Factors Influencing Innovation and Competitiveness in the Steel Industry

Working Paper 059

By

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1. Introduction

The history of the U.S. steel industry plays an important part in explaining the industry’s current sources of technological innovation, including it’s state of R&D activity. In the 1980’s, the U.S. steel industry experienced a devastating economic decline due in part to foreign competition. (see Hoerr, 1988) In the 1980’s alone, half of the 0.5 million work force employed in the U.S. steel industry lost their jobs, production of raw (unfinished) steel in the U.S. declined by more than 12 percent, and plant closures and downsizing brought the U.S. industry’s production capability down twenty-five percent. (Ahlbrandt et al., 1996) Amid financial pressures, the industry’s internal R&D operations experienced overall decreases of up to 75% in research staff budgets throughout the 1980’s. (Dennis, 1991; Fruehan, 1996)

In response to this disastrous economic decline, the integrated steel industry restructured itself. Both, established integrated producers and smaller minimill and specialty operations† in the U.S. steel industry contributed to an improving competitive position in the global marketplace. The large, integrated producers who restructured successfully did so by setting a clear vision of the industry’s future and communicated that vision throughout the company in a decentralized decision-making setting. The strategies embraced by these steel companies include elements of cost reduction, responsiveness to customers’ needs, quality, and productivity. Also, “the rejuvenation of the large integrated steel plants has been accomplished in a large part because of greater market orientation and more attention to the involvement of the work force in the decision-making process.” (Ahlbrandt et al., 1996) The improved economic condition is reflected in the industry’s investment in over 20 million tons of new capacity in the 1990’s.

Presently, the U.S. steel industry is going through a rapid technological revolution where major technological changes will continue to occur rapidly‡ even though research capabilities in the industry have been greatly reduced in the last fifteen years. For these reasons, the steel industry is an interesting case study in which to examine sources of innovation, R&D management practices, and the types of R&D conducted in an environment where competitive, technological, and economic obstacles must be overcome.

In this paper, changes in the steel industry’s production and financial performance, and changes in the structure of innovation and R&D activity in the steel industry over the last two
decades are discussed in Section 2 and Section 3, respectively. Section 4 presents major factors other than technological innovation that have influenced the steel industry's competitiveness, and their impact on the industry's innovation processes. The relationships between changes in the steel industry's financial and production performance, and the industry's innovation performance in the last few decades through the present are discussed in Section 5. Lastly, a summary and conclusions are presented in Section 6.
2. Changes in Industry Performance

A National Academy of Science steel industry study (Hannay & Steele, 1986) conducted in 1985 highlights the then present decline of the U.S. integrated steel industry, and states that the steel industry is no longer technologically progressive. The study found that of only 28 process advances under development, only direct reduction and continuous casting were likely to be adopted in the next five years. The lack of R&D activity in new process development was attributed to the high capital cost of the research, and low estimates of return on investment. As had been the case in the decade prior to 1985, the study concluded that leadership in technology alone would not rescue the domestic steel industry from its current economic slump; other factors such as foreign pressures on price and capacity, labor productivity, cost of raw materials, energy, labor, plant location in relation to markets, and future estimates of production over-capacity continue to harm the present and future economic vitality of the domestic steel industry. The following section examines the production, productivity and financial performance changes that have taken place in the U.S. steel industry for the last two decades.

2.1 Production and Market Share

The U.S. steel industry once dominated the world in the overall production of steel, but by the early 1980's, the U.S. steelmakers' share of the world steel market fell to approximately 10% due to foreign competition's expanded capacity and their implementation of new and improved technologies. In fact, by 1983, the Japanese market share in the world steel market had grown to 16 percent. Since that time, Japanese growth has slowed and its market share has decreased while the U.S. has made a partial comeback due to the downsizing and restructuring of the integrated mills and the strong entrance made by U.S. minimill producers.

For the last twenty years, production capacity in the U.S. has always exceeded the actual production of raw steel. (see Figure 2-1) This gap was largest in the early 1980's when imports of raw steel had also reached their highest point at 25 percent or more of the apparent U.S. steel supply. In 1983, the gap between capacity and production was about 75 million tons. Recently, this gap has narrowed significantly to about 10 million tons in 1994. In comparison with the world market, capacity has exceeded production by over 200 million tons for the last fifteen years. The
production gap has improved because the U.S. steel industry, especially the integrated producers, have improved their efficiency from a decade ago, and now are one of the lowest cost producers for their market. In addition, an improved capital investment per worker-hour ratio has increased productivity.

![Graph](image)

**Figure 2-1** U.S. Raw Steel Production and Capacity

In steel product markets where minimills have competed with integrated producers, the minimills have gained market because of their lower costs and resulting lower prices. The ability of the minimill to efficiently produce many types of steel products still exerts a constant pressure on the integrated producers. Today, U.S. minimill producers such as Nucor rank among the most efficient steelmakers in the world. (Fruehan et al., 1997) Most recently, integrated steel firms in developing countries such as Korea have become leaders in production efficiency which has supported a dramatic rise in profitability and market share. In fact, the Korean firm POSCO is currently the world’s most profitable integrated steelmaker, and arguably the most efficient. (Lieberman & Johnson, 1995) Brazil, another developing country, has also improved in production efficiency, and with its low labor costs may soon become a major factor in the global steel market.

2.2 Productivity

The U.S. steel industry has made remarkable improvements in productivity in the past 15 years. The usual measure of labor productivity is measured as man hours per tonne of steel produced.
The following section discusses the changes in labor, capital and total factor productivity in the U.S. steel industry over the last three decades. The section is based heavily on a study of productivity in the steel industry performed by Lieberman and Johnson (1995).

2.2.1 Labor Productivity
A standard measure of productivity in the steel industry has been labor productivity measured in labor-hours per ton produced. The labor productivity of the U.S. integrated producers has lagged behind foreign competition since the 1960’s. Furthermore, the integrated firms’ labor productivity has remained stagnant for almost two decades since 1964. However, labor productivity began to improve for U.S. steelmakers from a range of 7 to 14 labor-hours per ton in the early 1980’s to approximately 5 labor-hours per ton a decade later. (see Figure 2-2) In contrast, the labor productivity of Japanese steelmakers has remained steady at about 5 labor-hours per ton since the early 1970’s with only small incremental gains.

Figure 2-2 Labor-Hours per Ton Produced: U.S. Steel Firms

In addition to improvements throughout the 1980’s, further improvement in labor productivity has occurred in the U.S. steel industry in the 1990’s. This is illustrated in Figure 2-3 which shows the labor-hours per tonne for two major integrated producers, Bethlehem and U.S. Steel, and the largest scrap-based producer, Nucor.
NOTE: Labor-hours per tonne based on the metric ton (1000kg).


**Figure 2-3** Labor Productivity at U.S. Steel Firms

Although a standard measure, labor-hours per ton fails to account for differences in the extent of diversification and vertical integration by firms, nor does the measure account for differences in steel “quality” and the extent of finishing operations. Also, different companies measure labor-hours differently, and issues such as contracting and outsourcing bias the statistics. For example, in Japan over 50% of the non professionals in a plant are contract workers while in the U.S. this figure has increased as high as 25% in some plants. The total number of labor-hours per ton may be 20% higher in Japan and 10% higher in some U.S. plants. In non-union plants, the percentage of contract workers is generally lower, and in some cases zero.

