THE EVOLUTION OF BUSINESS ECOSYSTEMS: INTERSPECIES COMPETITION IN THE STEEL INDUSTRY

By

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Submitted to the System Design and Management Program
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Abstract

This thesis contributes toward the building of a theory of the evolution of business ecosystems by exploring the applicability of Piepenbrock's[1] theoretical framework to a commodity industrial setting, namely the U.S. steel industry from 1860-2010. As the evolution of business ecosystems framework posits the emergence of symbiotic inter-species competition between heterogeneous inter-organizational architectures, this thesis builds grounded theory by expanding Piepenbrock's original theoretical sample to include the following dominant firms in the U.S. steel industry: *United States Steel* and *Bethlehem Steel*, representing incumbents and *Nucor* and *Arcelor-Mittal*, representing late-entrants. Comparative historical analyses are performed to determine the evolution of the firms' *form, function* and *fitness:* specifically their inter-organizational architectures, their strategic choices in both market quantity and technological quality, and the maturity of the steel industry environment in both market quantity and technology quality.

The U.S. steel industry is demonstrated to currently be in a mature state, with slowing rates of growth in terms of both market quantity and technology quality (i.e. performance improvement trajectories of products and production processes). During the growth and maturing of this market environment, the inter-organizational architectures of the dominant incumbent firms of *United States Steel* and *Bethlehem Steel* appear to have evolved from integral to modular forms. As the market became mature, late-entrant firms of *Nucor* and *Arcelor-Mittal* appear to have entered with integral inter-organizational architectures, in which they compete on quality, cost and delivery dimensions enabled through stable long-term growth.

The findings of this thesis demonstrate that the evolution of business ecosystems appears to be a reasonably robust theoretical framework, which is useful in explaining why firms in the same industry vary systematically in performance over time. The investigation of inter-species competition in the U.S. steel industry expands the external validity or generalizability of the framework to include commodity industrial settings. The framework captures the evolution of *dominant designs* in enterprise architectures that oscillate between *modular* and *integral* states throughout an industry's life-cycle. Architectural innovation at the extended enterprise level in *Nucor* and *Arcelor-Mittal* is demonstrated to contribute to the failure of established firms *United States Steel* and *Bethlehem Steel.*

Thesis Supervisor: Dr. Theodore F. Piepenbrock, MIT Sloan School of Management

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[1] Piepenbrock, T.F. (2009). "Toward a Theory of the Evolution of Business Ecosystems." MIT PhD Thesis.

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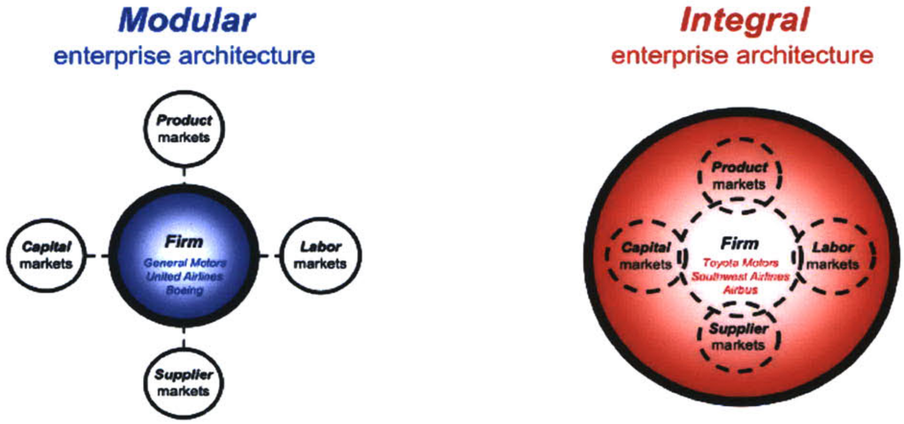
1. Introduction

1.1 The Evolution of Business Ecosystems (EBE) : The foundation theory for this research

"Why do firms in the same industry vary *systematically* in performance *over time*?" The answer to this question has eluded economists and sociologists ever since the question was seriously considered. This question is sought to be addressed in the work of Theodore F. Piepenbrock, PhD, MIT Engineering Systems Division, in his 2009 Doctoral thesis titled "Towards a Theory of Evolution of Business Ecosystems". Piepenbrock's work grew out of (among numerous other sources), the research of his doctoral committee members.[2]

Piepenbrock proposes the *architecture* of firms to be their most fundamental defining characteristic, based on which firms can be categorized into well-defined and largely immutable *species.* Piepenbrock defines architecture in terms of the strength, closeness and the specific morphology of relationships that exist between the core firm and the four markets that are its key stakeholders – Product Markets, Capital Markets, Supplier Markets and Labor Markets. The two categories of Enterprise architecture as defined by Piepenbrock are *Integral and Modular:*



Singular (Maximization of *Shareholder Value*)	**Objective Function**	**Plural** (Maximization of *Stakeholder Surplus*)
Narrow (*narrow* spatial, *short* temporal)	Enterprise **Boundaries**	**Broad** (*broad* spatial, *long* temporal)
Simple (*High* quantity of participants in a stakeholder class, *Low* quality of stakeholder relationships)	Stakeholder **Interfaces**	**Complex** (*Low* quantity of participants in a stakeholder class, *High* quality of stakeholder relationships)

Figure 1: Enterprise Architectures, Source - Piepenbrock, 2009

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[2] Charles H. Fine (*Clockspeed, 1998*), Deborah Nightingale et al (*Lean Enterprise Value,), The Resilient Enterprise (Yossi Sheffi, 2006), , MIT Sloan Fellows thesis 1988 (Carolyn Corvi, 200x)*

Per the conclusions of Piepenbrock's research, "Challenger" firms (within a given industry) having an *Integral* architecture (henceforth referred to as *red* firms, consistent with the terminology used in Piepenbrock, 2009) are seen to "take over" from their *blue* incumbent rivals (having a *Modular* architecture), during the period when an industry reaches maturity, and are seen to consistently outperform their *blue* rivals during the middle and late stages of an industry's lifecycle.

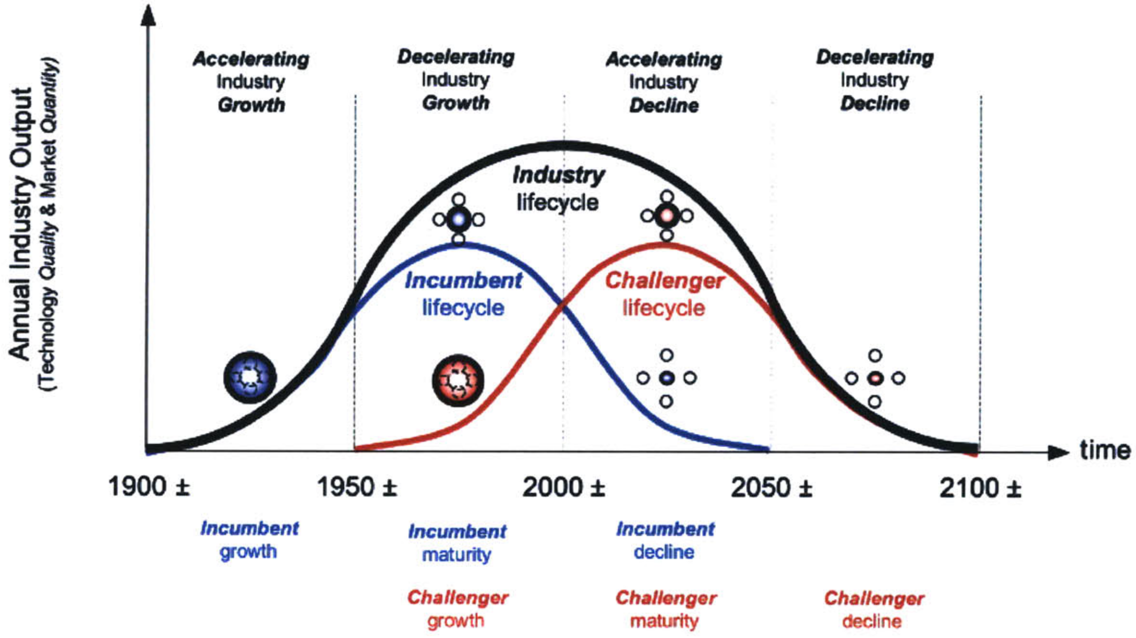

Figure 2: Schematic visualization of the evolution of the business environment, Source - Piepenbrock, 2009

Piepenbrock bases his conclusions on comprehensive analysis of a combination of qualitative data and longitudinal quantitative time-series data, primarily utilizing the *Case Study Research Method* of theory building (Eisenhardt, 1989). Piepenbrock chooses the following pairs of firms within three different industries for his analysis:

Manufacturing:	**The Aerospace Industry:**	***The Boeing Company*** **and** ***Airbus Industrie***
	The Auto Industry:	***General Motors*** **and** ***Toyota Motors***
Services:	**The Airline Industry:**	***United Airlines*** **and** ***Southwest Airlines***

Building on the Blue and Red Architectural typologies, Piepenbrock elucidates the influence of a firm's **Objective Function** (*Shareholder Value* vs. *Stakeholder Surplus)*, **Enterprise Boundaries** (*Narrowly Defined* vs. *Broadly Defined)* and **Stakeholder Interfaces** (*High functional Independence* vs. *High functional Interdependence)* to highlight the importance of **Architectural Leadership** as a key strategic capability in building and sustaining competitive advantage.

1.2 The Motivation of the present Thesis

While Piepenbrock's hypotheses are shown to be consistently validated across the three industries studied, there is a case for examining the broader applicability of the framework. While Piepenbrock's theoretical sample can claim variance along the dimensions of the Political Economy (e.g. US, Japan, Europe), and across the Manufacturing and Services sectors, a prominent factor that is common to all the firms studied is that the quality of the end product or service is a key source of competitive advantage. The present research primarily seeks to examine the validity of Piepenbrock's model in Commodity industries, where, in most cases, the end product necessarily conforms to a common expected standard, and the principal sources of competitive advantage might lie elsewhere.

Also adopting the *Case Study Research* method (Eisenhardt, 1989), and utilizing qualitative data as well as quantitative longitudinal time-series data, I shall examine the evolution of the **US Steel Industry**, with particular emphasis on the following :

- **Incumbents - The *United States Steel Corporation* (USS/ USX), *Bethlehem Steel***
- **Challenger - *Nucor Corporation, Arcelor Mittal***

Piepenbrock draws on Darwin's theory of evolution of natural/ biological ecosystems to examine and explain the evolution of business ecosystems. He posits two distinct *species* of firms that are distinguished by their specific morphology (architecture). Just as the specific morphology of an organism determines its survivability in a given natural environment, the specific architecture of a firm is posited to determine its survivability in a given business environment. Piepenbrock is "agnostic" to the question of whether *red* is "better" than *blue* or vice versa, and offers instead an *Architectural Contingency Theory,* building off the work of Structural Contingency theorists (e.g. Lawrence and Lorsch, 1967)[3]. As is inherent in the process of "natural selection" within the theory of evolution, the question of which is inherently *better* is less important than which one is *better suited* to the prevailing environment. The horse will beat the camel in an environment of lush green meadows, but the camel will prevail in an arid desert. It is therefore the *environment* which determines which species will prevail in the competition between species.

Piepenbrock approaches the question of evolution of business ecosystems from a four-pronged integrative perspective, comprised of System Architecture (*functional complexity*), System Dynamics (*dynamical complexity*), Human Dynamics (*behavioral complexity)* and Ecosystem Dynamics (*competitive complexity*), and the interaction between these. This represents a significantly different approach to previous work in business theory utilizing principles from the theory of Evolution, most of which tended to focus on *intra-species* rather than *inter-species* competition or focused on certain discrete episodic events, such as technological disruption.

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[3] Lawrence, P., and Lorsch, J., "Differentiation and Integration in Complex Organizations" Administrative Science Quarterly 12, (1967)

Prominently, the *Lotka-Volterra Predator – Prey model*[4] has been utilized by, among others, *J.M Utterback and C.W.I Pistorius*[5] to explain the dynamics of technological disruption, which causes one *technology* population to systematically displace the other. However, one key assumption of the Lotka- Volterra model is "During the process, the environment does not change in favor of one species and the genetic adaptation is sufficiently slow". This makes this method well-suited to model episodic phenomenon such as technological disruption and competitive dynamics between populations belonging to the same species, but ill-suited to trace the evolution of firms over the industry life cycle, in the course of which the business environment would necessarily undergo substantial change between epochs, with a corresponding change in the species that would be well-suited in a given environment.

This brings me to the first question that this thesis seeks to address. Given that the environment is a key determinant of the species which will dominate, and the morphology or architecture is a defining characteristic of a species, is it possible that certain business environments yield interaction dynamics between species that are substantially different from the ones identified by Piepenbrock? Specifically, "commoditization rate" is an important variable in Piepenbrock's numerical simulation model. However, in the case of commodity industries such as steel, this rate would effectively be instantaneous, since the products are commodities at the outset. I use the steel industry as a case study because the commodity business in general and the steel industry in particular, operate in a business environment that is, in many ways, significantly different from that of the cases studied by Piepenbrock. Piepenbrock identifies discrete lifecycle dynamics for the incumbent and challenger species, where at some stage the challenger completely takes over from the incumbent. However in the case of the steel industry, the minimill technology based challengers are critically dependant on the incumbent integrated steel plant manufacturers for the availability of raw material (steel scrap) for the major portion of the lifecycle.

In addition to establishing the validity of the theory in the steel industry by examining each of its propositions against the evidence of qualitative and quantitative data, I will explore the hypothesis that rather than the dynamic where the challenger completely displaces the incumbent, the steel industry is likely to see a symbiotic dynamic, where the incumbent survives to some degree until the late stages of the challenger's lifecycle.

The second question that this thesis seeks to continue to explore is "why are ***modular incumbents*** unable to evolve with the environment, to pre-empt the predation by ***integral challengers***?" and "What kind of *architectural leadership* would ensure that the organization consistently adapts to the environment?" To answer these questions, Piepenbrock draws on several existing theories, including adaptations of the "punctuated equilibrium" theory of Stephen Jay Gould[6] (Eldridge

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[4] Alfred James Lotka, 1925 / Vito Volterra, 1926

[5] Multi Mode Interaction among Technologies, Pistorius and Utterback, 1997

[6] Eldredge, N. and Gould, S. (1972) Punctuated Equilibria: An Alternative to Phyletic Gradualism, in T.J. Schopf (Ed.), Models in Paleobiology, 82-115, San Francisco: Freeman, Cooper & Co.

and Gould, 1972). Prominently, these include Tushman & Romanelli (1985)[7], Romanelli & Tushman[8] (1994) and Tushman and Anderson (1986)[9]. Gould's theory of *Punctuated Equilibrium* contrasts with the hitherto accepted theory of *Phyletic Gradualism*[10], which proposes a steady and continuous mechanism of evolution, with changes accumulating gradually and continuously over time.

"The central proposition of punctuated equilibrium embodies three concepts: stasis, punctuation and dominant relative frequency (Eldridge and Gould, 1972). Stasis refers to a long period of relatively unchanged form; punctuation is radical change over a short duration; and dominant relative frequency is the rate these events occur in a particular situation. Punctuated equilibrium was developed as an alternative to phyletic gradualism, which stresses consistent, cumulative changes to species.

Within the context of organizational behavior, the punctuated equilibrium model consists of deep structures, equilibrium periods and revolutionary periods. Deep structure is "the set of fundamental 'choices' a system has made of (1) the basic parts into which its units will be organized and (2) the basic activity patterns that will maintain its existence." (Gersick, 1991, p 14) Equilibrium periods are characterized by the maintenance of organizational structures and activity patterns, where small incremental adjustments are made to adjust for environmental changes without affecting the deep structure. Revolutionary periods occur due to significant changes in the environment that lead to wholesale upheaval where a system's deep structure comes apart, leaving it in disarray until the period ends and choices are made around which a new structure forms. (Gersick, 1991)"[11]

In the context of organizational theory, punctuated equilibrium would imply that architectural inertia arising from the "stickiness" of existing morphology would lead to prolonged *stasis,* preventing changes wrought through "mutations" (deliberate or otherwise) from accumulating. Hence when the environment changes, firms belonging to different *species* better adapted to the environment would displace the population of the existing dominant species before they are able to adapt to the changed environment. Hence, the crucial importance of *architectural leadership*

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[7] Tushman, M. and Romanelli, E. (1985) Organizational Evolution: A Metamorphosis Model of Convergence and Reorientation, in L.L. Cummings and B.M. Staw (Eds.), Research in Organizational Behavior, Vol 7, 171-222, Greenwich, CT: JAI Press

[8] Romanelli, E. and Tushman, M. (1994) Organizational Transformation as Punctuated Equilibrium: An Empirical Test, Academy of Management Journal, 37(5), 1141-1166.

[9] Tushman, M. and Anderson, P. (1986) Technological Discontinuities and Organizational Environments, Administrative Science Quarterly, 31(3), 439-465.

[10] Dawkins, Richard. *The Blind Watchmaker - Why the evidence of evolution reveals a universe without design.* W. W. Norton & Company. New York, 1996

[11]

to pro-actively overcome the forces of entropy and architectural inertia. In this thesis, I shall seek to explore different approaches to architectural leadership, including Radical /Deep Change[12] and Adaptive/ Self organizing Change[13].

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[12] *Hammer, Michael* 2004, Deep Change – How Operational Innovation can transform your company
[13] *Benyomin Beigmann Lichtenstein 2000,* Self- Oraganizing Transitions: A pattern among the chaos of transformative change.

2. Research Design

2.1 Research Methods

In evaluating the applicability of the theory proposed (Piepenbrock, 2009) to a wider domain, it becomes imperative to design the present research synergistically with the research methods used by Piepenbrock. The present research utilizes a non-random small-N, theoretical sample, primarily utilizing *Historical Comparative Analysis* using secondary sources of data. Consistent with Piepenbrock, 2009, this research utilizes the *Case Study Research* method of theory building (Eisenhardt, 1989)[14]. Use of research methods consistent with the theory being evaluated is also appropriate since the intent of this thesis is primarily to validate an existing theory, rather than to build a new theory.

2.1.1 Motivation

Piepenbrock's research produces a testable and falsifiable hypothesis, with the potential for validation across industries and domains. The hypothesis is seen to be consistently validated across the three industries studied in the original work. Further validation across different industry segments can most appropriately be done by testing the hypothesis on cases drawn from alternative industries. While validation of a "current state" across a large sample population is possible by utilizing alternative research methods using random, large-N sampling, the necessity of utilizing longitudinal time-series data to map the predictions of the theory across an industry's life-cycle, constrains this research to a case-based approach, utilizing a non-random, small-N sample.

2.1.2 Grounded Theory Building

Kathleen Eisenhardt's seminal paper on building theories from case-study research (Eisenhardt, 1989) builds upon previous work on *grounded theory building* by Glaser and Strauss (1967) and Strauss (1987). It specifically notes the effectiveness of this method in utilizing a combination of (sometimes contradictory or contrary) qualitative and quantitative data, to build a novel theory. To quote, "Attempts to reconcile evidence across cases, types of data, and different investigations, and between cases and literature increases the likelihood of creative reframing into a new theoretical vision"

The essential steps Case-study research method of theory building proposed by Eisenhardt is summarized in Eisenhardt's paper in a tabular form as below:

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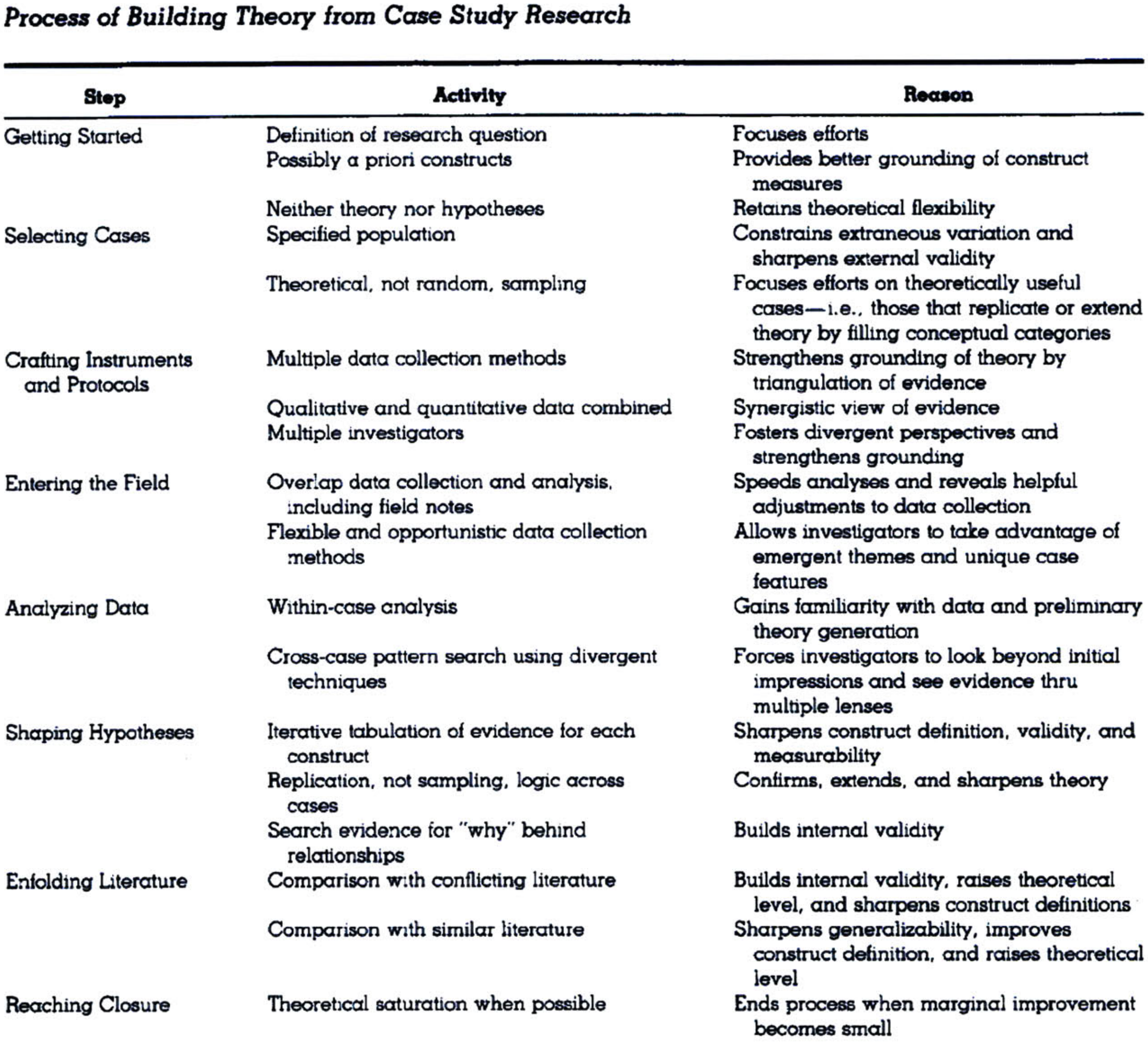
[14] Eisenhardt, Kathleen M, 1989, Building theories from case- study research



Process of Building Theory from Case Study Research

Step	Activity	Reason
Getting Started	Definition of research question	Focuses efforts
	Possibly a priori constructs	Provides better grounding of construct measures
	Neither theory nor hypotheses	Retains theoretical flexibility
Selecting Cases	Specified population	Constrains extraneous variation and sharpens external validity
	Theoretical, not random, sampling	Focuses efforts on theoretically useful cases—i.e., those that replicate or extend theory by filling conceptual categories
Crafting Instruments and Protocols	Multiple data collection methods	Strengthens grounding of theory by triangulation of evidence
	Qualitative and quantitative data combined	Synergistic view of evidence
	Multiple investigators	Fosters divergent perspectives and strengthens grounding
Entering the Field	Overlap data collection and analysis, including field notes	Speeds analyses and reveals helpful adjustments to data collection
	Flexible and opportunistic data collection methods	Allows investigators to take advantage of emergent themes and unique case features
Analyzing Data	Within-case analysis	Gains familiarity with data and preliminary theory generation
	Cross-case pattern search using divergent techniques	Forces investigators to look beyond initial impressions and see evidence thru multiple lenses
Shaping Hypotheses	Iterative tabulation of evidence for each construct	Sharpens construct definition, validity, and measurability
	Replication, not sampling, logic across cases	Confirms, extends, and sharpens theory
	Search evidence for "why" behind relationships	Builds internal validity
Enfolding Literature	Comparison with conflicting literature	Builds internal validity, raises theoretical level, and sharpens construct definitions
	Comparison with similar literature	Sharpens generalizability, improves construct definition, and raises theoretical level
Reaching Closure	Theoretical saturation when possible	Ends process when marginal improvement becomes small

Figure 3: Process of building theory from case study research, Source- Eisenhardt, 1989

Below, I shall elaborate on how the design of this research maps to the steps outlined above:

1) Getting Started: The principal research question builds on the research question of the foundation research (Piepenbrock, 2009), i.e. "Why do firms in the same industry vary *systematically* in performance *over time*?" The research question for this thesis is "Are the conclusions of Piepenbrock, 2009 generalizable across industries?" The specific industry studied is the US Steel industry. *a priori* constructs that are sought to be validated include the identification of *United States Steel Corporation* and *Bethlehem Steel* as "*Blue*" firms and *Nucor Steel* as a "*red*" firm, with *Arcelor – Mittal* being studied as an additional non-US "*red*" firm.

