | * | * | * | 5 |
| 7 | Plant G | * | * | * | * | * | 5 |
| 8 | Plant H | * | | * | | * | 3 |
| 9 | Plant I | * | * | * | * | * | 5 |
| 10 | Plant J | * | * | | | | 2 |
| **Total #** | | **7** | **4** | **4** | **3** | **4** | **22** |

* Plant on the frontier in the given year
# Total number of plants on the frontier in the given year
@ Number of times the plant was on the frontier during the period 2008-13.

**Table 3: Composition of the production frontier for variable return to scale**

| SN | Plant | 2008-09 | | 2009-10 | | 2010-11 | | 2011-12 | | 2012-13 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Efficiency Score | Rank | Efficiency Score | Rank | Efficiency Score | Rank | Efficiency Score | Rank | Efficiency Score | Rank |
| 1 | Plant A | 1.043 | 6 | 0.912 | 7 | 0.815 | 7 | 0.715 | 9 | 0.793 | 9 |
| 2 | Plant B | 0.872 | 10 | 0.883 | 9 | 0.724 | 8 | 0.726 | 8 | 0.851 | 7 |
| 3 | Plant C | 0.901 | 9 | 0.901 | 8 | 0.722 | 9 | 0.726 | 7 | 0.860 | 6 |
| 4 | Plant D | 0.917 | 8 | 0.878 | 10 | 0.698 | 10 | 0.700 | 10 | 0.822 | 8 |
| 5 | Plant E | 1.001 | 7 | 0.954 | 6 | 0.826 | 6 | 0.789 | 6 | 0.889 | 5 |
| 6 | Plant F | 1.311 | 1 | 1.358 | 1 | 1.565 | 2 | 1.482 | 2 | 1.393 | 3 |
| 7 | Plant G | 1.060 | 5 | 1.047 | 3 | 1.080 | 4 | 1.122 | 3 | 1.112 | 4 |
| 8 | Plant H | 1.298 | 3 | 0.987 | 5 | 1.535 | 3 | 0.974 | 4 | 1.472 | 2 |
| 9 | Plant I | 1.304 | 2 | 1.110 | 2 | 2.203 | 1 | 2.076 | 1 | 1.505 | 1 |
| 10 | Plant J | 1.077 | 4 | 1.014 | 4 | 0.837 | 5 | 0.813 | 5 | DNA | DNA |