To account for this bias, Lieberman and Johnson (1995) also measure labor productivity in terms of value-added per worker-hour which accounts for employee effort and the use of capital. Using the value-added metric, Figure 2-4 shows that labor productivity for U.S. steel firms remained stagnant between 20 and 25 value-added dollars (1980 U.S. dollars) per worker-hour up until the early 1980’s and began rising through the early 1990’s to between 28 and 38 value-added dollars per worker-hour. In comparison with the labor-hours per ton, the trends for labor productivity show steady improvement since the early 1980’s. In contrast, Japanese steelmakers show a dramatic increase in value-added per worker-hour increasing almost ten-fold since the late 1950’s, and ending between 38 to 48 value-added dollars per work-hour in the 1990’s. However, this dramatic increase is due heavily to the exclusion of workers who were dispatched to
unconsolidated subsidiaries and the heavy outsourcing initiated by Japanese steel firms, both of which were common practices in Japan that became frequent in the 1980’s.

**Figure 2-4** Value-Added per Worker-Hour: U.S. Steel Firms

2.2.2 Capital Productivity

Prior to 1980, the capital intensity of U.S. steel firms, measured by capital investment per worker experienced little growth. Because integrated steelmaking is a capital intensive and competitive global industry, U.S. producers found it difficult to earn the rates of return necessary to justify substantial new investment. In fact, no new integrated steel plants have been built in the U.S. in the last 35 years, and only recently has the industry invested in additional production capacity. (Fruehan et al., 1997) However, Figure 2-5 shows that U.S. capital intensity grew from a fixed investment per worker that was below $70,000 in 1980 to over $100,000 in 1993 driven primary by the massive downsizing at U.S. steel firms in the 1980’s. In contrast, when compared with Japan and Korea’s capital intensity throughout the 1980’s, the U.S. investment per employee is less than half that invested by Japan and four times less than Korean firms. These differences reflect slightly leaner staffing by Japan and Korean firms, and also higher rates of plant and equipment investment. However, one should note that the Korean government provided heavy subsidies to their steel industry, and the Japanese banking system encouraged heavy investment in the steel companies. (Fruehan et al., 1997)
2.2.3 Total Factor Productivity

Total factor productivity, which is regarded as a more appropriate measure of overall efficiency in production plants, is a weighted average of labor productivity and capital productivity. From the late 1950’s to the 1990’s, the total factor productivity of U.S. steel firms rose about 50 percent. (see Figure 2-6) In comparison with the Japanese and Korean steel industries, the total factor productivity for all three countries in the 1990’s is roughly equivalent. Interestingly, the steel industry in all three countries have shown very different trends in their capital and labor input, but they have each arrived at comparable efficiency levels in the last decade.
2.3 Quality Improvement

In addition to productivity improvements, steel quality has also improved dramatically in the U.S. during the last fifteen years. This has resulted primarily from technological advances such as secondary refining and continuous casting. However, it also has improved due to people working smarter. Training, continuing education and quality control have been critical in quality improvements.

One measure of quality improvements is customer acceptance. The U.S. steel industries most critical customer has been the automotive industry. A decade ago, rejection rates for steel of poor quality at automotive companies were typically three to six percent. Today, the rejection rates are about 0.5% which is a ten-fold improvement. Another example of quality improvements are the new steel grades and types that have been introduced. Over half of the steel grades or steel types produced today did not exist twenty years ago. An example of new steel grades are the corrosion resistant steels. Prior to the introduction of these new grades, automobiles in the northern U.S. would experience extensive corrosion or rust within five years. Today, automobiles which incorporate these new steel grades last fifteen years or longer before extensive corrosion and rust occurs. Furthermore, steels are stronger, lighter and more formable for specific applications and the production of complex products.

A significant driver for many of these quality improvements in the U.S. were the Japanese automobile transplants. They demanded higher quality steels than were previously produced, and they also required extensive quality control within the steel production plants. Once it was clear these high quality steels could be produced, the US automotive firms and other industrial manufacturers soon demanded similar quality from the steel industry.

2.4 New Products and Processes

It is difficult for the average consumer to realize that steel production is continually evolving, and that new steel products have been developed and are now in common use. Conventional thinking is that all steels are similar and haven’t changed. The fact is, half of the steel grades or types produced today did not exist fifteen years ago. Examples of these new steels include:
• **Corrosion Resistant Steels:** These are steels with a much higher corrosion resistance than conventional steels. The past decade has witnessed a significant improvement in the manufacture of corrosion resistant steels, particularly the development of new coating and galvanizing processes, as well as new methods of applying these coatings. New galvanizing processes include electric galvanizing and hot dip galvanizing which involve zinc and zinc-alloy coating of carbon-steels for increased corrosion resistance.

• **High Strength Low Alloy (HSLA) Steels:** These steels are much stronger than traditional steels and can reduce the amount of material required in the production, thus reducing the total weight of the steel. The steel industry has developed various HSLA steels whose strength parameters are based on different strengthening mechanisms. These include Micro Alloved Steels, Phosphor Alloved Steels and Bake-Hardening Steels.

• **Interstitial Free Steels:** These steels contain less than 50 ppm (parts per million) carbon, 20 ppm sulfur and 20 ppm nitrogen (called interstitial elements) and can be formed into intricate shapes without flaws. These steels are used extensively for exposed applications in the automotive industry. In the past two decades, building on basic research in materials science, a series of process developments have occurred, reducing the total concentration of these interstitial elements. These processes include clean steel ladle processes and vacuum degassing.

The development of these new steels was primarily driven by customer demand (Fruehan et al., 1994). However, new processes made it possible to produce new steels with superior properties, and some of those products were developed before there was a market demand for them. New processes were generally developed to allow the production of better quality steel or to reduce the cost of production.

Several major processes which have been developed or implemented by firms in the steel industry in the past decade are listed below:

• **Continuous Casting:** This process was developed previously but it's implementation grew from 30% of total U.S. steel production in 1980 to virtually 100% in 1995. This growth could only occur if a number of technical hurdles were overcome, which allowed the casting
of all grades of steel and improved quality with respect to surface imperfections and cracks. These improvements have proceeded incrementally and have resulted partly from an understanding of the reactions in the casting mold and partly from the development of casting models.

- **Secondary Refining:** This includes a number of processes such as desulfurization, inclusion removal, and reheating, which improved productivity and steel quality significantly. They also provide steelmakers much greater control over the composition of their steel output. The importance of these processes is highlighted by the fact that close to half of all steel is treated in a secondary refining vessel.

- **Vacuum Degassing:** This process involves the treatment of steel in a vessel under a vacuum. There are several types of vessels including recirculating degassers (DH, RH & RH-OB vessels) where only a portion of the steel melt passes through the evacuated area at any one time, and non-recirculating degassers (vacuum oxygen decarburization & vacuum arc degassing vessels) where the whole melt is exposed to the vacuum at the same time. All these processes degas the steel by introducing oxygen or an inert gas such as argon to the melt. These processes have allowed for the production of interstitial free steels and other special quality steels which represent over 20% of the total U.S. production of steel.