2) Selecting Cases: Theoretical, rather than random sampling was used, so as to enable in-depth study of the most appropriate cases. *United States Steel, Bethlehem Steel* and *Nucor* were selected on account of their being the largest and historically most prominent players in the US Steel industry. *Arcelor – Mittal* was also an obvious choice, on account of being the world's largest steel manufacturer, by far.
3) Crafting Instruments and Protocols: A combination of qualitative and quantitative data was used. Longitudinal time series data pertaining to production, sales, employees and productivity was used to trace the evolution of the firms studied over the past 50 to 100 years. Qualitative and anecdotal data was used to examine the architecture of the firms themselves, and their relationship with capital markets, supplier markets, consumer markets and labor markets.

> *"The amount of available information declines, probably by many orders of magnitude, in going from mental to written information and again by another similar large factor in going from written to numerical information. Furthermore, the character of information content changes as one moves from mental to written to numerical information. In* ***moving down*** *the diagram, there is a* ***progressively smaller*** *proportion of information about* ***structure and policies****."*
>
> \- *Jay Forrester, 1994*

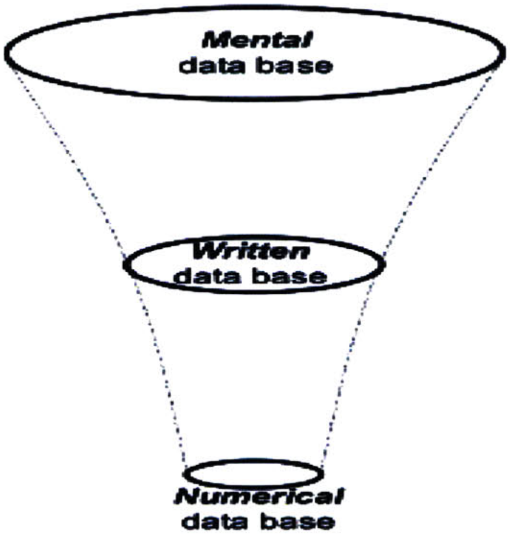


Figure 4: Mental vs. Numerical database, Source - Jay Forrester, 1994

This formulation by Jay Forrester highlights the value of tapping into qualitative data in addition to quantitative data. Much of the crucial data that enables a deeper insight into the structure and dynamics of an organization is hidden in the minds of the people in the organization, and never makes its way into numbers, charts and reports.

4) Entering the field: Flexible data collection methods were adopted, and data was analyzed as it was obtained.
5) Analyzing data: Within-case and between-cases analysis of qualitative and quantitative data was done to compare the architecture of the firms studied, and their evolutionary trajectories.
6) Shaping hypotheses: Relevant hypotheses about the firms under study were constructed through careful examination of the "why?" behind the data.
7) Enfolding Literature: The primary source of comparative literature was Piepenbrock's work on the evolution of business ecosystems. Additionally, the research draws upon a large variety of literature about the steel industry in general, and about the specific firms studied.
8) Reaching Closure: The primary intent of this thesis is fulfilled through validation of the Theory of EBE (*Piepenbrock, 2009*) in the domain of commodity industries (specifically the US Steel industry), and qualitative examination of the additional questions proposed in the research objective.

2.2 Case Studies (Theoretical Sample)

2.2.1 The Incumbents:

2.2.1.1 *United States Steel*

In a comparative study of the US steel industry, The *United States Steel Corporation* is an obvious choice, being the largest and historically the most dominant player in the industry. It is also most representative of the evolution of the mainstream steel industry in the US, and offers a lens for the examination of the steel industry in the US as a whole. A preliminary examination of the history of the firm also reveals structures typical of *blue* firms, as defined in Piepenbrock, 2009. *Kenneth Warren,* in his book **Big Steel: The first century of the United States Steel Corporation 1901- 2001** has the following to say about the firm:

"Some have traced the problems of US Steel to its ***relations with labor****. Certainly this relationship was* ***distant, frosty****, and* ***woefully lacking in sympathetic understanding*** *over the first third of its corporate history and has often been difficult since…"*

"Time and again US Steel was served and sometimes led by excellent men, but these executives were inhibited and crabbed by ***corporate unwieldiness, structures, traditions and defensive attitudes*** *(emphasis mine)".*

"There were not only too many plants, widely scattered, but there were also divisions and often disagreements between a ***distant, finance-dominated headquarters*** *and a system of production units made up of formerly independent companies and of product divisions, resulting in a rather* ***clumsy corporate structure****."*

2.2.1.2 *Bethlehem Steel*

Bethlehem steel is studied primarily as a supporting case for *US Steel*, since its evolution has followed a trajectory broadly similar to that of *US Steel*, until its bankruptcy in 2002. *Bethlehem Steel* data is utilized primarily as a comparator with *US Steel* and *Nucor*.

2.2.2 The Challengers

2.2.2.1 *Nucor*

"Success is not found in the ability to buy but in the ***ability to build, to serve, and to rekindle****"*

- Ken Iverson, Chairman of *Nucor Corporation*

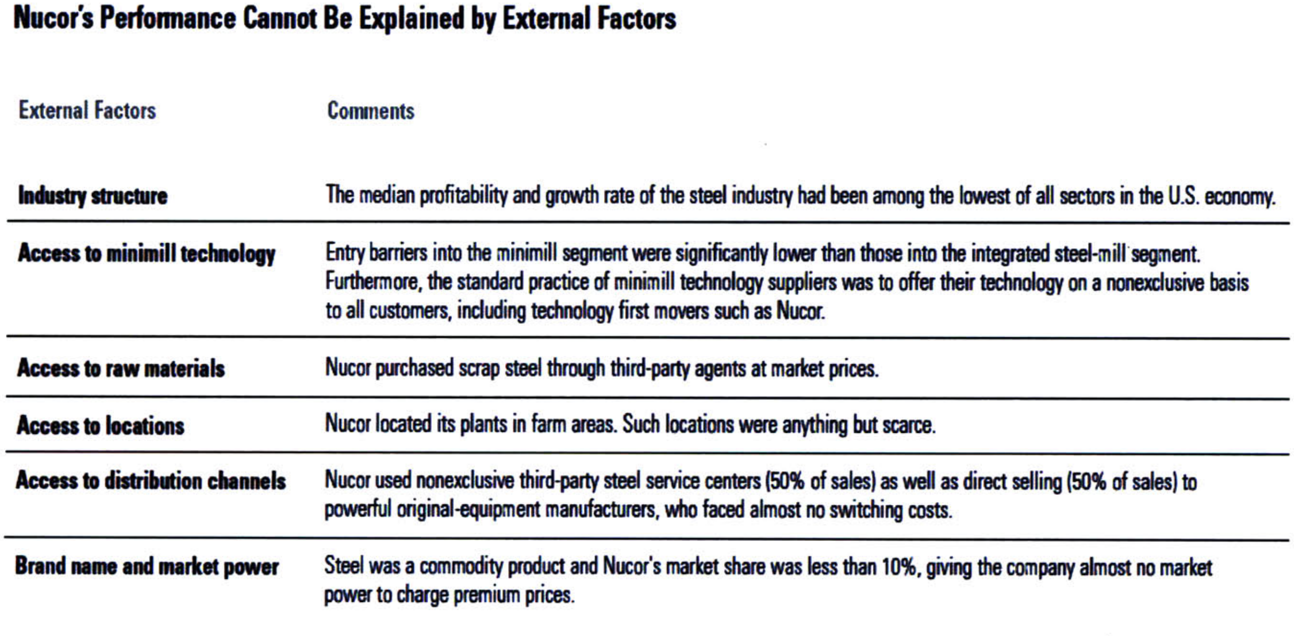
"I believe in ***long-term survival*** *over short-term profitability. I believe in* ***sharing the pain among all managers and employees****. I believe in* ***pushing decision-making as far down as it can go****. I believe*

in minimizing distinctions between managers and employees. I believe in paying people for their productivity. And I believe in keeping things simple."[15]

\- Ken Iverson, Chairman of *Nucor Corporation*

Nucor presents what seems like the ideal case of a *red* incumbent species.

In 1970, *United States Steel Corporation* had annual revenues of $4814 million, and *Nucor* Corporation had annual revenues of $51 million. In 2008, *United States Steel Corporation* had annual revenues of $ 23754 million and *Nucor* had annual revenues of $ 23663 million. Even more interestingly, in 1970, *US Steel* had revenue per employee of $ 25301 while that of *Nucor* was $ 35740. In 2008, revenue per employee had risen to 484776, while that of *Nucor* had shot up to $ 1090476. While it could be argued that the adoption of minimill technology provided a crucial advantage to *Nucor* that was not available to *US Steel*, the technology itself tells only part of the story. *Anil K. Gupta* and *Vijay Govindrajan*, in their paper "Knowledge Management's Social Dimension: Lessons from Nucor Steel"[16] highlight the reasons why the success of *Nucor* cannot entirely be explained by external factors:



Nucor's Perfomance Cannot Be Explained by External Factors

External Factors	Comments
Industry structure	The median profitability and growth rate of the steel industry had been among the lowest of all sectors in the U.S. economy.
Access to minimill technology	Entry barriers into the minimill segment were significantly lower than those into the integrated steel-mill segment. Furthermore, the standard practice of minimill technology suppliers was to offer their technology on a nonexclusive basis to all customers, including technology first movers such as Nucor.
Access to raw materials	Nucor purchased scrap steel through third-party agents at market prices.
Access to locations	Nucor located its plants in farm areas. Such locations were anything but scarce.
Access to distribution channels	Nucor used nonexclusive third-party steel service centers (50% of sales) as well as direct selling (50% of sales) to powerful original-equipment manufacturers, who faced almost no switching costs.
Brand name and market power	Steel was a commodity product and Nucor's market share was less than 10%, giving the company almost no market power to charge premium prices.

Figure 5: Source: Gupta & Govindrajan, 2000

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[15] "The art of keeping management simple: An interview with Ken Iverson of Nucor Steel" Harvard Management Update May 1998 pp5

[16] *Anil K. Gupta* and *Vijay Govindrajan*, "Knowledge Management's Social Dimension: Lessons from Nucor Steel", MIT Sloan Management Review, Fall 2000, Volume 42, Number1

2.2.2.2 *Arcelor – Mittal*

Arcelor Mittal is the largest steel company in the world by far. Its rise from relatively humble origin in the 1970s to its current position is the stuff of folklore. It's founder Laxmi Mittal began his career in the family's steel-making business in India in the early 1970s. His understanding of business cycles in the steel industry was a key competency that enabled him to build his empire.

He owed the meteoric rise of his business to his strategy of taking over distressed or loss making assets at dirt-cheap prices during economic downturns, and turning them around to profitability. While this acquisition-led growth ostensibly makes Arcelor-Mittal appear to have characteristics that are distinctly *blue modular*, a closer examination of its strategy for turning around loss-making firms reveals a different story. Sample quotes[17] originating from Arcelor Mittal leadership indicate its true architectural form:

"Mittal knew that good-quality scrap, the raw material for making steel, could be both difficult to source and costly. By supplementing his supplies with a substitute, direct-reduced iron (DRI), he found a solution to his raw-material problem that was both financially and technologically viable."

*"A number of elements make up the winning formula, including **targeted investment**, **cost cutting**, import of **modern management practice**, and the **sharing of best practice** among all plants."*

*"Aditya Mittal, son of Lakshmi Mittal and CFO, noted that "**employee commitment, capital-expenditure commitment** and media perception" were even more important than financial measures"*

*"Key to **reducing costs** and **improving performance** was the **Knowledge Management** Program. By benchmarking against the best in the Mittal Group, valuable knowledge transfer with respect to cost reduction occurred daily between plant managers. By pooling global expertise on a regular basis, the Mittal Group was able to **share and implement best practice, technical knowledge**, and target setting more quickly and efficiently than its competitors. The process of **knowledge sharing** occured **on various levels in the company** and was coordinated at the corporate level."*

"Once plants are twinned, the interaction between them is continuous and systematic. Operational and technical managers visit both plants regularly to benchmark key performance indicators, review technological needs, and compare operating and maintenance practices. The consistency and regularity of this interactive process allows twinned plants to implement and benefit from each other's best practices. Consequently, improvement at the plants continues in a structured manner."

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[17] Kumar Nirmalaya, Mohapatra Pradipta K. , Chandrasekhar Suj, 2009, *"India's Global Powerhouses- How they are taking on the world"*

*“**revive** the facilities, **invest** in the facilities, and provide **stability** not only to the **community** but also the **company** and the **country**.” – Aditya Mittal*

*It is **simple** and **strong** management. First you have to diagnose what is the real issue, and then you have to make sure that the management team and the company is completely focused on resolving the critical issue. Often when you do a turnaround, you think that everything is wrong with the company and try to change everything, and then you are in a quagmire. The focus has to be on understanding the number one critical issue and resolving it first with all focus, dedication, and time. As each turnaround situation has a different focus issue, identification of that focus issue and resolving it is the most important aspect.*

-Aditya Mittal

*“We have long believed that size and scale are vital, both to compete in a global marketplace and to manage supply and demand through the economic cycle. A **strong, sustainable** industry benefits all its **stakeholders—employees, customers and investors alike.”***

– LN Mittal

3. Evolution of the Global Steel Industry

3.1 Evolution of Technology (Quality)

In many ways, the evolution of the steel industry has traced the same path as the evolution of the modern industrial economy. The invention of the ***Bessemer converter*** in 1855 heralded not only the advent of the modern steel industry, but also the modern industrial economy. [18] The[19] steel industry, over the past 150 years, has seen four major epochs corresponding to four steelmaking technologies that have emerged over the period – The Bessemer Process (1855), The Open Hearth furnace or Siemens process (1857/ 1865), The Electric Arc furnace (1907), The Basic Oxygen Furnace or L-D Convertor (1952).

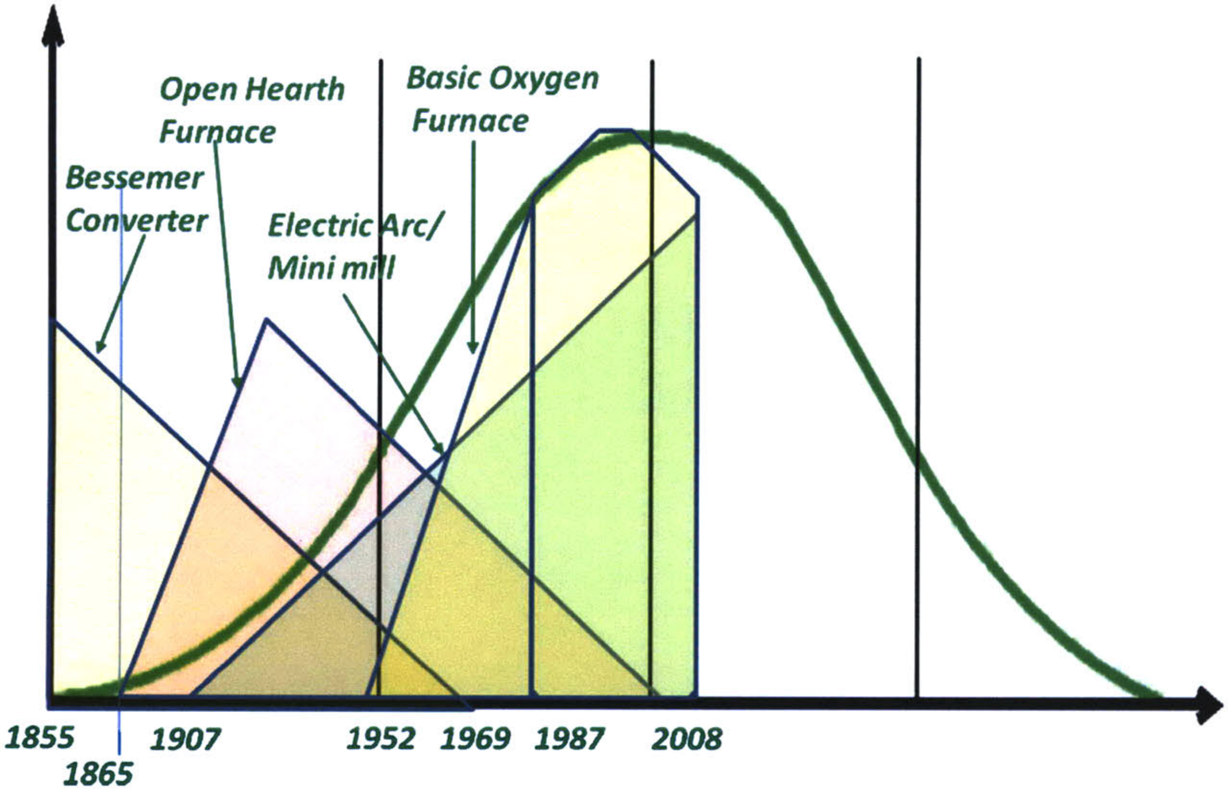

Figure 6: Technology Dominance epochs in the steel industry, a schematic visualization

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[18] **Diffusion of the Basic Oxygen Furnace in the U. S. Steel Industry ,** James B. Sumrall, Jr. *The Journal of Industrial Economics*, Vol. 30, No. 4 (Jun., 1982), pp. 421-437 ,Published by: Blackwell Publishing

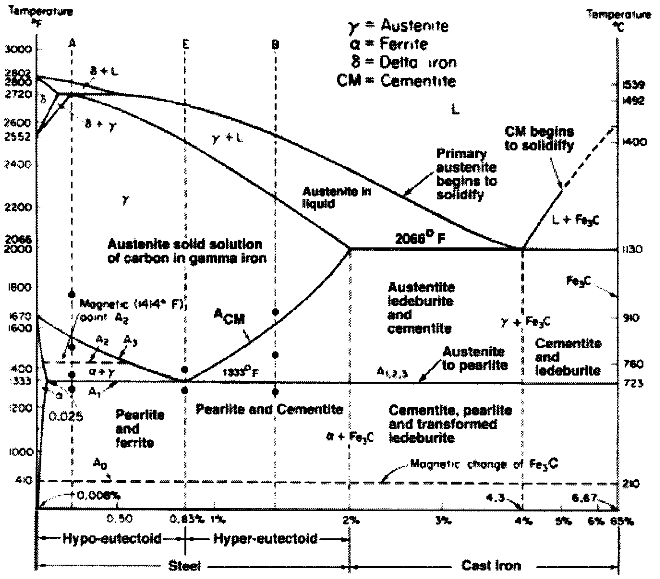
[19] **New Data on the Diffusion of the Basic Oxygen Furnace in the U. S. and Japan,** Leonard Lynn, *The Journal of Industrial Economics*, Vol. 30, No. 2 (Dec., 1981), pp. 123-135, Published by: Blackwell Publishing

3.1.1 Steel

Steel is an alloy of Iron (Fe) and Carbon (C), with carbon content ranging from 0.2% to 2.1%. The percentage of carbon determines the physical properties of Steel. Other alloying elements, such as Nickel, Chromium, Silicon, Manganese, Tungsten, Molybdenum, Vanadium, Copper etc. are frequently added to impart other desirable properties, such as ductility, tensile strength, hardness, resistance to oxidation, corrosion etc.

Steel is distinguished from Iron primarily through possession of a smaller percentage of Carbon, and fewer impurities such as Silicon, Sulfur and Phosphorus. Iron occurs naturally as an oxide of iron in the form of an ore. Iron is extracted from the oxide ore through a reduction process accomplished in a "*Blast Furnace*", which produces "*Pig Iron*", or through direct reduction using natural gas or coal, which produces "*Direct Reduced Iron*", also called "*Sponge Iron*".

[20]



Steel is then produced from Pig Iron by oxidizing the impurities and reducing carbon content through an oxidation process accomplished in a *Bessemer Convertor (until mid-20th century) / Open Hearth Furnace (until the late 20th century)/ Basic Oxygen Furnace (since the 1950s)*. Alloying elements are also added at this stage to impart additional properties as desired. Alternatively, Steel is produced from *Direct Reduced Iron* and/ or *Steel Scrap* through an electrolytic purification process using an *Electric Arc Furnace* or some variant thereof.

The Steel thus produced is cast in the form of *ingots* using conventional moulds, or directly as *blooms*, *billets* or other intermediate products using a *continuous caster*. These intermediate products are then either hot rolled, cold rolled, forged or die-cast into the finished products in finishing mills.

The schematic diagrams below illustrate the contemporary steel-making process:

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[20] Iron- Iron Carbide Phase diagram, Source -Materials Science and Metallurgy, 4th ed., Pollack, Prentice-Hall, 1988

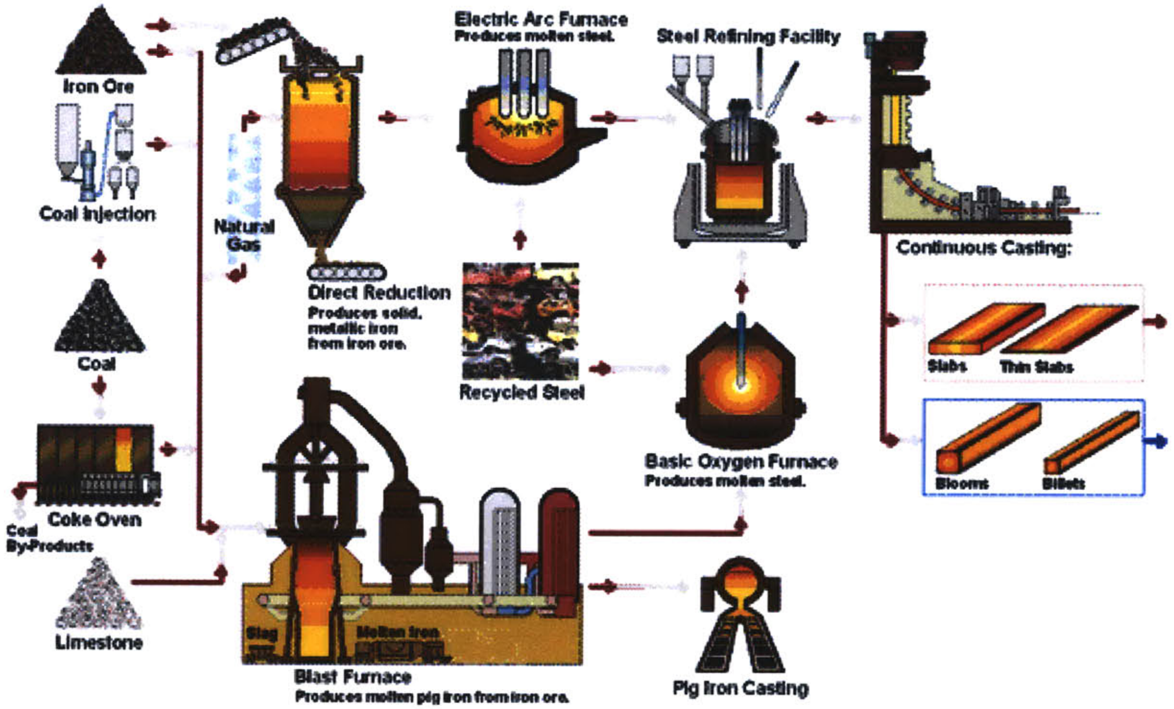


Figure 7: Contemporary Steel-making, Source: American Iron and Steel Institute

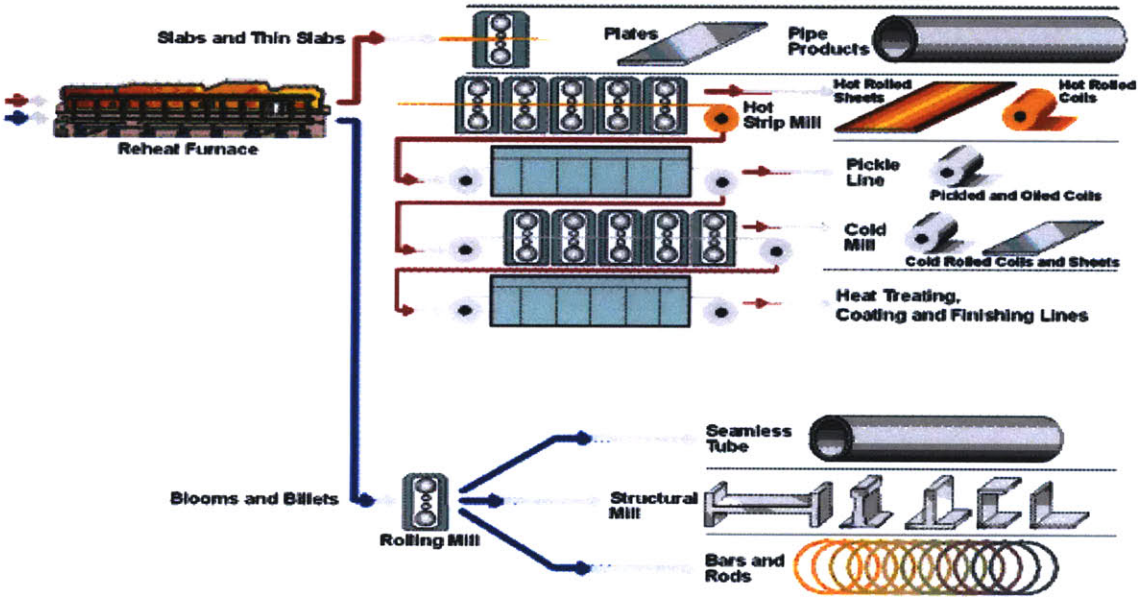


Figure 8: Steel Finishing, Source: American Iron and Steel Institute

3.1.2 The Bessemer Process

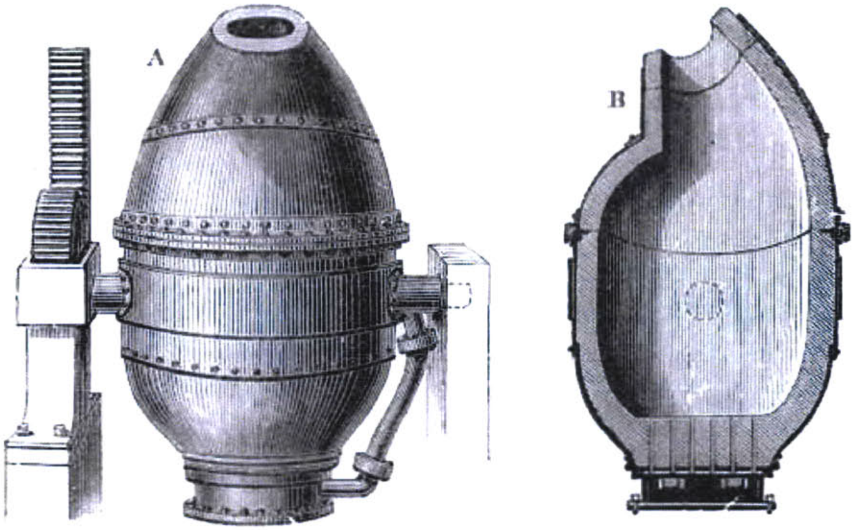
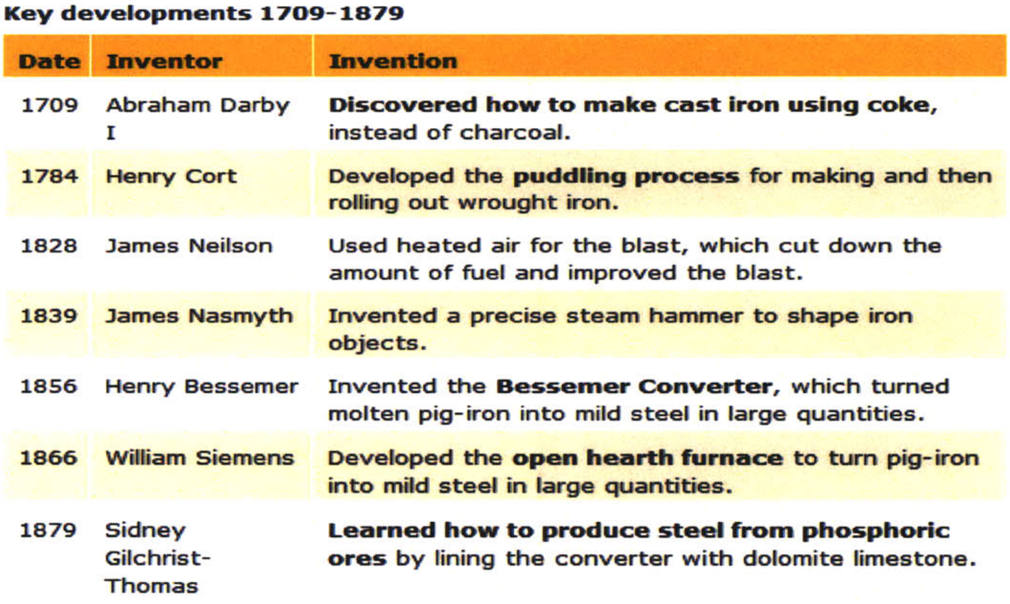