Note: DNA – Data Not Available

**Table 4: Ranking of Indian integrated steel plants during 2008-13**

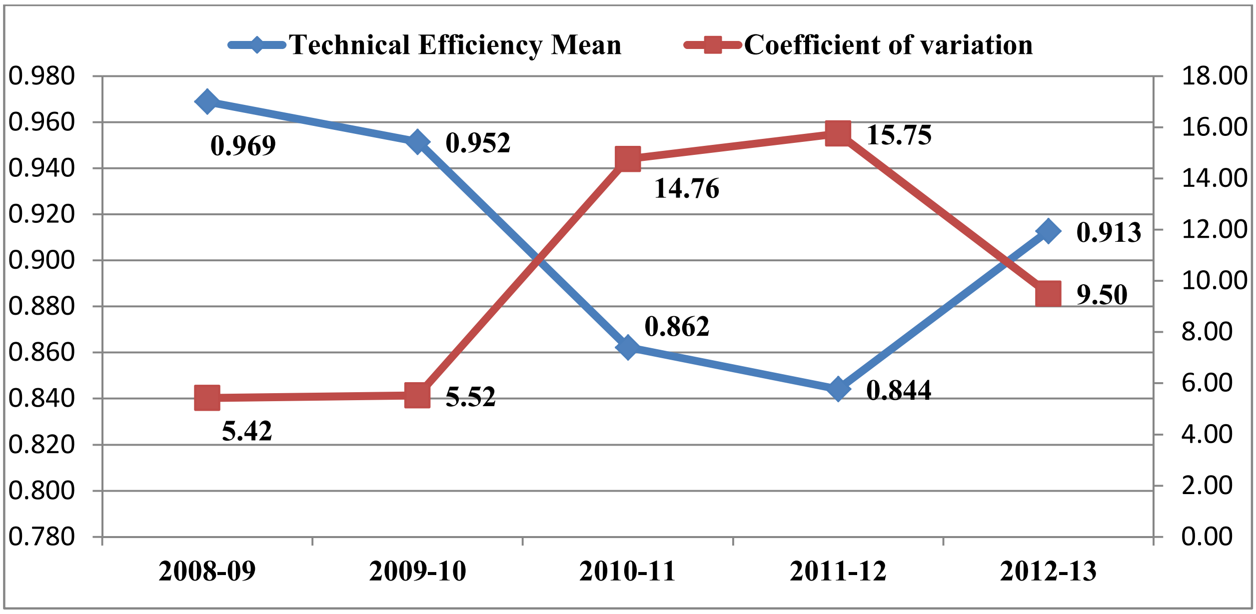


**Fig. 1: Overall technical efficiency of steel plants during 2008-13**

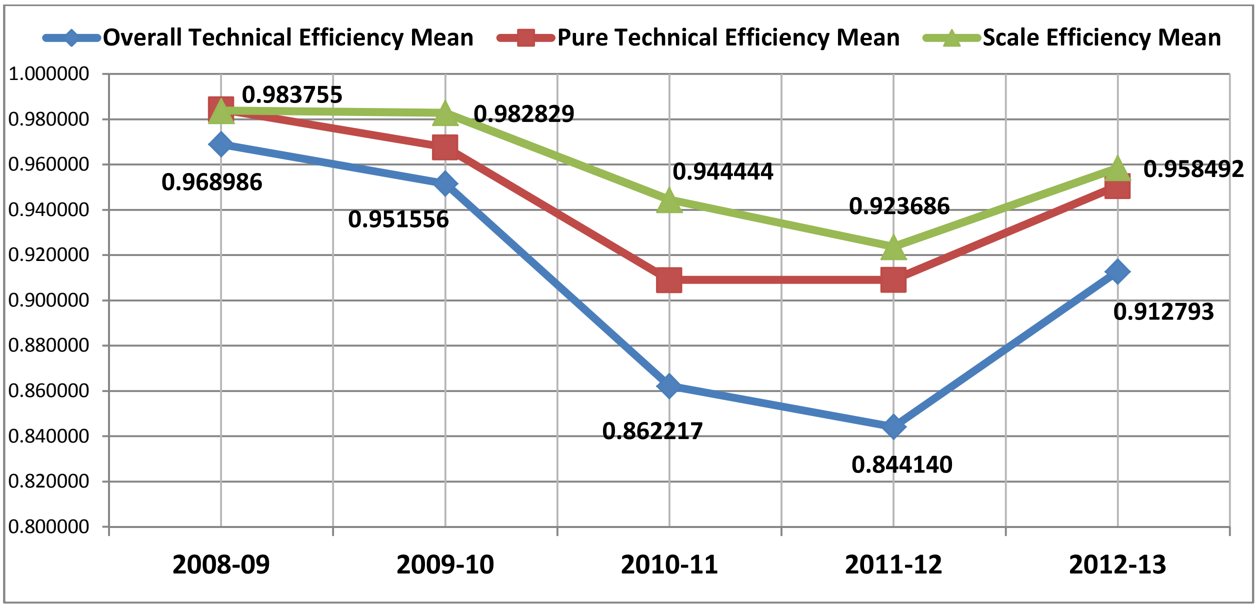


