Steel Industry Restructuring and Location

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1. Introduction

Steel matters. As a material, it is critical to the infrastructure of economic development and the consumer durables and capital goods that fuel that development. As an industry, nations have used steel manufacturing as an instrument of economic, social, and regional policies. As an industrial base for regional economies, the steel industry has helped to define the character and identity of great cities. By examining critical periods of restructuring in this industry, the role of economic geography as a competitive factor is readily exposed. Moreover, the consequences of industry restructuring play out dramatically in terms of the well being of regions. Whether examining the competitive factors linked to location or their consequences for regions, an important basis for explanation is to be found in steelmaking technology and related costs. The analysis offered in this chapter links technology-based competition, demand patterns, and managerial agency to describe and explain the process of restructuring in the American and global steel industries in terms of their economic geography.

Our analysis begins with a very brief explanation about how steel is made in order to help focus attention on some basic locational factors in the industry and provide a basis for explaining the relationship between alternative technologies and competition among steel firms. With this understanding, our analysis is framed by reference to long trends in industry restructuring as they play out for the geography of production in the United States. Subsequent sections of the chapter address the consequences of restructuring in terms of its spatial and regional dimensions. Our thesis is that technology-based competition, demand patterns, and managerial agency have been the primary drivers of the steel industry's fundamental restructuring. There are two related parts to our story: First, in Sections 2-6, we describe the transformation of the American steel industry in terms of the shift from the dominance of integrated steel to that of minimills. This shift in industry dominance was accompanied by a geographical shift away from the historical core of steel production in the Midwest to new locations closer to the growing markets of the South and Southwest. We argue that this dual shift was driven by an interlinked set of drivers, with technology-enabled changes in competition and the geographic displacement of demand being primary. The technology effects manifested themselves via two distinct pathways: changes in cost structure brought about by scrap-based steel production, and impact on competition between minimills and integrated producers. However, the visible hand of managerial agency (Chandler 1993) also played a role, in that decisions and investments by minimill managers - as well as by their counterparts in the integrated mills - served to hasten the shift.

Next, in Sections 7-9, we describe the transformation of the global steel industry – still under way - in terms of the shift in production and demand from the Triad regions (North America, Europe and Japan) to the rest of the world, and the rise of the steel multinational corporation (MNC) mainly through mergers and acquisitions (M&A) deals. This shift, in turn, was driven by the same set of three factors, prime among them being changes in demand patterns (manifested in the rise of China) and managerial innovation facilitated by new information technologies. The technology driver in this instance was not a production technology, but rather advanced information systems that greatly increased the geographical distance over which steel enterprises could be effectively managed. Managerial agency was manifested this time in aggressive growth-seeking by steel firm managers, as they engaged in global M&A and other expansion efforts, in many cases newly energized by worldwide liberalization and privatization trends. Thus, the dramatic restructuring of the steel industry in the United States and globally can be interpreted through the lens of technology-based competition, demand patterns, and managerial agency.

2. Making steel

In many parts of the world, and certainly in the popular image, steelmaking is defined by massive plant complexes that process material, beginning with iron ore, into semi-finished steel products that are sold to other manufacturers or service centers for further processing. This image is true for part of the industry, but a competing recycling technology also helps to define the modern steel industry – especially in United States, where more than one-half of all manufactured steel results from recycling ferrous scrap.

The concept of vertical integration in the steel industry was pioneered by Andrew Carnegie in the late nineteenth century. In 1890, the *Carnegie Steel Company* already included substantial holdings in coal, the primary energy source of steelmaking at that time, and Carnegie began to move, slowly at first, to acquire interests in the other key raw material – iron ore (Wall 1989, p. 587). By the end of that century, *Carnegie Steel* also tied materials acquisition to manufacturing with its own extensive railroad interests (Wall 1989, p. 623).

Today, the concept of an “integrated” steel company no longer relates to complete ownership in materials, transportation, and manufacturing, as it did for Carnegie. However, the fundamental process of integrated steelmaking remains largely unchanged in the sense that mill complexes include materials processing, iron making, and steelmaking. Figure 1 shows a simple schematic of the integrated steelmaking process. The actual conversion of iron ore takes place in a “blast furnace” that uses coke as a reduction agent and basic source of energy. The ore used in the blast furnace takes one of two forms: (1) pellets that are produced near the iron mine or (2) “sinter” produced at the steel mill by heating finely crushed iron ore along with coke powder and limestone (Hall 1997, p. 4-5). However, iron pellets are by far the largest form of iron used today in integrated mills (USGS 1998). Blast furnaces are closed pressurized vessels that are designed to run continuously for years at time. Depending on its design, the capacity of a blast furnace may be 1.5 million or more than 3 million tons per year, and scale economies in such furnaces are critically important. The crude "pig iron" produced in this process is transferred in molten form to the integrated mill's steelmaking operations, where carbon levels are reduced in a Basic Oxygen Furnace or "BOF". In turn, while still in molten form, steel is moved in ladles from the BOF to "secondary" steelmaking facilities where steel chemistries and carbon content can be tightly controlled for specific end uses. Steel takes its first solid form in continuous casting operations, where the cast product is committed to flat shapes (slabs used to make steel sheet or plates) or long shapes (billets or blooms, which have cross sections that are more nearly square or round).

[Figure 1 here]

The contrast between an integrated steel process and the alternative steel recycling process, which relies on the electric arc furnace (EAF), is dramatic, both in terms of complexity and, typically, the scale of operations. As shown in Figure 2, this alternative technology is much more direct. EAFs use post-consumer scrap metal such as old automobiles and appliances and scrap metal cast off in the manufacturing of steel products of many kinds. By melting the scrap metal from such sources, EAF producers recover steel that can be used to compete directly with ore-based mills.

[Figure 2 here]

The growth of electric furnace steelmaking in North America began to increase dramatically in the 1970's, and this was coincident with very important efficiency gains in this technology. See Barnett and Crandall (1986, 56-57). The price of scrap metal was very low at that time, and it gave scrap-based producers a significant cost advantage in certain product lines. In the decades to follow, the scale of many electric furnaces in terms of annual capacities increased to over one million tons, which approaches the low-end of the capacity range of integrated steelmaking. Moreover, as experience has increased with electric furnaces and technologies have advanced, it has become common for the furnace “charge” or input mix to include directly reduced iron (DRI) or pig iron. Input substitution between ferrous scrap and DRI or pig iron has greatly increased the product range of EAF producers by allowing them to more closely control the level of impurities in the scrap-based steels they produce.

3. Long trends in industry restructuring

Perspective on developments in steel technologies, like the advancement of electric furnace steel production, and the competitive forces that they help to shape can be gained by reference to long trends in the economic geography of American steel production. The historical geographic core of steel production in the United States is defined by three state-based districts: (1) Pennsylvania, including, of course, Pittsburgh, where integrated steelmaking began in the United States, (2) Illinois-Indiana, where Chicago-Gary is, by far, the largest production center, and (3) Ohio, especially areas bordering the Great Lakes near Cleveland. The overriding core-periphery trend in American steel production is unambiguous: Table 1 shows that the historical core region’s share of total steel production has declined monotonically for many decades, as population and overall American manufacturing activity shifted southward and westward. However, while this trend in steel production is evident, the factors underlying it have evolved in terms of technology and the nature of competition.

In the years immediately after World War II, explanation for the historical core region’s declining share meant, in practical terms, explaining why Pennsylvania, and Pittsburgh in particular, was losing its share of national steel production. As indicated in Table 1, from 1940 to 1970 the historical core region's share of steel production declined from 72 percent to 62 percent, with Pennsylvania accounting for seven points of the ten-point decline over this thirty-year period.

[Table 1 here]

Pittsburgh's early advantage in American steelmaking in the middle- to late-19th Century was found in its proximity to Western Pennsylvania's coal resources as well as the market position that Pittsburgh enjoyed when railroad systems began to move westward. Pittsburgh's distance from the source of the other great transferrable resource needed in steel production – iron ore – was of little disadvantage when integrated steelmaking began. North American iron ore travels primarily by boat or barge from mining areas in Michigan and Minnesota, and the transportation cost differentials related to iron ore simply did not offset the enormous advantage that Pittsburgh enjoyed by its proximity to metallurgical coking coal (Pittsburgh Regional Planning Association 1963, p. 262). The other major steel producing regions at the time in Ohio and Illinois-Indiana – all located on the Great Lakes – had superior water access to iron ore, but suffered relative to Pittsburgh in their proximity to sources of coking coal.

Based on this historical advantage, explanations for Pennsylvania's relative decline focused on two sources: (a) changes in technology that reduced locational cost advantage in Eastern production centers, and (b) changes in the spatial distribution of the market. Isard and Capron (1948) explain the cost side by very substantial progress in fuel efficiencies that reduced the amount of coke required in blast furnaces to produce pig iron. This weakened the advantage of production centers, like Pittsburgh, that are located close to sources of coking coal. See, also, Pittsburgh Regional Planning Association (1963, p. 273). The market disadvantage of production centers in Pennsylvania and other Eastern regions also is recognized as an important locational consideration by Isard and Capron (1948, p. 126) and by Pittsburgh Regional Planning Association (1963, p. 278). Later, Hekman (1978) argues that changes in the geographic distribution of the market are the most important basis for explaining changes in the distribution of steel production among regions.

An argument also can be made that the effect of market growth on steel plant capacities in the Midwest was enhanced by the weakening and ultimate demise of basing-point pricing in the steel industry. Under basing-point pricing, steel customers pay the F.O.B price at a given steel plant plus transportation costs from a pre-determined geographic basing point to the customer's plant location. Pittsburgh pricing, which prevailed until an F.T.C. ruling in 1924, set the transport costs on the basis of the customer's distance from Pittsburgh – regardless of where the steel was actually produced. After that date the number of basing points used by the industry expanded to include Chicago and other cities (Rogers 2009, p. 66), but the practice was not entirely eliminated until 1948 (Marengo 1955, p. 509). The ability of Pittsburgh mills to compete in markets located at the periphery of its market region was eroded when other cities were included in the multiple basing-point system. As the system was eliminated those other cities also lost the implicit market protection offered by this system. Consequently, the competitive position of steel plants located in distant regions was enhanced in geographic markets adjacent to their operations because of lower transportation costs, and the lower cost of delivered steel in these markets facilitated growth in steel consuming operations.