Figure 9: Bessemer Convertor, Source: "Discoveries & Inventions of the Nineteenth Century" (*R. Routledge, 1900*)

The invention of the Bessemer Convertor in 1855 marked the transition from "Craft" production to "Mass" production in the steel industry. Before the invention of the Bessemer furnace, Steel was an expensive metal, produced in relatively small quantities by expert craftsmen using carefully guarded techniques, in the form of "crucible steel" or "wrought iron".



Key developments 1709-1879

Date	Inventor	Invention
1709	Abraham Darby I	**Discovered how to make cast iron using coke,** instead of charcoal.
1784	Henry Cort	Developed the **puddling process** for making and then rolling out wrought iron.
1828	James Neilson	Used heated air for the blast, which cut down the amount of fuel and improved the blast.
1839	James Nasmyth	Invented a precise steam hammer to shape iron objects.
1856	Henry Bessemer	Invented the **Bessemer Converter,** which turned molten pig-iron into mild steel in large quantities.
1866	William Siemens	Developed the **open hearth furnace** to turn pig-iron into mild steel in large quantities.
1879	Sidney Gilchrist-Thomas	**Learned how to produce steel from phosphoric ores** by lining the converter with dolomite limestone.

Figure 10: Key early developments in Steel Technology, Source -BBC GCSE Bitesize

The Bessemer process, patented by Henry Bessemer in 1855, and independently discovered by William Kelly in 1851, enabled the mass production of steel for the first time. The process utilizes the principle of oxidation of impurities by blowing air through molten iron, with the oxidation process itself sustaining the heat and maintaining the iron in a molten state. The chief accomplishment of the Bessemer process was enabling the cost effective mass manufacture of steel products, providing a revolutionary impetus to industrial and infrastructure development, from the building of large bridges, railroads, skyscrapers and ships, to engines, automobiles, machinery, carriages, guns etc.

The success of the Bessemer Process was driven, in great measure, by Henry Bessemer himself. As *Thomas J Misa* notes:

"*While at least five English or American inventors devised processes for making steel by blowing steam or air through molten iron, it was Henry Bessemer's process that became the most widely used. His technical ingenuity was only the start. A close examination of Bessemer's inventive activities shows that his process was inspired by association with powerful institutions, especially the military, that his efforts to develop and commercialize his process rescued it from failure and obscurity, and that his considerable flair for publicity and patronage were as important to his overall success as his original technical conception.*"[21]

While the Bessemer process brought about a revolutionary change in industrial activity, the trajectory of development of the technology in Europe/ UK and in America were quite different, driven by the specific strategic imperatives and availability of raw material in the specific regions. As noted by *Misa,*

"Like most novel technologies, Bessemer's process contained a multiplicity of latent possibilities. In England and Europe, Bessemer converters produced a moderate quality, general-purpose steel used widely for structures, merchant steel, and rails. As modified by the Thomas process, European converters could convert high-phosphorus pig iron into acceptable steel. In the United States, however, the Bessemer process took a different path determined by the peculiar endowment of domestic natural resources and by the decisive influence of a leading consumer. To begin, there was never an "American" Thomas process, since American ores did not contain enough phosphorus to make the chemistry go. More important, the nation's fever for westward expansion produced a boom in transcontinental railroad building whose demands for iron and steel surpassed anything that European steelmakers could dream of. It was during the second of three great spurts of railroad construction that Bessemer production in the United States permanently exceeded that in Great Britain. This peculiar demand structure -- spiky and

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[21] Thomas J. Misa, *A Nation of Steel: The Making of Modern America, 1865-1925* Baltimore: Johns Hopkins University Press, 1995

cyclical -- encouraged the development of a rail-making process that could produce vast volumes on quick command. In response, American steelmakers developed those latent features of the Bessemer process that facilitated maximum production while ignoring other features that were needed for maximum quality. The resulting technology -- that of Bessemer steel rails -- was unique to the United States, and peculiarly adapted to the extensive phase of railroad building that lasted from around 1870 to 1890."[22]

Bessemer furnaces co-existed (in varying degrees) with Open-Hearth furnaces until the 1960s, when they were almost completely replaced with Basic Oxygen Furnaces or superior versions of Open Hearth Furnaces. The last Bessemer furnace in the US discontinued operation in 1968.

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[22] Thomas J. Misa, *A Nation of Steel: The Making of Modern America, 1865-1925* Baltimore: Johns Hopkins University Press, 1995

3.1.3 The Open- Hearth furnace or Siemens – Martin process

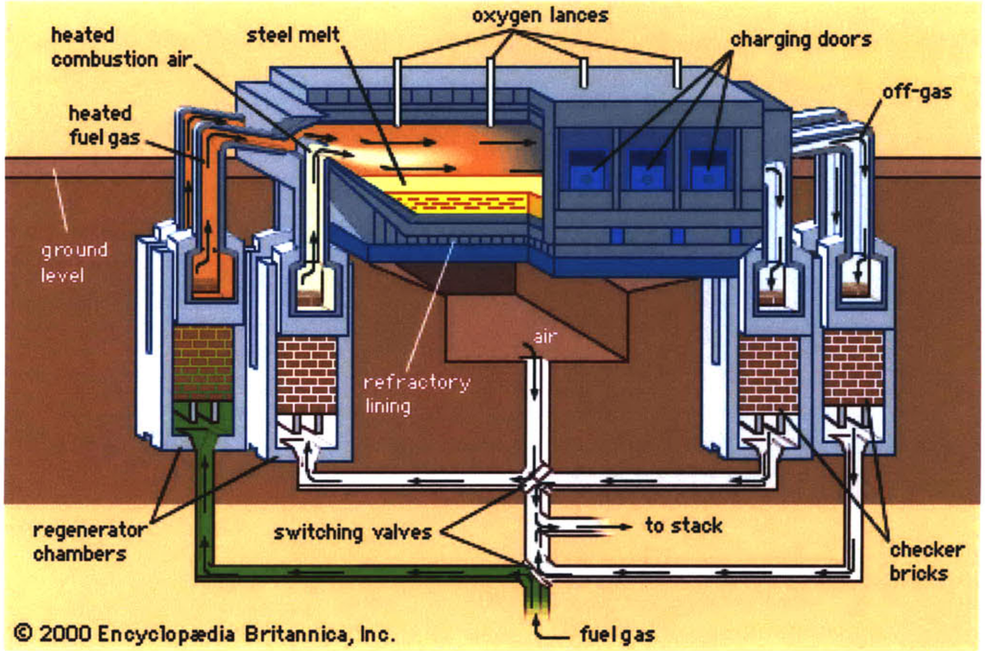

Figure 11: The Siemens- Martin Open Hearth Furnace, Source: Encyclopedia Brittanica 2000

In 1857, *Carl Wilhelm Siemens* developed the *Siemens Regenerative Furnace* , which used heat generated in the furnace to pre-heat fuel and air, regenerating 70- 80% of the heat. The temperatures attained were sufficient to melt steel. However it wasn't until 1865 that the furnace was actually used to make steel, by French engineer Pierre-Emile Martin, who took out a license for the furnace from Siemens. The process came to be known as the *Siemens – Martin process*, and the furnace as the *Open- Hearth Furnace*. While the process had significant strengths, it served to complement the *Bessemer Furnace* rather than replace it. Although it is able to process a larger quantity of steel in a single batch, the process is substantially slower than the Bessemer process. Being slower, it affords easier and better control over the process. As a result, the quality of steel produced by Open Hearth furnaces was generally better than that produced by Bessemer Convertors.

The trajectory of adoption of Open Hearth furnaces globally was somewhat slower than that of Bessemer Convertors until the 1920s, but it accelerated subsequently, and by the middle of the 20th century, the global installed capacity of Open Hearth furnaces significantly exceeded that of Bessemer Convertors. While Bessemer Convertors were almost entirely replaced by Basic Oxygen furnaces before the start of the 1970s, Open Hearth furnaces were replaced more gradually, with some surviving to the present day. Ukraine remains the only country producing a significant portion of its steel (almost 50%) using Open Hearth Furnaces.[23]

3.1.4 Basic Oxygen Furnace or L-D Convertor

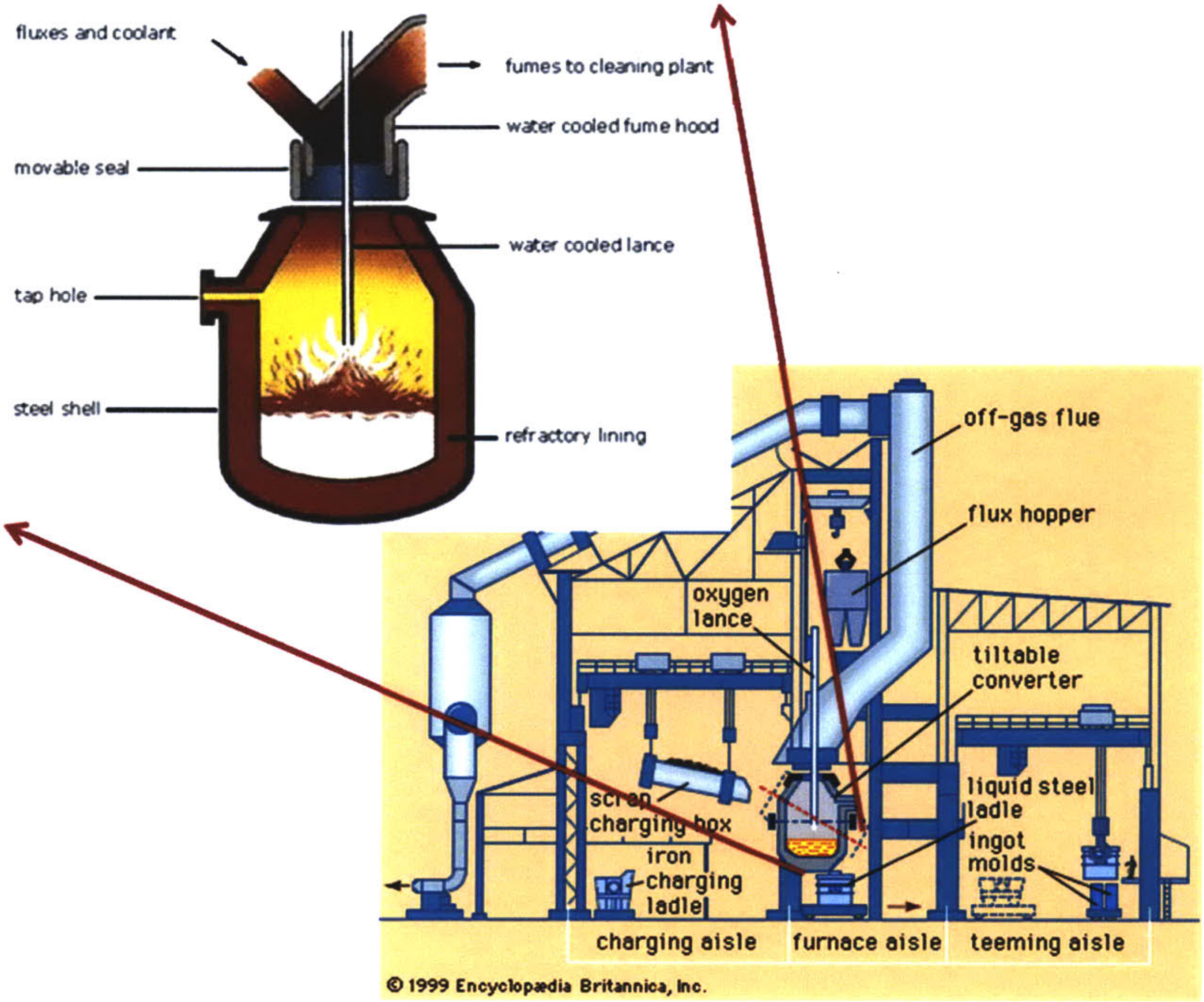

Figure 12: Basic Oxygen Furnace, Source - www.energytechpro.com and Encyclopedia Brittanica 1999

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[23] *Ernst Worrell, Nathan Martin, and Lynn Price*, 1999, Energy Efficiency and Carbon Dioxide Emissions Reduction Opportunities in the U.S. Iron and Steel Sector, Berkeley Laboratory

The Basic Oxygen Furnace (BOF), or *Linz – Donawitz (L-D) Convertor* was developed by Austrian firm *Voestalpine AG* in 1952. Linz and Donawitz are the names of the Austrian cities where the process was developed. The L-D Convertor is essentially an improvisation of the Bessemer Convertor, the primary difference being that Oxygen is blown into the ladle instead of air. The BOF is able to convert a charge of up to 350 tons of "hot metal" or Pig Iron into steel in as little as 40 minutes, as compared to the Open Hearth furnace, which takes several hours for an equivalent amount of charge.

The Basic Oxygen Furnace afforded significant cost savings per unit of steel produced as compared to earlier methods of producing Steel. While Steel makers globally, including Europe and Japan, were quick to realize these benefits and rapidly adopted the BOF, adoption in the US was slow, primarily on account of the *rigidity* and *inertia* of the large Steel Companies. As noted by *Prof. D Ault*,

"studies of the steel industry during the fifties and early sixties have indicated that the major cause of the deterioration of the ability of the U.S. industry to compete was the failure of increases in the productivity of US. steel workers to keep pace with increases in the wages and benefits paid to those workers. One of the principal causes for this lag in productivity was the failure of major U.S. producers to adopt the Basic Oxygen Furnace as rapidly as major foreign producers...despite the fact that the Oxygen converter proved to be capable of producing basic steel products at lower unit cost than any other production technique."[24]

The inability of US Steel producers to rapidly adopt the BOF was a major factor influencing the rapid decline in competitiveness of the US Steel industry *vis-à-vis* the foreign producers in the 1970s and 1980s. In 1968 the United States had converted 12.2% of its capacity to the BOF process, while Japan had 73.7% of its capacity in BOF; by 1980 these figures had risen to 80% and 100%, respectively (AISI, 1980)[25]. The crucial advantage afforded to Japanese manufacturers through the relative sluggishness of US producers enabled them to "dump" large quantities of cheap steel in the US, rendering the US producers uncompetitive. According to a Japanese executive cited in *Forbes* (March 3, 1978, p. 36) :

"Perhaps we were too aggressive in exporting to the United States, but the United States steel industry shares the blame because it failed to modernize."

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[24] *Ault, D.* "The Continued Deterioration of the Competitive Ability of the United States Steel Industry: The Development of Continuous Casting." Western Economic Journal, Vol. 11 (March 1973)

[25] Oster Sharon, "The diffusion of innovation among steel firms: the basic oxygen furnace", The Bell Journal of Economics, Vol. 13, No. 1 (Spring, 1982), pp. 45-56

Figure 13 below illustrates the relative adoption of steelmaking technologies in the US between 1950 and 2000. Figure 14 illustrates the relative adoption of Continuous Casting (a casting technology closely affiliated with the BOF) in the US, Japan and Germany:

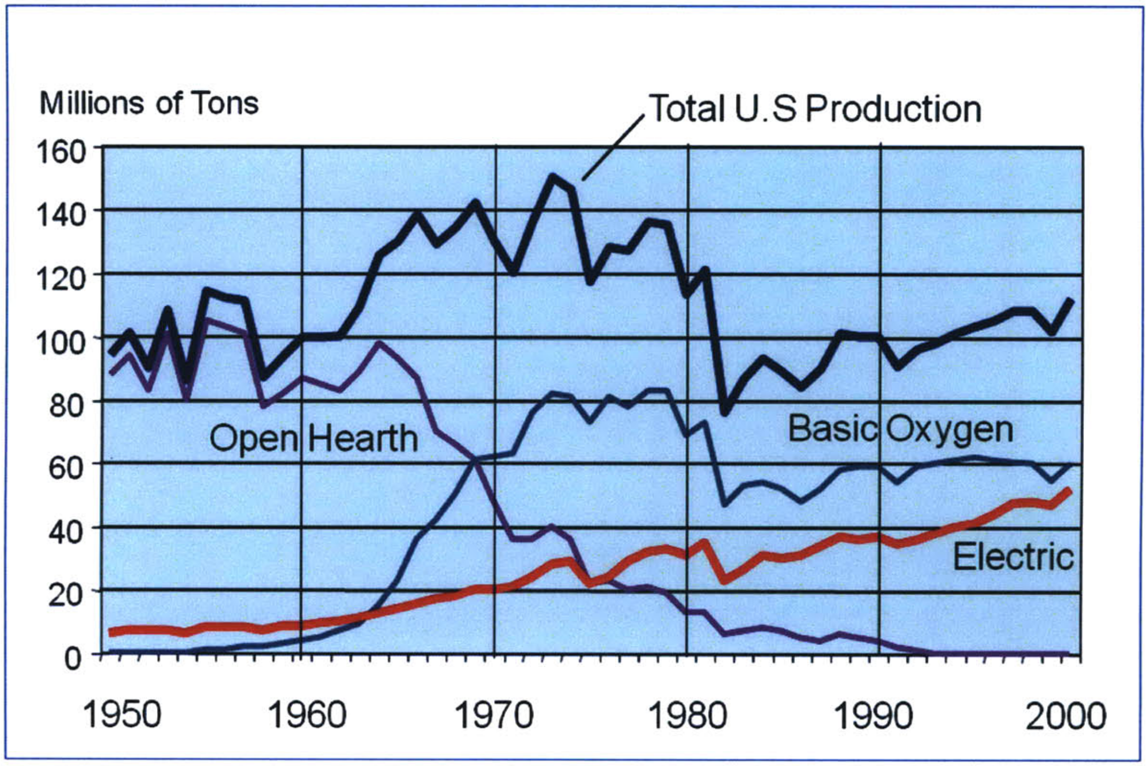

Figure 13: US Steel Production by Process, Source – American Iron and Steel Institute

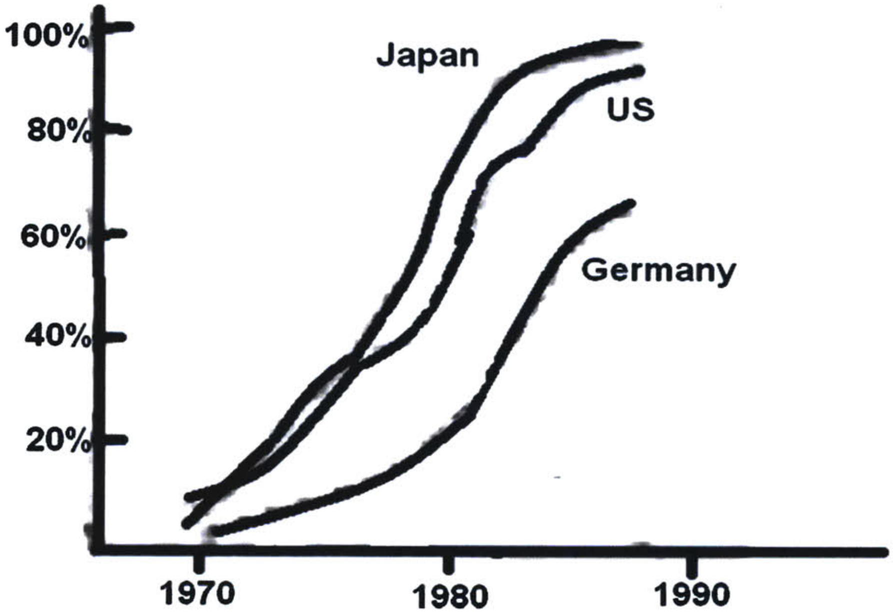

Figure 14: Adoption of Continuous Casting of Steel, Source - Hirooka and Hagiwara, 1992

3.1.5 Electric Arc Furnace/ Mini mills

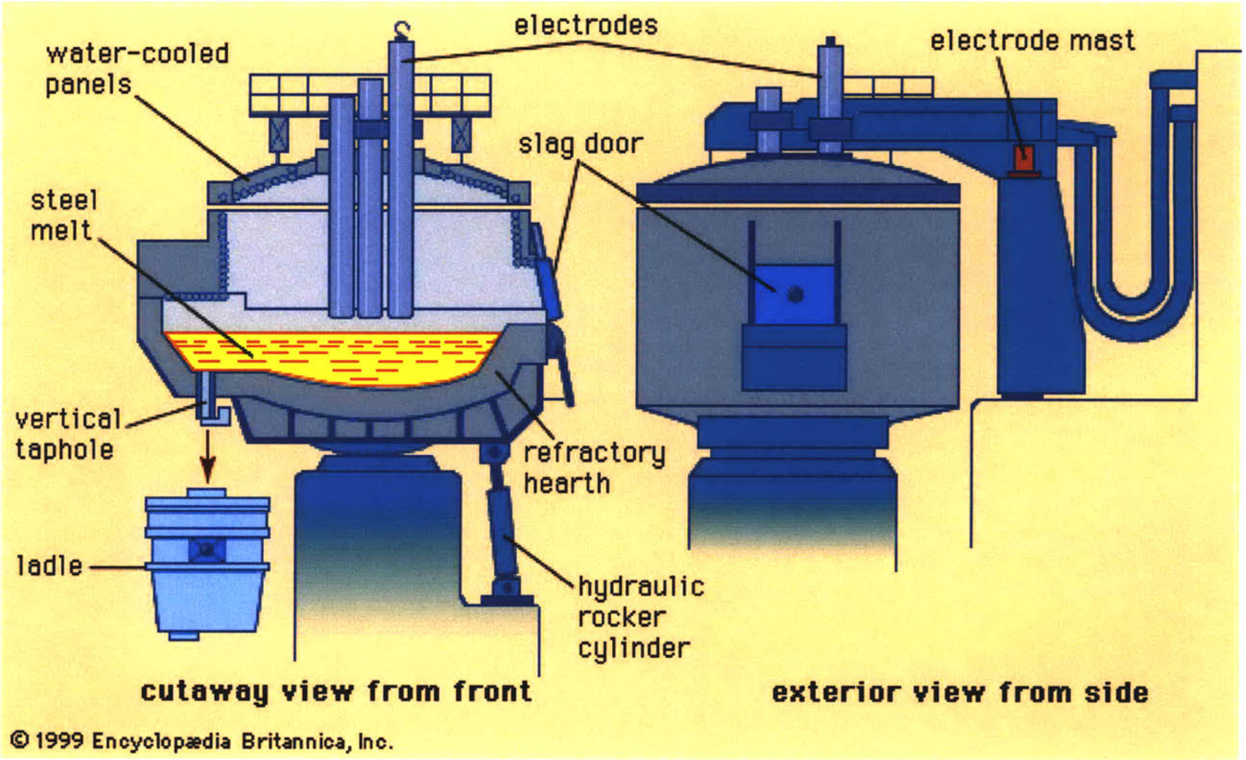

Figure15: Electric Arc Furnace, Source - Encyclopedia Brittanica, 1999

While the origin of the development of Electric Arc furnaces dates back to the early 19th century, it wasn't until the late 1960s that they came to be adopted for mainstream steel production. The first operational Electric Arc Furnaces were developed by *Paul Herolt* of France, with the first commercial plant being established in the US in 1907. The first Electric Arc Furnaces were used primarily to produce *specialty steels* such as *machine tools* and *spring steel.* During World War II, they were extensively used to produce alloy steels for military applications. However, large –scale production of commodity steel products using this route took off only later in the 1960s and 1970s.

