Project Completion Report

R&D in Indian Steel Industry: Issues and Cases

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Academy for Science, Policy Implementation and Research (ASPIRE)

ASPIRE was launched in 2010 by Department being incubated in project mode at the Administrative Staff College of India (ASCI), Hyderabad. It aims to provide a common platform for interconnecting and enhancing competencies in policy development and implementation emphasizing Science Technology and Innovation across various stakeholders and arms of the Government leading to evidence based decision making.

Some of the areas in which policy studies have been carried under ASPIRE include food price inflation, R&D in agriculture, pharmaceuticals, patents, steel related R&D and Innovation etc. Efforts are on to upscale the level of engagement of socio-economic ministries and public sector industries in ASPIRE for R&D management, Innovation and Policy including capacity building. During 2015-16, new studies apart from conducting a workshop on science technology and innovation ecosystem will be planned for evidence based policy interventions.

Acknowledgement

This study has been conducted under the aegis of the Academy of Science Policy Implementation and Research (ASPIRE) of the Department of Science and Technology, Government of India.

In conducting this study, I have received a lot of cooperation and support from the Dr. Krishnaswamy VijayRaghavan, FRS, Secretary Department of Science and Technology, and I am thankful to him for this support. The study could not have been contemplated and conducted without the active help and support of Dr. Parveen Arora, Advisor, Department of Science and Technology. Dr. Arora has not just been an advisor to the project but has taken keen interest in many facets of the study. Indeed many of the aspects of the study can be credited to Dr. Arora's ideas. A study of this nature could not have been completed without the active cooperation of the line Ministry i.e. Ministry of Steel. I have received great appreciation and cooperation from Shri U.P. Singh, Joint Secretary, Ministry of Steel, who personally wrote to all steel industry firms to help us in this endeavor. I thank him. Dr. S.K.Bhatnagar, Deputy Industrial Advisor, Ministry of Steel made many calls on my behalf to ensure that we got the data from the firms that we were looking for. I thank him for his efforts. I also thank all the firms that I visited for their hospitality and access. The response of the firms was truly overwhelming and it shows the tremendous energy of the industrial R&D manpower. Due to paucity of space, I am not able to name them individually but I thank all of them for their ideas and hospitality.

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Introduction

Steel is indispensable to the growth of an economy. The per capita steel consumption of a country reflects the living condition in a country. It is a complex industry in technological terms. Moreover, it has linkages with many other important industries of the economy and hence is extremely crucial to the economic health of a nation.

The global steel industry has witnessed changes in leadership more than once with the passage of time. The top producers have changed with time. United States of America had a predominant role in the global steel industry in the late eighteenth century and the early nineteenth century. The use of capital, labor and technology was optimized in the US steel industry to build an industry that was resilient and competitive. However, post WWII, technological changes were very fast and the choices adopted by the US steel industry led to the slow and steady erosion of its competitiveness. Small countries made smart new technology choices and moved ahead. Notable among them is Japan and South Korea. The increase in Japan's steel production after the war is an excellent indicator of the postwar industrial growth (Richardson, 1993).

Empirical evidence suggests that the global crude steel production share of Asian countries is increasing with each passing decade. China's share in global crude steel production was only 0.3% in 1950, which rose to 3.7% in 1975, to 17.8% in 2001 and stands at 45.1% in 2011. Japan, China and other Asian countries put together had a share of 3.7% of global crude steel production in 1950, which today stands at 64.3%. This rise of Asian countries in steel production has happened at the expense of NAFTA, EU and CIS (former USSR) countries. This change in the dynamics of production is an effect of long term planning and carefully crafted strategies of the Asian countries. Even though Japan, South Korea, and

China have adopted different strategies for enhancing their share of global steel production, the role played by their governments is similar and worth emulating.

There are various key features characterizing the steel industry. The facilities that are required to produce steel involve huge capital expenditure leading to substantial fixed production costs. As a consequence of this, only at a very high capacity utilization level the break-even point is reached. A significant feature of the steel industry is the presence of significant economies of scale. This implies that there is a fall in the production costs per unit with an increase in the capacity. Technically speaking, all the vessels used in the processes leading to steelmaking follow the "square-cube law". As the volume of these facilities increases at a faster rate than the surface, capacity increases faster than the investment costs. Moreover, enlarging the production scale by integrating all the stages of production in a single plant will lead to efficiency gains. A single company is more suitable for managing such a complex and continuous production flow and to fully tap the synergies. Average steel products of different companies can serve as near perfect substitutes of each other. However, if we focus on products from other industries, e.g. aluminium and fiberglass can substitute steel in the motor vehicles and appliance production. Although substitutability can be done in the long run, switching costs can be very high due to the changes that are required in the downstream production process. High capital requirements resulting in high capital expenditure is a barrier to entry in the steel industry. Scale economies may serve as another obstacle in entry into the industry as the minimum yearly output required for surviving and competing in the market may be higher than the break-even quantity.

Empirical studies show that the relationship between per capita GDP and per capita consumption of steel is directly proportional up to an inflexion point of its maxima, following which it is inversely related. This indicates that the consumption of steel plays an even more important role in the developing phase of any economy. The consumption of steel globally has been increasing in this century.

The world average steel consumption per capita has steadily increased from 150 kg in 2001 to 220 kg in 2010. The major push in this monotonically increasing consumption is noted mainly in the emerging economies. India, Brazil, Korea and Turkey have all entered the top 10 steel producer's list in the last 40 years after breaking through several barriers.

Even though Steel is categorized as a medium low technology industry by OECD classification, the benefits of investing in R&D is quite substantial. India has a fairly good capability in R&D in steel and can augment it to create a competitive advantage. Post 1991 liberalization of the economy in the country, R&D has not been given the focus it deserves, resulting in lowering of internal capability of the industry to cope with competition and crisis of raw materials in the near past. However, some of the better and forward looking private sector companies have realized the importance of R&D and are investing heavily in R&D. Firms like Tata Steel, JSW, SAIL, and NMDC are planning major investments in R&D. The government also has successful schemes to aid such private efforts to increase R&D investment through its Steel Development Fund. However, more effort from all the stakeholders is required to increase R&D spending and generate the benefits from R&D that can result in competitive advantage for the nation in this industry.

The Indian Steel Industry

The Indian iron and steel industry is more than hundred years old with a rich tradition of making good quality steel. Steelmaking has always been given a priority by the government right from Independence in 1947 when the country had only integrated steel plants, TISCO, IISCO and BISL. From 1950 to 1970, large public sector integrated steel plants were set up in Bhilai, Durgapur, Rourkela and Bokaro with imported technology from Russia and Germany. Following the liberalization of the country in 1991, many private sector companies have also set up integrated steel plants and presently the industry is classified into main producers including Steel Authority of India Ltd. (SAIL), Rashtriya Ispat Nigam Ltd. (RINL) and Tata Steel Ltd. and major producers including JSW Steel Ltd., Essar Steel India Ltd., JSW Ispat Steel Ltd. and JSPL, and other producers who operate mini steel plants based on EAF and IF technologies. As per official estimates, the Indian iron and steel industry contributes to around 2 percent of India's GDP and its weightage in the official index of industrial production is 6.2 percent.

The decade before liberalization saw very modest below 5 percent rate of growth. During the 9th Five-year Plan (1997-98 to 2001-02), both production and consumption started increasing and reached very impressive levels of 9.4 and 10.4 percent respectively during the 10th Plan (2002-03 to 2006-07). However, following the 2008 financial crisis and broadly mimicking international trends a near meltdown in the metals space, the 11th Plan production and consumption percentages are much lower than the 10th Plan highs.

Exports have also increased post-liberalization and attained impressive highs (5.24 million tonnes) at the end of 10th Plan period but due to steady reduction of import duties and customs duties from 150 percent to 5 percent, imports have also increased at a very rapid pace. In fact, India has regained the status of a net exporter of steel only in 2014 following a gap of six years due to this effect. Moreover, under WTO the country can only resort to a limited number and type of barriers to such imports.

The National Steel Policy 2005, having forecast a compounded annual growth of 7.3 percent per annum in steel production had estimated a goal of 100 million metric tonnes per annum target by 2019-20. If recent trends continue, this target will be achieved much before 2019-20 in 2016-17 as the production has grown at the rate of 8.2 percent during 2006-07 to 2010-11. Plans are already underway to install additional capacity to the tune of around 40 million metric tonnes, half of which will come from public sector plants. As already mentioned, the production of crude steel increased at the rate of 8.2 percent per annum from 50.817 million tonnes in 2006-07 to 78.001 million tonnes in 2010-11. However, the additional production by SAIL, TATA and RINL i.e. the main producers contributed a mere 6 percent (about 1.67 million tonnes). The capacity expansion undertaken by the major producers and other producers group was the primary contributing factor to this growth.