**Fig. 2: Technical and scale efficiencies of steel plants during 2008-13**

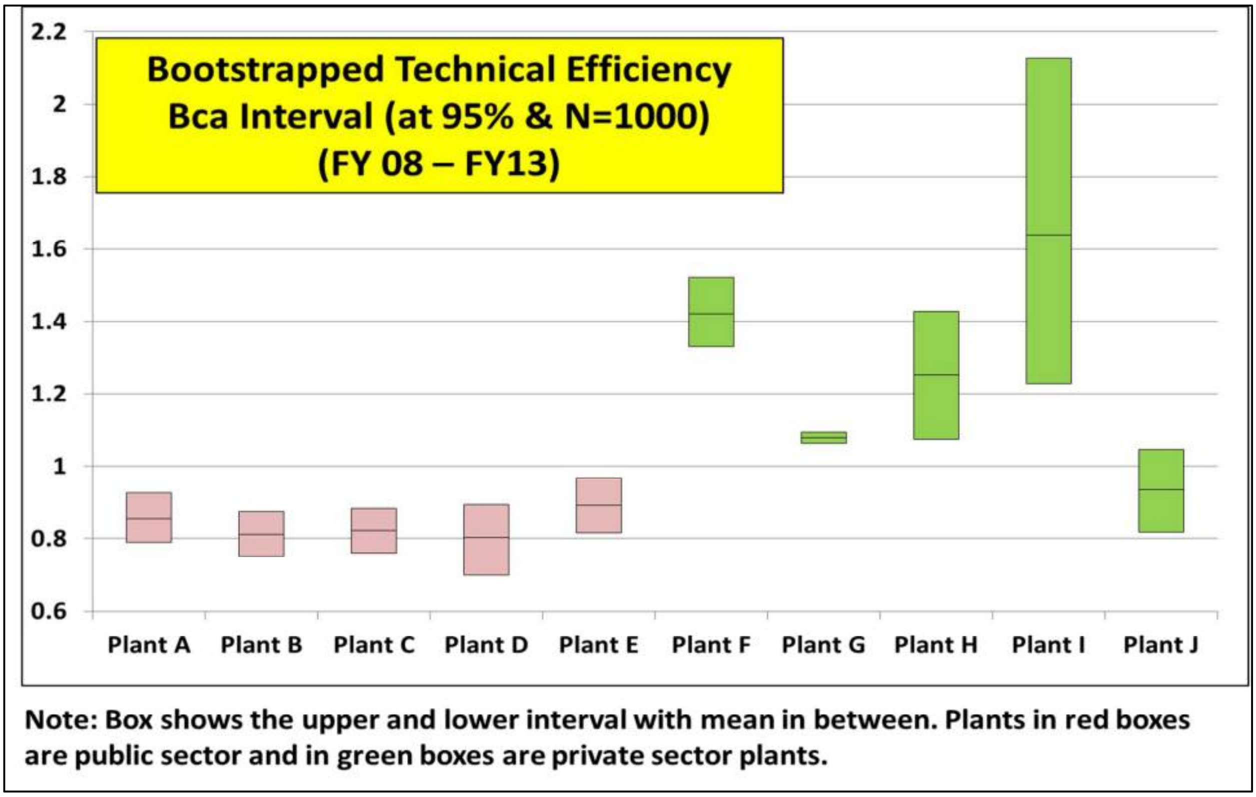


**Fig. 3: Plant-wise technical efficiency intervals using bootstrapping**

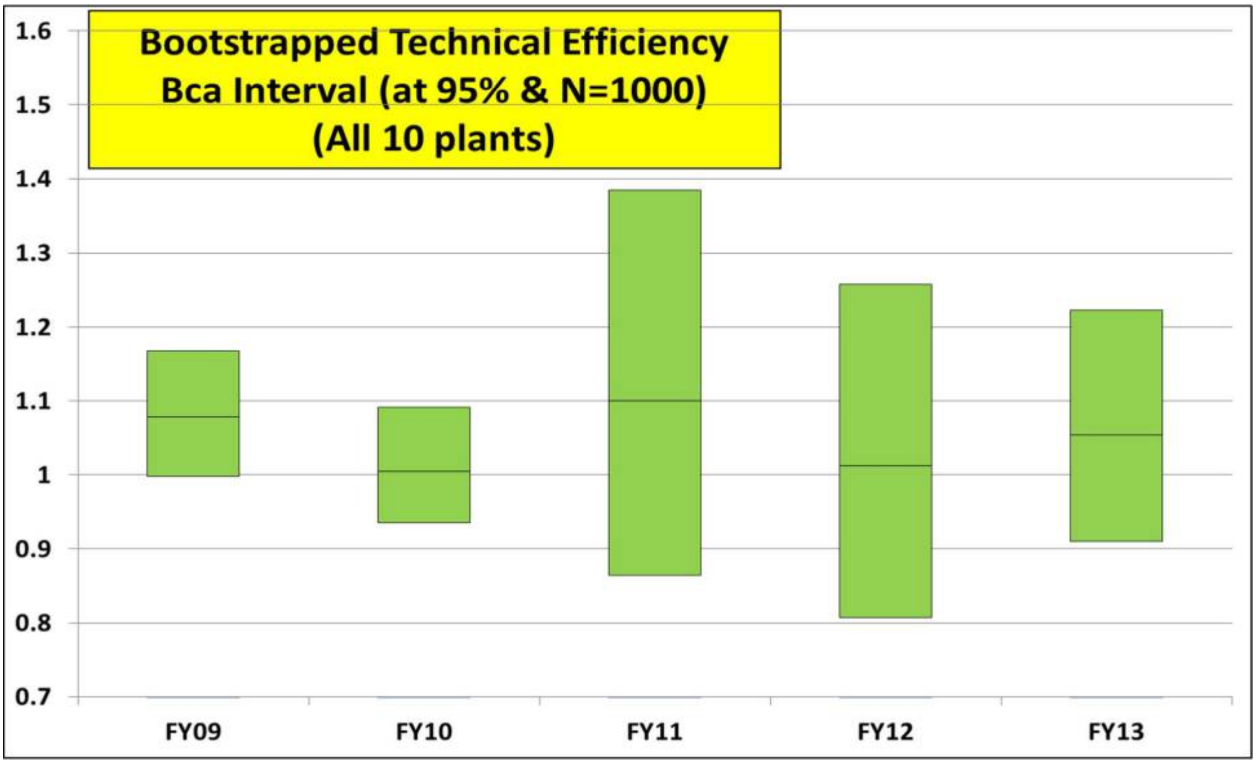