Unlike the trajectory of adoption of BOFs, where the US was a laggard as compared to Japan and Europe, the adoption of mini mill technology was a lot faster in the US as compared to elsewhere, the primary credit for this going to *Nucor Corporation*. Until the late 1980s, the rate of adoption was constrained by the limited range of steel products that the technology was able to support, with production from the mini mill route being confined to certain *long products* for infrastructure applications. This changed with the commissioning of Nucor's Crawfordsville, Indiana plant in 1989. As noted by *Louis L. Schorsch* in 1996, *"Such plants were still, however, precluded for technical reasons from participating in steel's largest market - the sheets used in automobiles, containers, and other major markets. This changed with the commissioning of Nucor's Crawfordsville, Indiana plant in 1989. The success of this facility initiated a surge of new ones that are revitalizing the US steel industry. By the end of this decade, world-class mini-sheet plants will represent more than 25 percent of US hot-band capacity. By 2000, almost 60 percent of American sheet capacity will be highly competitive by international standards, up from less than 20 percent in the early 1980s - an extraordinary turnaround."*[26]

As can be seen in fig. 16 below, while the adoption of the Basic Oxygen Furnace in the early years of the technology (1954- 1964) was substantially slower in the US than in Japan, the reverse was true in the case of the early years of Mini-mill technology (1989- 1999).

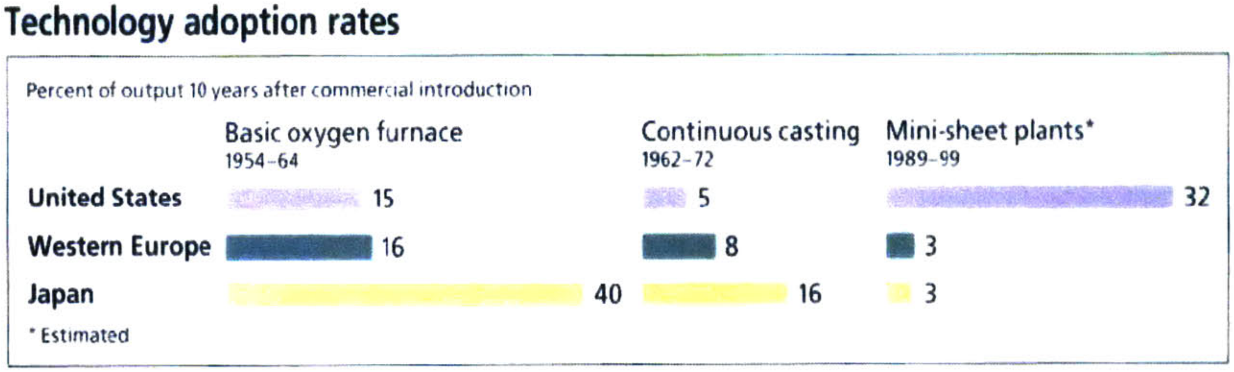

Figure 16: Technology adoption rates, Source - *Louis L. Schorsch,* McKinsey Quarterly, 1996, number 2

Mini-mills offer a significant advantage in terms of capital investment required, flexibility and agility and economies of scope. However the technology has not, until now, supported the same economies of scale as the traditional blast furnace/ BOF route. Figure 17 below illustrates the greater flexibility and agility afforded by the mini-mill supply chain as opposed to the conventional Blast Furnace/ BOF supply chain.

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[26] *Louis L. Schorsch*, 1996, "Why minimills give the US huge advantages in steel", THE McKINSEY QUARTERLY 1996, NUMBER *2*

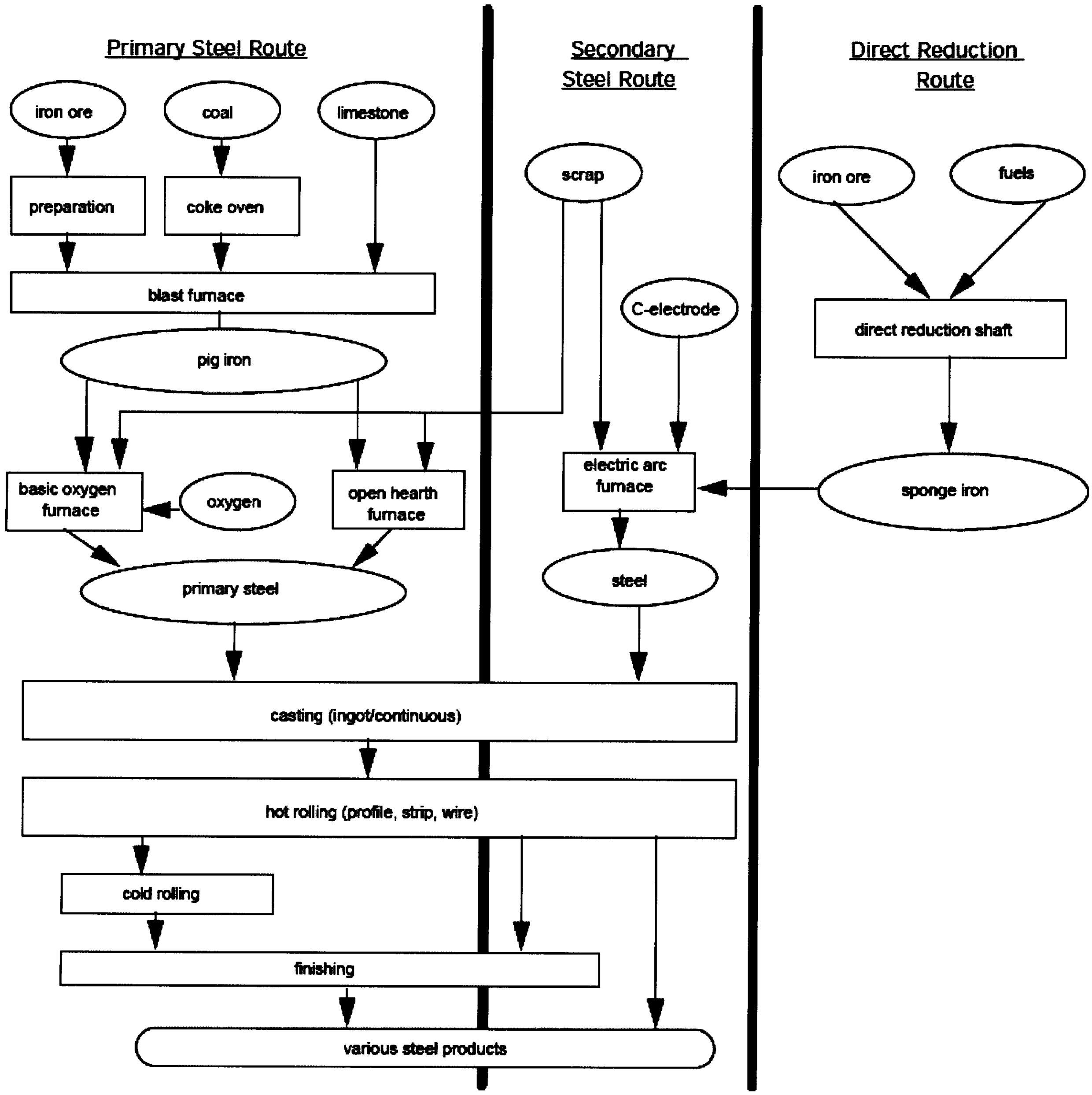


Figure17: Integrated vs. Mini-mill supply chain, Source: Worrell, Martin, Price, 1999

The principal factor driving the faster adoption of Mini-mills in the US than in Japan or Europe has been the lower cost and greater availability of the primary raw materials for the Electric Arc Furnace – Steel Scrap and Electricity. From Fig. 18, we can see that by 2003, steel production through the mini-mill route had already overtaken production through the BOF/ Open Hearth route in the US, which has not been the case elsewhere in the world.

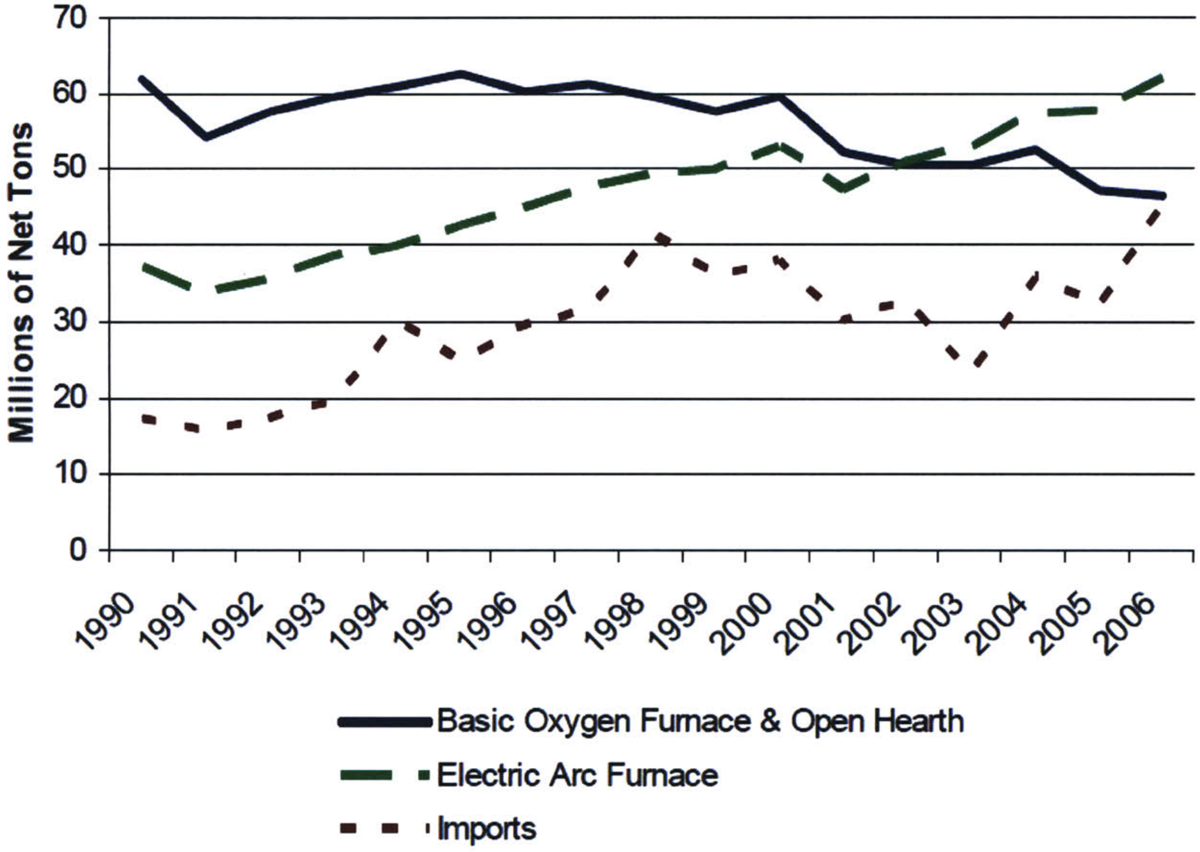


Figure 18: Sources of Steel in the US 1990 - 2007, Source - US Steel Policy Report, 2008

One potential impediment to the continued growth of mini-mills is an expected increase in the prices of Steel Scrap, the primary raw material, particularly in the US, as scrap-based production increases and the availability of scrap reduces. Taking cognizance of this fact, firms have been actively exploring alternatives to scrap, including *Direct Reduced Iron (DRI)* and *Iron-Carbide.* While DRI and Iron Carbide are commonly used in addition to scrap, in order to provide the quality desired for thin-slab casting or flat products, and some mini-mills (particularly outside the US) even utilize 100% DRI, current technologies render the exclusive use of DRI more expensive than both the scrap-based mini-mill route as well as the traditional BOF route. Anticipating a rise in scrap prices in 1994, Nucor took over a DRI facility in Trinidad, but abandoned it in 1998 after it proved unviable and non- cost competitive. Figure 19 below shows the comparative trends in scrap stocks and scrap consumption from 1885 to 1998. Barring innovations in scrap substitutes which make them substantially cheaper, a key determinant of the sustainability of the mini-mill model would be the continued increase in scrap stocks at a rate higher than apparent consumption.

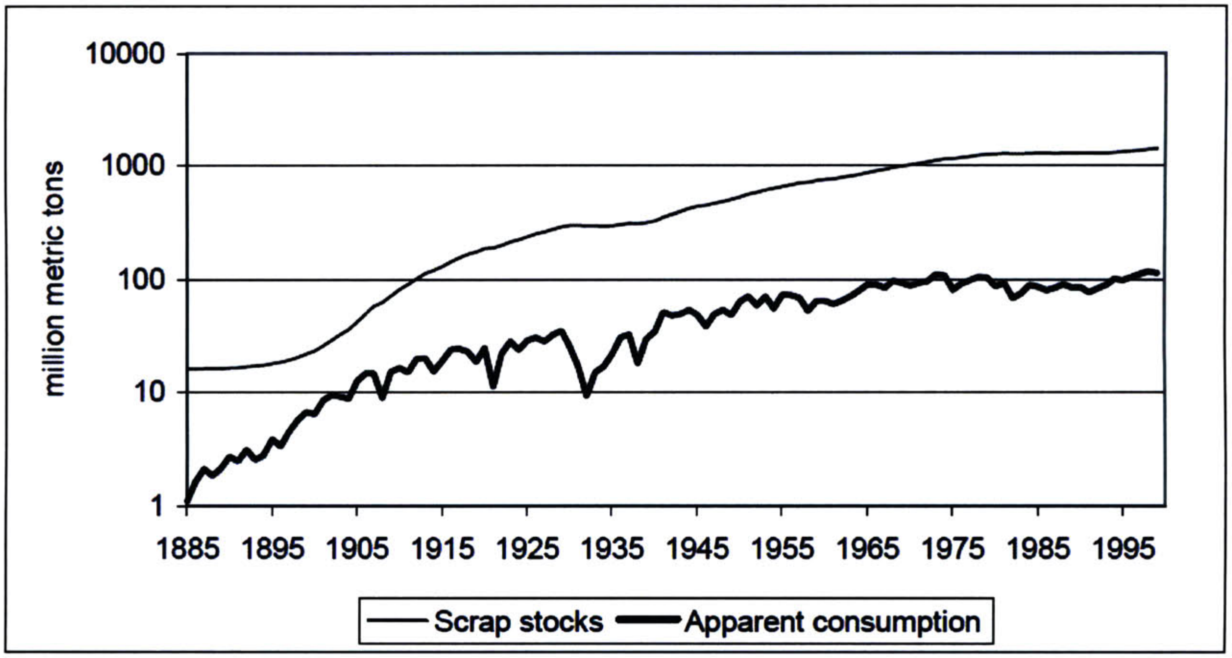


Figure 19: Scrap stocks and apparent consumption in the US, Source: Considine, Jablonowski, Considine, 2001

Figure 20 below illustrates the dynamics determining the competitiveness of mini-mills and entry of new players in the mini-mill market.

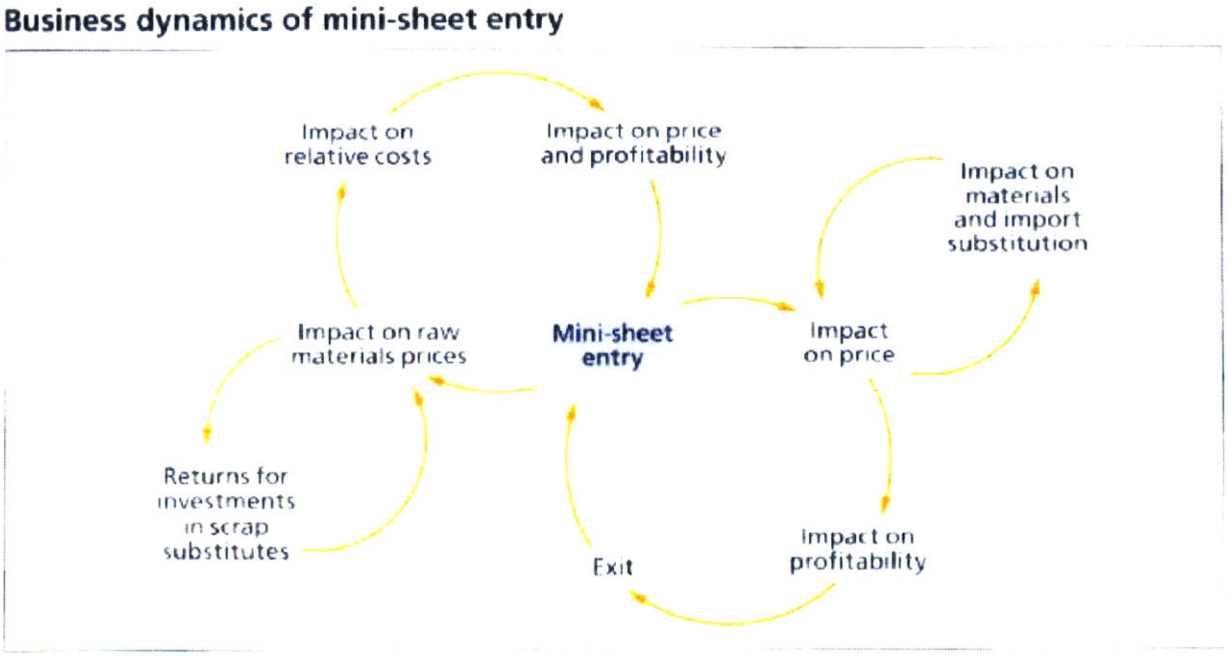
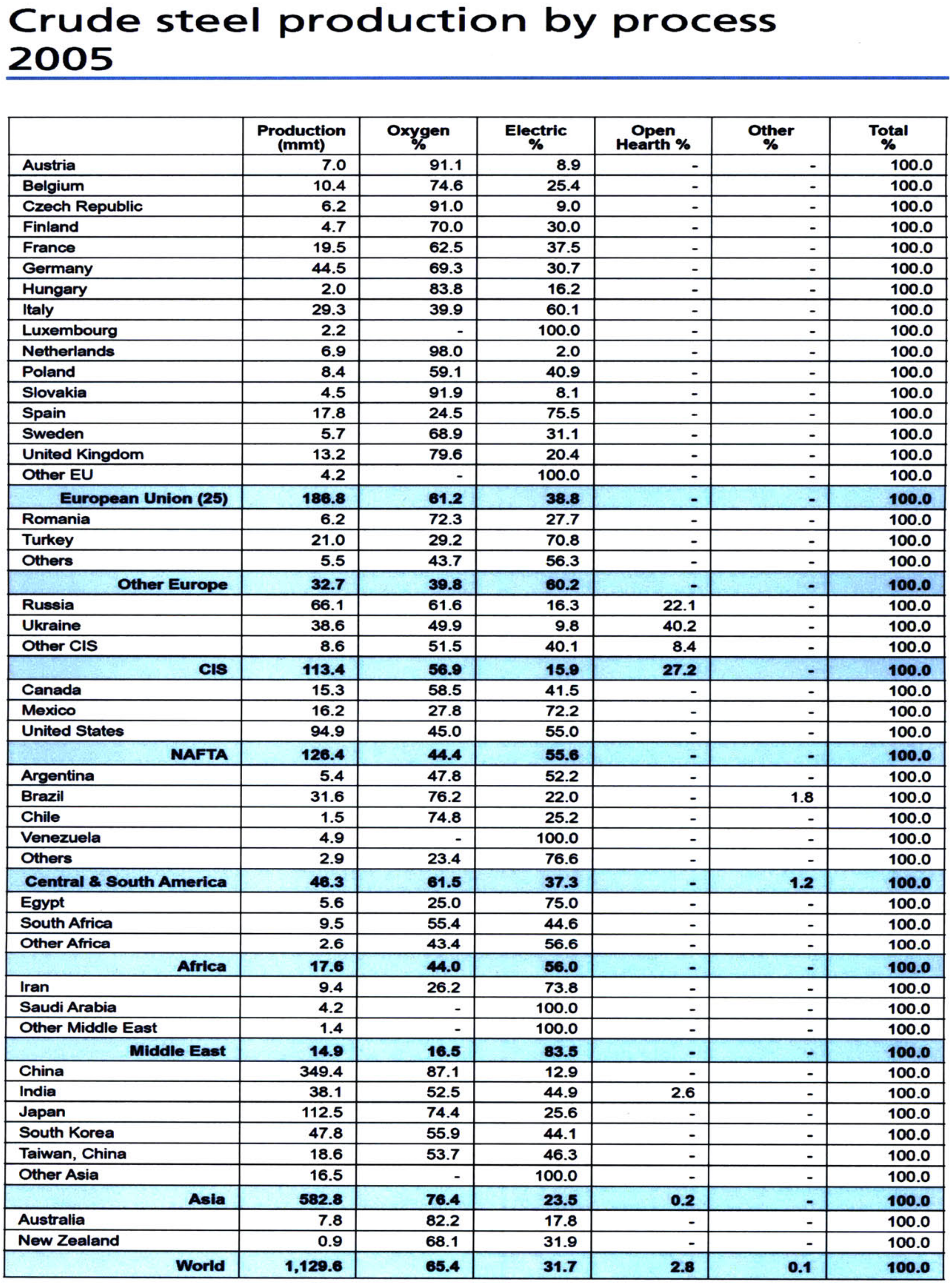


Figure19: Business dynamics of mini-sheet entry, Source - Louis L Schorsch, 1996



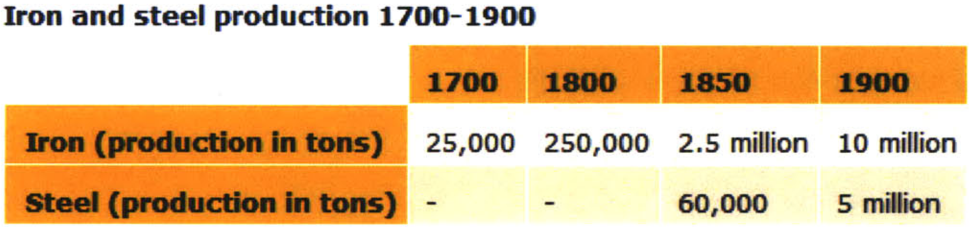
Crude steel production by process 2005

	Production (mmt)	Oxygen %	Electric %	Open Hearth %	Other %	Total %
Austria	7.0	91.1	8.9	-	-	100.0
Belgium	10.4	74.6	25.4	-	-	100.0
Czech Republic	6.2	91.0	9.0	-	-	100.0
Finland	4.7	70.0	30.0	-	-	100.0
France	19.5	62.5	37.5	-	-	100.0
Germany	44.5	69.3	30.7	-	-	100.0
Hungary	2.0	83.8	16.2	-	-	100.0
Italy	29.3	39.9	60.1	-	-	100.0
Luxembourg	2.2	-	100.0	-	-	100.0
Netherlands	6.9	98.0	2.0	-	-	100.0
Poland	8.4	59.1	40.9	-	-	100.0
Slovakia	4.5	91.9	8.1	-	-	100.0
Spain	17.8	24.5	75.5	-	-	100.0
Sweden	5.7	68.9	31.1	-	-	100.0
United Kingdom	13.2	79.6	20.4	-	-	100.0
Other EU	4.2	-	100.0	-	-	100.0
European Union (25)	**186.8**	**61.2**	**38.8**	**-**	**-**	**100.0**
Romania	6.2	72.3	27.7	-	-	100.0
Turkey	21.0	29.2	70.8	-	-	100.0
Others	5.5	43.7	56.3	-	-	100.0
Other Europe	**32.7**	**39.8**	**60.2**	**-**	**-**	**100.0**
Russia	66.1	61.6	16.3	22.1	-	100.0
Ukraine	38.6	49.9	9.8	40.2	-	100.0
Other CIS	8.6	51.5	40.1	8.4	-	100.0
CIS	**113.4**	**56.9**	**15.9**	**27.2**	**-**	**100.0**
Canada	15.3	58.5	41.5	-	-	100.0
Mexico	16.2	27.8	72.2	-	-	100.0
United States	94.9	45.0	55.0	-	-	100.0
NAFTA	**126.4**	**44.4**	**55.6**	**-**	**-**	**100.0**
Argentina	5.4	47.8	52.2	-	-	100.0
Brazil	31.6	76.2	22.0	-	1.8	100.0
Chile	1.5	74.8	25.2	-	-	100.0
Venezuela	4.9	-	100.0	-	-	100.0
Others	2.9	23.4	76.6	-	-	100.0
Central & South America	**46.3**	**61.5**	**37.3**	**-**	**1.2**	**100.0**
Egypt	5.6	25.0	75.0	-	-	100.0
South Africa	9.5	55.4	44.6	-	-	100.0
Other Africa	2.6	43.4	56.6	-	-	100.0
Africa	**17.6**	**44.0**	**56.0**	**-**	**-**	**100.0**
Iran	9.4	26.2	73.8	-	-	100.0
Saudi Arabia	4.2	-	100.0	-	-	100.0
Other Middle East	1.4	-	100.0	-	-	100.0
Middle East	**14.9**	**16.5**	**83.5**	**-**	**-**	**100.0**
China	349.4	87.1	12.9	-	-	100.0
India	38.1	52.5	44.9	2.6	-	100.0
Japan	112.5	74.4	25.6	-	-	100.0
South Korea	47.8	55.9	44.1	-	-	100.0
Taiwan, China	18.6	53.7	46.3	-	-	100.0
Other Asia	16.5	-	100.0	-	-	100.0
Asia	**582.8**	**76.4**	**23.5**	**0.2**	**-**	**100.0**
Australia	7.8	82.2	17.8	-	-	100.0
New Zealand	0.9	68.1	31.9	-	-	100.0
World	**1,129.6**	**65.4**	**31.7**	**2.8**	**0.1**	**100.0**

Figure21: Crude Steel Production by process, Source - International Iron & Steel Institute, 2006

3.2. Evolution of the Global Steel Market *(Quantity)*

Although the Iron and Steel Industry has a history almost as long as the history of all human economic activity, it was largely a low-volume "craft" industry until the invention of the Bessemer in the 1850s that it underwent a "mass-production" revolution. Figure 22 below shows the output of the Iron and Steel industry from 1700 to 1900. Figures 23 and 24 show the volume growth since that time.