Steel consumption increased at an annual rate of 8.8 percent from 2006-07 to 2010-11. A notable feature is a relative higher growth in domestic demand for steel compared to that with availability. The composition of the Indian steel industry has witnessed a significant change due to the introduction of new technologies. Various diverse technologies have contributed to the capacities created after deregulation. These technologies include COREX (JSW Steel Ltd), large-scale technologies which are the combinations of Electric Steel making and BF hot metal (Ispat Industries Ltd) etc.

Exports reached the peak value of 5.24 million tonnes at the end of 10th Plan and reached a negative growth rate of 9 percent and in 2010-11 was 3.46 million tonnes, whereas in the 11th Plan net imports have fluctuated from 1.4 million tonnes in 2008-09 to 4.3 million tonnes in 2009-10.

Even though India is the fourth largest producer of steel in the world, our per capita consumption is 51.7 kgs against the world average of 202.7 kgs. The report of the working group on steel of the 12 the Plan estimates demand to grow considerably during the 12th Plan with an annual average growth of 10.3 percent as compared to 8.1 percent during the last two decades i.e. 1991¬2011.

Capacity utilization rates during the 11th Plan ranged from 88 percent to 90 percent. Operating at such high capacity utilization rates is a strong signal that capacity additions have to be done in order to meet potential future demand. Increasing the level of R&D expenditure has been recognized as an urgent need. R&D expenditure has to be enhanced keeping in mind the need to cover the efficiency gaps, develop indigenous technologies and design equipment crucial to steel production.

One of the major areas of concern in the Indian iron and steel industry is the lack of R&D. Even in large integrated steel plants R&D expenditure year on year for decades has hovered around 0¬0.2 percent. In fact the National Steel Policy 2005 after flagging this as a major concern (the National Steel Policy 2005 estimated the R&D expenditure for the iron and steel industry as a percentage of its turnover at 0.26 percent) enunciated a plan to promote R&D in this sector. Even the 11th Five-year Plan has flagged this as a major issue and kept a goal of 1 percent of turnover as spending on R&D. However, in spite of such lofty goals, R&D has stagnated and is currently quite low, varying from 0.15 to 0.3 percent of the turnover. To reverse this trend the draft National Steel Policy 2012 lays out some interesting avenues for increasing this to its stated goal of 1.5 to 2 percent of turnover.

The National Steel Policy 2012 plans to attract both foreign and domestic investment and implement the investment intentions in order to achieve a target crude steel capacity level of 300 million tonnes by 2025-26 for meeting the domestic demand. It plans to ensure that there is easy availability of necessary raw materials and infrastructure to reach a projected production level of 275 million tonnes by 2025-26.

In 2013, India ranked fourth in the world in terms of crude steel production (Government of India, 2014). The first three positions were occupied by China, Japan and the USA. India was the world leader in sponge iron production in 2013. It contributed almost 25 percent to the total world sponge iron production. The quantity of crude steel produced by India in 2013-14 was 81.54 million tonnes. This was higher than the previous year's output by 4 percent. The capacity utilization of crude steel was 82 percent.

Significant Steel Producers in India

There are two categories under which Indian steel producers can be classified i.e. integrated and secondary (Indicus Analytics, 2009). The producers falling under the integrated category have their own plants for iron ore and coke. In these cases iron ore and coke form the main raw materials for the production. Presently three main firms can come under this category i.e. Steel

Authority of India Limited (SAIL), Tata Iron and Steel Co Ltd (TISCO) and Rashtriya Ispat Nigam Limited (RINL). Because of its huge production capacity, SAIL is the largest firm in this group. Companies under the secondary category use steel scrap. They can also use Direct Reduced Iron (DRI). The main secondary producers' category in India mainly consists of JSW Steel Ltd. and Essar Steel Ltd. The major portion of the mild steel production in this country is accounted for by the integrated producers while long steel products are mostly produced by the secondary firms.

Production:

The following table shows the production figures of steel in India.

Table 1: Total Finished Steel Production of India

Year	Total Finished Steel (alloy + non-alloy) (million tonnes or mt)			
	Production for sale	Import	Export	Real Consumption
2007-08	56.08	7.03	5.08	52.13
2008-09	57.16	5.84	4.44	52.35
2009-10	60.62	7.38	3.25	59.34
2010-11	68.62	6.66	3.64	66.42
2011-12 (prov)	73.42	6.83	4.04	70.92
Apr-Dec 2012-13 (prov)	56.72	5.79	3.78	53.53

(Source: Annual Report 2012-13)

The following table shows the crude steel production of India.

Table 2: Total crude steel production of India

Year	Crude Steel		
	Capacity (mt)	Production (mt)	Capacity utlisation (%)
2007-08	59.85	53.86	90
2008-09	66.34	58.44	88
2009-10	75	65.84	88
2010-11	80.36	70.67	88
2011-12 (prov)	89.29	73.79	83
Apr-Dec 2012-13 (prov)	91.66	58.33	85 (based on annualized production)

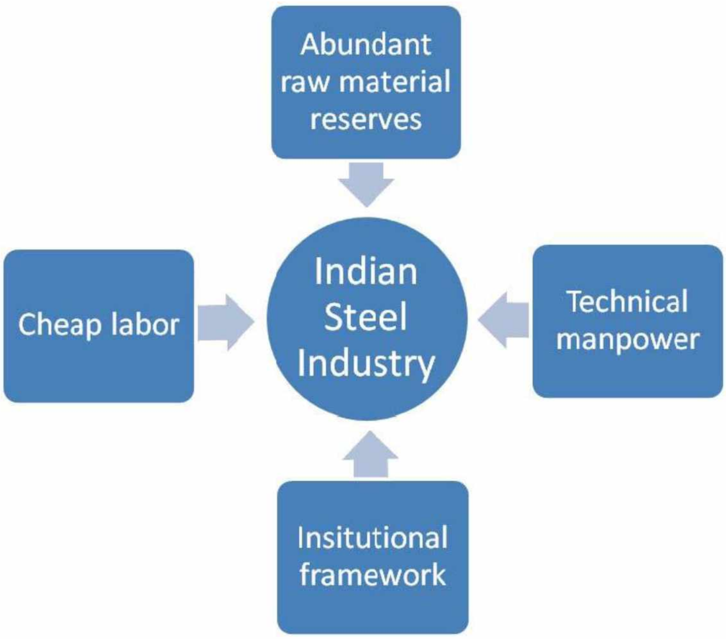
(Source: Annual Report 2012-13)

The CAGR of production of crude steel in India was 7.7 percent through the five years ending in 2011-12 (Annual Report 2012-13). This was the end of the 11th Five-Year Plan. The factor playing a crucial role in the growth of crude steel production was the capacity expansion which took place during this period. On the basis of CAGR the production of total finished steel witnessed a yearly growth rate of 6.9 percent and real consumption showed a growth rate of 8.7 percent during the 11th Five-Year Plan. As growth rate of consumption exceeded that of production India had become a net importer during this period.

Comparative advantage of India in Steel

India is one of the major steel-producing countries of the world. The steel industry of India makes a significant contribution to the GDP of the country (Annual Report 2012-13). Steel is inter-related with many other sectors of the economy. Hence steel has not just a direct impact on the economy but also indirect impacts affecting the output produced by other industries of the economy. India has many strategic advantages when it comes to production of steel. India is well-endowed with mineral resources. Iron ore and coal are two of the crucial components in the process of steelmaking. India has rich reserves of both as well as other raw materials required for the industry (Vadde & Srinivas, 2012). As a result of this the steel industry of India can avail raw materials at very cheap rates. India also has the advantage of a large pool of required labor. This feature lowers the cost of labor for the country. Furthermore, the Indian government has accorded high priority to the steel industry and hence the institutional framework is designed in a way which nurtures the steel industry. The strengths of the Indian steel industry can be presented through the following diagram.

Figure 1: Strengths of the Indian Steel Industry



The above diagram shows the key strengths of the steel industry in India.

The Indian iron and steel industry has abundant iron ore reserves. The iron ore is of high quality and it is more abundant in the eastern part of the country (Corporate Catalyst of India, 2014). Steel plants are spread over the entire country. However, major significant operations in the future are planned to be executed in the eastern region in order to ensure uninterrupted supply of iron ore at a low cost. Orissa is a state which is a preferred destination for steel companies because of its large reserves of raw material and coastline. It accounts for 25 percent of the country's iron ore and 20 percent of total coal supply. India has an advantage in terms of cost of labor. India has a large unutilized chunk of labor force in the agricultural sector (Calis, 2006). Even if urbanization takes place at a rapid pace, the continuous supply of additional labor from the agricultural sector of the will keep wages low.