While these geographic shifts were taking place after World War II, major investment decisions were undertaken by steel makers in the United States and abroad that would profoundly affect the competitive balance among firms in years to come. The Basic Oxygen Furnace (BOF) – which is today standard technology – emerged in the 1950s to compete with the dominant technology of that time, the Open Hearth (OH) furnace. Major expansions in steelmaking capacity were made in the United States, Europe, and Japan in the immediate post-war period. Throughout the 1950s, investments in new capacity in the United States were being made in OH furnaces – over thirty-nine million net tons of OH capacity were added during that decade out of a total U.S. capacity of 139 million tons (Hall 1997, p. 40). In contrast, European and Japanese steel makers invested in the emerging technology, BOF. A decade later, it was apparent that the BOF was superior, and OH furnaces began to be phased out of production worldwide.

Many factors, including investments in OH furnaces, combined during the 1950's and the 1960's to weaken the competiveness of integrated steel makers in the United States, and this long saga is well documented elsewhere. See, for example, Tiffany (1988). Among these factors, labor issues were very important. In effect, the large integrated steel firms purchased labor peace at a very high price in the sense that negotiated labor settlements built-in substantial cost disadvantages based on hourly rates, work rules, and retirement benefits (Hoerr 1988, 77-81; Hall 1997, 45-49). "Big steel" emerged from all of this as being especially vulnerable to competition from foreign producers, and in 1960, the United States – still a major world producer – became a net importer of raw steel. In addition, anemic growth in steel demand after World War II along with the maturation of infrastructure investment in the United States limited the opportunity to build new plants embodying new technology, without the closure of existing integrated mills. See Barnett and Crandall (1986, p. 97) for documentation concerning steel demand during this period.

Ironically, the replacement of OH furnaces with BOF's also helped to spur the growth of a new set of *domestic* competitors for U.S. integrated steel producers. The OH technology, which accounted for the largest share of steel production in the United States through the 1960s, could accept up to fifty percent ferrous scrap in the furnace charge. While superior in other ways, BOF's by comparison could accept only much smaller amounts of scrap metal, and relied much more heavily on the pig iron generated by blast furnaces. Thus, replacement of OH furnaces by BOF's in the 1960's drove down the market price of ferrous scrap. Small, independent steel producers emerged in the United States to take advantage of low scrap prices by using EAF technology, and these American "minimills" would reshape the economic geography of steel production in North America.

Also in the 1950's, concern by integrated steel firms with the depletion of high-grade iron ore deposits stimulated major investments that further tied integrated firms to ore-based technologies. Costly investments were made in "pelletizing" operations that could bring low-grade ores up to the high iron content levels necessary for steelmaking. In addition, integrated firms invested heavily to secure access to high-grade ores, especially in Canada and South America (Hall 1997, p. 39). As a consequence of these locationally fixed investments integrated firms were less able to respond to opportunities presented by emerging scrap-based furnace production.

In addition to the technological and economic factors discussed so far, managerial factors also played a key role. Christensen (2000) has provided rich analysis of key managerial factors that may have differentiated between minimills and integrated producers in terms of their response to EAF technology. In Christensen's (2000) account, EAF technology was a "disruptive technology" – one key characteristic of which is that, at its inception, it is markedly inferior to prevailing technologies. In the case of EAF steelmaking, as indicated earlier, it was initially hard to control the chemical qualities of the steel produced, because the scrap that went into the furnace often varied in its metallurgical composition. Thus, the only markets open to EAF products were low-end applications, such as construction re-bar. In contrast, more demanding applications such as automotive steel required more precise control of chemical qualities. Focusing on their high-value added customers, integrated producers chose to cede the lower-end markets to minimills employing EAF technology. Given their lower cost structure, minimill companies were able to serve even the lower end markets profitably.

However, a crucial characteristic of disruptive technology is that it gets better over time (Christensen, 2000). Bolstered by their profits, and incentivized by the prospect of moving upmarket, minimills like Nucor and Chaparral worked hard to improve steel quality, as well as invested in the equipment to make larger shapes. By the mid-1980s, they had captured not only the entire rebar market, but also the lion's share of the market for bars, rods and angles. Once again, constrained by their cost disadvantages and by the preferences of their existing customers, integrated producers retrenched from those markets, now reduced to flat steel products that demanded the highest levels of purity, Christensen's (2000) analysis brings to light the process through which rational managerial decisions in response to real technological, economic and customer pressures led to the ascendancy of the minimill.

4. Technology-based competition and industry restructuring

The profound effect of the minimill phenomenon on the economic geography of American steel manufacturing is revealed by reference to the long trends shown in Table 1. In the thirty-year period from 1970 to 2000, the historical core region's share of national steel production declined by a further 10 percentage points, just as it had in the previous thirty-year period. In the more recent period, however, integrated steel makers were challenged by competitors on two fronts, domestic and foreign, and Pennsylvania's declining share shows the consequences. By the end of the 20th Century, a steel era had ended, as Pennsylvania's share of national steel production declined from 23 percent to seven percent, and at the same time, rough parity in regional shares between the historical core and other regions made moot the very concept of core-periphery distinctions.

The ascendance of EAF technology is evident in Table 2, which shows average annual steel production in the United States by furnace type for recent decades. EAF steel production doubled from the decade of the 1960s to the 1970s, and has continued a trajectory of steady growth to the present day – now accounting for well over fifty percent of raw steel production in the United States. Open Hearth (OH) technology – which was the focus of immediate post-war investments by US integrated steel producers – was phased out rapidly and replaced by BOF technology in the 1960s and 1970s. By the 1980s, OH furnaces were clearly obsolete. Perhaps the most dramatic change revealed by Table 2 is the major decline observed in total steel production from the 1970s to the 1980s – all of which is accounted for by integrated steel firms.

[Table 2 here]

The restructuring in the steel industry that is implied by these data – decline by ore-based integrated firms and growth by scrap-based EAF firms – has had a profound effect on the economic geography of steel production in the United States. The 1981-1982 economic recession experienced in the United States triggered a series of major plant closures and capacity adjustments that reflected long-term strategic decisions by integrated steelmakers. In 1974 forty-five ore-based plants produced non-specialty steel in the United States, and by 1991, ore-based capacity had been eliminated in twenty-two of these plants (Beeson and Giarratani 1998, p. 425). Most of the plants involved were permanently closed; four remained open, but only with EAF capacity. Mirroring the production data presented in Table 2, the capacity of ore-based steel plants in the United States also has dropped very substantially in recent periods. From 1974 to 1991, total ore-based furnace capacity in the United States decreased from 140.5 million tons per year to 76 million tons per year, a decline of 45.9 percent (Beeson and Giarratani 1998, p. 435).

Figure 3 shows the way that these reductions played out in terms of the spatial distribution of ore-based steelmaking capacity in United States by focusing on total BOF capacity in state-based regions during the 1970s, 1980s, and 1990s. Sharp declines in northeastern regions (Region 4 and Region 10) and in the West (Region 9) contrast vividly with relatively stable capacity in other places, especially in the upper Midwest (Region 1, Region 2, and Region 3).

[Figure 3 here.]

The observed geographic patterns of ore-based capacity change are best understood in terms of a partitioning of the product markets for steel. As explained by Ahlbrandt, Fruehan and Giarratani (1996) in the process of restructuring, ore-based integrated producers largely focused the capacity of their plants toward flat products (steel slabs) and eliminated their capacities to produce long products (steel billets and blooms). At the time of this partitioning, with a very small number of exceptions, the product range of EAF plants was limited to the billets and blooms necessary to fashion products like construction beams, steel rods, and reinforcement bars. The cost advantage of EAF producers forced ore-based integrated producers out of these markets, except in circumstances where the ore-based firm produced bars or other long products with special characteristics in term of hardness or other attributes that were beyond the metallurgical range of EAF mills. Also recall the previous discussion of EAF technology as a “disruptive” force (Christensen 2000) that triggered managerial responses eventually leading to such partitioning. See Barnett and Crandall (1986) as well for corroborative detail. Inter-firm competition is not static, however, and the relentless incursion of EAF producers into the markets served by integrated firms continues to the present day.

The location of automobile plants and auto parts suppliers was an important consideration in restructuring by integrated steelmakers. In the 1980's, EAF producers had limited or no access to the markets for automotive steel, and BOF producers made capacity decisions accordingly. Plant locations in Illinois-Indiana and Ohio served the strategic needs of integrated producers and the evidence for this is clear in Figure 3. The very dramatic declines in BOF capacities in Pennsylvania and other states are a consequence of exit by integrated firms from the markets for long products, and growth or stability in BOF capacities elsewhere are a consequence of the focus by integrated firms on the markets for flat products – especially, steel sheet that is shipped in coils to manufacture automobiles and other goods (Beeson and Giarratani 1998).

5. Steel minimills and industry restructuring

While transport costs on materials and finished products are important in determining the profitability of steel minimills in the same way that these factors are important to integrated mills, the basic transferrable input used by minimills – ferrous scrap – is much more widely distributed than the iron ore and coking coal required by integrated mills. This suggests that regions where ferrous scrap is in surplus would be especially attractive minimill locations, given the proximity of a plant location to product markets. It also suggests that transportation infrastructure – rail networks and barge access for scrap, trucking for finished steel – will be important factors in plant location. Substantial electricity is required for scrap-based steel production, and the price of electricity also is a key locational factor.

Figure 4 shows the capacity of scrap-based steel production (EAF producers) in state-based regions during the 1970s, 1980s, and 1990s. In sharp contrast to the pattern observed for ore-based steel production (BOF producers), scrap-based plant capacity is widely dispersed and steady or growing in most regions. Very substantial decade-to-decade growth is found several regions, and especially in the southern and southeastern states. See Region 7 and Region 8.

[Figure 4 here.]

The contrast in locational patterns for ore-based and scrap-based producers is displayed vividly in Figure 5, which maps specific plant locations for each technology in 2003.

[Figure 5 here.]