- **Electrogalvanizing:** New processes were developed to improve the coating and, hence, the corrosion resistance of steels. These coatings usually involve the application of zinc or zinc-alloys to the carbon steel.

- **EAF High Productivity:** A number of process improvements, including ultra high power furnaces, carbon and oxygen injection, water cooled panels, etc. increased productivity by 200% and decreased electrical energy consumption by 30%.

2.5 Financial Performance

Some researchers have suggested that the competitive decline of the U.S. steel industry in the 1980’s has been attributed to inferior management practices and low labor productivity. Specifically, managers in U.S. steel firms had been criticized for promoting an incentive system that rewards short-term success, and fails to encourage capital investment in new technology that is needed to compete globally. However, in the last decade the U.S. steel industry has experienced
a steady turnaround in profitability and market share, and has invested in additional production capacity. In 1993, Baber et al. compiled financial data on the U.S. steel industry for the 1971-90 time period. (see Table 2-1) The following section, based primarily on Baber’s study (Baber et al., 1993), provides a summary and discussion of these financial performance statistics. However, it should be noted that since Baber’s study in 1993, the economic performance of the U.S. steel industry, and in particular the integrated sector, has improved significantly. In fact, U.S. integrated producers today have the highest profitability per ton of steel produced in the world.

Table 2-1 Summary of Financial Ratios (1971-90)

<table>
<thead>
<tr>
<th></th>
<th>All Industrials</th>
<th>Integrated</th>
<th>Non-Integrated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Return on Assets (ROA)</td>
<td>0.09</td>
<td>0.02</td>
<td>0.08</td>
</tr>
<tr>
<td>Net Income/Sales</td>
<td>0.05</td>
<td>-0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>Capital Expenditure Growth*</td>
<td>0.10</td>
<td>0.04</td>
<td>0.11</td>
</tr>
</tbody>
</table>

NOTE: Ratios are presented as mean values.

*Mean growth rate represents a geometric average over the 1971-90 time period

Using return on assets (ROA) as a measure of profitability, Baber’s study (see Figure 2-7) noted the following:

- The steel industry is less profitable than other U.S. industrial firms. Mean accounting rates of return are 2.95% for the steel industry compared with 9.17% for all U.S. industrials.
- The difference in profitability is attributed to the integrated steel firms with a mean return of 2.23% compared with 8.09% for non-integrated steel firms.
- Non-integrated firms that produce specialty steels are slightly more profitable than non-integrated carbon steel producers.
- The poor financial performance of the integrated steel firms is most substantial during the 1981-86 time period.
NOTE: The figure represents U.S. industrial firms

Figure 2-7  Return on Assets (ROA): U.S. Steel Firms

Although U.S. integrated steel producers have been generating a persistently lower return on assets than non-integrated producers and other industrial firms, the integrated firms have recently improved in profitability since the early 1980's. (see Table 2-2) This dramatic turnaround has occurred primarily because the industry has reduced its costs, increased production efficiency, and increased overall sales.

Table 2-2  Profitability Ratio: Return on Assets (%) 1975-93

<table>
<thead>
<tr>
<th></th>
<th>Integrated</th>
<th>Non-Integrated</th>
<th>S&amp;P 500 Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>All periods (1975-93)</td>
<td>-0.52</td>
<td>7.35</td>
<td>6.53</td>
</tr>
<tr>
<td>1975-81</td>
<td>4.33</td>
<td>9.57</td>
<td>7.59</td>
</tr>
<tr>
<td>1981-87</td>
<td>-6.81</td>
<td>5.06</td>
<td>6.59</td>
</tr>
<tr>
<td>1987-93</td>
<td>0.10</td>
<td>7.04</td>
<td>5.27</td>
</tr>
</tbody>
</table>


However, the relative production costs for integrated steel producers are substantially and consistently higher than the costs for non-integrated steel producers. Thus, integrated firms are unable to produce steel at costs that are less than prevailing prices which has led to low and sometimes negative profit margins. (see Figure 2-8)
NOTE: The □ represents U.S. industrial firms

SOURCE: Baber et al., 1993

**Figure 2-9** Net Income / Sales: U.S. Steel Firms

Because the integrated steel industry requires a capital intensive production effort, it is difficult to generate the necessary returns to adequately invest in capital improvements and new technology. As shown in Figure 2-9, the capital expenditure growth for U.S. integrated steelmakers is low and stagnant in the last three decades. In contrast, the rapid introduction of the minimill producers in the 1980's is illustrated by growth in capital spending by non-integrated carbon steel producers which is greater than the integrated producers, and also for all U.S. industrial firms.

NOTE: The □ represents U.S. industrial firms

SOURCE: Baber et al., 1993

**Figure 2-9** Capital Expenditure Growth
Since the economic decline in the early 1980's, overall sales for the U.S. steel industry have risen steadily from an average of $3.2 billion in 1986 to $4.8 billion in 1995 for integrated producers. (see Figure 2-10) In comparison, overall sales for the most profitable mini-mill producer, Nucor, have risen from $0.8 billion in 1986 to $3.5 billion in 1995. These sales trends combined with lower production costs and increased productivity suggest a remarkable economic turnaround for the U.S. steel industry which should continue into the near future. Today, overall sales by all U.S. steel producers are about 3 percent higher than in 1996, continuing an upward trend in recent years, and totaling about $36 billion in 1997 (Pittsburgh Post Gazette, 1997).

NOTE: Selected firms surrogates for U.S. integrated steel industry except Nucor, the leading minimill producer.
*Current year dollars.

SOURCE: Compact Disclosure (1997)

Figure 2-10 Overall Sales in Billions for Selected Steel Firms
3. Changes in the Structure of Innovation Processes

The U.S. steel industry is an interesting case study of R&D organization and decision-making due primarily to its recent history which has experienced near economic collapse, followed by a rebirth in which a continuous drive for improvement is the objective. (Ahlbrandt et al., 1996) By the 1980’s, a number of factors including global competition and domestic labor disputes contributed to seriously undermine the foundations of the U.S. steel industry. (Hoerr, 1988) As a result, the steel research community including both academic research and internal R&D operations became prime targets for budget cuts and downsizing. In the aftermath of these competitive and economic pressures, many of the industry’s large, integrated steel producers successfully restructured their organizations and operations.

Today however, still subject to both global and domestic competitive pressures, the U.S. steel industry requires revolutionary technological advances in some cases from its own R&D resources in order to remain competitive in the future. (Fruehan et al., 1995; Ahlbrandt et al., 1996) Thus, there is a motivation to explore R&D activity and project management practices within the U.S. steel industry in the wake of economic downsizing, while still faced with competitive, economic, and technological obstacles.

3.1 Reorganization of In-House R&D

The following section examines changes in the organization and structure of R&D activities in the U.S. steel industry based on survey data, case studies and patent analyses.