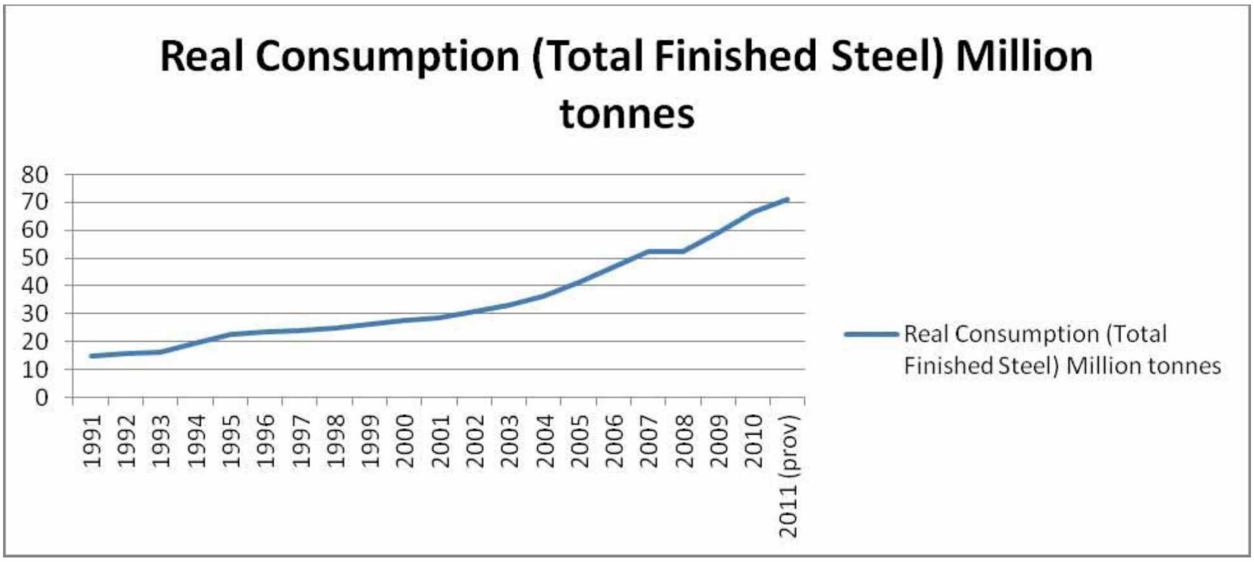
The Indian government has made various institutional reforms with the objective of the development of the steel industry. With the announcement of the new industrial policy, the government has removed many controls on price and distribution (Indicus Analytics, 2009).

Furthermore, foreign investment has been allowed in the sector. There has been liberalization of trade policies and import restrictions have been removed. Tariffs have reduced and steel prices are fixed by market forces. The National Steel Policy of 2012 encourages both foreign and domestic investment in the industry with target of reaching crude steel capacity of 300 million tonnes by 2025-26. It mentions R&D as a key focus area. It emphasizes on the need to research for developing technologies that enable efficient utilization of resources and do not have high environment cost.

Various new plants are coming up in India. India is slowly reaching international standards in terms of its technological developments and efficiency in the process of production (National Steel Policy 2012 (Draft)). India is already strong with respect to the established integrated steel plants and is poised for further benefits as the current capacity of these plants are being modernized and increased. India has a strong institutional structure in place which ensures that an element of competition is present in the industry.

Steel consumption is closely related to the economic growth of the country. According to Han (2012), as the GDP per capita of a country increases steel use per capita increases and reaches the maximum at a particular level. After this stage, with further increases in the per capita GDP the per capita steel consumption declines and eventually stabilizes. Hence it can be concluded that the trend in steel use over the years can point at the economic situation the country is currently in. The following graph shows the trend in steel consumption of India since 1991.

Figure 2: Trend of real consumption over the years



This figure shows that there has been a continuous rise in the real consumption of total finished steel in India. Since steel is a crucial indicator of the performance of an economy, it can be concluded from the above graph that there has been satisfactory economic growth in the country during this period.

Research and Development in Indian Steel Industry

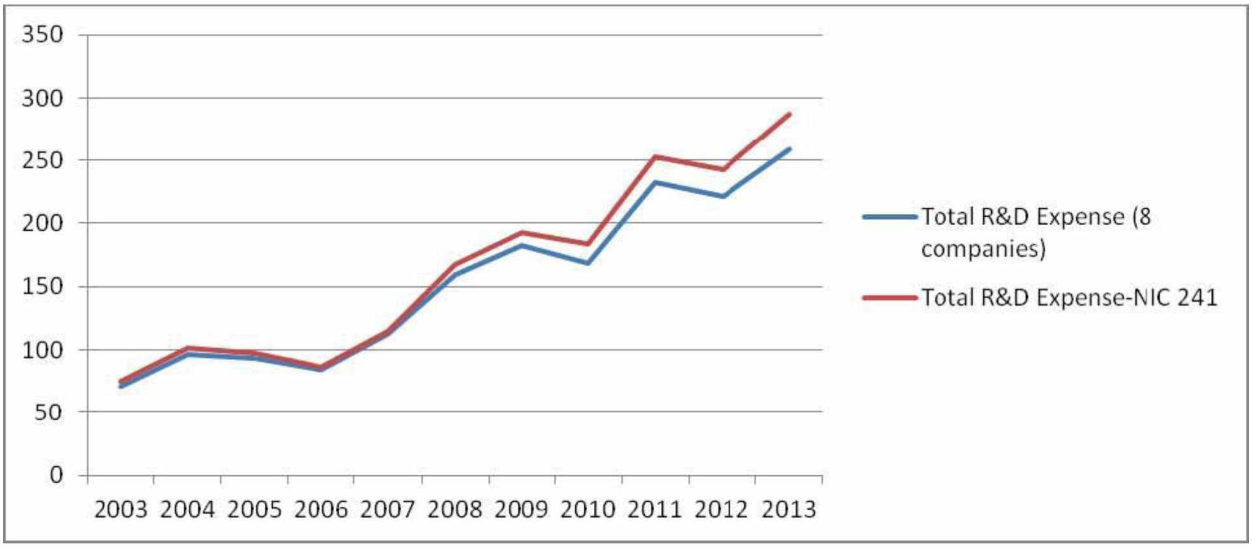
Research and development is crucial for the steel industry. It is necessary for the long term prosperity of the industry. However, the overall investment in R&D in the steel industry has not been up to the desired level. Not all the firms in the industry have consistent R&D expenditure. Gradually, there has been a change in the scenario. While earlier almost the entire R&D expenditure of the industry used to be undertaken by only a handful of firms, there has been some R&D investment by other firms in the recent past.

Model

In this section we are reporting an attempt to establish a relation between R&D expenditure, net sales, import of capital good and paid up equity capital of a select set of steel producers in India. The data has been taken from CMIE database which in turn collects data from the annual financial results of firms. A select set of companies J S W Steel Ltd., Jindal Stainless Ltd., Jindal Steel & Power Ltd., Mahindra Ugine Steel Co. Ltd., Mukand Ltd., Rashtriya Ispat Nigam Ltd., Steel Authority Of India Ltd., and Tata Steel Ltd., who invest in R&D regularly have been identified and analyzed. These firms have been selected because of their significant market shares and consistent R&D expenditure. These selected firms are collectively responsible for a major chunk of the total production of the industry.