One remarkable implication of EAF capacity growth is that it has changed the very concept of a "steel" region in the United States. For most readers, the fact that the northeast corner of Arkansas, a very rural state, is home to one of the largest steel producing counties in the United States would come as a great surprise. Yet, this location along the Mississippi River can claim two large scrap-based EAF steel mills and has a total steelmaking capacity that is greater than the current steelmaking capacity in all of Pennsylvania. Moreover, the plant capacity in Arkansas was built on two green field sites with one start-up in 1987, *Nucor-Yamato Steel Company* in Blytheville AR, and a second start-up in 1992, *Nucor Steel's* facility in Hickman AR. In order to understand this phenomenon fully, it is important to appreciate the process by which scrap-based EAF producers emerged as formidable competitors with ore-based integrated mills.

Although electric furnace steel production has a much longer history, the beginning of the market insurgence by steel minimills in the United States can be dated to late 1950s and early 1960s when a small number of firms used the cost advantages they enjoyed from scrap-based manufacturing to produce reinforcement bars for concrete used in the construction industry (Hall 1997, p. 154-157). The plants involved were often at the periphery of market areas served by integrated steel producers and were buffered from competition by advantage in transportation costs (Barnett and Crandall 1886, p. 19). In these locations, minimills enjoyed very significant advantage in production cost: ferrous scrap was abundant, easily accessible, and available at low prices; EAF mills had very low capital costs relative to integrated mills; and electricity costs were low (Ahlbrandt, Fruehan, and Giarratani 1996) in the peripheral locations. These advantages, most particularly low capital costs, allowed minimills to exploit highly local markets for steel products in small scale plants.

The most formidable challenges to ore-based producers began in the latter part of the 1960s and the 1970s, when minimill producers began taking advantage of their success by reinvesting profits to replicate successful mills within a multi-plant firm structure. *Florida Steel Corporation* began this pattern, while retaining its focus on producing steel products for local construction markets (Hall 1997, p. 158-159). *Nucor Steel* was among the market entrants that followed the multi-plant pattern, but along with several other minimill producers, *Nucor* began to scale up plant capacities, extend its product range beyond construction steels, and serve much wider market areas (Barnett and Crandall 1986, p. 19). Expansion in scale, product range, and geographic markets placed EAF producers like *Nucor* in direct competition with integrated firms, and continuously improving EAF technologies added to the advantage of these insurgent firms over time. Beeson and Giarratani (1998) provide statistical evidence linking reductions in ore-based capacities across space and the closure of integrated plant directly to this minimill challenge.

The transformation of minimills from small scale plants serving local markets to larger scale plants serving broad markets explains the patterns observed in Figure 4, and is plainly evident in Table 3, which documents the size distribution of minimills in 1978 and 2003. Over this period, the number of minimills increased by nearly fifty percent and total minimill capacity tripled. Median plant capacity ratchets up from 350 thousand tons per year in 1978 to 750 thousand tons per year in 2003, and average plant capacity begins to approach one million tons by the end of the period. Indeed, in 2003, nearly one-third of existing "minimills" have an annual capacity of one million or more tons.

[Table 3 here.]

6. Minimill cost advantage

An important part of the cost advantage enjoyed by minimills was their early adoption of continuous casting technology. In most modern mills, steel takes its first solid form only as it passes from secondary steelmaking operations in a mill through a continuous caster. The earlier technology required pouring molten steel into casts to create "ingots" that could be placed in inventory for later use. Transforming ingots into billets, blooms, or slabs required re-melting before further processing in separate rolling mills. The costs of capital and energy required for ingot casting and re-melting are very substantial, and continuous casting is much more cost effective.

Scrap-based minimills began adopting continuous casting in the early 1960s, and the technology quickly became standard for minimills as EAF capacity expanded. By comparison, integrated mills adopted the technology only with a very substantial time lag, due, in part, to the challenges imposed by casting slabs at large volume (Warren 2001, p. 256). Further, integrated producers may have experienced “lock-in” effects from the geometry of their prior commitments: e.g., at its Mon Valley plant, US Steel was constrained by the need to work with a furnace and a rolling mill situated ten miles apart – a configuration consistent with existing casting technology (Ghemawat 1997). The net result of this difference in adoption rates was a direct cost savings for minimills that may have approached $40-$50 per ton of steel (Rogers 2009, p. 132).

Beyond this direct cost-savings per ton, continuous casting technology also was a linchpin for the introduction of modern manufacturing techniques to the American steel industry. Ahlbrandt, Fruehan, and Giarratani (1996, 89-90) explain that by investing simultaneously in continuous casting technology, human capital, and human resource practices that encourage the decentralization of decision making on the shop floor, steel manufacturers were taking advantage of important complementarities that had a tremendous impact on productivity. The basis for these gains was laid out clearly by Womack, Jones, and Roos (1990). In this widely read book on the automobile industry, the authors show how the elimination of inventories in production lines enables a process of “lean manufacturing” that provides a basis for substantial efficiency gains and quality improvements. The introduction of continuous casting in the steel industry had exactly these effects, and by doing so it enhanced the importance of human resource considerations in plant location decisions.

The importance of human resources in the link between technology and production efficiency is highlighted by the experience of *Nucor Steel*, which has served as a model for many other firms in the way that it ties together technology, human resources, and the process of production to enhance its competitiveness (Ghemawat 1995, 1997). The heart of Nucor’s labor model is a pay-for-performance system keyed to quality-based production, but this is imbedded in a much larger corporate culture that decentralizes decision making and encourages a get-it-done approach to problem solving (Ahlbrandt, Fruehan, and Giarratani 1996, 74-78). Nucor is not the only steelmaker with these characteristics, but its influence on the industry has been very important, and the kind of "high-performance" workplace that Nucor and other firms apply can result in substantial productivity gains (Ichniowski, Shaw and Prennushi, 1997).

Minimill producers striving to implement Nucor-like work systems place a premium on labor flexibility in terms of cross-skilling. For example, most of these firms rely on a very limited number of job categories so that workers in a given category have and use a number of different skills across a wide range of tasks. On a given day one worker might spend part of the day monitoring process controls and another part of the same day in maintenance activities. Because of the emphasis on decentralization in decision making, problem solving is valued and encouraged. This labor model encourages minimills to seek locations for new plants where workers could be trained in a flexible work environment. While many minimills are non-union and others are unionized, the spatial distribution of these producers strongly favors right-to-work states.

The management of human resources was not the only area in which minimills followed sophisticated approaches that enhanced their competitive advantage. Staying with the example of Nucor, another key factor was efficient management of capital, which was critical in the capital-intensive steel industry (Ghemawat 1997). During its period of growth, Nucor demonstrated a cadence of building or rebuilding one plant a year, acting as its own general contractor in each instance. This approach provided not only significant knowledge spillovers in between plant construction and operations, but also superior capital efficiency – allowing Nucor to build its first thin-slab caster for an investment estimated to be 25% less than it would have cost rivals, and to achieve operating break-even a year and half sooner (Ghemawat 1997).

In addition to labor factors, the locational cost advantage of EAF mills depends especially on the availability and price of ferrous scrap – the primary transferrable input for EAF steel making. Figure 6 shows clearly the cost advantage enjoyed by minimills away from the core Northeast and Midwest. Along with lower electricity prices – pointed out earlier – this factor further reinforced the attractiveness of production locations in what was previously the periphery.

[Figure 6 here.]

A summary of our key arguments is appropriate as we conclude this part of the chapter. Over the decades, the regional structure of the American steel industry changed drastically as a result of three interacting drivers. The evolution of EAF technology changed the relative cost positions of industry players, propelling significant growth for mini-mills. Economic growth in the South led to new markets for steel in areas away from the traditional industrial clusters of the Midwest, and minimills were able to situate themselves closer to those markets. Managerial agency intervened in the form of aggressive growth-seeking by minimill firms such as Nucor, and a corresponding tendency on the part of integrated producers to retrench away from markets that were targeted by the minimills. Thus, technology-based competition, demand shifts and managerial agency worked jointly to bring about the regional shifts we described in the American steel industry.

In order to provide the global context to our story, we now turn to the restructuring of the world steel industry. In addition to merely providing context, however, we find that the same three drivers may explain the global restructuring that is currently under way. Demand shifts away from the Triad markets (US, Japan and the European Community), new information technologies that facilitate worldwide managerial coordination, and aggressive managers seeking to reconfigure the industry to their own advantage – our analysis shows these to be drivers of the steel industry's globalization, much as they were in the case of the American steel industry.

7. The global dispersion of demand

Observers have noted three eras in the history of the global steel industry (e.g., Laplace Conseil 2003) – the pre-War national era, the period from the Second World War to the 1970s oil crisis, and the period since 1973, which is often viewed as culminating in the globalization of the steel industry. Two key developments underlying the globalization of the industry were liberalization (the freeing of political and strategic restrictions) and the attendant privatization of steel companies. Historically, governments around the world tended to heavily support their domestic steel producers, reflecting both concerns about preserving employment in a sector with powerful labor unions, and the entrenched view that the steel industry was "strategic" for industrial and military reasons. In the 1980s, 60% of the world's steelmaking capacity was government-owned (Wall Street Journal 2005). Subsequently, however, reflecting the *zeitgeist* of liberalization as well as inability to continue to bear the economic costs of inefficient government-owned plants, much of this capacity was privatized – bringing government ownership down to 40% of capacity by 2005 (Wall Street Journal 2005). In the Triad nations, where government ownership was less of a factor, bankruptcy restructuring facilitated the shedding of legacy costs, such as pension obligations, leading quickly to the emergence of a robust global market for steel assets.

While the large-scale liberation of steel companies from government ownership and/or political strictures that kept them domestic was an important factor, however, the globalization of the industry is most apparent if we examine changes in the global demand pattern. In 1960, the United States accounted for 26% of world steel markets, and the Triad nations for 56% (Old, 1985). Parallel to the “core to periphery” shift noted earlier within the American steel industry, the world industry has undergone a massive structural shift in terms of the geographic location of steel production. (See Figures 7 and 8].