Iron and steel production 1700-1900

	1700	1800	1850	1900
Iron (production in tons)	25,000	250,000	2.5 million	10 million
Steel (production in tons)	-	-	60,000	5 million

Figure 22: Iron and Steel production, 1700-1900, Source - BBC GCSE Bitesize

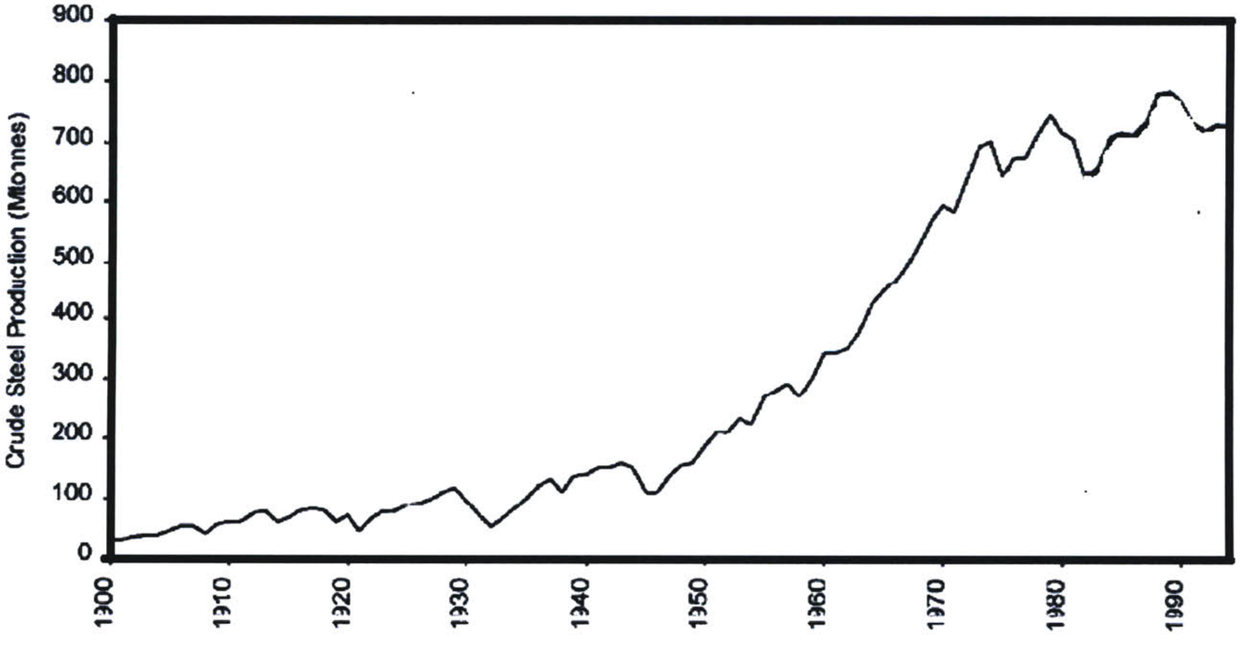


Figure 23: Global Steel Production 1900 – 1994 Source: IISI, 1996; Wodlinger et al, 1997

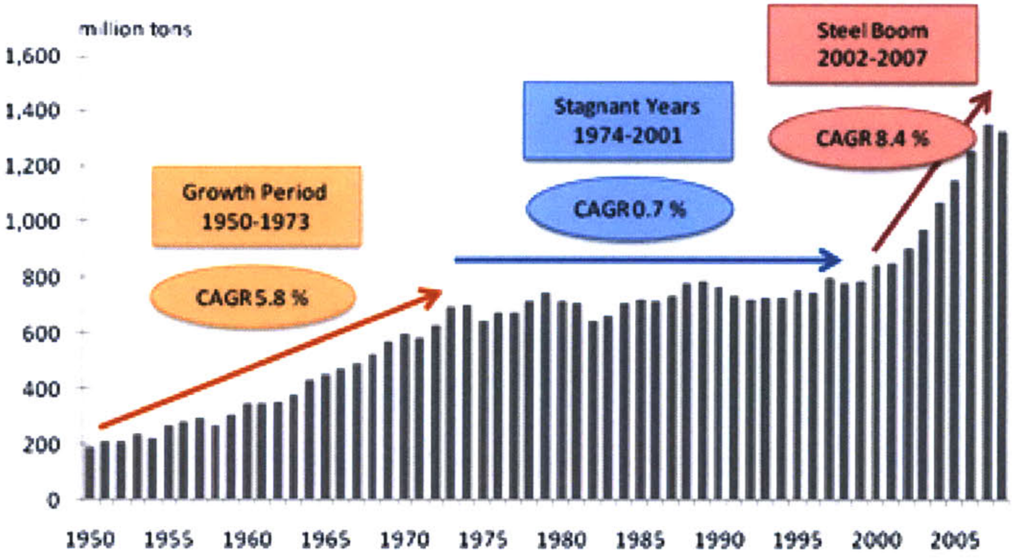


Figure24: Global Steel Production, 1950 – 2007, Source: WSA

Figures 25 below illustrated of the principal *volume* epochs that the Steel Industry has seen until now. Figure 26 is a schematic visualization of the Global Steel industry life cycle.

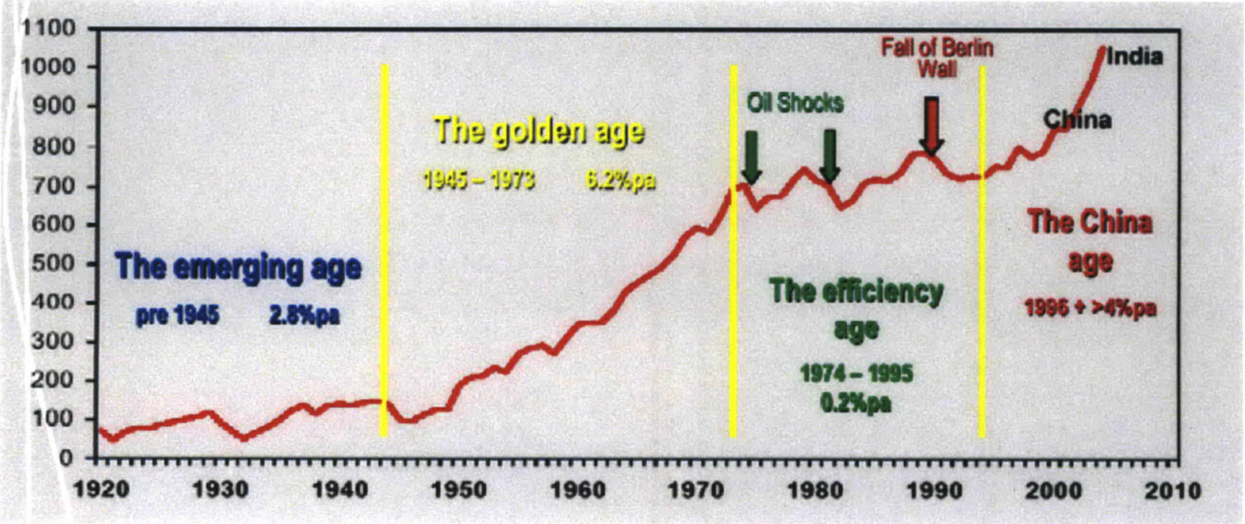


Figure 25: Principal Volume Epochs, Source: BHP Billiton

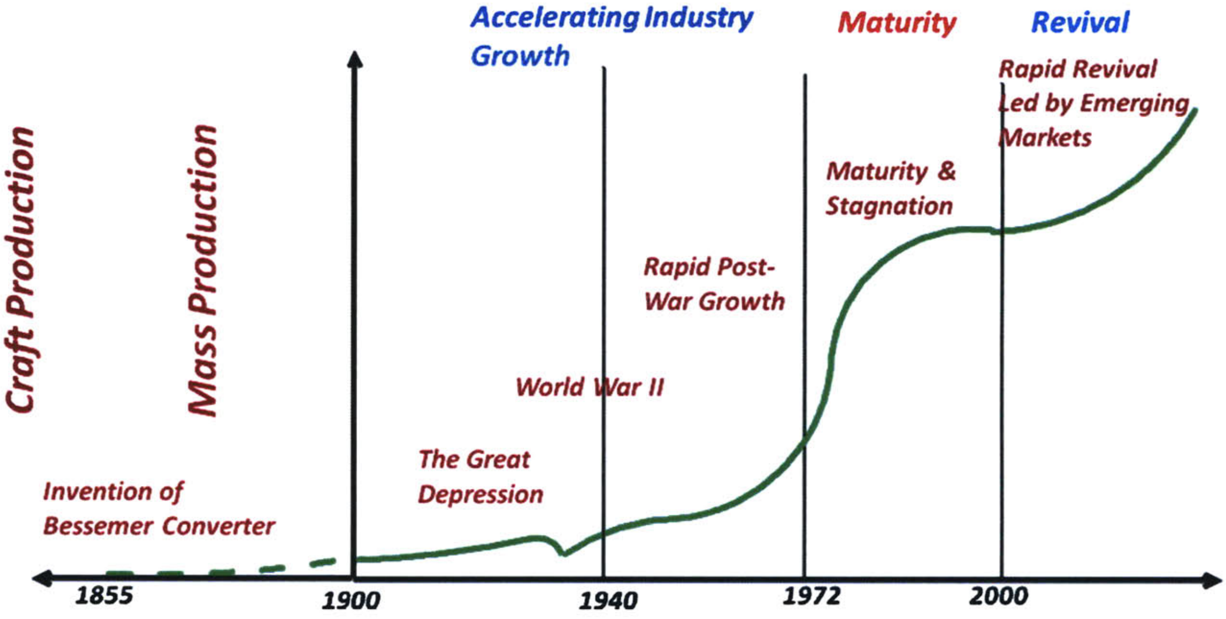


Figure 25: Schematic Visualization of the Global Steel Industry Lifecycle

Steel being an essential ingredient of infrastructure products as well as consumer durables, the Steel industry business cycles have historically closely tracked the larger economic cycles. Until the mid-1940s, volume growth was low, although it was influenced by business cycles of the time, including a decline during the great depression, followed by an arms and ammunition – led revival during the 2nd world war. However, volume growth really took off only after the end of the 2nd world war, with the onset of the consumer revolution of the 1950s and 1960s. Following a period of rapid growth until the early 1970s, the Steel market entered a period of stagnation, with the demand of infrastructure as well as consumer products in the industrialized economies stagnating.

The US Steel industry was more deeply impacted than most other economies, with the 1970s seeing a large increase in cheaper imports from Japan. A prominent factor contributing to this was the failure of prominent US players to keep pace with technological change in the steel industry. The *red* business environment that emerged in the US, saw the decline of traditional steel firms including *US Steel* and *Bethlehem Steel*, and the emergence of leaner, process- focused firms such as *Nucor* . While the global steel industry saw a rapid revival with the start of the 21st century, led primarily by rapid growth of the emerging economies (most prominently China), the benefits of this revival were, for the most part, not available to US firms. In 1900, 37% of global steel was produced in the US. In contrast, the share of the whole of North America in 2008 was 14.5%, as compared to 40% for Asia. With the locus of the Steel Industry having shifter away from the west, and with the US having largely lost the cost battle, the volume growth since 2000 has been absorbed mostly by the non-US firms such as *Arcelor-Mittal*, with the US Steel industry continuing to stagnate in terms of volume growth.

In terms of current and anticipated volumes globally, the global steel industry appears to be in the early stages of a new lifecycle that started towards the end of the 20th century. In 2006, global steel production was 65.3% above the production 10 years ago, and 45.7% above the production 5 years ago. This indicates growth at an accelerating pace. Most of this growth is taking place in the emerging economies, particularly China. However the US Steel industry appears to be firmly in the "decline" stage, with volumes stagnating in the 1990s, after a rapid decline that started in the early 1970s.

Fig. 26 below indicates the market shares of the major global players as of 2006.

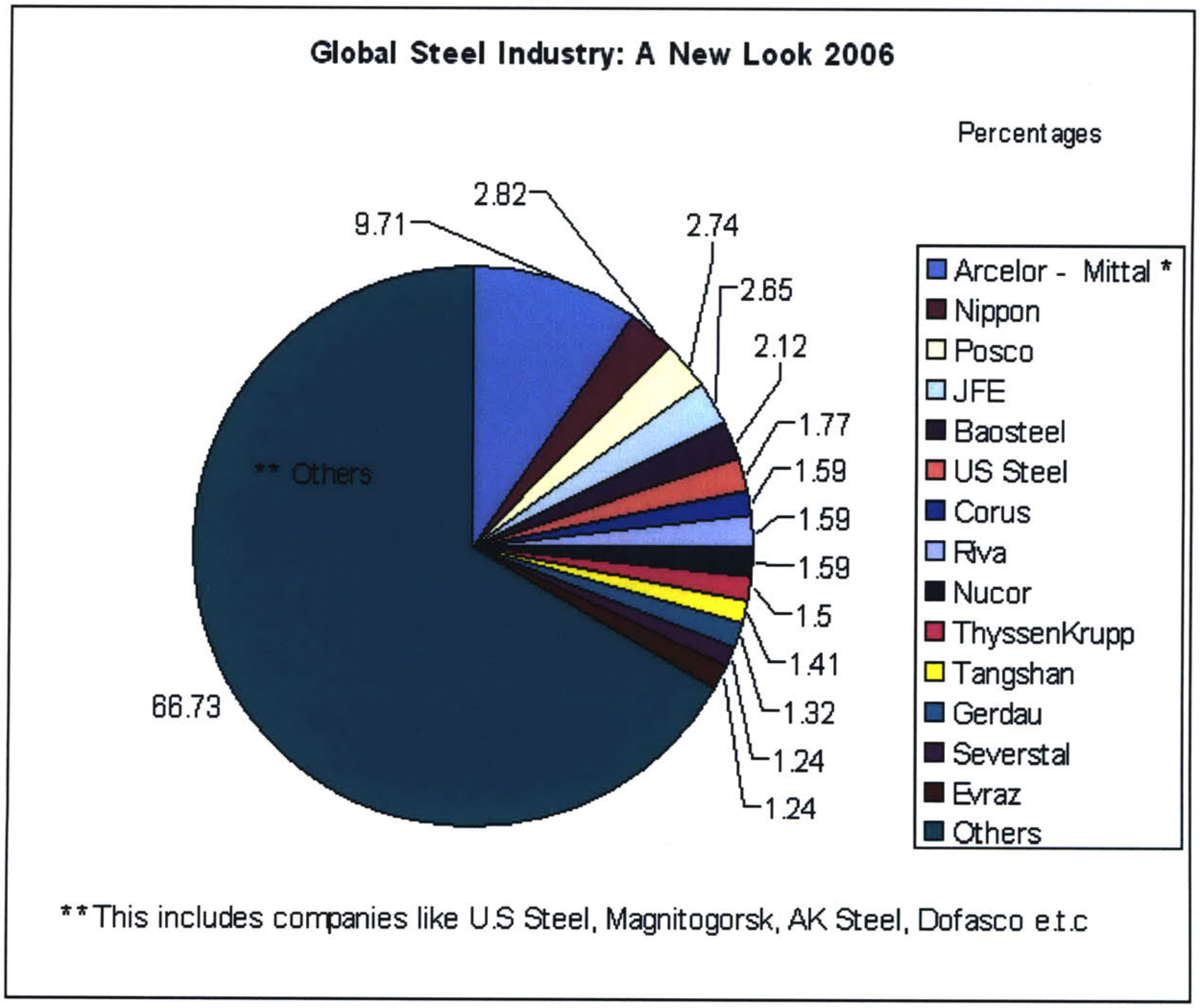
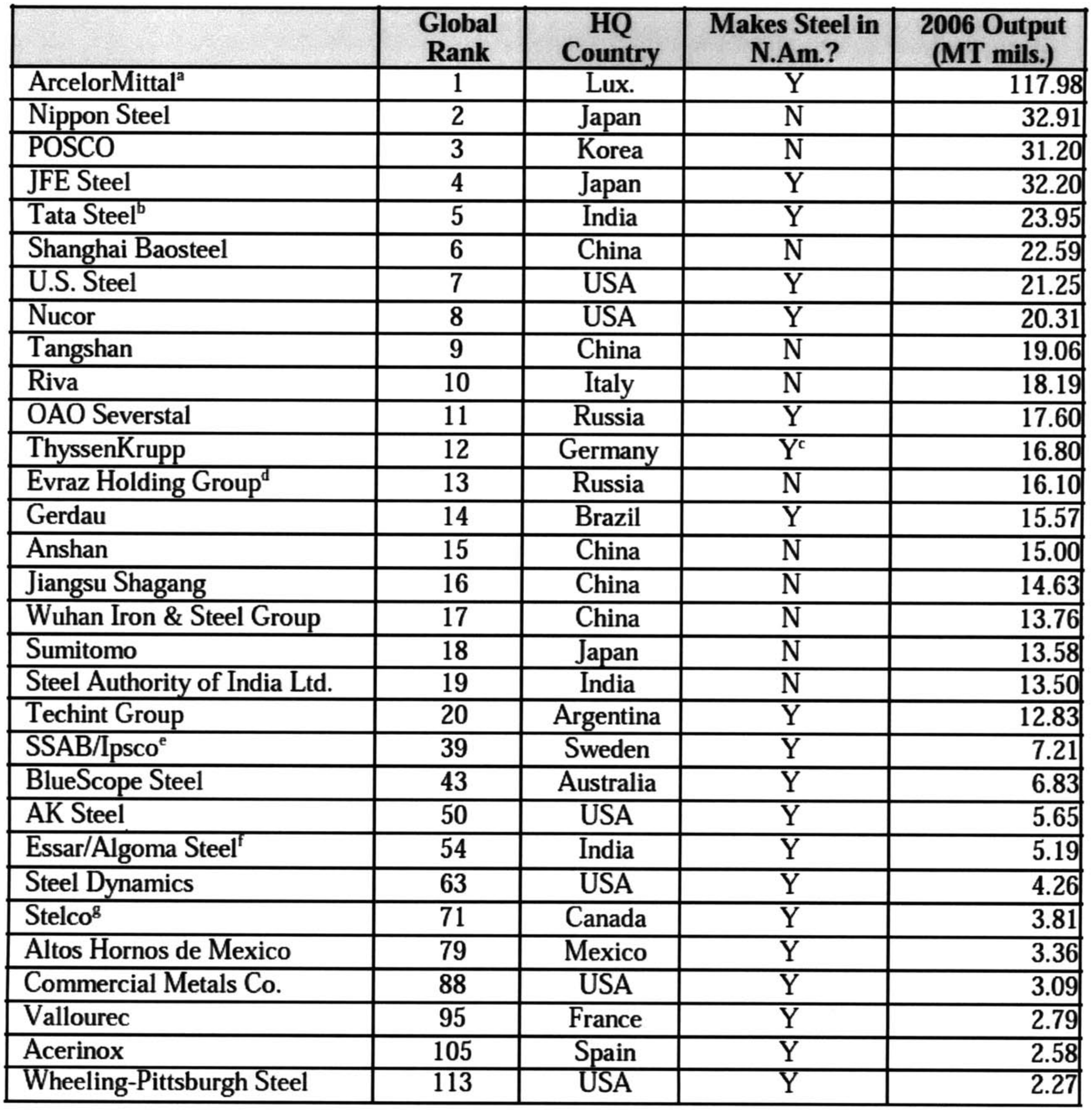


Figure 26: 2006 Global Market-share of Steel Producers, Source – Salman Anwar, KWR International, 2006



	Global Rank	HQ Country	Makes Steel in N.Am.?	2006 Output (MT mils.)
ArcelorMittal[a]	1	Lux.	Y	117.98
Nippon Steel	2	Japan	N	32.91
POSCO	3	Korea	N	31.20
JFE Steel	4	Japan	Y	32.20
Tata Steel[b]	5	India	Y	23.95
Shanghai Baosteel	6	China	N	22.59
U.S. Steel	7	USA	Y	21.25
Nucor	8	USA	Y	20.31
Tangshan	9	China	N	19.06
Riva	10	Italy	N	18.19
OAO Severstal	11	Russia	Y	17.60
ThyssenKrupp	12	Germany	Y[c]	16.80
Evraz Holding Group[d]	13	Russia	N	16.10
Gerdau	14	Brazil	Y	15.57
Anshan	15	China	N	15.00
Jiangsu Shagang	16	China	N	14.63
Wuhan Iron & Steel Group	17	China	N	13.76
Sumitomo	18	Japan	N	13.58
Steel Authority of India Ltd.	19	India	N	13.50
Techint Group	20	Argentina	Y	12.83
SSAB/Ipsco[e]	39	Sweden	Y	7.21
BlueScope Steel	43	Australia	Y	6.83
AK Steel	50	USA	Y	5.65
Essar/Algoma Steel[f]	54	India	Y	5.19
Steel Dynamics	63	USA	Y	4.26
Stelco[g]	71	Canada	Y	3.81
Altos Hornos de Mexico	79	Mexico	Y	3.36
Commercial Metals Co.	88	USA	Y	3.09
Vallourec	95	France	Y	2.79
Acerinox	105	Spain	Y	2.58
Wheeling-Pittsburgh Steel	113	USA	Y	2.27

Figure 27: Top Global and North American Steel Producers, Source - US Steel Policy Report, 2008

3.2.1 Evolution of the Steel Market in the US (Quantity)

The trajectory of evolution in the quantity space in the US Steel industry has been somewhat different than that of the global steel industry. While the global market experienced a plateau in the 1970s and 1980s, before reviving in the late 1990s on account of resurgent demand from China and India, the US steel market peaked in the early 1970s. The US market experienced a net negative growth from the early 1970s and mid-1980s, and has been stagnant ever since.

However, a comparison of the evolution of *production* growth (*Fig. 28*) in the US with the *consumption* growth (*Fig. 29*) reveals a slightly different picture. Although *production* declined or stagnated in the period between 1978 and 2000, *consumption* trends slightly upwards during the period. As can also be seen from *Fig 29*, a sharp rise in imports (and stagnant exports) appears to account for most of this differential. The failure of the US Steel industry to engage in rapid process innovation in the 1970s, led to them ceding ground to the Japanese, who had a significantly lower cost of production, and were able to supply steel at much lower rates than their American counterparts. In the 1990s, when the Japanese lost some of their competitive edge, the American market was flooded with cheap imports from China.

However, in the midst of this apparent crisis, minimill-based steel producers, led by *Nucor*, were able to carve out a profitable niche. In the words of RW Crandall:

> *"The minimills of today have their genesis in the 1960s when demand growth slowed in the USA. As scrap prices fell relative to iron ore costs and as the costs of integrated steel companies began to rise in the wake of expensive labor agreements and their inability to build efficient, new plants, steel fabricators began to look for cheaper sources of steel, particularly for construction uses (Barnett and Crandall, 1986). Florida Steel and Nucor, in particular, began to build small, electric furnace plants to produce bar products. By 1970, the minimill revolution was underway..."*[27]

A glance at the historical evolution of capacity utilization in the US Steel industry (*Fig. 30*) also reveals a crisis of under-utilized capacity in the early 1980s, similar to an equivalent crisis during the great depression of the 1930s.