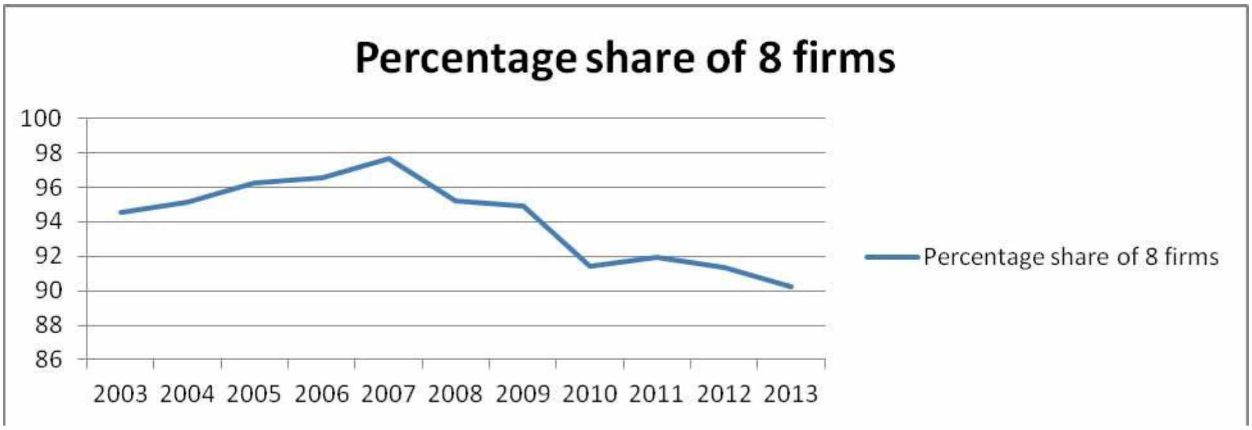
We now show the share of eight firms in the R&D expenditure and net sales of the total steel industry. The firms are JSW Steel Ltd, Jindal Stainless Ltd, Jindal Steel & Power Ltd, Mahindra Ugine Steel Co. Ltd, Mukand Ltd, Rashtriya Ispat Nigam Ltd, Steel Authority of India Ltd and Tata Steel Ltd.

Figure 3: Share of 8 firms in total R&D expense



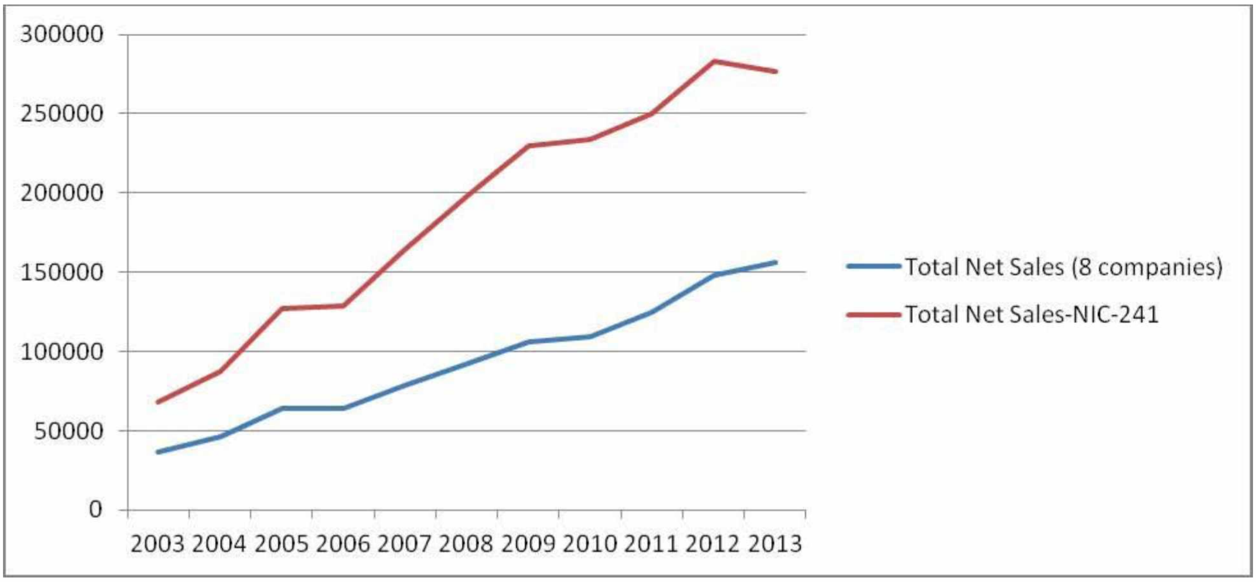
Initially almost the entire R&D expenditure of the industry was undertaken by these eight firms. However, with time more firms are investing in R&D.

Figure 4: Percentage share of 8 firms



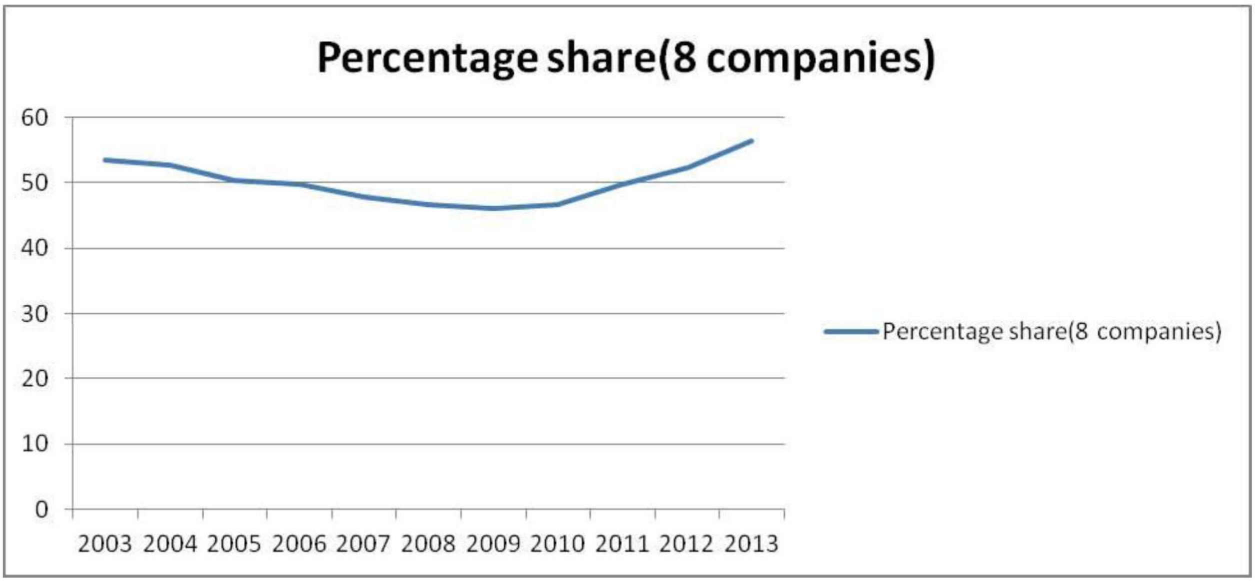
The above graph shows that the share of the eight firms in the total R&D expenditure of the industry rose initially and then declined.

Figure 5: Share of 8 firms in total Net Sales of the industry



The share of the eight firms in the total net sales of the industry has been gradually declining with time.

Figure 6: Percentage share of eight firms



The percentage share of the eight firms in the total net sales of the industry does not show very steep fluctuations.

A panel dataset has been prepared of these company's data from 2003 to 2013. Following log transformation of the variables, the summary statistics are as given in Table 3 below.

Table 3: Summary Statistics of variables.

Variable	Mean	Median	Std. Dev.	C.V.
l_Netsales	8.65838	8.89852	1.33034	0.153647
l_Importofcapitalgoods_cif_	4.27900	5.13480	2.95133	0.689723
l_Profitaftertax	6.52234	7.12660	1.86487	0.285920
l_Paidupequitycapital	5.34665	4.69893	2.25276	0.421341
l_NewR_DExpense	1.74822	1.23944	Std. Dev.	C.V.

Results

The panel data was analyzed using GRETL software. Initially a pooled OLS model was developed followed by a Fixed Effects Model which was rejected in favour of a Random Effects Model after conducting the Hausman Test in which p-value was registered as greater than 0.05 thereby accepting the Random Effects Model.

Random-effects (GLS)

Dependent variable: l_NewR_DExpense

'Within' variance = 0.411418

'Between' variance = 0.0421448

	Coefficient	Std. Error	t-ratio	p-value	
const	-8.65846	0.952618	-9.0891	<0.00001	***
l_Netsales	0.887368	0.189843	4.6742	0.00002	***
l_Importofcapitalgoods_cif_	-0.143881	0.0540674	-2.6611	0.01010	**
l_Paidupequitycapital	0.203676	0.0994951	2.0471	0.04527	**
Dum_Pub	0.00726465	0.321731	0.0226	0.98206	
l_Profitaftertax	0.358306	0.107962	3.3188	0.00158	***

Mean dependent var	2.097085		S.D. dependent var	1.888756
Sum squared resid	21.88095		S.E. of regression	0.614213
Log-likelihood	-56.08130		Akaike criterion	124.1626
Schwarz criterion	137.0214		Hannan-Quinn	129.2200

As the model shows, the coefficients signs are all as expected and that R&D expenditure shows a robust relationship with net sales, profit after tax, Import of capital good and paid up equity capital. The model clearly shows that larger firms will invest more on R&D. Also, the inverse relationship with import of capital good and R&D expenditure is interesting to note and will have implications for the future policy decisions. Profit having a direct relationship with R&D expenditure is also a good indication for policy makers to tailor mechanism of policy and to convince private firms to come into an arrangement of public private partnerships on R&D in future.