[Figures 7 and 8 here]

Two observations are worth making here. Figure 7 demonstrates compellingly that Asia is now the center of gravity of steel production, accounting for over 60% of all steel produced. Figure 8 breaks down the Asia numbers even further, pinpointing simultaneously, the relatively stable role of Japan, the massive growth in China, and the significant room for growth in India. The well-known geo-economic shifts that comprise the slowing of growth in the Triad and the emergence of growth markets elsewhere (e.g., the BRIC nations) are clearly the fundamental drivers of the shift toward regions that were hitherto peripheral. In particular, it is useful to note one factor that is here to stay: steel intensity declines in the developed world. Crude steel consumption has stabilized at 400 kg per capita in the developed world – with low population growth and the shift to service-based economies, this steel intensity is not expected to increase. In contrast, however, China’s steel consumption in 2010 was 450 kg per capita, and rising, driven by huge investments in infrastructure. Nor is China’s hunger for steel expected to slow down any time soon, as suggested by two yardsticks (BHPBilliton 2012): First, China’s car penetration density in 2010 was 32 cars per thousand persons, compared to 423 in the United States. Second, China has only 32 square meters of urban residential floor space per capita, compared to 73 in the United States.

The second observation is that, important as China is, this is not entirely a China story: the rest of the developing world (ex-China) consumed over 400m tones of steel in 2010, and the 2000-2010 CAGR was 5.6%. (Arcelor Mittal 2011). That there is even more room for growth outside China is illustrated by comparing steel intensity numbers. India, lagging behind China on infrastructure investment and industrialization, consumed 60 kg per capita. The comparable number for other developing countries (apart from China and India) was 102 kg per capita. With a population base of nearly 5.5 billion, and driven by industrialization and urbanization, thus, the emerging markets are where the demand and demand growth are expected to be. For a firm-level illustration: At Arcelor Mittal, which is the world's largest steel producer, over 1/3 of current shipments go to the emerging markets (Arcelor Mittal 2011).

8. The emergence of the steel MNC

Accompanying the demand and production shifts from the Triad nations to the emerging markets noted above is the emergence of the steel MNC. Unlike similar or related industries such as Aluminum or mining, both of which witnessed the emergence of MNCs decades ago, steel companies are latecomers to multinational operations. In fact, it was the merger of three European national steelmakers to create Arcelor in 2001 that heralded the rise of the large-scale MNC in the steel industry. The adoption of the MNC form can be seen as a natural response to the industry dynamics noted earlier: The large increased demand in China/ Asia combined with the importance of operating on a global scale (global customers and global competition) led to the pressure for consolidation in a fragmented industry (IBM 2007). Given the powerful economic rationale against creating new capacity in many regions of the world, M&A were the primary means of global expansion for the established steelmakers. Figures 9 and 10 lay out the extent and impact of M&A activity in the global steel industry.

[Figures 9 and 10 here]

At its peak in 2006-2007, the steel industry witnessed a total of 323 M&A transactions over the two years, with a peak in dollar value of close to US$ 79 billion in 2006 (Figure 9). Although the number and size of deals has declined since then, the pace of consolidation continues. Figure 10 demonstrates that the rankings of the top steel producers have been routinely upset by consolidation deals. For example, Arcelor became the world's Number One steelmaker in 2001 as a direct result of the merger that created it. Similarly, NKK of Japan climbed from the 8^{th} position in 2002 to 4^{th} (as JFE) upon its merger with Kawasaki Steel. The appearance of new Chinese steelmakers on the Top Ten list is also directly attributable to M&A transactions.

Figure 10 also reminds us that, despite the considerable consolidation that has taken place, the steel industry remains highly fragmented. The total share of production accounted for by the Top Ten (i.e., C10) has barely changed during this period, in fact declining slightly to 0.24 in 2010 from 0.25 in 2000. By way of a rough comparison, the top five iron ore producers accounted for over 40% of the iron ore market (PwC 2004).

One important implication of the cross-border M&A phenomenon was that foreign ownership of steelmaking assets became reality, a far cry from the past preoccupation with domestic ownership of an industry that was widely held to be strategic in nature. At one point, it was estimated that foreign steelmakers owned 42% of steel capacity in the NAFTA region (Blume, 2008).

Thus, M&A played a critical role as an instrument of corporate initiative that fundamentally reshaped the industry and impelled the emergence of the steel MNC. We view the prevalence of M&A in this context as an expression of managerial agency that took place in the context of demand shifts, but was distinct from it. A counterexample serves to make this point: Tiffany (1987) has noted that US Steel did not pursue the clear opportunity to expand in Europe when that continent's steel plants lay in shambles at the end of the First World War. Tiffany (1987) attributes this to a judgment on the part of Wall Street financiers, the potential providers of expansion capital, that there were greater profits to be made by lending directly to Europeans to rebuild their own industry than by supporting US Steel's expansion. In such a view, managerial judgment may have led to the path not taken (of internationalization). However, in the late 1990s and then the 2000s, steel industry managers arrived at a different conclusion, and that has clearly led to a different set of outcomes.

It should also be noted that the M&A transactions did not emerge only from established steel companies from the prior core, i.e., developed world companies. In fact, arguably, one of the key instigators of the industry consolidation wave was a virtual outsider, Laxmi Nivas Mittal, who got his start running a small mini-mill in Indonesia (Ghemawat & Madhavan 2011). Developed world steelmakers have indeed accounted for many large cross-border deals. However, steel producers from the emerging markets have also been active players – e.g., Tata Steel's acquisition of Corus in 2007, and Gerdau's transactions in North America. Kumar & Chadha (2009) provide a useful comparative analysis of Indian and Chinese outward FDI in the steel industry. The trend in domestic M&A is also similarly represented across the key nations. In China, for example, the fragmentation of the steel industry, with its implications for efficiency and competitiveness, is a matter of great concern to policy makers. In 2008, China's top ten domestic steelmakers accounted for 42.5% of total output (i.e., C10 = 42.5). According to the Chinese government's 2005 *Development Policies for the Iron and Steel Industry*, the target C10 for 2020 is over 70 (KPMG 2009).

One key aspect of the evolution of the steel industry relates to its interface with the mining industry. With the growth in demand for steel inputs such as iron ore and coal, as well as the increasing concentration in the mining sector, it's clear that ensuring access to raw materials is a key concern for steelmakers. One outcome has been vertical integration: Indeed, much of the value that Mittal saw in acquiring post-Soviet steel mills may have been in the captive mines that came with the factories rather than in their steelmaking capacity Ghemawat (2007). This dialectical dynamic comprising concentrated market power on the part of the miners and the search for mineral self-sufficiency on the part of steelmakers will have interesting results – e.g., more direct attempts to buy up mines, such as Arcelor Mittal's 2011 attempt to gain control of Macarthur Coal, and the emergence of "haves" and "have-nots" in the steel industry in terms of mineral self-sufficiency (Lichtenstein, 2011) - with attendant implications for valuation differentials that may in turn drive further merger activity.

In our description of structural changes in the US steel industry, technology played a key role – minimills employed scrap-based production technology to direct great competitive pressure at integrated producers. Interestingly, technology plays a parallel role in the ongoing restructuring of the global steel industry, although with an important difference. The US domestic story recounted earlier was driven by production technology, i.e., the rise of EAF production. In the globalization case, we propose that it was not production technology, but rather supporting organizational technologies that mattered – specifically, sophisticated information technology tools that triggered managerial innovations and in turn facilitated the creation and ongoing management of the MNC form. Two examples serve to illustrate: ThyssenKrupp's use of networked computer systems to bring about global integration, Arcelor Mittal's coordination of inter-regional demand patterns through advanced information systems.

In ThyssenKrupp's case, we see how high-technology communication tools make possible a production chain that is dispersed over three continents (Wall Street Journal 2010). ThyssenKrupp is a pioneer in stitching together a truly global steel supply chain, with a plant in Sepetiba, Brazil making steel slabs, which are then rolled and treated in Alabama for higher-value added applications. A small team based in Rotterdam uses networked computer systems to coordinate customer orders, slab production, and further processing efficiently. ThyssenKrupp sees itself as a "virtual integrated steel mill" (Wall Street Journal 2010). Industry accounts suggest that the company has been able to create significant efficiencies in production and logistics cost by virtue of this networking technology.

In Arcelor Mittal's case, evidence suggests that significant managerial attention and the effective use of information systems (including knowledge transfer) have allowed it to leverage its resources globally as well as to respond in nuanced ways to regional differences market needs. At the time of their merger in 2006, there was a significant difference in technological capability between Arcelor and Mittal Steel. While Arcelor and Mittal Steel were roughly the same size, Arcelor's annual R&D outlay was more than 10 times that of Mittal Steel, with the result that Mittal mills tended to lag their Arcelor counterparts in efficiency, reliability, and quality of steel (BusinessWeek 2010). When you have a global company that demonstrates such stark differences in technology levels, leveraging advanced technology from the better units to the other units represents "low hanging fruit," as compared to developing new technology. As evidence, consider how Arcelor Mittal's 2006 Activity Report (Arcelor Mittal 2006) opens its description of R&D accomplishments (page 61): "The merger has added a new dimension to the R&D effort by widening the range of potential applications for existing technical know-how and permitting the better use of this expanded R&D resource in order to accelerate project work." A more graphic explanation of the technology transfer process is provided by Business Week (2010):

> “To tap into that expertise, Burns Harbor recently dispatched a team of engineers to Sidmar, Arcelor's crown jewel, in Ghent, Belgium. The idea was to figure out why, with the exact same inputs, the Europeans were able to squeeze about 7% more steel out of their mills than the U.S. plants could. The Americans relished the candlelight dinners in the old quarter of Ghent, but they were even more wowed by the advanced technology and shop-floor know-how they saw in Belgium. Now, they're gearing up to use a Sidmar device called a bomb that can be plunged into molten steel to sample its chemical properties and detect imperfections early on. The Mittals are pushing for just that sort of knowledge exchange across the company's global network, from Brazil to Kazakhstan. The many cultures now under the Arcelor Mittal flag provide "an inexhaustible source of competitive advantage," says Greg Ludkovsky, the company's chief technology officer for the Americas.””

The main point here is that the Arcelor Mittal merger resulted in a much larger platform of application sites over which existing technologies could be leveraged. In other words, absent the merger, each of these technologies would have suffered from a much smaller scope of application, thus reducing the return on investment for that particular technology.