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[27] Crandall, Robert W., 1996, *"From competitiveness to competition : The threat of minimills to large national steel companies"*

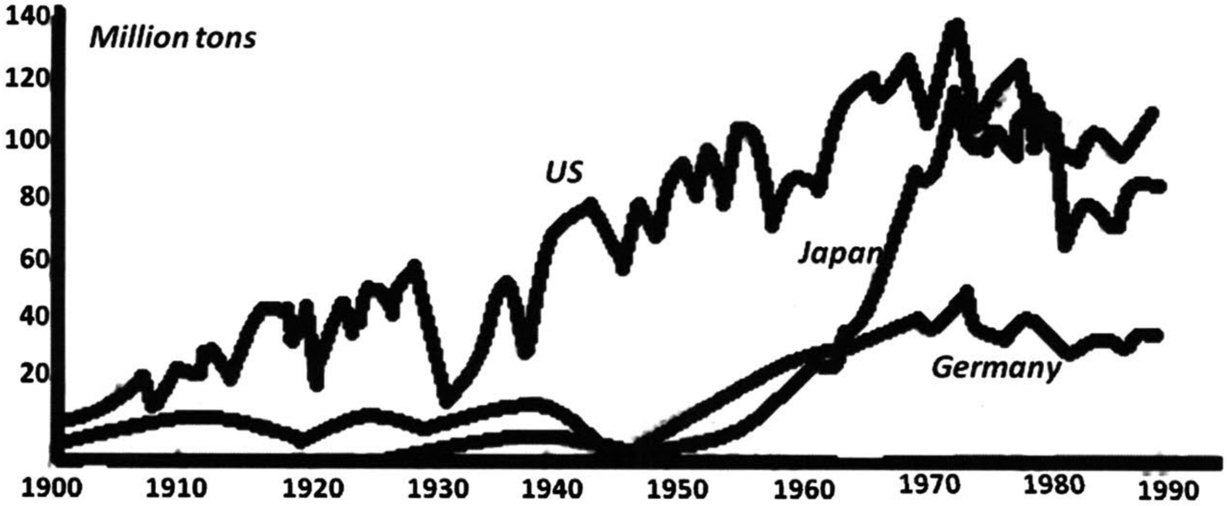


Figure 28: Production (million tons), US, Japan, Germany, Source- Hirooka and Hagiwara, 1992

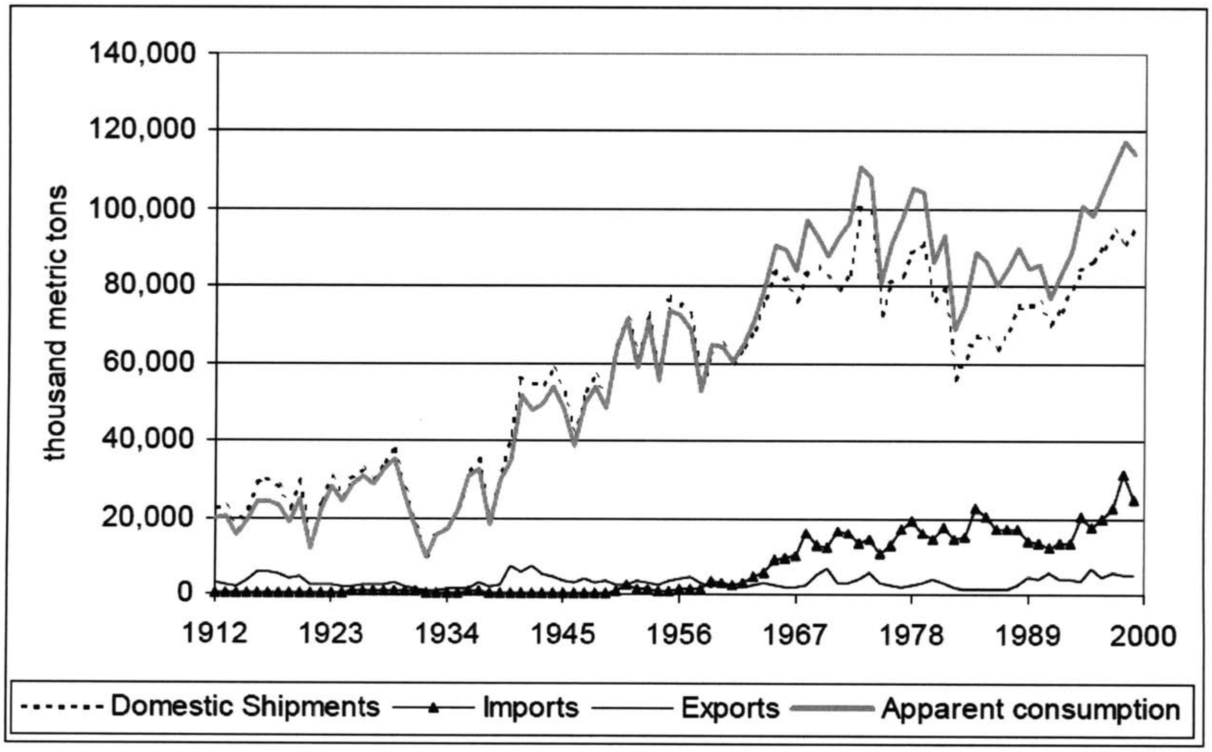


Figure 29: Apparent US Consumption, Source: Timothy J. Considine, Christopher Jablonowski, Donita M. Considine, 2001

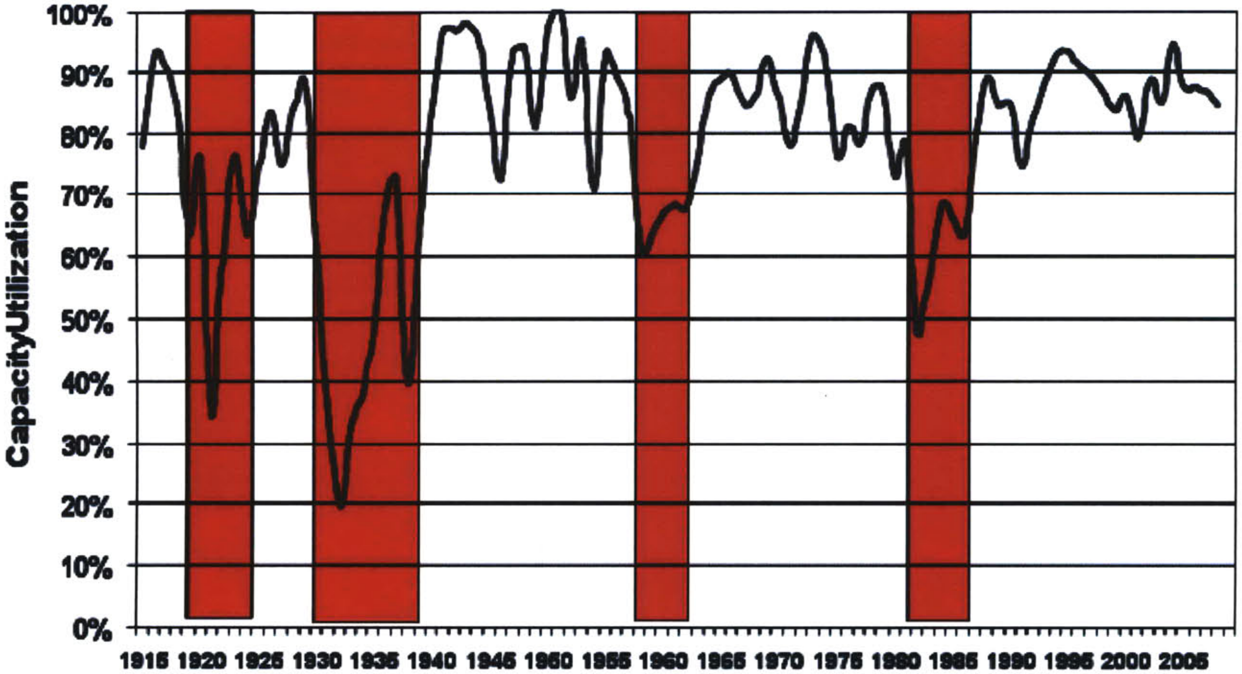
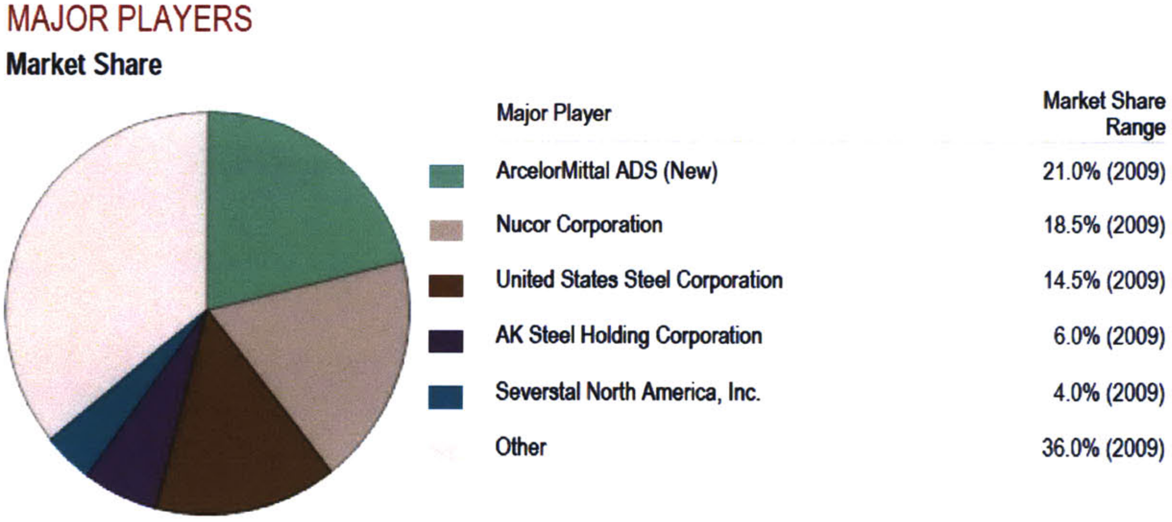


Figure 30: US Annual Raw Steel Capacity Utilization, Source - www.first-river.com

As of 2009, the biggest Steel producers in the United States, and their market shares were as below:



MAJOR PLAYERS

Market Share

	Major Player	Market Share Range
🟩	ArcelorMittal ADS (New)	21.0% (2009)
■	Nucor Corporation	18.5% (2009)
■	United States Steel Corporation	14.5% (2009)
■	AK Steel Holding Corporation	6.0% (2009)
🟦	Severstal North America, Inc.	4.0% (2009)
	Other	36.0% (2009)

Figure 31: Major steel producers in the US, Source: IBISWorld Industry Report August 18 2009

Schematically, the evolution of the US Steel industry in the Quantity space can be visualized as below:

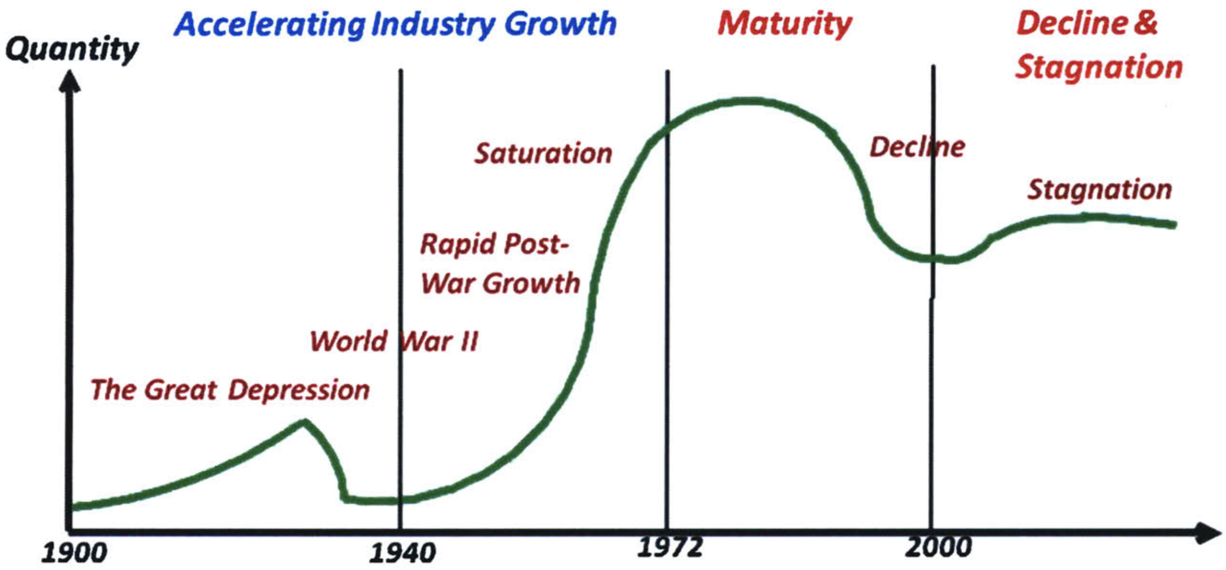


Figure 32: Schematic Visualization of the US Steel Industry Lifecycle

3.3 Brief Case Histories of Sample firms

While the specific details of the histories of the sample firms are not vital to this study, a comparison of the histories is instructive in highlighting the differences in the circumstances and the business environment in which each firm evolved. Provided below are brief case histories of one representative firm of each type- The ***United States Steel Corporation*** and ***Nucor Corporation.***

3.3.1 *United States Steel Corporation*

The *United States Steel Corporation* was incorporated on February 25, 1901, with an authorized capitalization of $1.4 billion, the first billion-dollar corporation in history. This was the result of the ambitious merger of ten different companies - American Bridge Company, American Sheet Steel Company, American Steel Hoop Company, American Steel & Wire Company, American Tin Plate Company, Carnegie Steel Company, Federal Steel Company, Lake Superior Consolidated Iron Mines, National Steel Company, and National Tube Company.

The events leading up to this merger are synonymous with the early history of the steel industry in the United States. In the late 19th century, the steel industry represented a typically *blue* environment, with demand for steel far outpacing supply, and new and better technologies being actively sought and developed. Several fledgling companies competed in the market, and dominant players had yet to emerge.

Andrew Carnegie, who can be called the founding father of the US Steel industry, started out as a bobbin boy in a cotton mill. Recognizing the vital importance of railroads to the economy of the time, he made a stake in the railroad business, and started to invest in the iron industry in 1864. In 1873, he started to establish steel plants using the *Bessemer Steel making process.* He was a ruthless competitor, who led the Carnegie Steel company to be the largest steelmaker by the end of the 19th century.

Charles M. Schwab was another prominent personality, closely associated with the early history of the steel industry in the United States. In 1897, Carnegie appointed Schwab, a veteran who had made his way up the ranks in the Carnegie organization, as president of Carnegie Steel.

Other prominent personalities associated with the merger included *John Pierpont Morgan*, a prominent financier and founder of the *Federal Steel Company,* and *Elbert Henry Gary*, a lawyer, former judge, and director of the *Illinois Steel Company*. Morgan, encouraged by the rapid acceleration in steel demand in the late 19th century, as well as rumors of Carnegie's expressed desire to retire from the business, was the principal driver of the merger. Morgan hoped to dominate the steel market by creating a centralized conglomerate. The pivotal event preceding the merger was a legendary dinner at New York's University club held in December 1900, in the course of which, the proposed structure and details of the new organization were outlined. Charles Schwab became the President of US Steel, with Gary as the Chairman of the board of directors as well as the executive committee.

Following early differences and conflicts of personality in the new organization, Schwab resigned in 1903 to take control of the *Bethlehem Steel Corporation*, a company that he was able to eventually grow into the country's second-largest steel producer.

The history of *US Steel* has been marked by rapid fluctuations in production and financial performance, as well as continual acquisitions, divestitures, consolidations, reorganizations, and bitter labor disputes. US Steel's market share dropped from about 66% in 1901 to about 33% in the period between 1930 and 1950. Despite the fluctuations, US Steel was largely a profitable enterprise in its early years. The spike in steel demand due to World War I as well as World War II yielded hugely positive dividends for the company, even while the great depression of the 1920s brought it nearly to the brink. Prominent among the labor disputes of the early era was the one related to abolition of the 12-hour work day, which was the norm in the steel industry in the early 20th century. "U.S. Steel's labor relations have historically been adversarial, characterized by divisive negotiations, often bitter strikes, and settlements that were sometimes economically disastrous for the company and, in the long run, for its employees".[28]

After his death in 1927, Gary was succeeded by J.P Morgan Jr. as chairman of the board of directors. However, during the period between 1927 and 1938, *US Steel* was effectively under the leadership of Myron C. Taylor, chairman of the finance committee from 1927 to 1934 and chairman of the board from 1932 until his resignation in 1938. During his tenure, Taylor was responsible for a significant amount of restructuring, rationalization of capacity, as well as modernization. Another prominent *US Steel* Chairman during the first half of the 19th century was Irving S. Olds, who took over as chairman in 1940, and oversaw a period of rapid expansion following the post-war economic boom. US Steel revenues rose more than four times from $611 million in 1938 to more than $3.5 billion in 1951. Following a major reorganization started in 1951 and completed in 1953, four major operational subsidiaries of *US Steel* were consolidated into a single company, *The United States Steel Corporation*. The 1950s were marked by more labor disputes, including one of the longest strikes in the company's history which started in April 1952, following company's refusal to allow substantial wage increases and tighter closed-shop rules.

Although the 1950s proved to be generally profitable for the company, excessive capital spending and rising operating costs combined with relatively stable prices began to take their toll on the company's profitability by the end of the decade. The 1960s saw a period of slow growth, consolidation and reorganization. During this period, foreign competitors, prominently the Japanese, were aggressively investing in new technology including Basic Oxygen furnaces, which afforded much better efficiencies. US Steel's failure to make equivalent investments

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[28] *International Directory of Company Histories*, Vol. 50. St. James Press, 2003

would prove to be its undoing in the 1970s. By the early 1970s, prospects for long-term growth in the steel industry were becoming rapidly dimmer, following rising costs, aggressive pricing and competition from foreign producers.

The 1970s saw progressive erosion of profitability, with large scale closures of unprofitable operations. In 1979, US Steel suffered a loss of $293 million. The then Chairman and CEO, David M. Roderick undertook an extensive liquidation of unprofitable assets. In 1979, 13 steel facilities were closed with an $809 million write-off. With the steel business continuing to perform poorly, the company started to diversify into oil & gas, beginning in 1982 with a $6.2 billion acquisition of the *Marathon Oil Company*. The continued diversification and rationalization resulted in the shutting down of more than 150 steelmaking facilities and a reduction in steelmaking capacity by over 30% by 1985. Roderick cut 54% of white-collar jobs, laid off about 100,000 production workers, and sold $3 billion in assets. Continued diversification saw the $3.6 billion acquisition of Texas Oil & Gas Corporation in 1986.

In July 1986 *United States Steel Corporation* changed its name to *USX Corporation* to reflect the company's diversification into oil and gas. The company survived a corporate raid by *Carl Icahn* in 1986. This event was followed by a period of aggressive restructuring and spin-off of unproductive assets which continued into the 1990s, which saw the company emerge as the lowest-cost fully integrated steel producer in the United States by 1993. Between 1983 and 1990, the company reduced its total no. of employees by 56%. In a belated attempt to bring quality up to par with foreign competitors, *US Steel* forged joint ventures with companies such as Japan's *Kobe Steel* and *Korea's Pohang Iron and Steel Co.*

These measures proved insufficient as the company continued to reel under the pressure of sagging demand and overcapacity, in addition to the crippling effects of "legacy costs" associated with the pension and health benefits that union contracts obligated them to pay to the thousands of retired and laid-off employees that had resulted from the restructurings of the previous decades. The 1990s saw USX aggressively participating in efforts to lobby government to impose prohibitive "anti-dumping" tariffs on foreign steel. It was only in 2001 that such tariffs were actually imposed.

At the turn of the century, the company emerged leaner and more productive, and reclaimed its original name of *United States Steel Corporation*, emerging out of the holding company, USX Corporation. Attempts at a merger with the bankrupt Bethlehem Steel Company in 2002 proved unsuccessful. In 2003, after a stiff acquisition battle with *AK Steel*, *US Steel* acquired *National Steel* (US subsidiary of NKK) for about $1.1 billion in cash. With a combined capacity of around 20 million tons of steel annually, *US Steel* stands as the *third* largest steel producer in the US, after *Mittal Steel ADS and Nucor Steel.*

3.3.2 *Nucor Corporation*

Although *Nucor* emerged as a primarily steel-producing company only in the late 1960s, it traces its origins to the turn of the 20th century, when its parent company, *Olds Motor Works*, was founded by automobile inventor Ransom Eli Olds. In 1904, the firm's name was changed to R.E Olds company, and then to *Reo Motor Company*.

The emergence of *Nucor* as a primarily steel-producing company was more a result of accident than design. The automobile company founded by Olds performed erratically until 1955, when shareholders forced a takeover of Nuclear Consultants, a fringe property of the Reo Motor Company, leading to the firm being reborn as *Nuclear Corporation*, a firm focused on nuclear instrumentation, nuclear energy, chemicals, and electronics. The nuclear energy focused business of the firm proved to be largely unprofitable, and the firm was sustained largely by unrelated acquisitions. Prominent among these was *Vulcraft*, a metal fabrication business specializing in steel joists and girders. A key event was *F. Kenneth Iverson* becoming general manager of the *Vulcraft* division in 1962. Over the early sixties, Vulcraft emerged as the only profitable operation of the firm. By 1965, Nuclear Corporation verged on bankruptcy, and Iverson, heading the only profitable unit of the company, was appointed president and CEO of the firm.

Nucor acquired its name in 1972. Before that, in 1968, Iverson had already set the firm on a historic course in the first of several momentous decisions leading to Nucor adopting the minimill technology to produce steel from scrap. The idea was to make steel at a lower cost than foreign producers, but producing steel through the conventional route would have entailed direct competition with *US Steel*, a key supplier of *Vulcraft*. The minimill route was the compromise solution that would achieve the aim of producing steel at a low cost, without upsetting *big steel*. The *architectural leadership* shown by Iverson in the early years defined the course the company was to take. According to *Success* magazine:

> *Iverson "recruited farmers, sharecroppers, and salesmen to do the dirty, often dangerous work of making steel. High technology and untrained troops made for a volatile mix, and delays and catastrophes caused stock prices to drop to pennies. But a legendary company culture was born: inventive, resourceful, team oriented, inspired by impossible challenges."*

As *Nucor* continued to make inroads into *big steel's* territory, it entered the production of *steel deck* in 1977 and *cold finished steel bars* in 1979. *Nucor* entered the 1980s as one of the top 20 steel manufacturers in the US, with sales of $430 million and net earnings of $42 million. It was also the largest producer of steel joists in the country. In the growth filled 1970s (a time that saw a significant decline in the output of *Nucor's* major competitors), the only negative incident was a mill fire in 1974 that killed four *Nucor* employees, and invited wide media criticism. However the culture and systems instituted by *Iverson* in the early years saw *Nucor* employees stand steadfastly by the company. According to *David Gardner* and *Tom Gardner*:

"...in a time when so many industrial manufacturers employ unionized labor, to this day Nucor remains a union-free company. How? By offering its employees far better options than most union workers ever see. Nucor offers an incentive package to even its lowest- salaries employees. In fact, the incentive package makes it possible for workers to earn more than twice their base wages should they execute their production goals. Also, Nucor offers guaranteed scholarships for employees' children. And – what union has ever been able to achieve this? – no Nucor employee has ever been laid off. In lean times (and there are always those), everyone "shares the pain" (that's what they call it) by coming to work for fewer hours during the week. Over the decades, Iverson has instituted these policies and numerous others; all emerge out of an egalitarian spirit, some are unusual, and all are in place today"[29]

A key feature of *Nucor* was the (non-existent) hierarchy. Only four management layers exist inside the company:

Layer 1	Chairman / Vice Chairman / President
Layer 2	Vice President / Plant General Manager
Layer 3	Department Manager
Layer 4	Supervisor

All wear identical hard-hats. Decision-making is bottom-up rather than top-down. The firm structure is set up for instant innovation and rapid decision-making.

Until the mid-1980s, minimills were a relatively unrefined technology, lacking the capacity to produce *sheet steel*, a relatively high-end product segment that was served exclusively be the integrated steel producers. In 1986, Iverson decided to tackle this final frontier. In a risky move, he decided to acquire thin-slab casting technology from SMS Schloemann-Siemag of Germany. The technology had never been tested before, and the total investment cost was estimated at $340 million[30], which was almost equal to *Nucor's* net worth at that time. Experimental production had started by mid-1989 at a new plant at Crawfordsville, Indiana.

The move paid rich dividends for the company. The technology saw the company break into the last bastion of the integrated steel world, and contributed to the accelerated decline of the tradition steel producers in the US. In 1988, Nucor established a joint venture with Japanese steelmaker Yamato Kogyo to produce wide-flange beams.