Issues in R&D of the steel sector in India

The Indian steel industry is lagging behind many foreign countries mainly with respect to the efficiency and R&D (Ministry of Steel, Government of India). The older plants of the industry suffer from obsolete technology. The industry also suffers from poor quality of raw materials. There is a high degree of alumina in iron ore. Furthermore, there is also the problem of high amount of ash in coking coal. These factors lead to increase in consumption of energy and produces high slag volume. Therefore, it is necessary for the industry to undertake R&D initiatives in order to address these issues for the sustainability of the industry in the future.

SAIL and Tata Steel are two companies that undertake substantial R&D activities (Ministry of Steel, 2011). An important field of research by these companies has been product development. However, major part of their R&D work has been focused on solving existing and short-term problems. There has not been much emphasis on path breaking technologies. The main reason behind this is the low importance given to R&D by the management of the companies. This results in lesser allocation of available resources to R&D. As a consequence of this there is hardly any visionary research initiatives which are aimed at the long-term sustainability of the industry. The amount of money invested by Indian firms on R&D is highly inadequate. It ranges from 0.15 percent to 0.25 percent of the sales of the companies.

The situation of R&D in other countries is markedly different from that of India. China, Japan and South Korea are some of such countries. The steel companies in these countries have stateof-the-art in-house research laboratories. They also collaborate with external laboratories. Academic institutions are also keen enthusiastic in their research on steel. As a consequence of this the R&D investment by steel companies is very high in these countries.

Till date in India minor improvements have taken place in steel technologies (Ministry of Steel, 2011). However, overall the activities have not been adequate. There is very little focus on indigenous technology which is necessary for solving the country-specific problems of the industry. Forming new manufacturing facilities and expanding the existing capacity have been emphasized in private sector investment instead of R&D. Quality control laboratories have also been focused on. Of late there has been some increase in the efforts by growing firms towards setting up of R&D facilities.

As production capacity of the country gets expanded the steel industry of the country should focus on inventing new technologies. This will help the industry to compete on an international level. India has sufficient raw material reserves but adding value to those resources is necessary. This can be made possible through R&D.

Although the technological achievements of the steel plants in India with respect to raw material and energy consumption and adhering to environmental norms has been showing a favorable trend over the years, India is yet lagging behind the plants operating in the developed countries. The reasons why the domestic plants are still lagging behind are poor input quality and obsolescence of existing plant technologies. Improvement in the nature of technology and quality of input can salvage this situation. The benefits enjoyed by the industry due to low cost factors of production i.e. iron ore and labor have been reducing gradually. Efforts have to be made in order to reduce cost and improve the quality through technological initiatives.

Import dependency is very high with respect to coking coal. This is because of the poor quality of the domestic coal. Technological initiatives need to be taken in this regard. Utilization of modern beneficiation processes will improve quantity and quality of the output produced. High gangue content in ore and high ash in coke generates a lot of slag which adversely impacts productivity and energy consumption. Technological intervention that will address this issue is required. In-house technological initiatives in the form of R&D are necessary. New technologies like ROMELT, HISMELT/HYSARNA can be adopted to suit Indian conditions. Moreover, the industry has to focus on product and process development due to the rising customer expectations in terms of quality of steel and grade requirements.

R&D results of public-funded research are not utilized by the industry during the process of steelmaking. In order to generate outcomes of national importance, translational research has to done on these outputs. Translational research in the country needs to be encouraged. Steel Technology Centres in PPP mode can be established in the industrial premises in order to encourage translational research. Human and institutional capabilities of R&D have to be strengthened to widen the R&D base.

There is a need for appropriate manpower from the field of engineering for the development of the industry. R&D in steel industry requires technical personnel who can comprehend latest technologies, solve complex issues and generate innovative solutions. The reasons for the low availability of the desired manpower are complex in nature. The entrance tests which have to be cleared for getting admission in engineering colleges are rigorous in nature. Moreover, after putting the time and financial resources into obtaining the engineering degree, the students prefer better paying jobs than those available in the manufacturing sector. As a result of this the steel industry loses out on quality manpower. Attractive pay packages have to be given to students to join the manufacturing industry. There exists a gap between the needs of the industry and the skill developed in the engineering colleges of the country. Metallurgical engineering as a separate field of study should be given priority. The curriculum should be modified according to the changing needs of the industry. There is a requirement for personnel not just for steel operations as well as R&D. Scholarships given to students pursuing research related to the steel industry should be increased.

In order to encourage R&D in the steel industry the government had decided to fund R&D projects in the iron and steel industry upto Rs 150 crore every year. However, the performance under this has not been satisfactory over the past few years. This is primarily because of inadequate R&D infrastructure in the steel firms.

Case studies of Industrial R&D in Four Indian Steel Corporations

SAIL

Steel Authority of India Ltd. (SAIL) is the largest and fully integrated steel company in India. Both basic and special steels are produced by the firm. It supplies steel to most of the key sectors of India like defence, railways and power, to name a few. It produces a wide variety of steel products. It has five integrated plants. There are three more special steel plants owned by SAIL. These plants are located strategically close to the raw material sources. It is a Maharatna of the country's Central Public Sector Enterprises. SAIL had 101878 employees as on 31st March, 2013 (Steel Authority of India Limited, 2013).

SAIL has its own research and development facility, Research and Development Centre for Iron and Steel (RDCIS), which is located at Ranchi. It aids in the production of quality steel and also conducts research in order to design novel technologies which are beneficial for the steel industry. Other than this, there are Centre for Engineering and Technology (CET), Management Training Institute (MTI) and Safety Organization, which are in-house facilities of SAIL. Furthermore, SAIL has the Environment Management Division and Growth Division which have their headquarters in Kolkata. RDCIS works on various projects in different spheres of iron and steel technology. It employs 236 scientists and engineers. The laboratory has 300 modern diagnostic research equipment (Steel Authority of India Limited). In the future, the focus of RDCIS lays on helping plants achieve full capacity, implementing the R&D master plan, participating in the development of new products and encouraging collaborative research efforts. The research themes under which RDCIS plans to conduct research are coke and coal technology, raw material technology, blast furnace technology, steelmaking, casting technology and refractory, conservation of energy, rolling technology, automation and engineering and product development technology.

Collaboration of SAIL:

In 2010, SAIL entered into collaboration with Kobe Steel Ltd of Japan. The collaboration areas cover technology and projects (Kobe Steel,2010). The feasibility of a joint venture which uses ITmk3 iron-making process of Kobe Steel Ltd is being studied by the two firms. Special research works will be undertaken with respect to finished products. These products will be automobile products, products for power plants (nuclear and conventional), special alloy steel, bars and stainless steel tube to name a few. RDCIS has entered into an agreement with UNDP/PMC and Ministry of Steel, Government of India for updating document on "Data gathering and analysis of Eco-tech options" in the rolling mill sector of steel in India. Another MoU was signed with M/s IOC, Mumbai, for developing Roll-Bite lubrication technology required for Hot Strip Mill. Both these projects have been completed. It has also entered into an agreement with M/s. HIsmelt Corporation Pty. Ltd., Australia, for developing a process of iron making with domestic non-coking coals through the HIsmelt/HIsarna process. Along with coals iron ore fines are also used for developing this process.

Tata Steel:

Tata Steel has the reputation of being the first integrated private steel company of Asia. It was established in 1907. Today it globally ranks second in terms of geographical diversification. In the year 2008, Tata Steel India won the Deming Application Prize 2008 for Total Quality Management. It became the first integrated plant globally outside Japan to win this. Furthermore, in 2012, it won the Deming Grand Prize 2012. Tata Steel built India's first integrated steel plant in Jamshedpur in 1907. The company also has two projects in Jharkhand and Chattisgarh in the pipeline. The company gains its competitive advantage from the ownership of mines. Hence it has necessary control over raw material sources. Some of its products are agricultural implements, bearings, auto components, tubes and wires.

The research and development centres of Tata Steel are located in IJmuiden in Netherlands, Rotherham and Cleveland in the UK and Jamshedpur in India (Tata Steel). Raw materials, blast furnace productivity, steelmaking process, development of new products and improvement of existing processes are mainly the spheres on which R&D in conducted. The research teams of Tata Steel are working on development of products. Automotive sector research involves developing high strength steels, novel forming techniques, advanced joining techniques, innovative coatings and longer component life. The research teams also focus on the life cycle and sustainability of the products. Tata Steel has 35905 employees as on 31st March, 2013.