A second aspect with regard to technology in the case of Arcelor Mittal is represented by the company’s approach to balancing global scale with responsiveness to local pressures. One specific instance: Demand and product requirements for steel vary across markets, and Arcelor Mittal needed to view demand regionally in order to optimize production and customer service. However, internal data on approx. 200,000 customers were scattered across 30+ systems. With IBM’s help, Arcelor Mittal developed an integrated system that provides managers with a unified view of regional patterns in demand. (IBM 2010).

To summarize the second part of our story, we propose that the geographic restructuring of the global steel industry should be understood in terms of the rise of steel production and consumption in the emerging markets as well as the rise of the steel MNC. The drivers of this fundamental shift, it turns out, are the same three drivers we noted earlier in the American industry's case: technology-based competition (although this time with a focus on information technology, not steel production techniques), demand shifts, and managerial agency.

9. Patterns in the restructuring of the industry.

Before concluding the Chapter, we would like to point out two features of the regional restructuring that we have described in the US steel industry and in the global industry. The first feature can be summarized as a shift from the "Core-Periphery" model to one of "multipolarity." The second feature can be summarized as a regional model of globalization. Below, we briefly discuss each in turn.

In both the US domestic industry and at the global level, our analysis suggests the relative decline of the hitherto core and the ascendancy of the periphery. However, even more fundamentally, the data and trends perhaps suggest the irrelevance of the core-periphery model itself. Specifically, what we see is not merely a switch in the roles or the emergence of new cores and new peripheries, but rather a new structure in which different regions are much more equally balanced. Although it might appear that China is the new core and all other regions are peripheries, the steel intensity trends noted earlier suggest that this is not sustainable beyond the medium term. As emerging nations other than China gain speed on their own industrialization trajectories, we are likely to see greater balance across the regions. More important, assessed through the lens of global reach and strategic capability of its steel companies, it is hard to describe China as the core. As a rough illustration, the companies in the list of Top ten steel producers in 2010 (see Figure 10) represent China (3 companies), Japan (2 companies) and Europe, South Korea, India, United States, and Brazil (1 company each). This raises the intriguing possibility that, rather than the core-periphery model, multipolarity may be more suitable as a descriptor of the global steel industry of the future.

Experience also suggests that the globalization of the steel industry has not followed a “flat earth” model, in which patterns of competition are uniform, but rather a “semiglobalization” model (Ghemawat 2007) that is much more nuanced and complex. Despite the growth of China and importance of steel MNCs, steel markets continue to be regional rather than frictionlessly global. A significant portion of steel exports consists of regional exports, and a steel producer in Germany is more likely to be in direct competition with a rival in Poland rather than in Brazil. Ghemawat (2007) points out that regionally focused strategies are a discrete family of strategies that need to complement local and global initiatives. From the steel industry’s standpoint, this exacerbates the organizational complexity associated with global footprints – in that strong regional hubs need to be created, with technological and managerial support for extensive knowledge-sharing both regionally and inter-regionally. Policymakers should take note as well – keeping up with the industry’s restructuring implies developing new global approaches as well as closer regional coordination.

10. Summary and conclusions

In this chapter, we proposed technology-based competition, demand patterns, and managerial agency as explanatory variables for the process of restructuring in the American steel industry in terms of its economic geography and in the context of sweeping changes in the industry’s global structure. After World War II and leading through the 1960's, the industrial structure of the American steel industry was dominated by large integrated steel producers. During this period, competition was primarily among integrated firms and the location decisions taken during the period concerned individual production units within those firms. Subsequently, in the 1970's and on through the 1990's, steel minimills emerged in the United States to challenge the market share of integrated producers. Finally, with the turn of the century, world steel markets began to reshape based on globalization. Energized by industry liberalization and privatization in many parts of the world, and supported by information technology and managerial innovations that increased spans of control, managerial agency manifested itself in the form of aggressive M&A to create the first large-scale steel MNCs. By examining these critical periods of restructuring in the American industry as well as in the industry globally, the role of economic geography as a competitive factor is exposed. In the process, we hope to have provided context for understanding the regional and spatial implications of competitive adjustment.

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Figure 1

Integrated Steelmaking Schematic

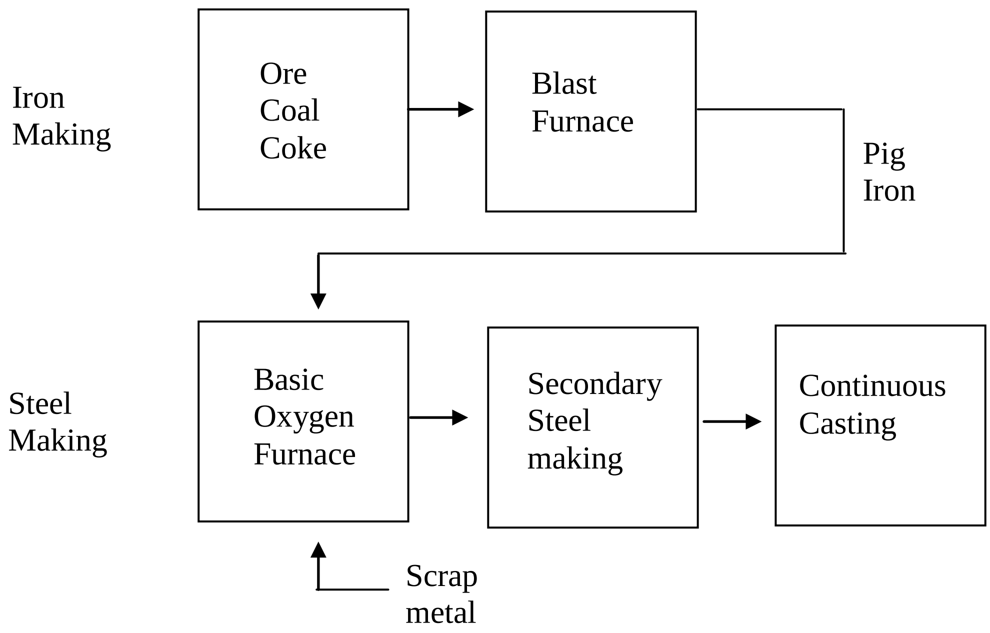


Figure 2

Electric Arc Furnace Steelmaking Schematic

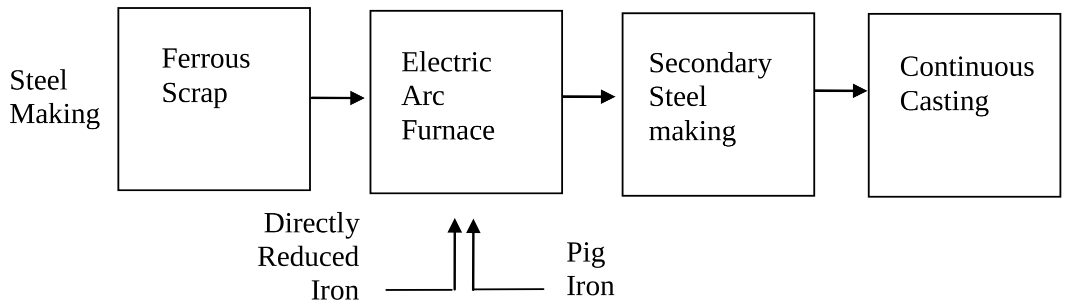


Table 1

Regional Percentage Shares of U.S. Steel Production, 1940 – 2008

	OH	PA	IL-IN	Historical Core Region Sub-total	All Other States	Total
1940	21	30	21	72	28	100%
1950	19	28	20	68	32	100%
1960	17	24	22	64	36	100%
1970	16	23	23	62	38	100%
1980	14	21	26	61	39	100%
1990	17	12	29	58	42	100%
2000	16	7	29	52	48	100%
2008	15	6	29	50	50	100%

Source: American Iron and Steel Institute (various years), *Annual Statistical Report*, Washington, D.C., USA: American Iron and Steel Institute.

Table 2

Steel Production by Furnace Type:
Average Annual Production for Each Decade, 1960s - 2000s

(Millions of Net Tons)

	Open Hearth	Basic Oxygen	Electric Arc	Total (All Furnaces)
1960-69	82.3*	24.4	13.0	119.7
1970-79	30.0	76.3	26.3	132.6
1980-89	6.9	56.0	31.3	94.2
1990-99	0.5	59.1	41.8	101.4
2000-08	0.0	49.7	55.7	105.4