**Fig. 4: Year-wise technical efficiency intervals using bootstrapping**

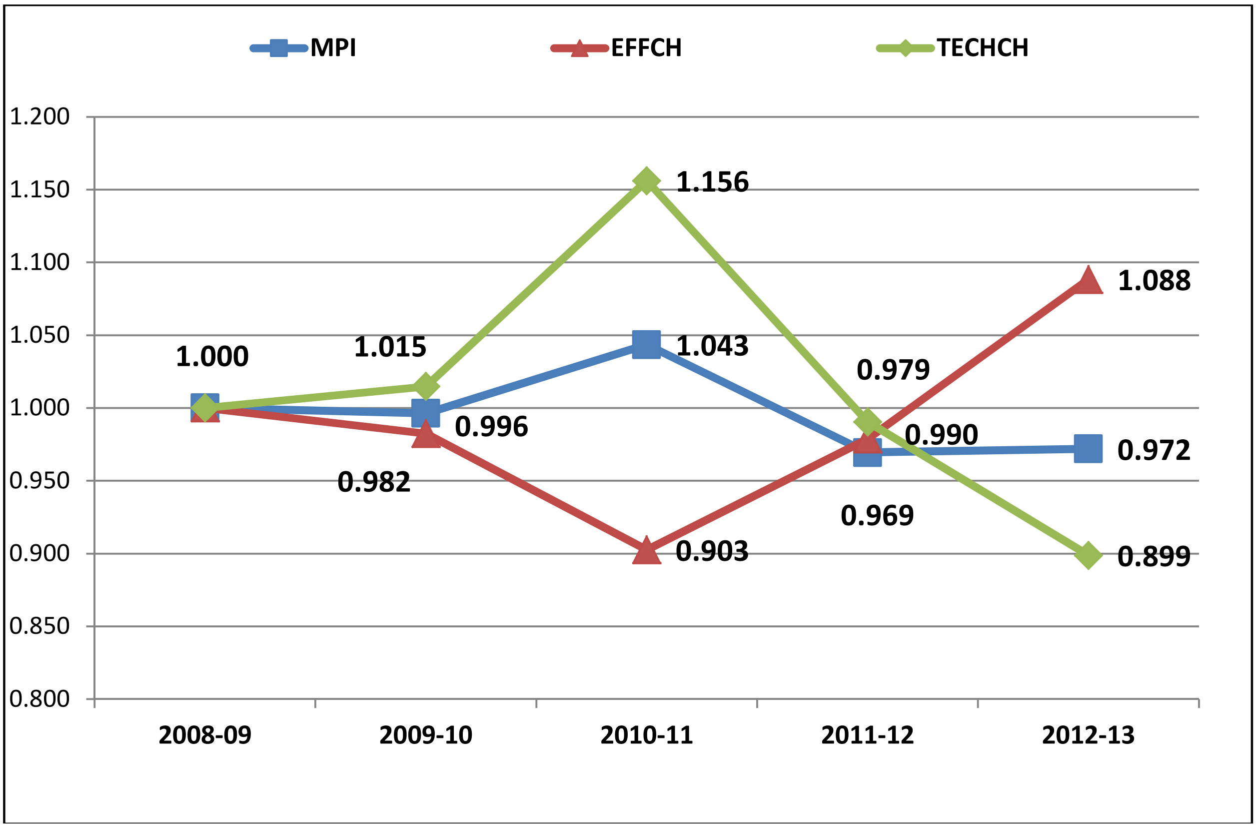


Fig. 5: Changes in the Malmquist productivity index and its components during 2008-13