Tata Steel R&D centre in Jamshedpur has modern facilities for carrying out research. The centre is well-equipped with crushers and magnetic separators (Tata Steel). It also has shaking tables and latest microscopes. Its facilities include Beneficiation Laboratory, Pot-grate sinter Laboratory, Pelletization Laboratory, High temperature Laboratory, Blast Furnace models laboratory and a facility for softening and melting test. In addition to these it has Water Modeling laboratory, Corrosion Laboratory and many NDT facilities. The computational facilities, tools for thermodynamics and multiscale modeling are also commendable.

The following diagrams show the trends of the performance indicators of the company.

Collaboration of Tata Steel:

Tata Steel (Europe) has collaborated with Dye Solar Cell (DSC). It began in 2006 with Corus (Dyesol). However, eventually Tata Steel Europe bought it. The objective is to add DSC photovoltaic technology into the steel used for manufacturing roofs. The technology is environment-friendly in nature. If this technology is used by building for their roofing it will reduce the carbon footprint of the structure. This is a great initiative towards a green future. In FY2012, this collaboration of Dyesol and Tata Steel Europe completed a study on process capabilities and intellectual property on metal applications. Tata Steel has collaborations with Central Institute of Mining & Fuel Research- Dhanbad, Indian Association for the Cultivation of Sciences and Bidhan Chandra Krishi Vishwavidyalaya, Nadia, for research on raw materials. In the field of products and product applications it has collaborations with IIT-Kharagpur, IIT-Powai, IISc-

Bangalore, Jadavpur University and Pune Engineering College. In ironmaking and steelmaking it has collaborations with National Metallurgical Laboratory, IIT-Delhi and International Advanced Research Centre for Powder Metallurgy and New Materials. Finally, in the sphere of environment and new technology it has collaborations with Technofour, Pune, IIT-Madras, JAMIPOL- Jamshedpur and Associated Chemical Technology- Jamshedpur.

JSW Steel:

JSW Steel is one of the leading private steel companies in India. It is valued at $9 billion and is present in over six regions in India. It has made its presence felt in US, South America and Africa. The company focuses on the use of innovative technology for its production. The company has struck certain key partnership agreements with global giants like JFE Steel, Marubeni Isuzu Steel, Praxair and Severfield Rowen Plc (JSW Steel). The advanced technology has helped the firm in becoming one of the lowest-cost steel producers across the globe. The company's focus on technological development has made it famous across the world for its high-end, value added steel. High value steels make up almost 40 percent of the company's products today. The company has set a target of 50 percent. It produces a variety of products including galvanized steel, rebars, color coated products and wire-rods.

In the next five years, JSW Steel plans to focus its R&D initiatives on developing technology which increases the magnetic susceptibility of BHQ ores and slimes for maximization of recovery, synthetic coke through the utilization of non-coking coals, slag kinker, integrated process control system which will lead to energy and emission optimization, advanced steel grades, well-developed process control systems, cost-efficient products. It also plans to emphasize on developing technologies which will enable process waste recovery, recycling and CO2 sequestration.

Collaboration of JSW Steel:

JSW Steel collaborated with JFE Steel in 2012. JFE will supply the technology that will help in producing non-oriented electrical steel sheets at the Bellary plant of JSW (Kulkarni, M. 2012). JFE Steel has a reputation for its manufacturing technology required for electrical steel. This shall help JSW in producing CRNGO grade electrical steel. JSW will then supply these to its customers which comprises local and foreign-affiliated firms operating in India.

NMDC

NMDC Ltd is fully owned by the Indian government. It was established in the year 1958. The steel ministry exercises administrative control over the company. Since its formation, the company has been exploring many minerals. Some of the minerals are iron ore, copper and dolomite. Its R&D Centre is ISO 9001 certified. The 'Centre for Excellence' status in the sphere of processing of minerals has been conferred upon it by the expert Group of UNIDO. It has made commendable contribution to the mining sector of the country. It has been declared a 'Navratna' Public Sector Enterprise in 2008. The ore generated from its Bailadila sector mines is excellent in nature. Because of this it has replaced the iron ore pellets in the process of sponge iron making. As a result of this, it has become a crucial raw material provider to Essar Steel, Ispat Industries and Vikram Ispat. Furthermore, it is responsible for the provision of the entire raw material requirement of the Vishakhapatnam Steel Plant.

In the future, NMDC plans to research the impact of synthetic flux which is made out of iron ore slime and calcined lime in BOF. Developing an eco friendly tailing disposal system, studying the caking behavior of fine bulk solids and the impact of the same on silo design parameters, researching the utilization of Dolo-char waste in iron ore sintering processes so that it can replace coke to some extent form some of the core issues it intends to do in the next five years. Furthermore, recovering iron values and pure silicon dioxide from the remains of lean grade iron ore tailing, studying value addition to the scale of the mill and studying beneficiation with goethite rich iron ores of the country are also on the company's research agenda.

Collaboration of NMDC:

In collaboration with M/s Carbonite, NMDC is trying to improve coke quality (NMDC Limited, 2013). It has collaborated with IMMT-Bhubaneswar for developing entrained flow-Gasification System through the utilisation of non-coking coal (F-grade) mixed with dolochar for the purpose of thermal applications. It has collaborated with IIT-Hyderabad for the improvement of the efficiency of Dense Medium in the separation of high NGM coal samples. This will be done through GPU based CFD method and also PEPT method. Another project plans to optimize energy for comminution for hard ores. This project targets energy optimization for the purpose of beneficiation of inferior grade iron ores. It has entered into collaboration with JNTU- Hyderabad for critically analyzing Accretion formation (Ring) in the Rotary kiln process at SIU, Palvancha. Characterization and beneficiation studies are the focus areas for NMDC's collaboration with CSIRO, Australia. It is also engaged in collaborative works with NML- Jamshedpur and IIT-Chennai.

Comparison of the firms on the basis of some performance metrics

The following portion contains inter-firm comparison on the basis of some common performance metrics.