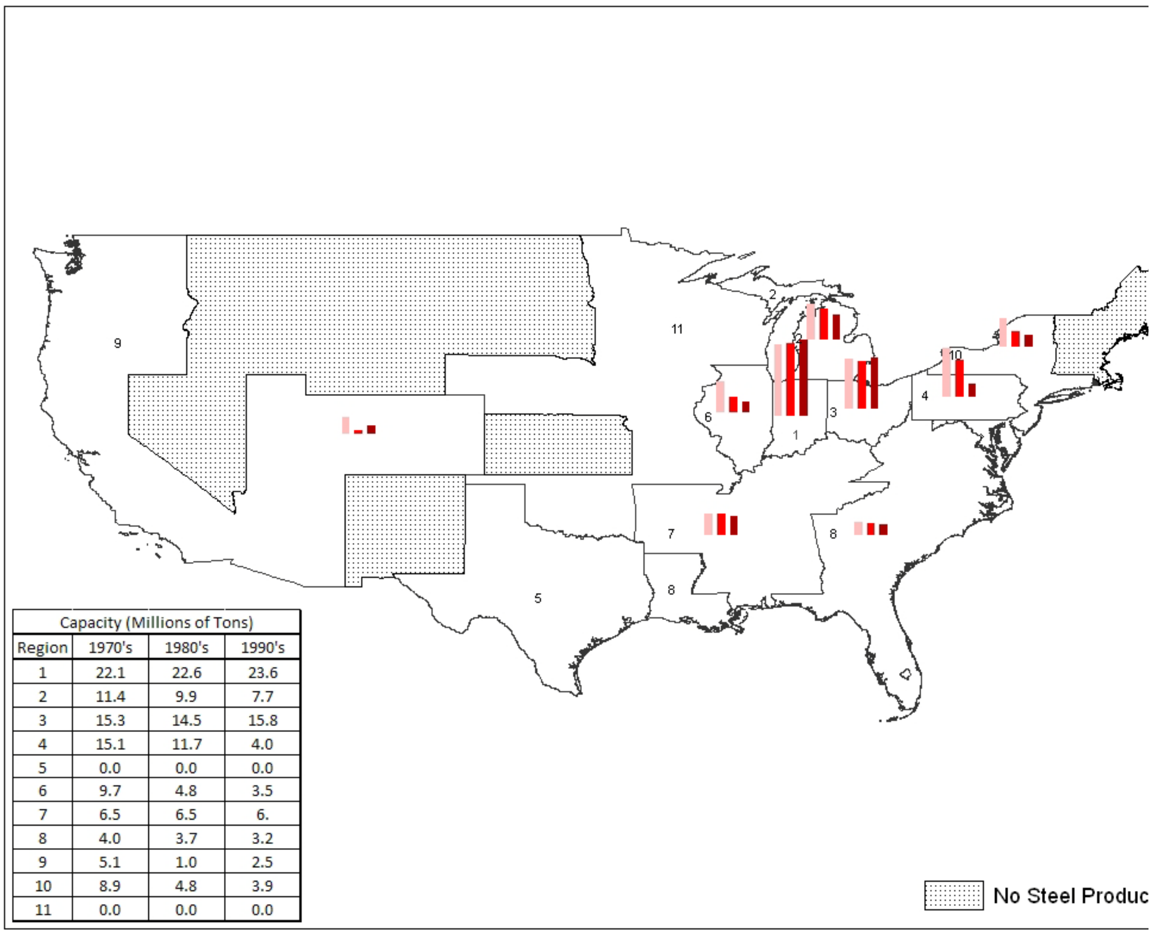
*Note: Includes a small amount of production from Bessemer furnaces, which were completely decommissioned in the United States by 1968.

Source: American Iron and Steel Institute (various years), *Annual Statistical Report*, Washington, D.C., USA: American Iron and Steel Institute.

Figure 3

Basic Oxygen Furnace (BOF) Capacity in State-based Regions:
Annual Average Capacity in each Decade, 1970s, 1980s, and 1990s

(Millions of Tons)



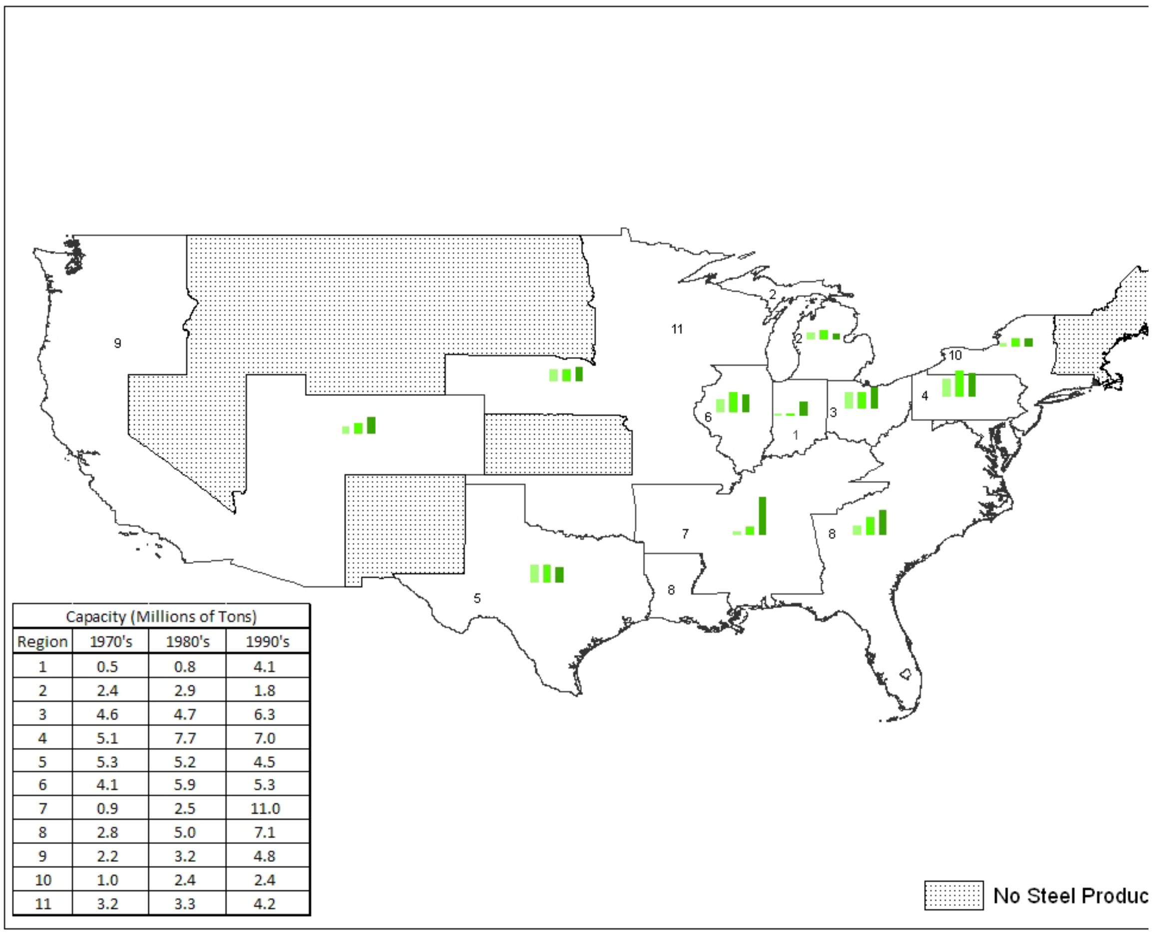
Capacity (Millions of Tons)			
Region	1970's	1980's	1990's
1	22.1	22.6	23.6
2	11.4	9.9	7.7
3	15.3	14.5	15.8
4	15.1	11.7	4.0
5	0.0	0.0	0.0
6	9.7	4.8	3.5
7	6.5	6.5	6.
8	4.0	3.7	3.2
9	5.1	1.0	2.5
10	8.9	4.8	3.9
11	0.0	0.0	0.0

Source: Center for Industry Studies, *US Steel Plant Database*, Pittsburgh, PA, USA: University of Pittsburgh.

Figure 4

Electric Arc Furnace (EAF) Capacity in State-based Regions:
Annual Average Capacity in each Decade, 1970s, 1980s, and 1990s

(Millions of Tons)

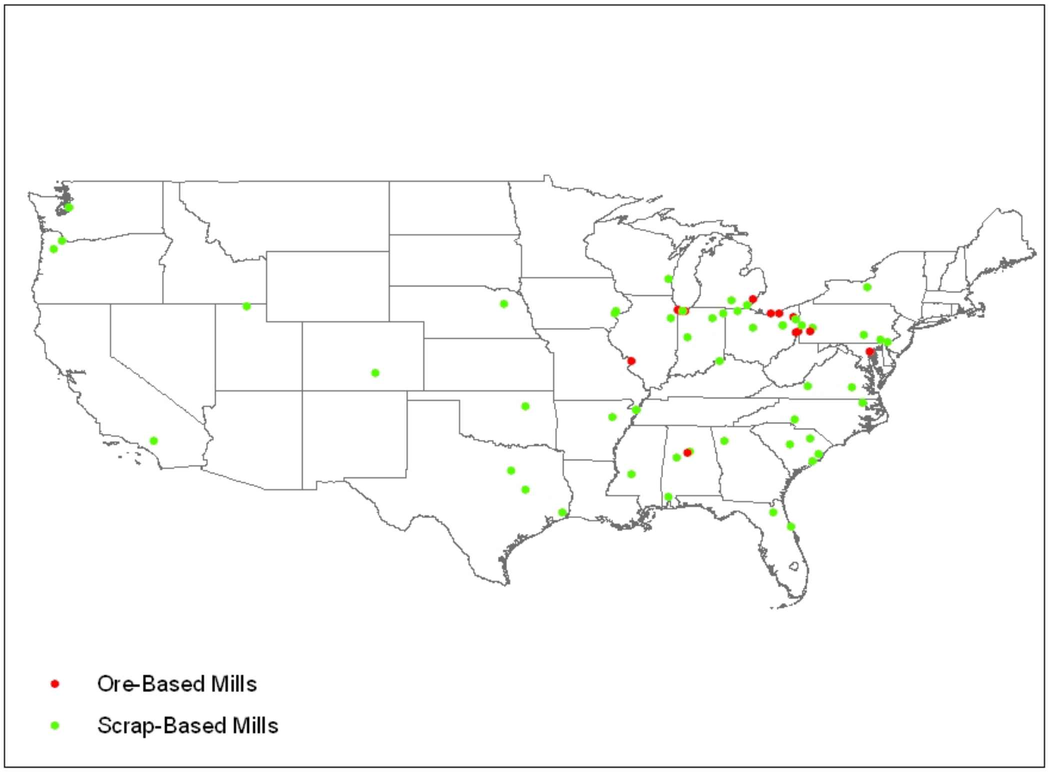


Capacity (Millions of Tons)			
Region	1970's	1980's	1990's
1	0.5	0.8	4.1
2	2.4	2.9	1.8
3	4.6	4.7	6.3
4	5.1	7.7	7.0
5	5.3	5.2	4.5
6	4.1	5.9	5.3
7	0.9	2.5	11.0
8	2.8	5.0	7.1
9	2.2	3.2	4.8
10	1.0	2.4	2.4
11	3.2	3.3	4.2

Source: Center for Industry Studies, *US Steel Plant Database*, Pittsburgh, PA, USA: University of Pittsburgh.

Figure 5

Location of Steel Plants in the United States, 2003



Source: Center for Industry Studies, *US Steel Plant Database*, Pittsburgh, PA, USA: University of Pittsburgh.