3.1.1 Survey Data of R&D Structure and Operation

Based on two recent surveys (Fruehan, 1994; Fruehan et al., 1995) of R&D activity in the global steel industry, the following section examines changes in R&D expenditures, personnel, and research effort.
R&D Expenditures

A recent survey (Fruehan et al., 1995) of steel companies regarding their current and future R&D capabilities found that most of the large North American integrated steel producers spend only about 0.5% of sales on R&D activities while a number of the other producers spend little or nothing. (see Figure 3-1) In comparison, the international firms that were surveyed indicated that they spend about 1.0% of sales on R&D activities. Also, the survey found that less than half of the U.S. companies which identified a given technology area as critical did not have a significant R&D program in place to address their critical technology concerns.

![Diagram](image)

NOTE: Selected firms are surrogates for the U.S. integrated steel industry.
NOTE: There was no data available for Weirton in 1980, and for Armco in 1995.

Figure 3-1  R&D Expenditures / Sales for Integrated Producers

R&D Personnel

In parallel with the steel industry’s economic decline in the early 1980’s, the average number of R&D personnel in integrated steel companies declined 43% from 498 personnel in 1980 to 282 personnel in 1985. A few of the largest integrated firms displaced as many as 60-90% of their R&D personnel in the early 1980’s. (see Figure 3-2) This sharp decline in personnel was followed by a steady decline that continued into the 1990’s where the average number of R&D personnel dropped 46% between 1985 and 1995.
The downsizing of R&D personnel is comparable to the total number of employees released from integrated firms in the last two decades. However, the average percentage of R&D personnel to total employees in integrated firms actually rose slightly from 0.6% in 1980 to over 1% in the 1990's.\(^6\)

Minimills producers have always had very few R&D personnel in their employ. In fact, Nucor, a leading minimill producer had designated only 4 employees as R&D personnel in 1991. Although small in number, the R&D personnel in minimills grew slightly from the mid-1980's to the present.

Even with large declines in R&D personnel, U.S. steel firms retained more professional R&D staff (i.e., those with relevant college degrees) than non-degreed staff. (see Figure 3-3) In fact, about 40% of the professional R&D personnel at two of the largest integrated companies currently hold doctorate degrees.
R&D Effort

Even after the economic decline in the early 1980's, the R&D organizations at integrated firms spent about three times more effort on long-term, applied research than on short-term research as had also been the case prior to the 1980's. (see Figure 3-4) However, only one large integrated firm performed some fundamental research in 1991. Most firms abandoned their fundamental research to focus primarily on applied R&D and technical assistance projects. In contrast, non-integrated firms had spread their effort evenly between short-term and long-term R&D with no focus on fundamental research at all.

NOTE: One integrated firm spent 11% effort on fundamental research.
NOTE: For integrated firms, 8.3% of the effort is other research.

Figure 3-4 Average Distribution of R&D Effort by Project Type in 1991
By 1995, the shift in R&D effort at U.S. steel firms was dramatic. Integrated producers focused over three times more effort on short-term, technical assistance, and almost twice the effort on short-term, applied research than on long-term product and process research. (see Figure 3-5) Similarly, non-integrated firms spent more than twice their effort on short-term technical assistance than on long-term research.

These changes not only represent a shift in the type of research conducted by R&D organizations in the steel industry, but also a shift in the R&D organization’s technical objectives and their relationship with the production plants, suppliers and customers. Due to budget and personnel constraints, the R&D organizations at integrated firms had to focus primarily on the problems, requests and requirements of the production plants and their suppliers and customers, and spend less effort on risky and long-term research.

![Graph showing average distribution of R&D effort by project type in 1995.]

NOTE: No firms conduct fundamental research.

**Figure 3-5** Average Distribution of R&D Effort by Project Type in 1995

### 3.1.2 Case Studies of R&D Structure and Operation

In discussions with past and present R&D directors and managers at several large, integrated and non-integrated U.S. steel producers, (Vislosky, 1996) it is evident that substantial organizational change took place in the R&D divisions within the steel industry. These changes can be categorized into three different business eras for the U.S. steel industry: 1) the decades prior to the 1980’s when the U.S. steel industry dominated the world marketplace; 2) the early to mid-1980’s when the integrated steel industry experienced a difficult financial period; and 3) the
1990's where the integrated steel firms have made a steady financial comeback to become profitable once again, and non-integrated firms continue to have seasonally strong profitability.

In the decades prior to the 1980's, the freedom and large budget enjoyed by the R&D organizations in the U.S. steel industry were in concert with the current corporate attitude towards R&D. At that time, major industrial companies including the steel industry wanted to showcase an R&D facility and their R&D activities to their customers and the public at large. The first major change in the steel industry’s R&D environment coincided with the drop in sales and profitability in the early 1980's. In an effort to control the falling profitability in as short a time as possible, corporate officers cut back on the budget and personnel in every business unit of the company. The R&D organization experienced the largest cutbacks, and had to lay off up to 75% of their personnel. This was detrimental to the industry because a firm’s innovative performance is linked to its existing knowledge base and the skills of its R&D personnel. (Cohen, 1990) The release of a large portion of R&D personnel and the resultant decrease in research capability caused R&D organizations to restructure their R&D efforts and find new sources of funding. The following is a summary of the organizational and structural changes that took place in R&D organizations within the U.S. steel industry since the 1970's.

**Integrated Steel Firms**
In the 1960's and 1970's, the integrated producer dominated the worldwide marketplace for steel. The integrated firms enjoyed large profit margins due to their large market share and control of prices. As a result of this economic prosperity, the R&D organizations within the firms enjoyed large budgets and freedom to pursue many different types of relevant research. The R&D budget was funded by the corporation, and the number of personnel remained relatively constant. The headquarters for R&D was centrally located, but the R&D organization serviced all business units and holdings of the firm. At the time, many of the integrated producers were vertically integrated. They owned and operated not only the iron and steelmaking operations, but they also owned the raw material’s suppliers, and the process equipment producers. The R&D organization retained the skills and capability to service each of these separate business units and their unique needs.

The R&D organizations were typically hierarchical in structure. Typically, a research director, or in some cases a vice president of research oversaw all R&D operations in the firm.
Reporting to the director or vice president were the managers of each division. The divisions were organized by technology area such as steelmaking, chemicals, and products. Sub-divisions existed to address specific process and product technologies within each area. In addition, there was usually a lab devoted to fundamental research. Since the R&D organizations were staffed by competent and skilled individuals trained in the various disciplines related to the steel firm’s operations, most of the firm’s research needs were performed in-house. In addition, rather than outsource research, U.S. steel firms actually sold some of their technology to other firms here and abroad.

Most R&D projects originated from within the R&D organization as suggestions and proposals by the research staff. The motivation behind new projects was often initiated from a competitor’s activities, customer and plant requests, and improvements to products and processes. Most projects at any one time were on-going from the previous years, and new projects would be introduced annually. These research projects consisted mainly of applied process and product research with an average three year life span. In addition, the R&D organization would service the various business units of the firm by providing technical service and addressing short-term research problems. The U.S. steel industry’s R&D organizations prior to the 1980’s were stable and vibrant research environments. However, the steel companies did not always utilize their R&D resources effectively.