Shortage and rising cost of steel scrap in the early 1990s prompted a search for alternative inputs, which resulted in one of the few less successful ventures of *Nucor*. built an experimental $65 million plant in Trinidad and Tobago that would process cheap iron ore from Brazil to make iron carbide, an economical substitute for direct-reduced iron. The plant had an annual capacity of

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[29] David Gardner, Tom Gardner, 1999, The Motley fool's Rule Breakers Rule Makers: The foolish guide to picking stocks

[30] Pankaj Ghemawat and Henricus J Stander III, 1992, *Nucor at the Crossroads*, Harvard Business School Publishing

320,000 tons. Although the conversion process itself worked flawlessly, the plant faced several technical problems and mechanical breakdowns. The project ended up being a year behind schedule with significant cost overruns, prompting investor concern and a slide in the stock price.

Even as the company continued to grow rapidly, in January 1996, COO John D. Correnti succeeded Iverson as CEO, with Iverson remaining on as chairman of the board. Correnti continued the high growth trajectory while continuing to build the "*Nucor* culture" put in place by Iverson. Correnti resigned as CEO in 1999 with Chairman David Aycock assuming his duties. In September 2000, Daniel R Dimicco, a former EVP, took over as CEO. Dimicco was appointed Chairman in 2006.

In early 2000, Nucor entered into a joint venture with Australia's Broken Hill Proprietary Corporation and Japan's Ishikawajima-Harima Heavy Industries for *strip casting* technology. This technology allowed the production of steel in smaller, cheaper plants. In March 2001 *Nucor* acquired a significant stake in *Auburn Steel*, a producer of merchant steel bar, for $115 million.

In 2002 *Nucor* established a joint venture with *Companhia Vale do Rio Doce (Vale),* a Brazilian producer and exporter of iron-ore pellets, to develop low-cost iron based products. In the same year *Nucor* purchased Alabama-based Trico Steel, a *sheet steel* producer, for approximately $116 million. In late 2002 *Nucor* acquired financially troubled *Birmingham Steel* for $615 million.

Nucor Steel Kingman, LLC, a subsidiary of *Nucor Corporation*, purchased the Kingman, Arizona rebar and wire rod rolling unit of North Star Steel for around $35 million in 2003. Its Vulcraft unit saw an increase in non-residential building construction in 2004, which boosted sales of joist girders, steel deck, and steel joists. *Nucor* bought Corus Tuscaloosa (now called Nucor Tuscaloosa) in mid-2004, a producer of coiled plate with an annual capacity of around 700,000 tons. The following year saw the company purchase Ohio's Marion Steel for approximately $110 million. The mill was added to *Nucor's* bar products line.

Record high prices in the industry (led by high demand throughout the world) led to record high sales in 2004. As a matter of fact, *Nucor's* first half of the year outpaced previous annual highs, and the company achieved that feat again in the second half.

The company named CEO DiMicco chairman in 2006. *Nucor* currently stands as the second largest steel producer in the United States, behind *Arcelor Mittal ADS.*

4. Analysis and Results

4.1 Theory of EBE – Validation

While attempting to validate the theory of evolution of business ecosystems, I shall use a methodology similar to the one employed by Piepenbrock. I shall present each of the propositions of the theory and examine the degree to which they are corroborated by qualitative and quantitative data from the steel industry firms studied.

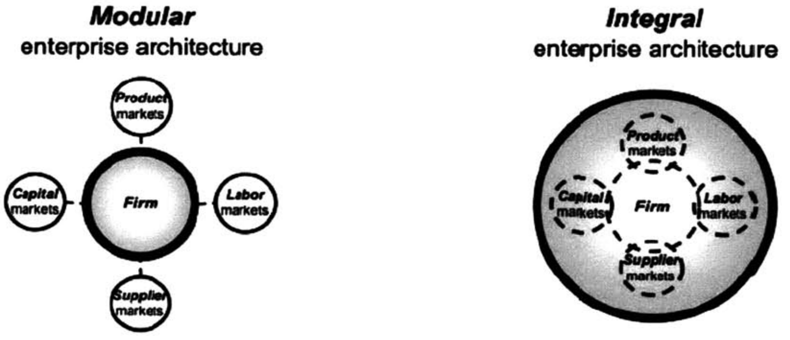
4.1.1 Architectural Forms

By way of background, I shall restate Piepenbrock's Axioms pertaining to architectural typology below:

***Axiom 1**: When modular enterprise architectures are observed empirically, the focal firm's objective function will tend toward singluar maximization of shareholder value. Conversely when integral enterprise architectures are observed empirically, the focal firm's objective function will tend toward pluralistic maximization of stakeholder surplus.*

***Axiom 2**: When modular enterprise architectures are observed empirically, the spatiotemporal boundaries of the focal firm will be relatively narrow and coincident with the boundaries of the firm and the time expectations of its shareholders. Conversely when integral enterprise architectures are observed empirically, the spatio-temporal boundaries of the focal firm will be relatively broad and beyond the boundaries of the firm and its shareholders.*

***Axiom 3**: When modular enterprise architectures are observed empirically, the focal firm will tend to have a higher quantity of lower quality (i.e. contract-based) interactions within each stakeholder group. Conversely when integral enterprise architectures are observed empirically, the focal firm will tend to have a lower quantity of higher quality (i.e. relationship-based) interactions within each stakeholder group.*



Singular (Maximization of *Shareholder Value*)	**Objective Function**	***Plural*** (Maximization of *Stakeholder Surplus*)
Narrow (*narrow* spatial, *short* temporal)	Enterprise **Boundaries**	***Broad*** (*broad* spatial, *long* temporal)
Simple (*High* quantity of participants in a stakeholder class, *Low* quality of stakeholder relationships)	Stakeholder **Interfaces**	***Complex*** (*Low* quantity of participants in a stakeholder class, *High* quality of stakeholder relationships)

Figure 33: Typology of Enterprise architectures, Source: Piepenbrock, 2009

When examining these axioms in the light of qualitative data, the architectural forms of the firms investigated begin to become apparent:

Table 1: Sample Qualitative Data indicating Architectural Forms

Firm	Quotation/ Anecdote with Source
United States Steel Corporation ***(Modular)***	From *Big Steel, The first century of the United States Steel Corporation*, by *Kenneth Warren*: *"Some have traced the problems of US Steel to its **relations with labor**. Certainly this relationship was **distant, frosty**, and **woefully lacking in sympathetic understanding** over the first third of its corporate history and has often been difficult since…"* *"Time and again US Steel was served and sometimes led by excellent men, but these executives were inhibited and crabbed by **corporate unwieldiness, structures, traditions and defensive attitudes**".* *"There were not only too many plants, widely scattered, but there were also divisions and often disagreements between a **distant, finance-dominated headquarters** and a system of production units made up of formerly independent companies and of product divisions, resulting in a rather **clumsy corporate structure**."* [31] *Benjamin Stolberg on Judge Gary, former Chairman of US Steel: "He never saw a blast furnace until after he died"*
Bethlehem Steel ***(Modular)***	*"…But Grace's successors had far more than personal image to worry about. The patriarch's system had created a company divided into **tight departments** headed by vice presidents accustomed to being answerable only to the man at the top. They were **extremely protective of their ground**. No craft union within the steel plant was any more sensitive to encroachment. Naturally, this **rigidity** was hardly conducive to an open exchange of ideas when overall corporate decisions had to be made."* - John Strohmeyer, 1986, "*Crisis in Bethlehem*", pg85 "*The characteristic that each department had in common was that they were **fiefdoms**, going way back. The turf was inviolable and prizes did not go for objective intelligence or academic training. Rarely were promotions based on merit*"[32]

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[31] Kenneth Warren, *"Big Steel: The first century of the United States Steel Corporation"*

[32] John Strohmeyer, 1986, "*Crisis in Bethlehem*", pg85

	- John F. Heinz, former Bethlehem employee *“The Bethlehem board was not made of men who would relinquish control. They came up in the business believing they controlled everything that was conducted in the area”*[33] - Bernard “Bun” Broeker, former EVP of Bethlehem
Nucor Corporation ***(Integral)***	*Success is not found in the ability to buy but in the **ability to build, to serve, and to rekindle**”* -Ken Iverson, Former Chairman of *Nucor Corporation* *“I believe in **long-term survival** over short-term profitability. I believe in **sharing the pain among all managers and employees**. I believe in **pushing decision-making as far down as it can go**. I believe in minimizing distinctions between managers and employees. I believe in paying people for their productivity. And I believe in keeping things simple.”* - Ken Iverson, Former Chairman of *Nucor Corporation* *And make no mistake: We will never lose sight of the fact that our most valuable asset is our more than 11,400 employees and their families!* -Dan Dimicco, Chairman of *Nucor Corporation* *“It's a combination of constantly challenging and creating focus on issues important to the success of our company, shareholders and employees but not being overbearing. It's giving people the freedom, resources and training to do their jobs but not getting in their way.”* -Dan Dimicco, Chairman of *Nucor Corporation* *“Our view is this is just the initial payoff of the disciplined execution of our strategic plan. We have always taken a long term approach toward building our business.”* -Dan Dimicco, Chairman of *Nucor Corporation* *“We call what we do "Nucorizing" — we say, "listen guys, we have two choices. You can deal with this issue by working together as a team or we can centralize this back at corporate. Which way do you want it?" With the entrepreneurial type of people we hire, you know what the answer is”* -Dan Dimicco, Chairman of *Nucor Corporation* *“The employee profit-sharing plan devised by E. Kenneth Iverson, Nucor’s*

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[33] John Strohmeyer, 1986, “*Crisis in Bethlehem*”, pg58

aggressive chairman, is a model for the industry, and has been a persuasive reason why Nucor employees choose not to affiliate with a union"

-John Strohmeyer, *"Crisis in Bethlehem Steel"*

Only four layers of management exist: Chairman, Vice Chairman and President; Vice President-General Manager; Department Managers; supervisor/Professional; and hourly employees. Only 22 employees eight managers and 14 administrative employees work in the corporate headquarters. Senior executives do not have company cars, dining rooms, executive parking spaces or corporate jets. Everyone from the janitors to the CEO has the same basic but generous benefits plan.

-Gregory P. Smith, *"How Nucor rewards Performance and Productivity", 2001*

Nucor's employee relations philosophy is simple and effective:

- *Employees should have the opportunity to earn according their productivity.*
- *If employees do their job well today, they should have a job tomorrow. (They haven't laid off employees in 28 years.)*
- *Employees have a right to be treated fairly. The company listens to employees through crew meetings, department meetings, shop dinners and employee surveys.*
- *Employees must have an avenue of appeal if they believe they have been treated unfairly. This complaint procedure allows employees to carry their complaints to the President of the company.*

-Gregory P. Smith, *"How Nucor rewards Performance and Productivity", 2001*

The average income for a Nucor hourly employee was double that of the average factory worker in the rural locations where Nucor built its plants. Nucor was creating wealth in places like Utah that would become, in the 1990's and beyond thanks in part to Nucor, hot spots of progress and growth.

- Steven Brockerman, "*Ken Iverson: Man of Steel, Part II*", 2006

I truly believe that Nucor's success has been 70% culture and 30% technology.

- Ken Iverson, "*The art of keeping Management Simple*", 1998

Core Values *practiced* by *Nucor*:

- *Treating employees fairly and with respect*
- *Employees should feel confident that if they do their job properly,*

	they will have their job tomorrow • *Humility, specially within management* • *Management Belief that "spontaneous order" will produce superior results compared to "controlled order"* • *Trust among employees and within employees and management* • *Intellectual honesty* • *Continuous Improvement* • *Openness* • *Freedom to make mistakes as long as you learn from them* • *Flat management structure, streamlined chain of command* • *Employees should have the opportunity to earn according to their productivity* • *Employees should expect a safe work environment* • *Uncompromising quality, responsive service and competitive pricing* • *Integrity in pricing* • *Simplicity* - Bill Nobles and Judy Redpath, 1995, "*Market-based Management- A key to Nucor's success*"
Arcelor Mittal ***(Integral)***	From "India's Global Powerhouses- How they are taking on the world" , Chapter 2, 2009, *Nirmalya Kumar, Pradipta K. Mohapatra, and Suj Chandrasekhar:* *"Mittal knew that good-quality scrap, the raw material for making steel, could be both difficult to source and costly. By supplementing his supplies with a substitute, direct-reduced iron (DRI), he found a solution to his raw-material problem that was both financially and technologically viable."* *"A number of elements make up the winning formula, including **targeted investment**, **cost cutting**, import of **modern management practice**, and the **sharing of best practice** among all plants."* *"Aditya Mittal, son of Lakshmi Mittal and CFO, noted that "**employee commitment, capital-expenditure commitment** and media perception" were even more important than financial measures"* *"Key to **reducing costs** and **improving performance** was the **Knowledge Management** Program. By benchmarking against the best in the Mittal Group, valuable knowledge transfer with respect to cost reduction occurred daily between plant managers. By pooling global expertise on a regular basis, the Mittal Group was able to **share and implement best practice, technical knowledge**, and target setting more quickly and efficiently than its competitors. The process of **knowledge sharing** occured **on various levels in the company** and was coordinated at the corporate level."* *Once plants are twinned, the interaction between them is continuous and systematic. Operational and technical managers visit both plants regularly to benchmark key performance indicators, review technological needs, and compare operating and maintenance practices. The consistency and regularity of this*

	interactive process allows twinned plants to implement and benefit from each other's best practices. Consequently, improvement at the plants continues in a structured manner." *"**revive** the facilities, **invest** in the facilities, and provide **stability** not only to the **community** but also the **company** and the **country**." – Aditya Mittal* *It is **simple** and **strong** management. First you have to diagnose what is the real issue, and then you have to make sure that the management team and the company is completely focused on resolving the critical issue. Often when you do a turnaround, you think that everything is wrong with the company and try to change everything, and then you are in a quagmire. The focus has to be on understanding the number one critical issue and resolving it first with all focus, dedication, and time. As each turnaround situation has a different focus issue, identification of that focus issue and resolving it is the most important aspect.* *-Aditya Mittal* *"We have long believed that size and scale are vital, both to compete in a global marketplace and to manage supply and demand through the economic cycle. A **strong, sustainable** industry benefits all its **stakeholders—employees, customers and investors alike."*** *– LN Mittal*

4.1.2 Managerial *Variation*: Architecture-Function Relationship

Further examining each of Piepenbrock's propositions for their validity in the steel industry, I shall first examine the support lent by steel industry data to his propositions related to **Managerial Variation.** The first of these propositions, Proposition 1a, relates to the *Quantity* of firm growth:

4.1.2.1 Proposition 1a: *Quantity* of Firm Growth

Proposition 1a: When modular enterprise architectures are observed empirically, the focal firm's operational strategy will tend toward unstable growth; it will have relatively high short-term speed, but relatively low long-term speed. Conversely when integral enterprise architectures are observed empirically, the focal firm's operational strategy will tend toward stable growth; it will have relatively low short-term speed, but relatively high long-term speed.

Piepenbrock proposes the following graphical representation of the likely trajectory of Quantity growth for each architectural type:

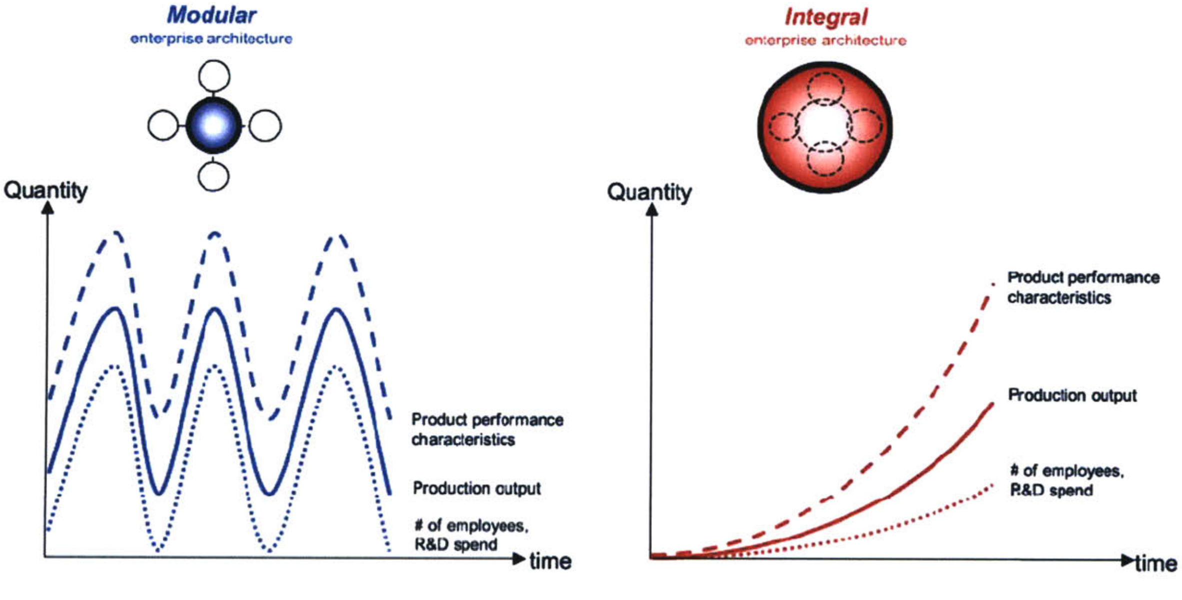

Figure 34: Comparison of Stable vs Unstable growth, Source: Piepenbrock, 2009

As per Piepenbrock,

For short time horizons, the absolute value of the rate of change of output of the modular enterprises tends to always exceed the rate of change of output of integral enterprises. Mathematically, this can be expressed as:

$|dQm/dt| > |dQi/dt|$ (for small dt)

For longer time horizons, the absolute value of the rate of change of output of the integral enterprises tends to always exceed the rate of change of output of long enterprises. Mathematically, this can be expressed as:

$|dQm/dt| < |dQi/dt|$ (for large dt)

An examination of Quantitative empirical data mapping output growth over time appears to validate Proposition 1a in the context of the Steel Industry. The expectation is that the modular architecture of *US Steel* and *Bethlehem* would grow at higher short-term rates, but lower long term rates, displaying periodic or cyclical oscillations, and vice-versa in the case of the integral architecture of *Nucor* and *Arcelor-Mittal*. This is indeed apparent from the longitudinal production data below, in Fig. 35 and Fig. 36:

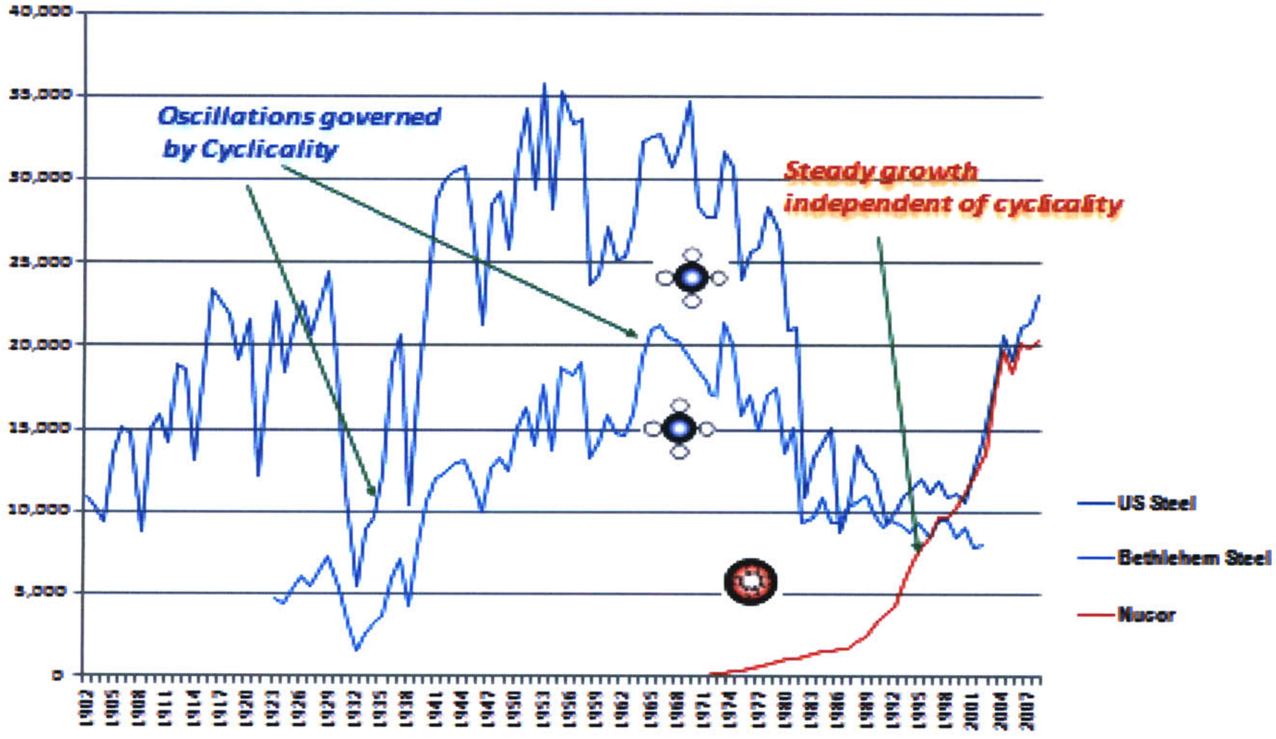

Figure 35: Production (1000s of net tons), *excluding Arcelor Mittal*

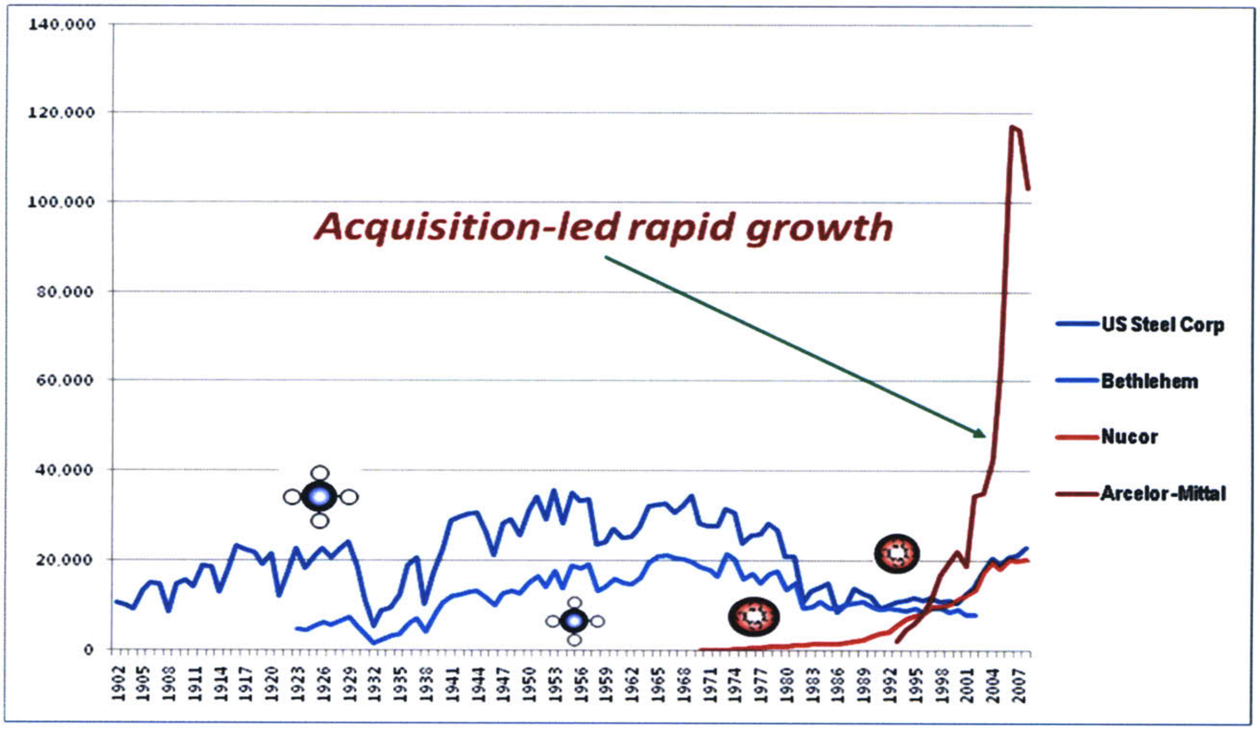

Figure 36: Production (1000s of net tons), including Arcelor Mittal

While the relatively high short-term rate of growth of *Arcelor-Mittal* appears to diverge from the behavior expected from on account of Proposition 1a, the absence of oscillations or noise is noteworthy. It is also noteworthy that although this growth, in the case of *Arcelor-Mittal*, is driven primarily by acquisitions, the policies implemented by the firm in the acquired firms are able to avoid the oscillatory behavior characteristic of Modular architecture.

These findings perfectly reflect those of Piepenbrock:

Qualitatively, after nearly 100 years of dominance, the market-share leading incumbents, US Steel and Bethlehem, are eventually overtaken by the late-entrant challengers, *Nucor* and *Arcelor-Mittal.* Piepenbrock, in his examination of Boeing vs. Airbus, notes the following points:

1) during an upturn, the rate of change of output growth of a modular enterprise architecture generally exceeds that of an integral enterprise architecture; 2) during a downturn, the rate of change of output decline of a modular enterprise architecture generally exceeds that of an integral enterprise architecture; and 3) negative growth of an integral enterprise architecture is rare. These three observations combine to state that the long-term growth rates of integral enterprise architectures exceed those of modular enterprise architecture. Finally, note that the late-entrant appears to experience a prolonged incubation period of relatively low production, while capabilities are presumably built. This behavior might imply the need for patient capital.