Table 3

Size Distribution of U.S. Steel Minimills
by Plant Capacity, 1978 and 2003

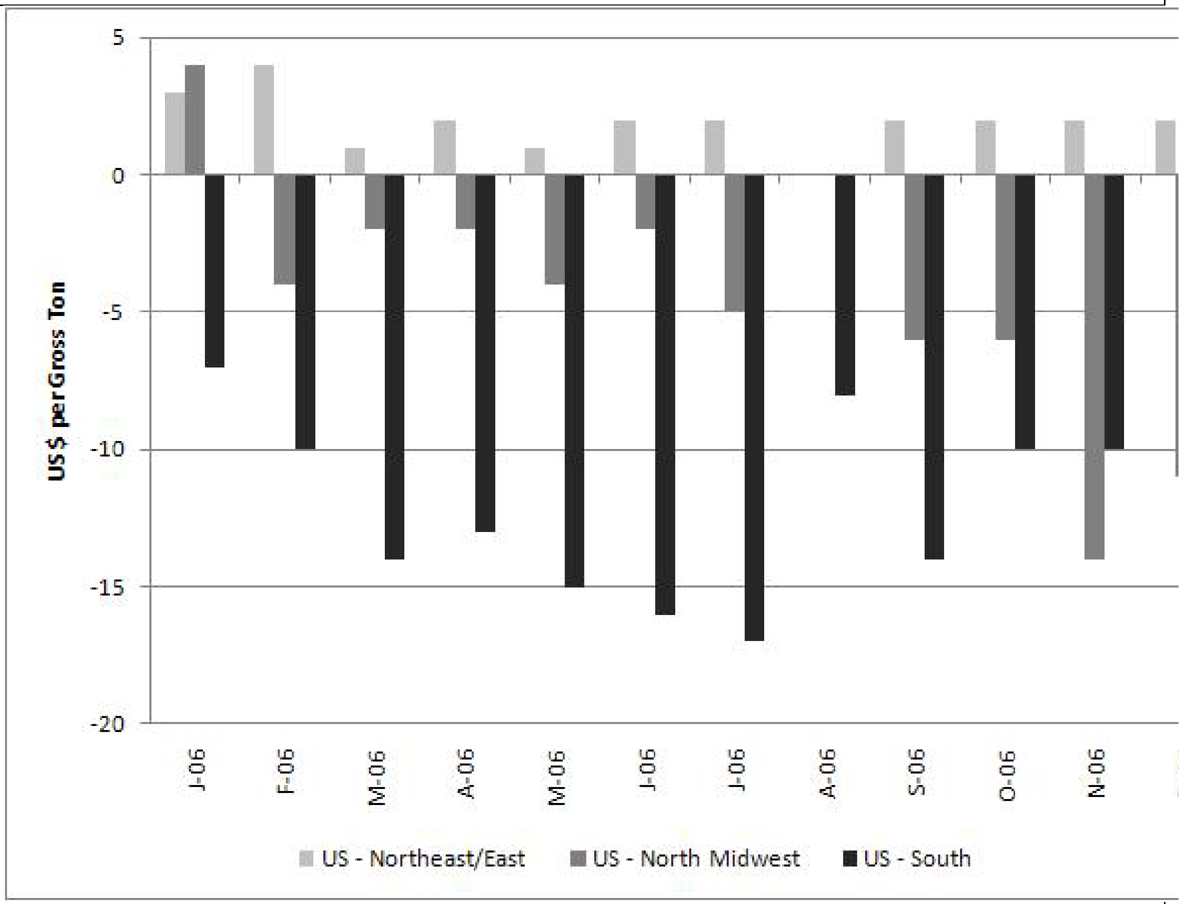
Plant Capacity (Thousands of Tons)	1978 (Number of Minimill Plants)	2003 (Number of Minimill Plants)
1,000 or more	3	22
800 – 999	4	10
600 – 799	4	15
400 – 599	9	13
200 – 399	13	4
Less than 200	11	1
Total number of minimill plants	44	65
Total minimill plant capacity	20,293	61,089
Average minimill plant capacity	461	940
Median minimill plant capacity	350	750

Source: Center for Industry Studies, *US Steel Plant Database*, Pittsburgh, PA, USA: University of Pittsburgh.

Figure 6

Regional Price Differentials Based on the RMDAS™ Ferrous Scrap Price Index: Monthly Price for Prompt Industrial Composite, 2006

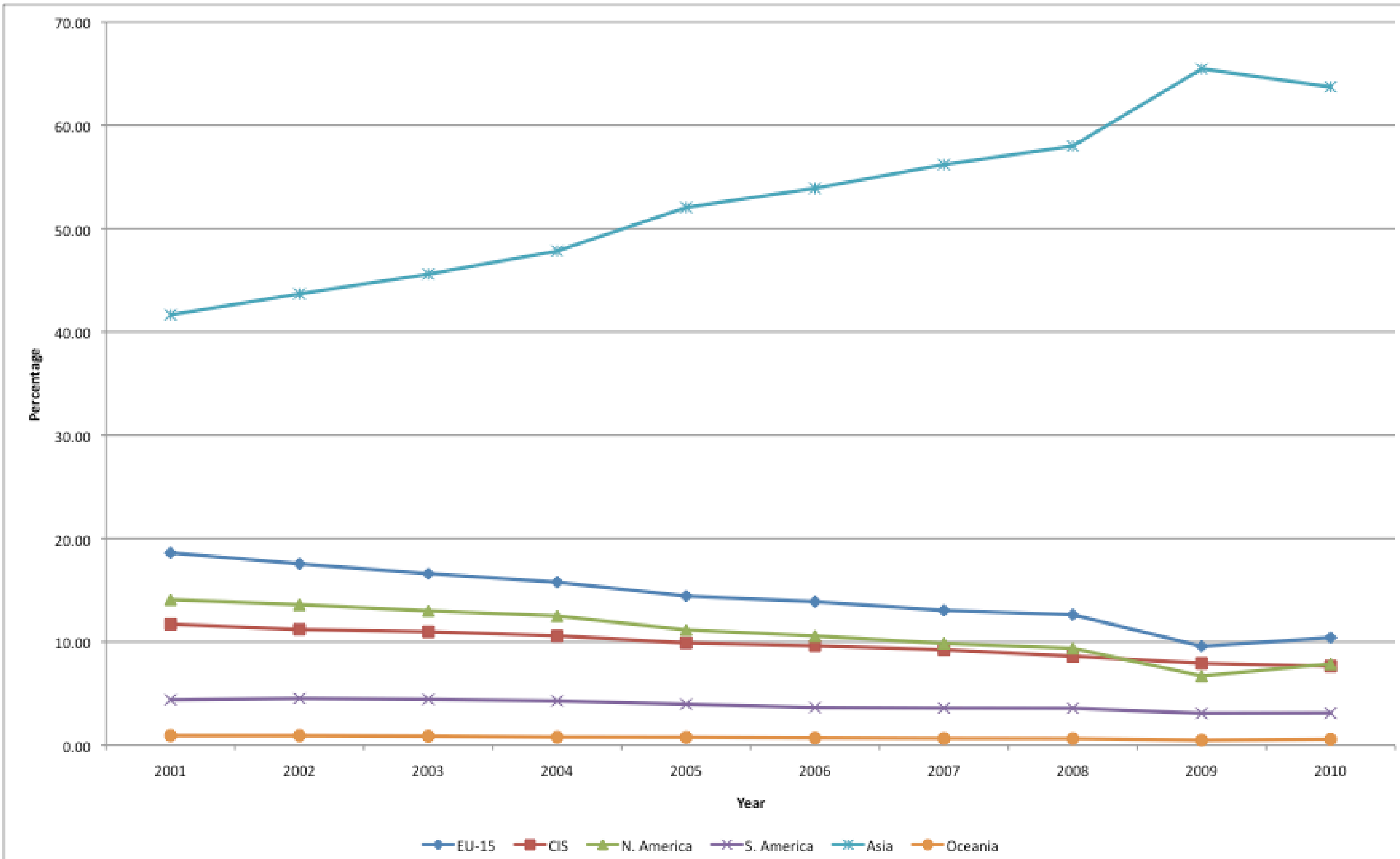
(Delivered Price – U.S. Weighted Average)



Source: Management Science Associates' (MSA) Raw Material Data Aggregation Service™ (RMDAS): http://rmdasindex.msa.com/