Unfortunately, the dominance of the U.S. steel industry came to abrupt end in the early 1980’s. For reasons discussed earlier in this paper, the profitability of the integrated steel producers experienced a sharp decline. As a result of the industry’s financial demise, most of the U.S. integrated steel firms reduced the budget and personnel in many different business units. The R&D organization was considered an expensive luxury in these difficult financial times. Many firm’s cut back heavily or put a halt on most of their R&D operations other than technical services.

The R&D organization was forced to sell its services to the rest of the firm, and research projects were funded by individual business units throughout the firm (e.g., production plants). In some cases, the research was still funded by the corporation, but the R&D organization was responsible for advocating its worth and the value of each project directly to the production units.
Research objectives had shifted to an opposite extreme where technical assistance and problem solving became the primary focus of the R&D organization. Of course, long-term applied research still took place, but most often only if such research would directly benefit the customers and the production plants. In addition, the costs, time schedule and results of applied research were always under scrutiny by upper management, and immediate beneficial outcomes were expected from all research projects.

This environment caused the integrated steel industry to focus on short-term gains and immediate results from research. R&D organizations were more inclined to pursue less risky, incremental research projects that were of direct relevance to their customers and production plants. As a result, the integrated steel industry introduced very few new technological advances in its production processes, and product advances were more often incremental improvements rather than new products or processes.

This cautious and incremental R&D environment continued throughout the 1980's. Only recently has the U.S. steel industry experienced a modest comeback in the global marketplace. As a result, the remaining R&D organizations in the industry have examined their current operations. Although small in budget and personnel, these organizations are beginning to reexamine their role in the context of the firm by incorporating directly the corporate strategic plan, the firm's marketing plan, and input from the plants, suppliers and end-users into their technical plan. In addition, these organizations are making efforts to pursue long-term, applied research, partner with competing firms, and partner with end-users (e.g., the Ultralight Steel Auto Body partnership between Porsche Engineering Services, Inc. (1995) and 15 participating steel firms) in order to continue the steady growth and reemergence as a competitive industry in the worldwide steel market.

**Non-Integrated Steel Firms**

Unlike the integrated steel producing firms, R&D organizations in non-integrated firms experienced very different changes in structure and organization. Very few non-integrated firms have any formal R&D organization. Most of these firms have small research groups that provide technical assistance to the plants. The non-integrated producers were much less affected by the
economic downturn in the U.S. steel industry in the early 1980’s. In fact, the non-integrated producers actually contributed to the economic woes of the integrated producers by acquiring some of their market share in high quality, complex products.

Case Study Conclusions
Prior to the financial decline of the U.S. steel industry in the 1980’s, the R&D divisions of integrated steel firms were stable organizations that maintained consistent levels of staff, budget, and research projects. Although the R&D divisions serviced the various business units of the firm by addressing short-term problems and requests, they were also free to conduct many on-going applied research projects to improve the products, processes and operations of the firm. In the early 1980’s, the budgets and staff of R&D divisions were cut by as much as 75% in only a few years. Some R&D organizations had to adopt an external vision of survival by focusing more on customer needs while others were forced to sell their skills and services to the production plants who were their primary customers, and their primary source of funding. Most of the R&D effort was focused on technical assistance and solving short-term problems for the plants. In addition, most of the applied research provided incremental improvements in products and processes.

By the 1990’s, the financial stability of the U.S. steel industry had steadied. Like the pre-1980’s, the R&D division maintained a consistent level of staff, budget, and projects. However, the R&D organizations are now smaller, leaner and customer-focused. The R&D divisions that remain in the U.S. steel industry have attempted to conduct more applied research that is relevant to corporate strategy and more in line with the firm’s marketing plans. In addition, some R&D organizations are reinvesting in long-term strategic research. The technical plan is no longer an isolated list of projects originating from within the R&D division. Instead, the R&D organization is integrating its technical plan with the other strategic aspects of the firm that it services including operations, marketing, and corporate management, as well as the production plants, suppliers and end-users.

3.1.3 Patent Trends in U.S. Steel Firms
As part of the Sloan Steel Industry Study (Fruehan et al., 1997), Chacar and Lieberman (1996) conducted a research project which examined the patent trends in steelmaking technologies during
the period between 1975 and 1994. The study found that there have been major changes in the patenting trends of U.S. steel firms since the early 1980's. These trends are discussed in the following section.

Overall Patenting Trends
Through the 1970's there was a decline in the overall patenting for steel related technologies. This was followed by a period of relative stabilization during the 1980's and 1990's. However, the share of patents assigned to U.S. inventors has dropped significantly during this same time period from about 50% during the pre-1980 period to about 37% in 1994. This included a period of slight increase during the late-1980's and a drop in the early-1990's. This drop in the U.S. share has been offset by a huge increase in patents assigned to Japanese inventors. Patenting rates by issue year for U.S. inventors are shown in Figure 3-6.

![Graph showing annual numbers of patents issued from 1975 to 1994]

**Figure 3-6** Steelmaking Technologies Related Patents for U.S. Firms

Process Versus Product Patenting Trends
During that same time period there has been a relative stabilization of the number of process and product patents. In this study (Chacar, 1996), process patents are defined as those that are classified under classes 164 and 420 and product patents were defined as those that are classified
under classes 75, 148 and 428. For the U.S., following the overall patenting trends, there has been a decrease in both process and product patents from the pre-1985 period to the post-1985 period.

Figure 3-7 U.S. Steel Product and Process Patenting

However, as seen in Figure 3-7 above, the percentage of process patents has increased over that same time period from about 45 percent to slightly under 55 percent. Again, Japan's share of both process and product patents rose during that period and the rest of the world's share, including Germany, stagnated.

Patenting Trends by Technology Class

Looking at patenting trends within specific steel technologies allows us to determine whether the U.S. is losing its technological edge in all steelmaking technologies or if its maintaining an advantage in specific areas of innovation. Although the share of the U.S. across all patent classes has dropped significantly, this is not the case if we look at some specific technologies. Whereas, the United States has seen a decline in steel patenting in Metal Treatment of Particulate (subclass 148/105), it has maintained superiority in patenting in Alloys with Rare Earth Metals (subclass 420/83) and Apparatus for Endless Shaping (subclass 164/429). The U.S. has also maintained its superiority in Continuous Casting Technologies (subclass 428/472.2). However, these trends do
not hold if we examine the patents at a higher level of aggregation. Each of the five main classes that were examined (75, 148, 164, 420, and 428) follows trends similar to those for the overall patenting discussed earlier.

Figures 3-8 & 3-9 below show the U.S. patenting trends for two of the subclasses discussed above. Figure 3-8 shows U.S. patenting in subclass 164/429, Apparatus for Endless Shaping and Figure 3-9 shows U.S. patenting in subclass 428/472.2, Continuous Casting Technologies.

![Bar chart showing percentage of total patents granted over time.](chart)

**Figure 3-8**  Apparatus for Endless Shaping: U.S. Patents Granted
Figure 3-9  Continuous or Semi-Continuous Casting: U.S. Patents Granted

3.2 Sources of Innovation

This section will discuss the various internal sources of innovation that affect a firm's overall innovative process. We will first discuss the firm's own R&D laboratories and joint ventures between companies, both domestic and international. We will then comment on innovations originating with suppliers and finally on university contributions to industrial innovation.