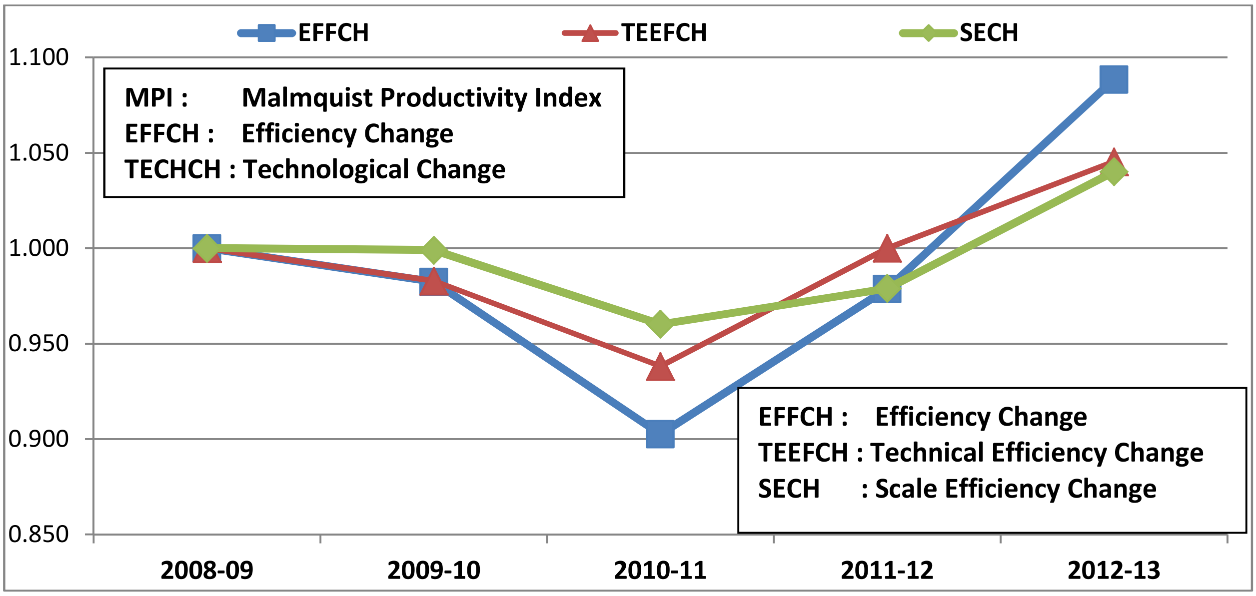


**Fig. 6: Efficiency change of steel plants and its components during 2008-13**

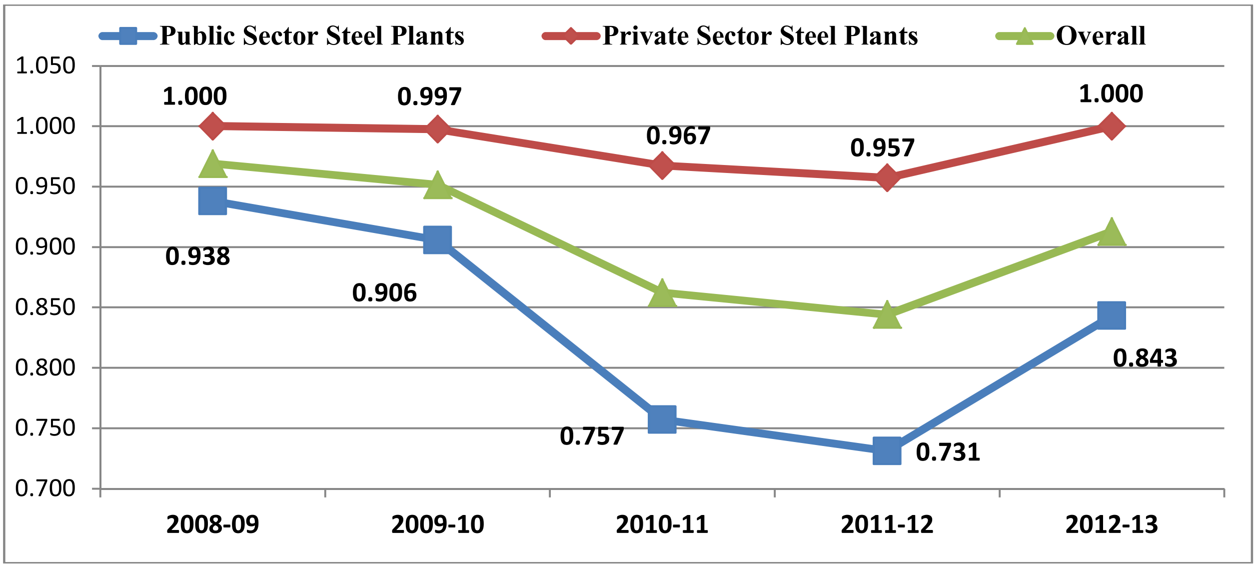


**Fig. 7a: Technical efficiency of