Figure 7

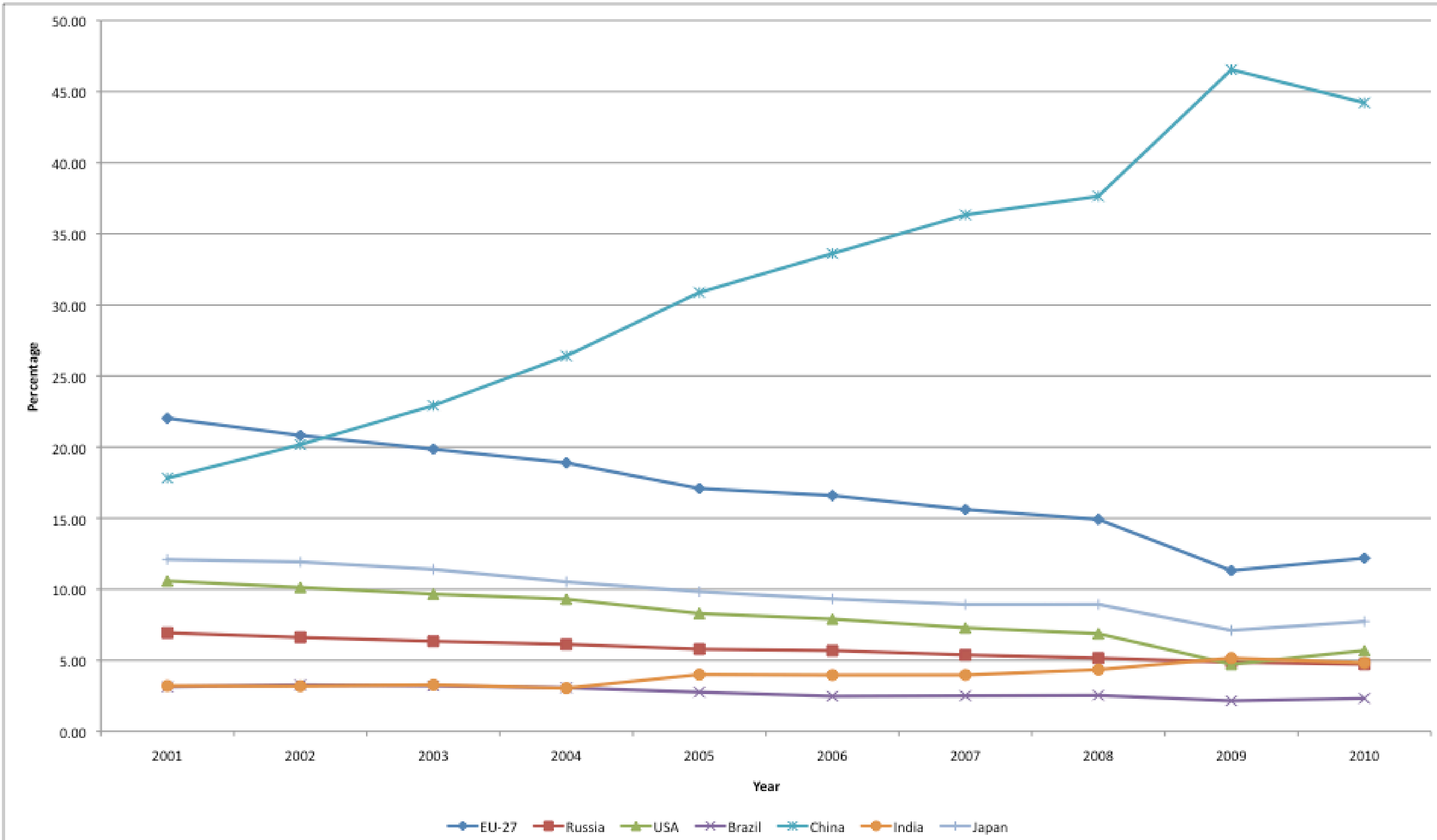
The Shift to Asia:
Crude Steel Production Share Across World Regions



Source: World Steel Association

Figure 8

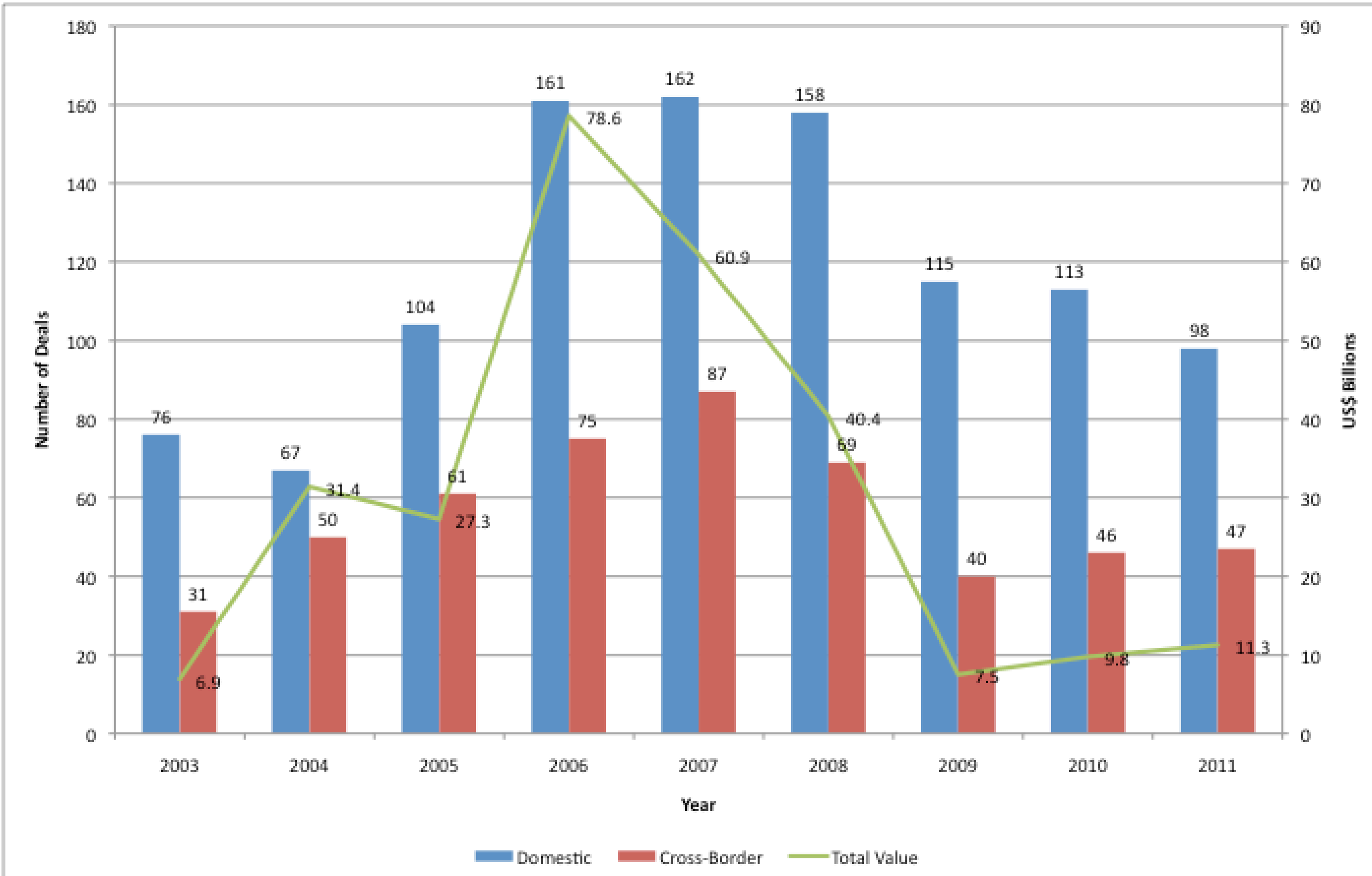
The Rise of China:
Crude Steel Production Share in Key Markets



Source: World Steel Association

Figure 9

M&A Deal Activity in the Global Steel Industry



Source: pwc Metal Deals: Forging Ahead, various annual issues

Figure 10

How Megadeals Reshaped Industry Leadership:
Top 10 Steel Producers (Million Metric Tonnes)
* indicates a steelmaker that improved its Top 10 standing by means of major acquisition(s) in that year

	2010		2009		2008		2007	
1	ArcelorMittal	98.2	ArcelorMittal	77.5	ArcelorMittal	103.3	ArcelorMittal	116.4
2	Baosteel	37.0	Baosteel	31.3	Nippon Steel	37.5	Nippon Steel	35.7
3	POSCO	35.4	POSCO	31.1	*Baosteel Gp.	35.4	JFE	34.0
4	Nippon Steel	35.0	Nippon Steel	26.5	POSCO	34.7	POSCO	31.1
5	JFE	31.1	JFE	25.8	Hebei Steel Gp.	33.3	Baosteel Gp.	28.6
6	Jiangsu Shagang	23.2	Jiangsu Shagang	20.5	JFE	33.0	*Tata Steel	26.5
7	Tata Steel	23.2	Tata Steel	20.5	Wuhan Steel Gp.	27.7	Anshan-Benxi	23.6
8	US Steel	22.3	Ansteel	20.1	Tata Steel	24.4	Jiangsu Shagang Gp.	22.9
9	Ansteel	22.1	Severstal	16.7	Jiangsu Shagang Gp.	23.3	Tangshan	22.8
10	Gerdau	18.7	Evraz	15.3	US Steel	23.2	US Steel	21.5
Total		346.2		285.3		375.8		363.1
World production		1417.3		1232.4		1329.2		1346.6
C10		0.24		0.23		0.28		0.27
C4		0.15		0.14		0.16		0.16
	2006		2005		2004		2003	
1	*ArcelorMittal	117.2	Mittal Steel	63.0	Arcelor	46.9	Arcelor	42.8
2	Nippon Steel	32.7	Arcelor	46.9	*Mittal Steel	42.8	LNM Gp.	35.3
3	JFE	32.0	Nippon Steel	32.0	Nippon Steel	32.4	Nippon Steel	31.3
4	POSCO	30.1	POSCO	30.5	JFE	31.6	*JFE	30.2
5	Baosteel Gp.	22.5	JFE	29.9	POSCO	30.2	POSCO	28.9
6	US Steel	21.2	Baosteel	22.7	Shanghai Baosteel	21.4	Shanghai Baosteel	19.9
7	Nucor	20.3	US Steel	19.3	US Steel	20.8	Corus Gp.	19.1
8	Tangshan	19.1	Nucor	18.4	Corus Gp.	19.0	US Steel	17.9
9	Corus Gp.	18.3	Corus Gp.	18.2	Nucor	17.9	ThyssenKrupp	16.1
10	Riva Gp.	18.2	Riva	17.5	ThyssenKrupp	17.6	Nucor	15.8
Total		331.6		298.4		280.6		257.3
World production		1247.1		1144.0		1071.4		969.9
C10		0.27		0.26		0.26		0.27
C4		0.17		0.15		0.14		0.14
	2002		2001		2000			
1	Arcelor	44.0	*Arcelor	43.1	Nippon Steel	28.4		
2	*LNM Gp.	34.8	POSCO	27.8	POSCO	27.7		
3	Nippon Steel	29.8	Nippon Steel	26.2	Arbed	24.1		
4	POSCO	28.1	Ispat Int.	19.2	LNM	22.4		
5	Shanghai Baosteel	19.5	Shanghai Baosteel	19.1	Usinor	21.0		
6	Corus	16.8	Corus	18.1	Corus	20.0		
7	ThyssenKrupp	16.4	ThyssenKrupp	16.2	ThyssenKrupp	17.7		
8	NKK	15.2	Riva	15.0	Shanghai Baosteel	17.7		
9	Riva	15.0	NKK	14.8	NKK	16.0		
10	US Steel	14.4	Kawasaki	13.3	Riva	12.8		
Total		234.0		212.8		207.8		
World production		904.2		851.1		848.0		
C10		0.26		0.25		0.25		
C4		0.15		0.14		0.12		

Source: World Steel Association