Figure 7: Trend of R&D expenditure/Completed projects

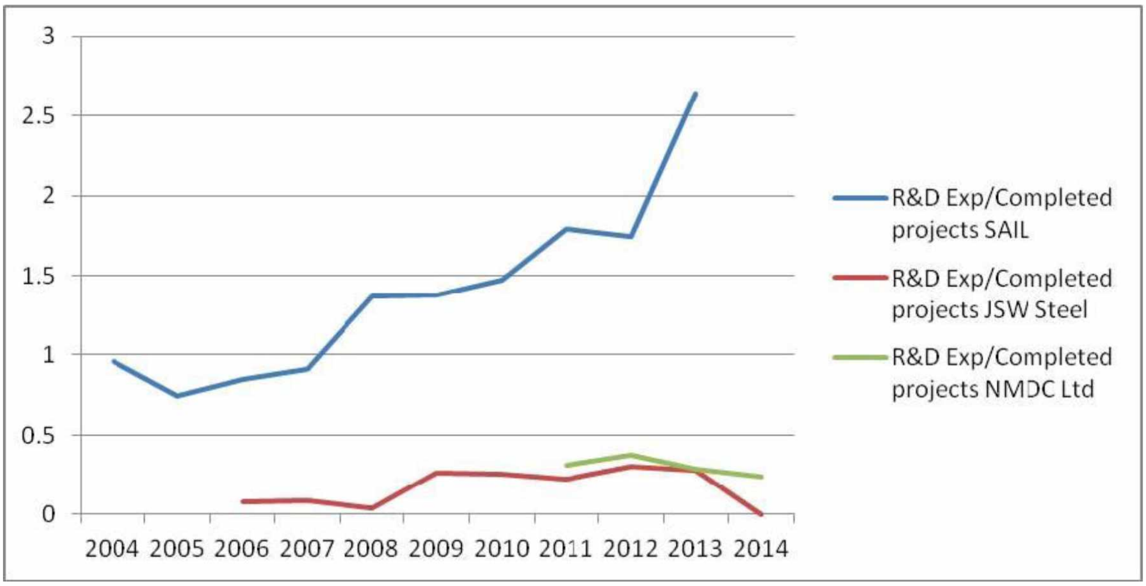
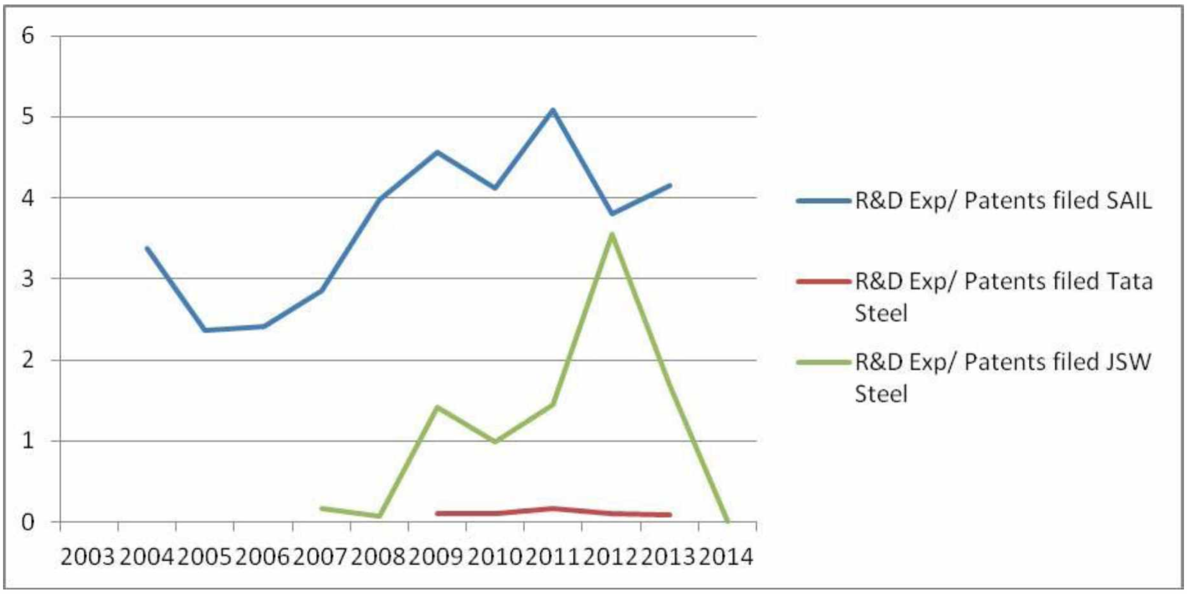
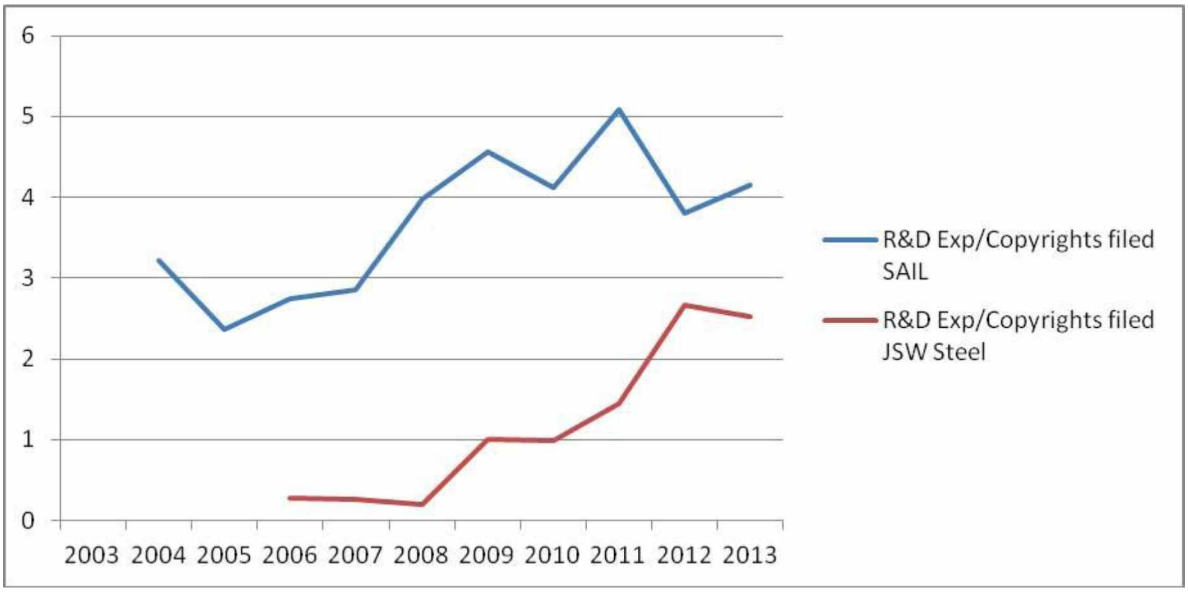


Figure 8: Trend of R&D expenditure/Patents filed



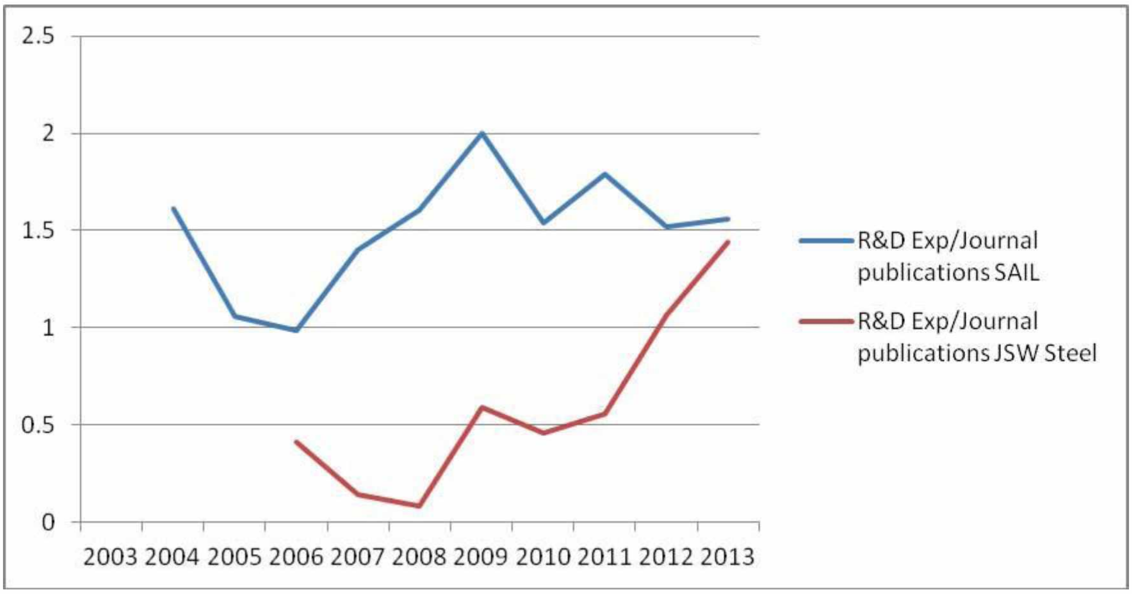
Although, throughout SAIL is leading among all the firms, in 2012 JSW Steel came almost at the same level as SAIL but then it reduced.

Figure 9: Trend of R&D Expenditure/Copyrights filed



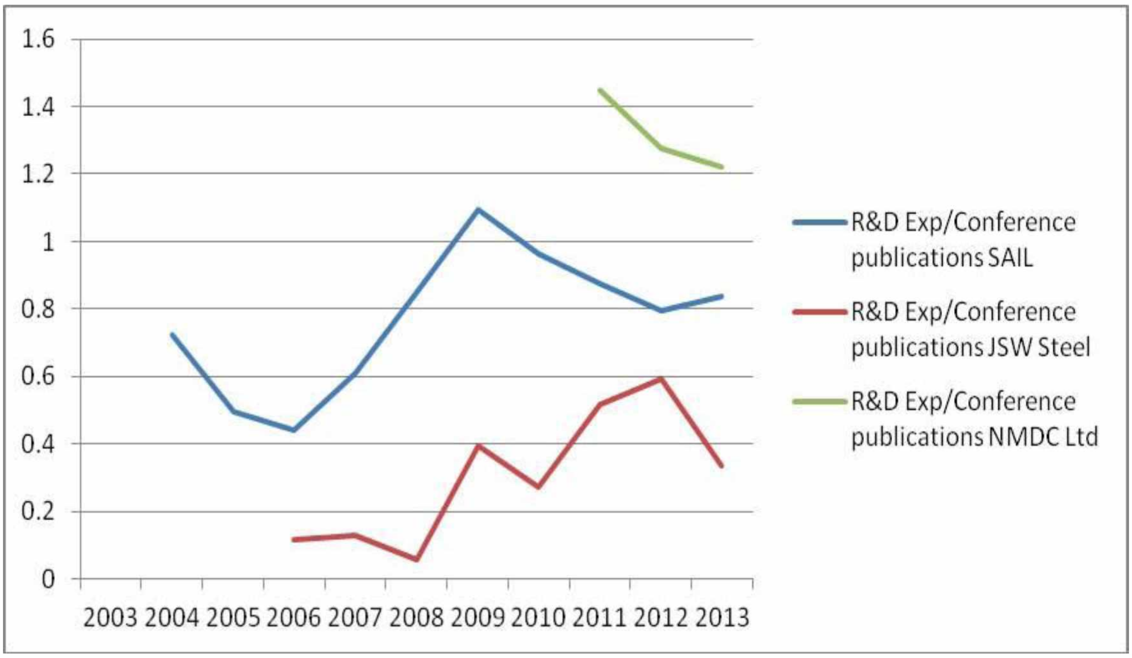
SAIL is clearly leading in this parameter also. SAIL saw a drastic fall in 2012 but then it improved again.