Indian steel plants with management control**

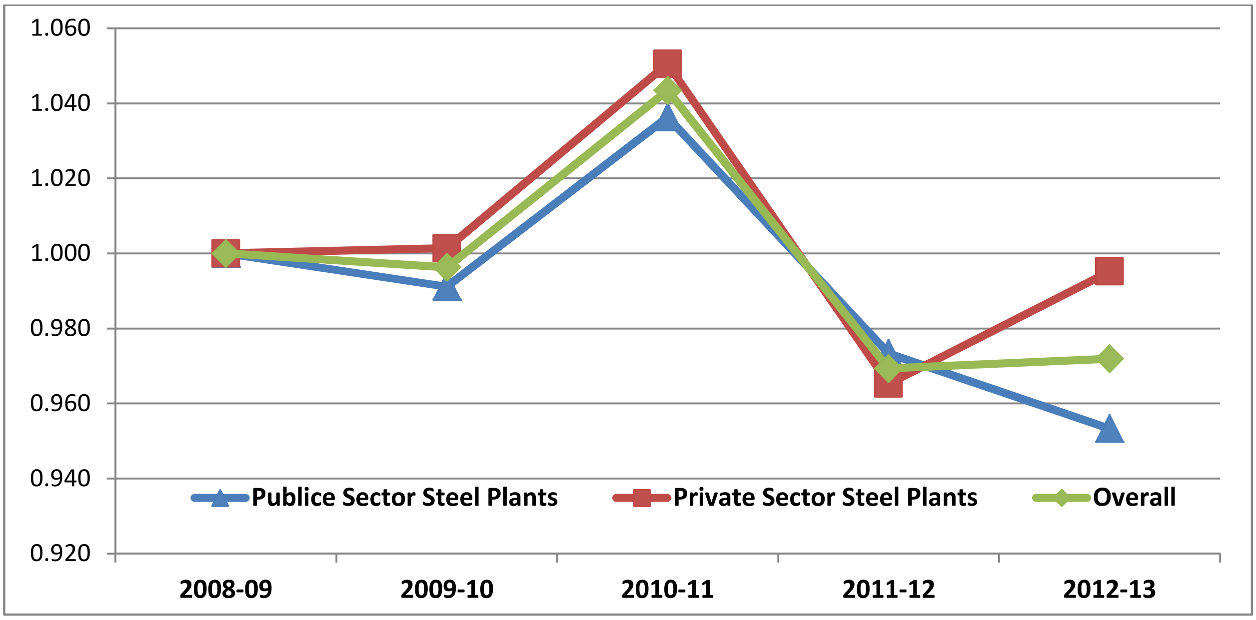


**Fig. 7b: Malmquist productivity index of steel plants with management control**

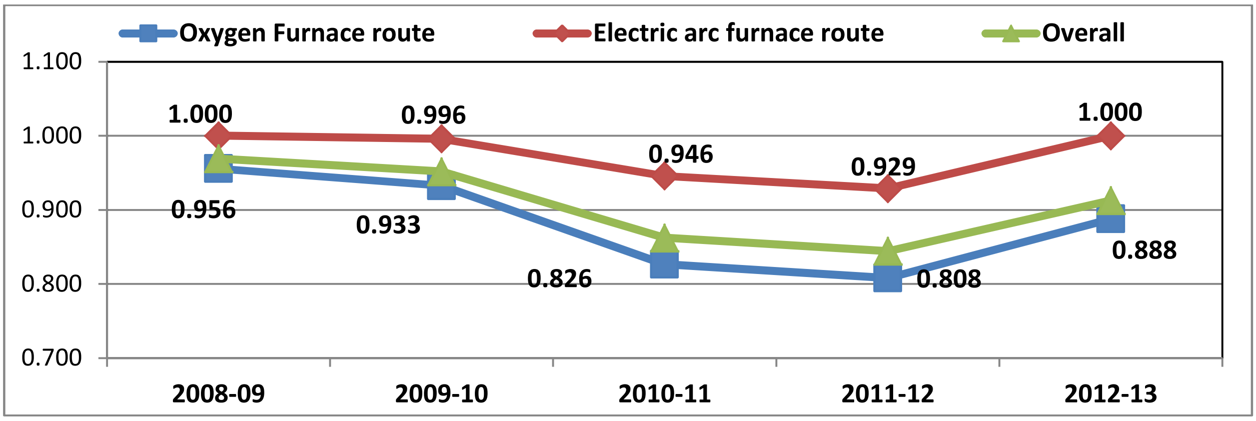