3.2.1 Firm's own R&D Laboratories

One of the main sources of innovation in the steel industry remains a firm's own internal R&D labs. This has remained the case despite the major cutbacks in in-house R&D activities that most steel firms went through in the mid to late 1970's. These cutbacks have resulted in smaller numbers of available man-hours that can be devoted to performing general innovative research which has a higher chance of yielding breakthrough innovations. Instead, most of the internal effort has been devoted to research that can result in incremental improvements to existing innovations. In addition, most researchers at firms' central research centers have taken on the role of technical consultants to the firms' various steel producing plants. For example, researchers could be called on to help the engineers at a plant solve a technical problem that may have arisen, affecting the way a machine functions or the quality of its output. Or conversely, a
plant engineer can contact the company’s research center and ask that a research experiment be performed. This could be a study of the effect of the addition of a certain amount of an alloy to a grade of steel or the effect of altering the water jet pressure in a sheet steel rolling line.

3.2.2 Joint Ventures with Other Steel Companies

Most U.S. steel firms have joint ventures or general technology agreements (GTA) with other domestic and, often, foreign producers. The four best examples of joint ventures are listed in Table 3-1.

Table 3-1 Examples of Joint Ventures in the U.S. Steel Industry

<table>
<thead>
<tr>
<th>Company</th>
<th>Venture</th>
<th>Partners</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inland</td>
<td>INTEK</td>
<td>Nippon Steel</td>
<td>Cold rolled sheet</td>
</tr>
<tr>
<td></td>
<td>INKOTE</td>
<td>Nippon Steel</td>
<td>Coated sheet</td>
</tr>
<tr>
<td>USX</td>
<td>USS-Kobe Lorain</td>
<td>Kobe</td>
<td>Steel plant</td>
</tr>
<tr>
<td></td>
<td>UPL</td>
<td>POSCO</td>
<td>Finishing plant</td>
</tr>
<tr>
<td>LTV</td>
<td>Trico Steel</td>
<td>Sumitomo/</td>
<td>Steel plant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>British Steel</td>
<td></td>
</tr>
</tbody>
</table>

The joint ventures between Inland Steel and Nippon Steel involved state of the art facilities. Although, they helped reduce the cost and time of production, they do not justify the high capital investment which was required. Also, there has been little innovation spill-over to other areas of the firms. The USS-Kobe plant is virtually an independent company and, in many ways, does not perform as well as other USS plants. The USX venture with POSCO has not lead to major innovation in USX itself. The Trico plant is only beginning operation (1997) and it is difficult to assess its impact.

The best example of GTAs is the GTA between Inland Steel and Nippon Steel. Nippon Steel had as many as one hundred engineers teaching Inland Steel engineers how to improve the quality of their automotive steels. Their primary focus was on the Japanese auto transplants. Sumitomo Metals also has long term agreements with LTV Steel, and other U.S. companies have reasonably successful agreements with Japanese companies. However, joint agreements with companies from countries other than Japan have been less productive.
The best example of joint research agreements is the agreement between USS and Bethlehem Steel. About 5 to 10% of both companies’ research is on selected joint projects. This program has been considered successful and has lead to innovation. Other examples, such as those on strip casting projects between a number of companies have been unsuccessful.

To date, joint ventures with foreign producers have had limited innovation spill over to other parts of the company. GTAs have been successful when focused on a specific task, whereas the general exchanges have not lead to significant innovation.

3.2.3 Innovations by Suppliers
There have been major innovations by suppliers of technology to the steel industry (Fruehan et al., 1994). The best known example is the SMS thin slab caster which has caused a revolution in steelmaking. Other examples include innovations in EAF steelmaking, continuous casting and finishing. With the decrease in steel industry research technology suppliers must and have taken a major responsibility for equipment innovations. Joint developments with U.S. firms are extensive and generally viewed as successful (Dennis, 1991).

3.2.4 University Contribution to Innovation
Universities have not aimed their research to make a major innovation but rather develop the basic information to aid the steel and steel supply companies in their activities. The two major research consortiums are at the Colorado School of Mines for steel rolling and finishing research, and at Carnegie Mellon University (CMU) for ironmaking, steelmaking and casting. These centers received nearly all their funding from industry with over 20 industrial partners in each. The center at CMU is international with about ten non-U.S. firms. Whereas it is difficult to show that university research alone produced any major innovations, it is clear that it has provided the fundamental understanding which has supported new innovations.

Universities also contribute to innovation in the steel industry through consulting activities between industry engineers and individual professors. This exchange of ideas although less formal than contacts through the steel centers described above, is nevertheless important. It provides a means for university professors to share results and insights from their various research projects which might be of help to engineers in industry.
Universities contribute as well by the transfer of knowledge through people. When young graduates or more seasoned academics join a steel firm, they bring with them a fresh perspective and greater creativity. This also provides industry with an almost continuous stream of young talent to utilize.

Although it is difficult to quantify what the sources of innovation are, a recent Sloan Study project has attempted to accomplish this by performing an article citation count in patents relating to specific innovations. Preliminary results show that university authored articles accounted for close to 20% of article citations in patents issued for interstitial free steel and about 30% of article citations in patents relating to direct ironmaking. (Cheij, 1997)

3.3 Future Directions of Innovation

As part of the study of R&D activity, a number of possible major new technologies were identified. The companies surveyed were asked which of the new technologies were critical to them and whether they had a related research program. As shown in Figure 3-10, typically 50-75% of respondents indicated that the technologies were important but only half of those indicated that they had a related research program.

![Diagram](image)

**NOTE:** Percentage of respondents from Fruehan and Uljon (1995) survey.

**NOTE:** Respondents include 28 domestic and international steel firms.

**Figure 3-10** Important and Current Technology Areas

These results indicate a gap between the steel industry's technical needs and its R&D resources due to the capital intensive nature of these innovations. In order to address this gap, steel
producers may be required to participate in collaborative efforts with competitors, customers and suppliers in order to offset the project costs.
4. Other Factors Influencing Competitiveness and Innovation

Technological innovation is only one factor which influences competitiveness. In this section the other major factors are briefly discussed along with any impact they have had on innovation. Table 4-1 summarizes the

**Human Resources**

As discussed earlier, workers' productivity has increased by nearly 300% in the past decade. This has not only been accomplished by new technologies but also by innovative HR practices. These improvements reduced labor costs by over $100 per tonne or 25% of the total cost of production. Labor consideration has been a driver for technological change but rarely has it contributed to innovation.

When new technologies are introduced in union facilities it is usually necessary to negotiate new agreements to take advantage of the new developments. Of the 20 million tonnes of new capacity being built in the U.S., virtually none is in union plants. Labor currently represents 10-15% of the total costs of steel production in existing plants, and less than 10% in new plants. Therefore, there is only room for small improvements in this area.