Figure 10: Trend of R&D expenditure/Journal publications



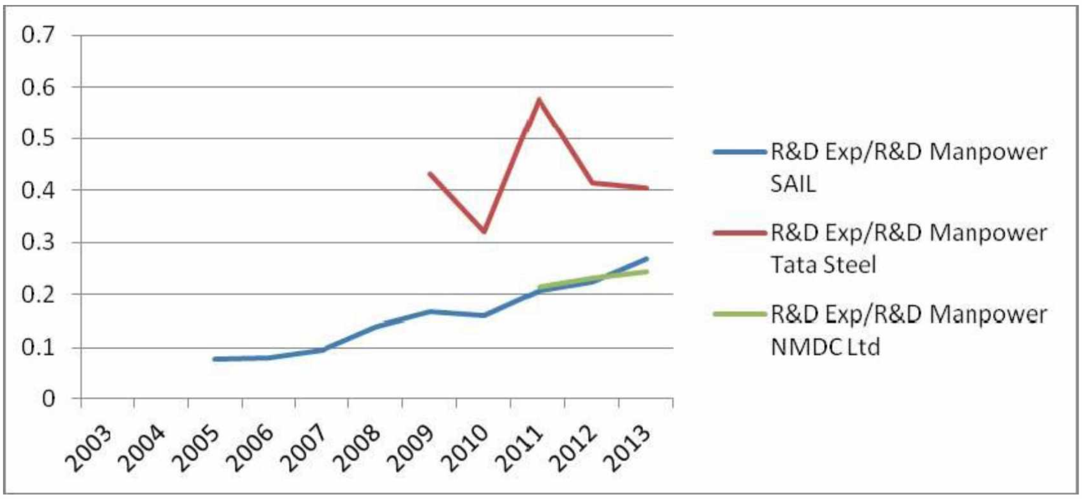
Although SAIL has been leading throughout, JSW has almost reached the level of SAIL. JSW Steel improved drastically after 2011.

Figure 11: Trend of R&D expenditure/Conference publications



NMDC is leading in this parameter. There is a large gap between NMDC and SAIL.

Figure 12: Trend of R&D expenditure/ R&D manpower



Tata Steel is leading by a large amount in this parameter. NMDC and SAIL are almost at the same level after 2011. In collaboration with M/s Carbonite, NMDC is trying to improve coke quality (NMDC Limited, 2013).

Recommendations and conclusion

1. Funding

a. Increasing investment in R&D through PPP:

The model developed in the earlier section clearly shows, the coefficients signs are all as expected and that R&D expenditure shows a robust relationship with net sales, profit after tax, Import of capital good and paid up equity capital. The model clearly shows that larger firms will invest more on R&D. Also, the inverse relationship with import of capital good and R&D expenditure is interesting to note and will have implications for the future policy decisions. Profit having a direct relationship with R&D expenditure is also a good indication for policy makers to tailor mechanism of policy and to convince private firms to come into an arrangement of public private partnerships on R&D in future. Hence the government should shed its pro SME focus with respect to engaging with industry and prepare scheme that encourages big firms to engage with the government to increase R&D spending. The R&D scheme under SDF in Ministry of Steel needs to be strengthened as only about 180 crores have been spent on R&D since the inception of the scheme a score years ago.

b. Reverse the mechanism of funding R&D At present all R&D in steel industry is based on the interest of the principal investigator to conduct a particular kind of research. The present mechanism of funding R&D is that the PI submits a proposal based on his capability and interest which then gets vetted at different levels and after a due diligence process the funds are transferred to the PI. This needs to change to a EU type format in which the government after due process identifies a set of major R&D gaps in steel R&D and invites proposal from PIs to bridge those gaps. A competition amongst PIs will improve the quality of proposals and the government will through this mechanism ensure that the R&D is aligned to national priorities in its steel industry vision.

c. Collaboration: The government must therefore ensure that the end result of its funding of R&D in this industry reaches the ultimate beneficiary which is industry. Hence every R&D project must ensure that they have a strategy for dissemination of the results and translating the benefits to industry. Hence it is advisable that each such project have a industry partner who would be willing to invest a part of the money of the R&D project and be willing to take up the results of the project for implementation in its units.

d. Dissemination: The results of the R&D should be disseminated in conferences, workshops for wider traction of the results. All firms in the industry must be made aware of the findings of each R&D projects. This will ensure that there is no repetition of work.

2. Investing in building capability

The other problem of R&D in the steel industry is that good quality manpower is not readily available. Since R&D in steel has been neglected for more than a decade and half, the R&D facilities in academic institutions have not grown beyond the traditional pockets in the eastern part of the country. In fact, there is a handful of academic institutions that develop manpower in steel R&D. Even in these institutions, due to the isolation of academia from the industry, the quality of R&D manpower beign developed is not industry ready. The focus of academic institutions on Material Science as a frontier field of research and thereby neglecting traditional fields that the steel industry needs like Metallurgy etc., is also another reason for the morass in steel R&D in academia leading to poor quality R&D manpower being produced in such organizations. The government therefore needs to come up with a concerned initiative to rejuvenate steel related R&D in academic institutions so that the R&D manpower available in such institutions is gainfully employed in pursuit of achieving competitive advantage for Indian Steel and as a secondary benefit, the upcoming R&D manpower being developed in these institutions can also be developed according to industry standards.

3. Change management practices in industry

a. Low priority for R&D: A series of visits to industrial R&D units across the country and across public and private sector revealed that R&D has over the years lost its pride of place in these organizations. The rationale for having such elaborate R&D infrastructure in these industrial units when they came up was import substitution. Following the liberalization of the country in 1991, technology acquisition from foreign sources became easy and routine. Instead of focussing on import substitution, companies began acquiring technology en mass from foreign countries to become competitive. Domestic and internal R&D of these companies therefore lost focus. Over the years the manpower strength in many such industrial units were drastically reduced. In RDCIS the R&D manpower today is less than half its peak strength in the 80's. It is only now in recent years that the industry has woken up to the need to cultivate their own internal R&D. This trend too is only evident in the forward looking private steel manufacturing companies like Tata Steel and JSW Steel. These companies have now realised that investing in R&D yields results and that to remain competitive in both the domestic market and in international markets, internal R&D has to be strengthened. This new found enthusiasm in private steel manufacturers for R&D is also due to the fact that many companies are facing quite insurmountable problems regarding the availability of quality ores and coal. Since the solution to such India specific problems cannot be found in acquiring technologies from foreign shores, the industry is depending on internal R&D talent to solve such problems. Whatever the reason, the trend of renewed emphasis on R&D by some steel companies is a welcome trend, which in turn needs to be supported by the government. For the first time in many years, the industry seems to be convinced about the need for domestic R&D and is investing on its own in creating mammoth R&D infrastructure, not just for tax benefits and other secondary benefits but to leverage R&D for increasing their competitiveness. The government therefore needs to create a national plan for R&D in steel with partnership from industry.

b. In many companies especially in public sector companies, R&D is considered as a punishment posting with no incentives for growth. The major issues of people posted in R&D are

i. Very few opportunities for growth

ii. Engineers prefer production related jobs for easier promotion option

iii. Low level of collaboration

R&D management practices not followed and same practices of plant are followed. While R&D needs special focus of HR, the same is not extended to R&D professionals

Innovation management in not the focus.

Even though Steel is categorized as a medium low technology industry by OECD classification, the benefits of investing in R&D is quite substantial. India has a fairly good capability in R&D in steel and can augment it to create a competitive advantage. Post 1991 liberalization of the economy in the country, R&D has not been given the focus it deserves, resulting in lowering of internal capability of the industry to cope with competition and crisis of raw materials in the near past. However, the above measures will help the R&D in this industry to emerge stronger in the near future. Due to the strong historical background of R&D in this sector, the absorption potential of funds is also high making it the right industry to invest in.

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About NSTMIS:

The National Science and Technology Management Information System (NSTMIS), a division of Department of Science and Technology (DST) has been entrusted with the task of building the information base on a continuous basis on resources devoted to scientific and technological activities for policy planning in the country.

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