**Fig. 8: Technical efficiency of steel plants with route followed**

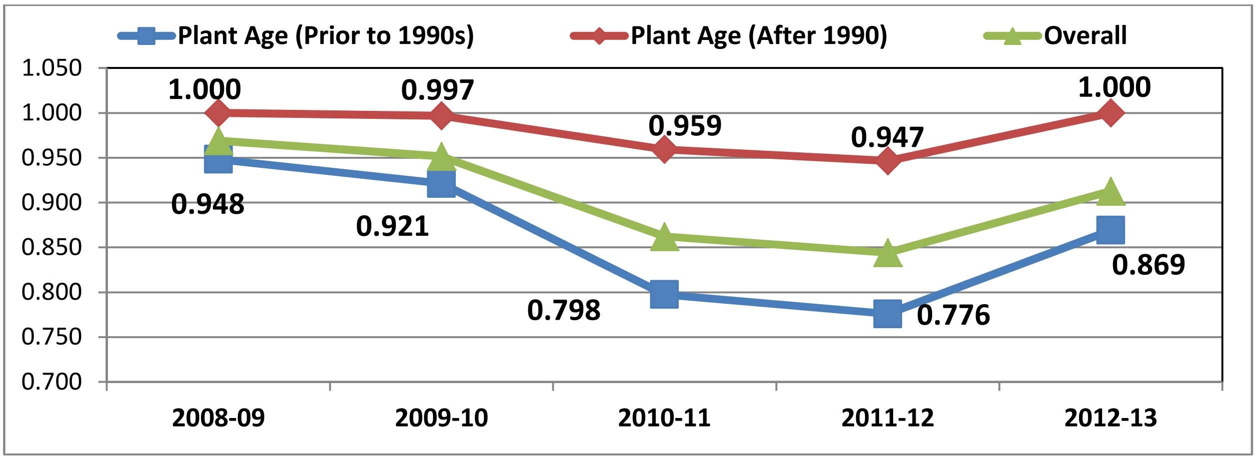


**Fig. 9: Technical efficiency of steel plants with age (year of commissioning)**