**Trade Issues**

Trade, particularly unfair trade, has been a major competitive factor in the U.S. In general, the steel industry is profitable when capacity utilization rates are over 90% and unprofitable when they are below 80%. Imports have averaged about 18-20% during the last decade, but have been over 25% in the past. When imports are high, capacity utilization may decrease resulting in poor financial performance. Imports depend largely on exchange rates and relative production requirements in the U.S. and abroad. Import sources are shifting from Europe and Japan to developing companies. Currently, the U.S. industry is the low cost producer for its domestic market. Imports generally result from the inability of domestic producers to fill all the country's needs or overproduction in the exporting countries. Trade affects profits and therefore the resources available for innovation.
Minimills
Minimills have been a tremendous source of innovation, including innovations in technology, management and human resources. This is in part due to their flexibility with regards to process, labor relations and management. They have not necessarily developed technological concepts but have implemented, adapted and optimized processes effectively. The classic example is thin slab casting which was developed in Germany but successful commercialized in the U.S.. Other areas in which minimills are leaders in innovation include scrap substitutes and electric furnace improvements. The minimills have also had a tremendous effect on competitiveness by reducing steel costs and forcing the integrated industry to restructure by closing inefficient plants and concentrating on high quality steels.

Customers
Customers, and in particular the automotive industry, have been a source of both competitiveness and innovation. Spurred by the Japanese auto transplants, there was a significant amount of competitive pressure on steel makers, from foreign and domestic auto producers, to improve quality. This occurred both for integrated flat rolled steels as well as for special bar quality (SBQ) steels produced by scrap based EAF plants or minimills.

At the same time, customers also became a source of innovation. Steel producers worked with the auto industry to improve the quality of existing steels and to develop new and improved steels. An example of this collaboration is the optimization of the production of corrosion resistant steels and their use.

Foreign Investment
Foreign companies, in particular Japanese companies, have invested heavily in the U.S. steel industry. In particular, Nippon Kokan owns much of National Steel, Nippon Steel has invested in Inland Steel and much of AK Steel (Armco) was at one time largely owned by Kawasaki Steel. Much was expected in terms of technology transfer from Japan. However, these investments proved to be poor and little technological innovations resulted. In fact, these companies have done poorer than similar integrated companies. Soon after Kawasaki Steel sold its interest in AK Steel, AK became very profitable under U.S. management.
Whereas Japanese investment in the U.S. auto industry has been highly successful, its investment in the steel industry has been a relative failure both in terms of finances and innovation. The reasons for this failure are the subject of a new research project in the Sloan Steel Industry Study.

**Regulatory Policy**

Regulatory policy has been a major driver of technological innovation, but it is not a source for innovation. In particular, environmental regulation is driving innovations in ironmaking including the elimination of cokemaking and the recycling of waste. In addition, this past year in response to concerns about global warming, some of the largest firms in the U.S. steel industry recently formed a coalition with the American Institute of Iron and Steelmaking to present an industry voluntary plan to cut emissions of greenhouse gases by 10 percent from 1990 levels by the year 2010 (Pittsburgh Post Gazette, 1997). In return, the industry officials requested that the government provide more federal investment in R&D, as well as tax incentives for development of new energy-efficient technologies. Thus, current environmental issues influence the types of R&D projects pursued by the steel industry, and new federal investments in R&D may indirectly dictate the types of projects that are funded thereby hindering competitiveness by diverting resources to satisfy regulations which could have been used for bringing about innovation.

**Education and Training**

Education and training of workers in the steel industry is continually evolving in order to keep up with and respond to new technological innovations which are changing the industry. This is very important in order to ensure that the work force is always up to date on the latest products and processes which the company wants to produce. Workers will be better equipped to handle new machinery and to produce higher quality steel. Approximately 75% of the steel industry’s on the job training is associated with new and emerging technologies.

**Government Support of R & D**

The federal government, particularly through the Department of Energy, has provided a significant stimulus to technological innovation. In particular, their funding of programs in direct
ironmaking and process control have been effective. They have been effective, in part, because they have not attempted to manage the programs but have provided resources to help meet the country’s needs. The results of their support are beginning to have some impact on competitiveness. The full effect of these results may not be fully realized for ten years or more in the U.S.

In Europe, and Japan, government funding has been much greater and has had more effect on innovations. In Japan MITI has sponsored many large “National Projects”. In Europe, governments have also funded individual projects and institutes devoted to steel.

**Internationally Funded R&D**

There has been surprisingly little international funding for R&D. There have been technology exchanges by individual companies but little actual joint research or development. There has been extensive regionally funded R&D, particularly within the European Union (EU). For many years steel companies in countries in the European Union (Common Market) have been taxed on each tonne of steel produced. The tax has funded a range of R&D activities ranging from fundamental university and institute research to major commercial demonstration projects, such as coal injection into blast furnaces. The EU program has been reasonably successful and will continue to be so. The American Iron and Steel Institute carries out research sponsored by U.S., Canadian and Mexican companies. The AISI program is voluntary and much smaller than the EU program.

There is one major international program in response to the “Partnership for a New Generation of Vehicles”. A group of over 20 companies from Japan, Europe and America are funding work to develop a steel based automobile to be more fuel efficient, the Ultra Light Steel Body Program (Porsche Engineering Services, 1995).

Table 4-1 summarizes the impact that each of the major factors described above have on the competitiveness and innovative productivity of U.S. steel firms. Only minimills and customers have had a high impact on both the competitiveness and innovative productivity of steel firms relative to the other factors. Also, most of the other factors which have a high impact on either competitiveness or innovative productivity have a low or medium impact on the other. This
suggests that all the factors mentioned above are important and influence in some way the U.S. steel industry's competitive standing and innovative productivity.

**Table 4-1**  Relative impact of factors other than R&D on competitiveness and innovation

<table>
<thead>
<tr>
<th>Factor</th>
<th>Competitiveness</th>
<th>Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human Resources</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>Trade Issues</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>Mini Mills</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Customers</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Foreign Investments</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Regulatory Policy</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Education and Training</td>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>Government Support of R&amp;D</td>
<td>L</td>
<td>H*</td>
</tr>
<tr>
<td>Internationally Funded R&amp;D</td>
<td>L</td>
<td>M*</td>
</tr>
</tbody>
</table>

* NOTE:  H = High, M = Medium, and L = Low.

*Government funded R&D has had a major effect in Japan and Europe but or medium in the US.

*International funding has had a minor effect in the US and Japan but high in Europe.
5. Links between the Innovation Process & Industry Performance

It could be argued that an investment in R&D takes 5 to 10 years to show its full return and that the U.S. industry is currently benefiting from previous R&D. At best, this is only partially true. It has been 10 years since the major R&D restructuring of the 1980’s and the industry is currently doing better than anytime in recent history.

First, it should be stressed that technological innovation alone does not determine a firm’s competitiveness. As discussed in previous sections, other factors including human resources, trade issues, foreign investment, regulatory policies, and funding sources have as great an impact on competitiveness in the U.S. industry. Specifically, market selection, and management of the firm’s capital and human resources are critical factors that have and continue to affect the competitiveness of the U.S. steel industry. However, there are dramatic examples of technology innovation that clearly affect competitiveness. In particular, the use of thin-slab casting techniques by Nucor and other minimill producers, and other quality improvement innovations that have been implemented by a number of major integrated companies in order to produce the highest quality steel at the lowest cost have allowed both types of steel producers to achieve higher levels of productivity and profitability in recent years.

Although new innovations do affect competitiveness in the steel industry, there is no obvious trend between the industry’s in-house R&D spending and its economic performance. In fact, R&D spending at the major integrated firms had decreased drastically in the mid-1980’s while at the same time or soon after, these firms began making their greatest productivity increases followed by increases in profitability. The minimill producers have had little or no in-house R&D, and yet performed well during this same period. It could be argued that they are living off the research of others. In contrast, it is not clear whether the major international firms such as Nippon Steel, Usinor and POSCO have had good financial performance because of their relatively large investment in R&D, or if they were able to invest heavily in R&D because of good financial performance. Again, the question of how R&D spending is related to economic performance is not obvious in the global steel industry.

The improved economic performance of the U.S. steel industry may be due more to the effective use of R&D resources, capabilities and the organization, and less to the investment in
R&D. When the integrated firms restructured their operations which included the reorganization of in-house R&D in order to cut costs and improve productivity, they lost a large part of their R&D capability and skills. However, the R&D organization became more efficient, and focused more directly on production and customer relevant issues. The in-house R&D organization formed tighter relationships with the production plants, suppliers and customers. The acquisition of new technology innovations came more from other sources including particular suppliers and foreign steel producers. The “not invented here” syndrome which had been prevalent prior to the 1980's had almost disappeared completely. Today, the R&D organizations of integrated producers remain relatively small and few, but they are leading the integrated steel industry to sustain a competitive advantage with technical plans that incorporate the various strategic positions of the firm, and a long-term outlook on developing new process and product innovations that will provide high quality steel products at the lowest production costs.

In contrast, minimill producers have always effectively utilized innovations developed elsewhere. This is one reason why large R&D organizations never emerged in the minimill sector. The U.S. minimills became international leaders in the commercialization of a series of processes which led to the development of continuous steel processing. This process improved the conversion time of raw materials to finished products from months to ten hours or less. As such, the minimill sector has achieved astounding production efficiency and high profitability in the last two decades. The minimill industry’s effective adoption and commercialization of innovations from other sources has been a large determinant of their competitiveness and economic success.

For the U.S. steel industry as a whole, R&D resources have been more effectively utilized in collaborative research efforts involving a number of companies, both domestic and foreign, their suppliers, and to a lesser degree, universities. These collaborations have contributed to both the industry’s innovative and economic performance especially in the last decade.

In summary, whereas R&D resources have decreased dramatically, the U.S. steel industry’s technology innovation process as a whole has improved. Factors such as the effective management of R&D and technological resources, the acquisition of technology and innovative ideas from suppliers, customers and competing steel producers, and collaborative research efforts have all created an environment that fosters improvements in production efficiency, technological developments, economic prosperity, and global competitiveness.
6. Summary and Conclusions

It is evident today that the U.S. steel industry has made a tremendous comeback in its competitiveness. Although the integrated steel industry experienced a near economic collapse in the early 1980's, it restructured its organizations and operations to once again become a competing force in the global steel market. By restructuring, which included a massive downsizing of operations, the closing of inefficient plants, and strategic investments in new plants and technologies, the U.S. steel industry has achieved healthy and growing profitability and productivity. Although a number of different factors discussed in this paper have contributed to the industry's turnaround, both the development or acquisition of new innovations, and the efficient implementation of these innovations played a significant role.

This paper documents the changes in the U.S. steel industry's production, productivity, profits, R&D and patent activity before, after and during the industry's restructuring period in the 1980's. It also examines the industry's development and acquisition of technology, and the various sources of innovations and technology including in-house R&D, relationships with suppliers and customers, government funded R&D, and collaborative research with various partners. In addition, it discusses the various facets of the industry’s R&D activity as well as other factors that may influence the industry's competitiveness. In summary, the major conclusions from the paper follow:

- Due to major restructuring, the U.S. steel industry is again highly competitive and profitable.
- The personnel and budget for in-house R&D have been greatly reduced, and are far less than the in-house R&D investments made by major foreign competitors. However, the total factor productivity between the U.S. and international steel producers are comparable.
- In-house R&D organizations are not, as of yet, addressing many of the industry’s long-term concerns. However, the focus of R&D has become much better integrated with the strategic, marketing and production plans of the firm.
- Major integrated companies have restructured their in-house R&D to be more responsive to the needs, requests and requirements of the entire organization, its suppliers and customers.
• Innovation is coming from sources other than in-house R&D, such as suppliers, foreign steel firms and collaborative efforts with various partners.

• Patenting by U.S. steel firms has decreased significantly, but the U.S. still dominates in the patenting of some steel-related technologies.

• There are a number of factors other than technology that have an effect on competitiveness. In particular, market focus, management of capital and human resources, foreign trade and exchange rates have had a major impact on the industry’s competitiveness.

• In the past decade, the U.S. steel industry has been reasonably effective in being innovative. However, the industry has consistently lagged behind its major foreign competitors who are often the leaders in technological innovation in the steel industry (Cyert and Fruehan, 1996). In the 1980’s, U.S. steel firms often exploited technology that was already in place and being used by foreign producers in order to fill a specialized market niche (Ahlbrandt et al., 1996). In the next decade, it may be necessary for the U.S. steel industry to rely more on its own innovations in order to improve competitiveness, or invest in more collaborative technical efforts.
References


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1 Minimill producers use electric arc furnaces (EAFs) to produce high-quality specialty steels.
2 As evidenced by the recent explosion of EAF-Thin Slab casting plants, and other recent technological advances including massive coal injection in the blast furnace, and the large production of ultra clean and interstitial free (i.e., carbon free) steels. (Albrandt et al., 1996)
3 A recent survey of steel companies regarding their current and future R&D capabilities conducted by Fruehan and Uljon (1995) found that most of the large North American integrated steel producers spend only about 0.5% of sales on R&D activities while a number of the other producers spend little or nothing. In comparison, the international firms that were surveyed indicated that they spend about 1.0% of sales on R&D activities. Also, the survey found that less than half of the U.S. companies which identified a given technology area as critical did not have a significant R&D program in place to address their critical technology concerns.
4 Value-added is the difference between a firm's total sales and its purchases of raw materials and contracted services.
5 ROA is determined from the product of asset turnover and profit margin.
6 Average percentages determined from the total employees in the four largest integrated producing firms: Bethlehem, Inland, National, and U.S. Steel.
7 Discussions were held in-person or by phone during the 1996-97 time period.
8 The study defined the steelmaking patents as those that are classified within specific subclasses under one of the following five classes: 75, 148, 164, 420 or 428.
9 Through fiscal year 1994, the U.S. Department of Energy has committed about $95 million for past and present R&D projects in the steel industry (Cyert and Fruehan, 1996).
Figure 2-2  Labor-Hours per Ton Produced: U.S. Steel Firms

Figure 2-4  Value-Added per Worker-Hour: U.S. Steel Firms
Figure 2-5  Fixed Capital per Employee: U.S. Steel Firms

Figure 2-6  Total Factor Productivity: U.S. Steel Firms
Figure 2-7  Return on Assets (ROA): U.S. Steel Firms

Figure 2-8  Net Income / Sales: U.S. Steel Firms
Figure 2-9  Capital Expenditure Growth