It is noteworthy that *each* of these points hold true in the above examination of the Quantity growth of US Steel, Bethlehem Steel, Nucor and Arcelor- Mittal. The prolonged "incubation period" is not evident in the data for Arcelor-Mittal, but can be inferred from the fact Mittal Steel was founded by Laxmi Mittal in 1976, but volumes in 1993 were still very low in comparison to the competition.

Table 2: Summary of data supporting Proposition 1a

Focal Firm	Enterprise Architecture	*Quantity* growth during *Intra*-Species Competition	*Quantity* growth during *Inter*-Species Competition
US Steel	**Modular**	**1902 - 1969 CAGR = 1.74%**	**1970 – 2008 CAGR = -0.54%**
Bethlehem Steel	**Modular**	**1923 – 1969 CAGR = 3.14%**	**1979 – 2002 CAGR = -2.6%**
Nucor	**Integral**		**1970 – 2008 CAGR = 16.79%**
Arcelor – Mittal	**Integral**		**1993 – 2008 CAGR = 28.87%**

As can be seen from the table above, *Quantitatively*, over the long term (during the period of inter- species competition), both Nucor and Arcelor Mittal are seen to have hugely higher growth rates with CAGR of 16.79% and 28.87% respectively, in comparison to a CAGR (-)0.54% and (-) 2.6% shown by the incumbents, *US Steel* and *Bethlehem* respectively. Piepenbrock notes in his comparison of the *quantity* performance of Toyota and GM that " *the polynomials cross – i.e. competitive dominance switches – after the incumbent species has peaked in output growth rates, while before the challenger species has inflected*". This behavior can be noted in the steel industry examples too.

4.1.2.2 Proposition 1b: *Quality* of Firm Growth

Proposition 1b: When integral enterprise architectures are observed empirically, the focal firm will be engaged in exploration (or radical innovation in either products or processes) of niche markets. Conversely, when modular enterprise architectures are observed empirically, the focal firm will be engaged in exploitation of mass markets.

This proposition certainly appears to be validated in the case of the steel industry. For over a century until the present time, the "Big Steel" firms had focused on mass production technologies derived from the blast furnace/ Open Hearth furnace/ Basic Oxygen Furnace, and producing steel from iron ore. The focus had always been on producing large volumes for the mass market. In the early 1970s, when Nucor started producing steel from scrap rather than ore, using the "niche" EAF technology, it was still an unrefined technology which was not seen by the "big steel" firms as a significant threat to their model. As the decade wore on, EAF technology improved rapidly resulting in a rapid erosion of the market-share of *US Steel* and *Bethlehem*.

Qualitative data supporting the proposition is tabulated below:

Table 3: Sample Qualitative data supporting Proposition 1b

Firm	Quotation/ Anecdote with Source
US Steel/ Bethlehem Steel **(Modular)**	*"Looking Ahead, this nation will need new 'greenfield' plants if a substantial part of this country's steel requirement is to be provided by domestic producers. Such installations will benefit from economies of scale and from adoption of technology that can only be fully implemented in a new integrated operation. In anticipation of this, US Steel has engaged in extensive planning for a 'greenfield' plant… Assuming favorable results from these steps, the Corporation will be well positioned to consider proceeding with this project when the cost-price relationship justifies the investment".* - US Steel, "Annual Report for 1977,"5 *From Carnegie forward, American steel companies had designed each of their plants to function as a single operation; from ore refinement to blast furnace to casting, steel manufacturing was one integrated operation. As such, Big Steel in its heyday made big profits. Until those big profits became a big draw for every looter who could somehow get his hands into the till of the American steel companies--and until the U.S. government sanctioned that looting, putting itself first in what would become a long line of thieves.* - Steven Brockerman, 2006, "*Ken Iverson: Man of Steel, Part II*"
Nucor **(Integral)**	*"Nucor's strategy focused on two major competencies: building steel manufacturing facilities economically and operating them productively. The company's hallmarks were continuous innovation, modern equipment, individualized customer service, and a commitment to producing high-quality steel and steel products at competitive prices. Nucor was the first in the industry to adopt a number of new products and*

	innovative processes, including thin-slab cast steel, iron carbide, and the direct casting of stainless wire". - Vijay Govindarajan, 2000, Dartmouth Tuck School of Business, Nucor Corporation (A) *Though Iverson insisted that Big Steel could be made profitable if America's steel companies would simply think in terms of manning efficiency--eliminating the featherbedding both on the line and in the office--the hard facts were that even using this approach would still require an abundance of start-up capital from any newcomer in the field. In 1968, Vulcraft and Nuclear just didn't have that sort of investment capital.* *So Ken took a different approach. He decided not to make steel from refined ore but from scrap metal in what is called a mini-mill. This was how the Europeans were able to make such inexpensive steel. Ken Iverson took their idea and pioneered it in America. In so doing, Ken took integrated steel making to the next level, in a mini-mill process that even the Europeans had not tried.* - Steven Brockerman, 2006, "*Ken Iverson: Man of Steel, Part II*" *Many snickered at Ken Iverson's plan, including Big Steel--until he started to build new mini-mill steel plants as fast as others were closing their large steel plants.* - Steven Brockerman, 2006, "*Ken Iverson: Man of Steel, Part II*" *"...in a time when so many industrial manufacturers employ unionized labor, to this day Nucor remains a union-free company. How? By offering its employees far better options than most union workers ever see. Nucor offers an incentive package to even its lowest- salaries employees. In fact, the incentive package makes it possible for workers to earn more than twice their base wages should they execute their production goals. Also, Nucor offers guaranteed scholarships for employees' children. And – what union has ever been able to achieve this? – no Nucor employee has ever been laid off. In lean times (and there are always those), everyone "shares the pain" (that's what they call it) by coming to work for fewer hours during the week. Over the decades, Iverson has instituted these policies and numerous others; all emerge out of an egalitarian spirit, some are unusual, and all are in place today".*[34]
Arcelor-Mittal **(Integral)**	*"Mittal knew that good-quality scrap, the raw material for making steel, could be both difficult to source and costly. By supplementing his supplies with a substitute, direct-reduced iron (DRI), he found a solution to his raw-material problem that was both financially and technologically viable."* -"India's Global Powerhouses- How they are taking on the world" , Chapter 2, 2009, *Nirmalya Kumar, Pradipta K. Mohapatra, and Suj Chandrasekhar*

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[34] David Gardner, Tom Gardner, 1999, The Motley fool's Rule Breakers Rule Makers: The foolish guide to picking stocks

	*"A number of elements make up the winning formula, including **targeted investment**, **cost cutting**, import of **modern management practice**, and the **sharing of best practice** among all plants."* *- Nirmalya Kumar, Pradipta K. Mohapatra, and Suj Chandrasekhar*

The bar chart below illustrates how technological change resulted in the "big steel" producers being edged out by the minimills:

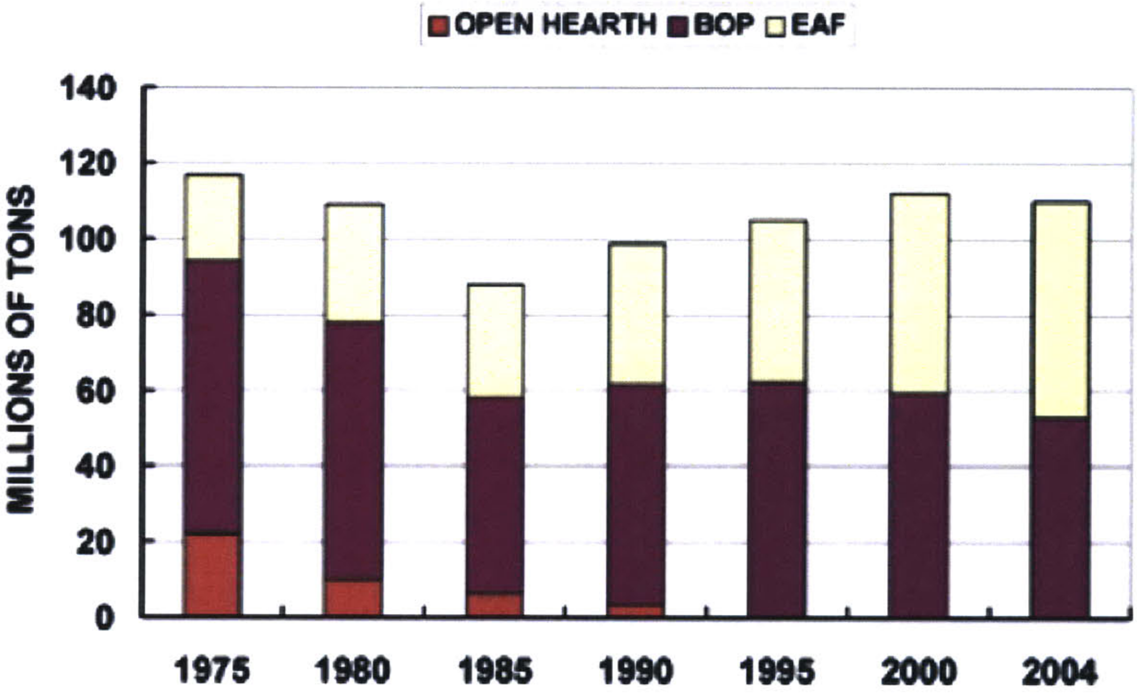

Figure 37: Source: The Minimill story, AIST J. Keith Brimacombe Memorial Lecture at AISTech 2006

Fig. 18 and Fig. 37 above indicate how the efficient and cost-effective mini-mills have overtaken the conventional BOFs in the US, with the inflexion point occurring in 2002, eventually resulting in the challenger Nucor replacing the incumbents US Steel and Bethlehem as a dominant player. The difference in the *quality* of growth between Nucor and the incumbents, supporting Proposition 1B, is also apparent in the quantitative data pertaining to *Revenue growth*, *Labor Productivity*, and *Revenue per Employee (Fig. 40, 42 and 42)*, provided later in support of Proposition 2

In support of Proposition 1b, Piepenbrock proposes, and validates, the following relationship between Relative Performance and Relative Cost:

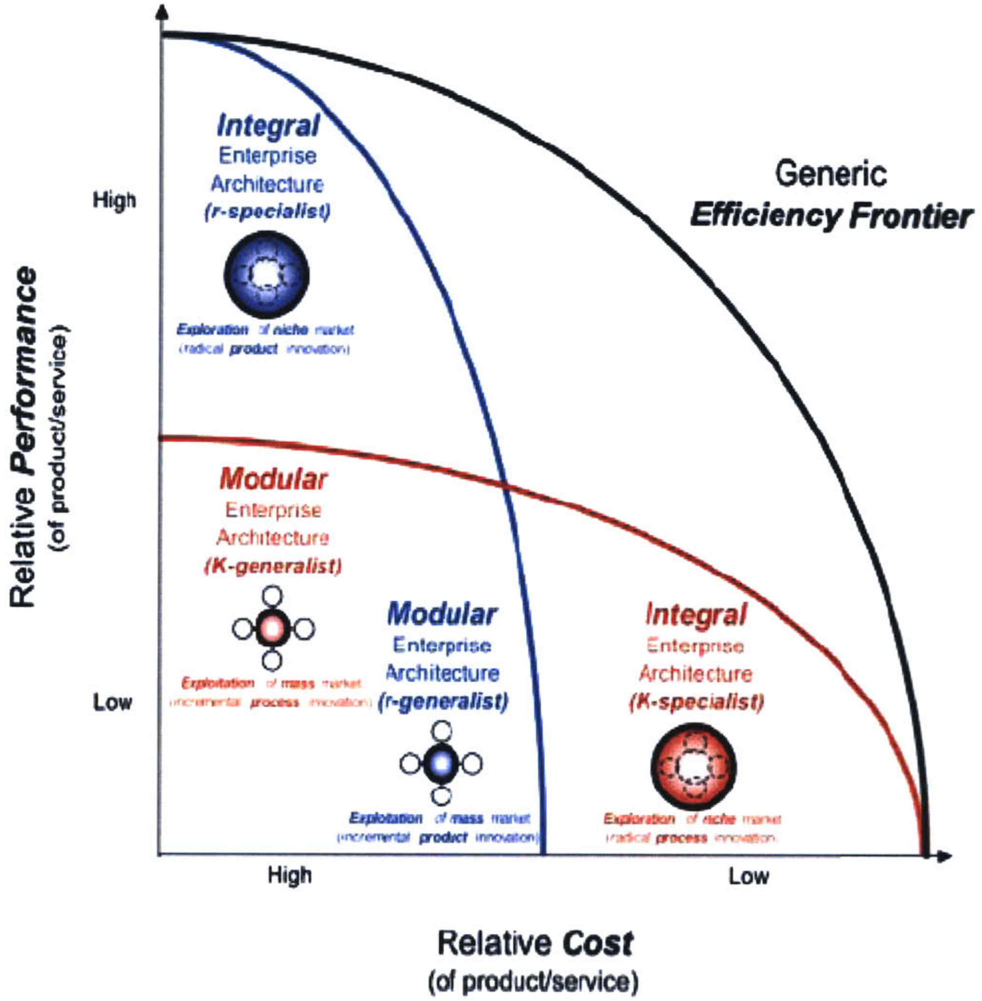

Figure 38: Exploration and Exploitation in the Strategic Position Space, Source: Piepenbrock, 2009

The general form of this relationship is also seen to hold true in the case of the steel industry. In the 1970s, when Nucor first adopted the mini-mill model, the technology was unrefined, and unsuited to the production of high-grade steels. Rapid advancement in EAF technology led to a performance level that was similar or slightly lower than the traditional route, at a significantly lower cost:

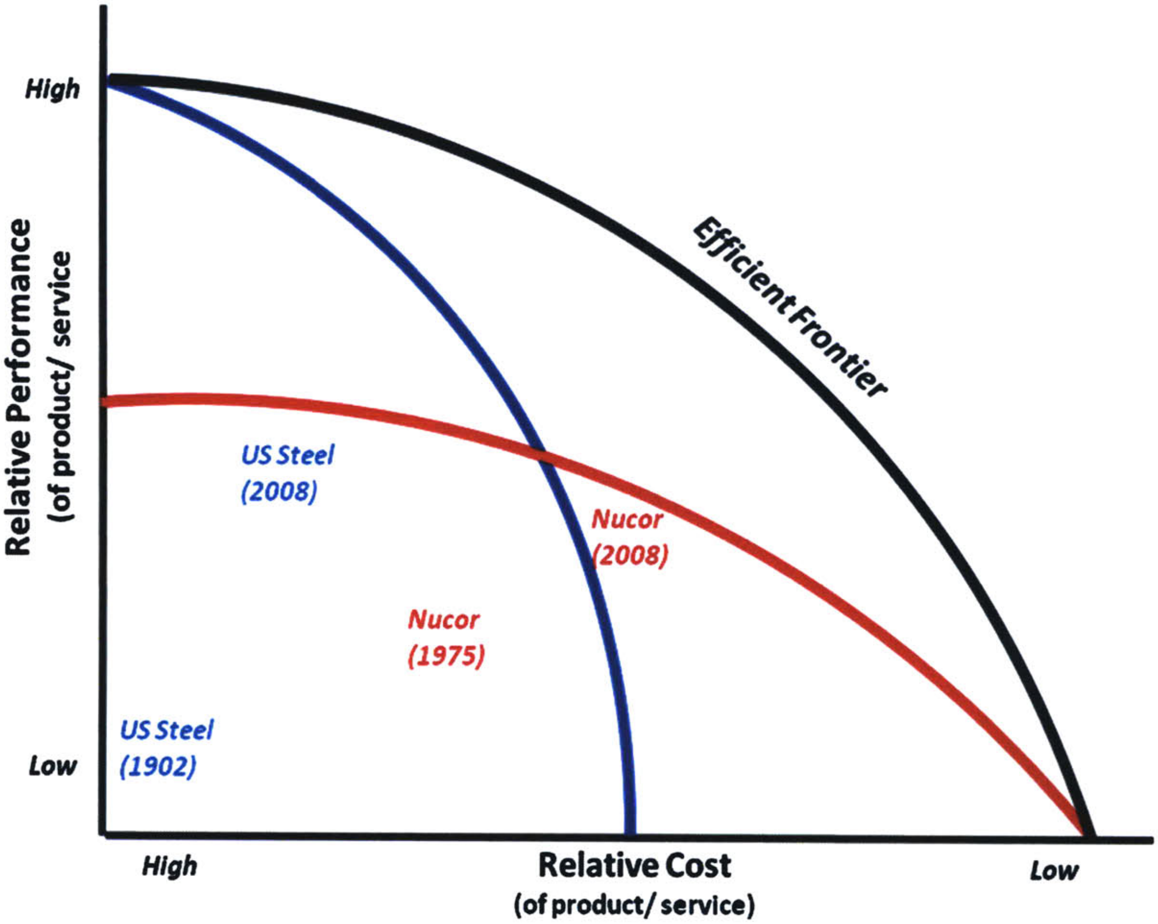

Figure 39: *Quality* Space of Competing Enterprise architectures in the Steel Industry

4.1.3 Competitive *Selection*: Function – Performance Relationship

Piepenbrock's second set of propositions pertain to the relationship between enterprise architecture and *economic* or *financial* performance. He highlights the paradox generated by *superior* financial performance of *integral architecture*, which is focused on maximizing *stakeholder surplus*, as opposed to *modular architecture*, which is focused on maximizing *shareholder value*.

4.1.3.1 Proposition 2a: Quantity of firm performance (Revenues):

Proposition 2a: When competing modular and integral enterprise architectures are observed empirically, the focal firm of the modular enterprise architecture will tend to have lower long term rates of revenue growth, relative to the focal firm of the integral enterprise architecture.

A glance at the quantitative time-series Revenue data (*fig. 40*) appears to validate this proposition. The Revenue growth chart reinforces Proposition 2a, with modular architecture exhibiting oscillating, cyclical growth with high short-term but low long-term growth rates.

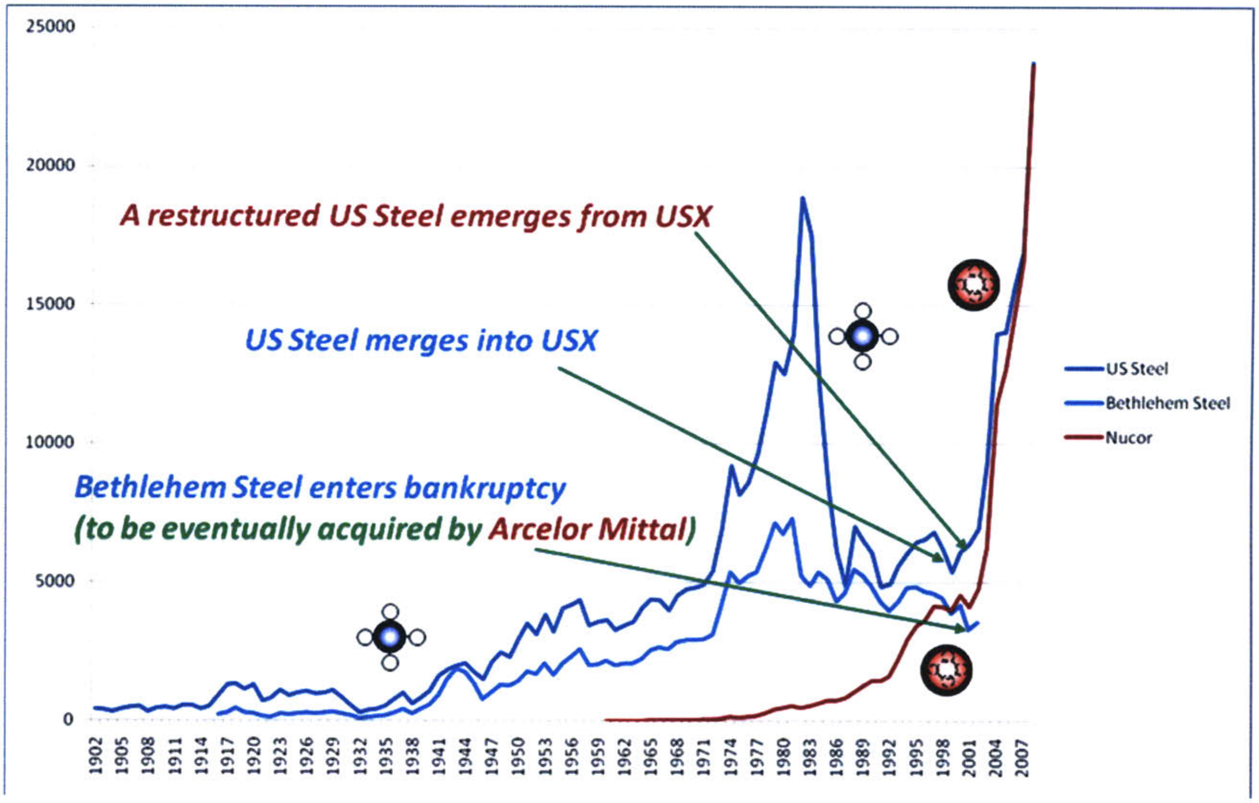

Figure 40: Revenue, millions of dollars

Table 4: Summary of data supporting Proposition 2a

Focal Firm	Enterprise Architecture	*Revenue* growth during *Intra*-Species Competition	*Revenue* growth during *Inter*-Species Competition
US Steel	**Modular**	**1902 - 1969 CAGR = 3.7%**	**1970 – 2008 CAGR = 4.3 %**
Bethlehem Steel	**Modular**	**1916 – 1969 CAGR = 5.0 %**	**1979 – 2002 CAGR = 0.6%**
Nucor	**Integral**		**1970 – 2008 CAGR = 17.6%**

4.1.3.2 Proposition 2b: Quality of Firm Performance

The second of Piepenbrock's propositions about firm performance relates to the *quality* of firm performance:

Proposition 2b: When competing modular and integral enterprise architectures are observed empirically, the focal firm of the modular enterprise architecture will tend to have lower longterm rates of profit growth, relative to the focal firm of the integral enterprise architecture.

Diverging somewhat from Piepenbrock, I use *Labor Productivity*, *Revenue per Employee* and *total no. of employees* as measures of the *quality* of firm performance. With the Steel industry being a labor-intensive industry, and the wage bill being a crucial determinant of profitability, these would be more appropriate metrics for measuring firm performance.

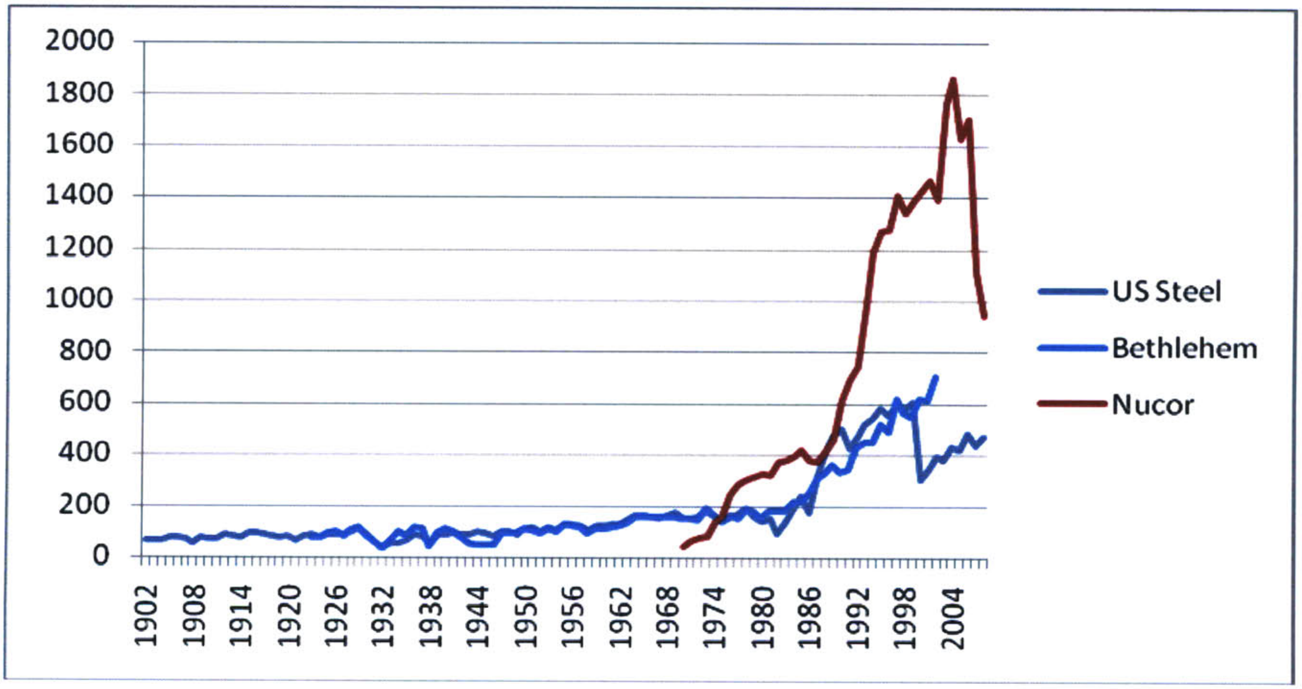

Figure 41: Labor Productivity (Tons per Employee)

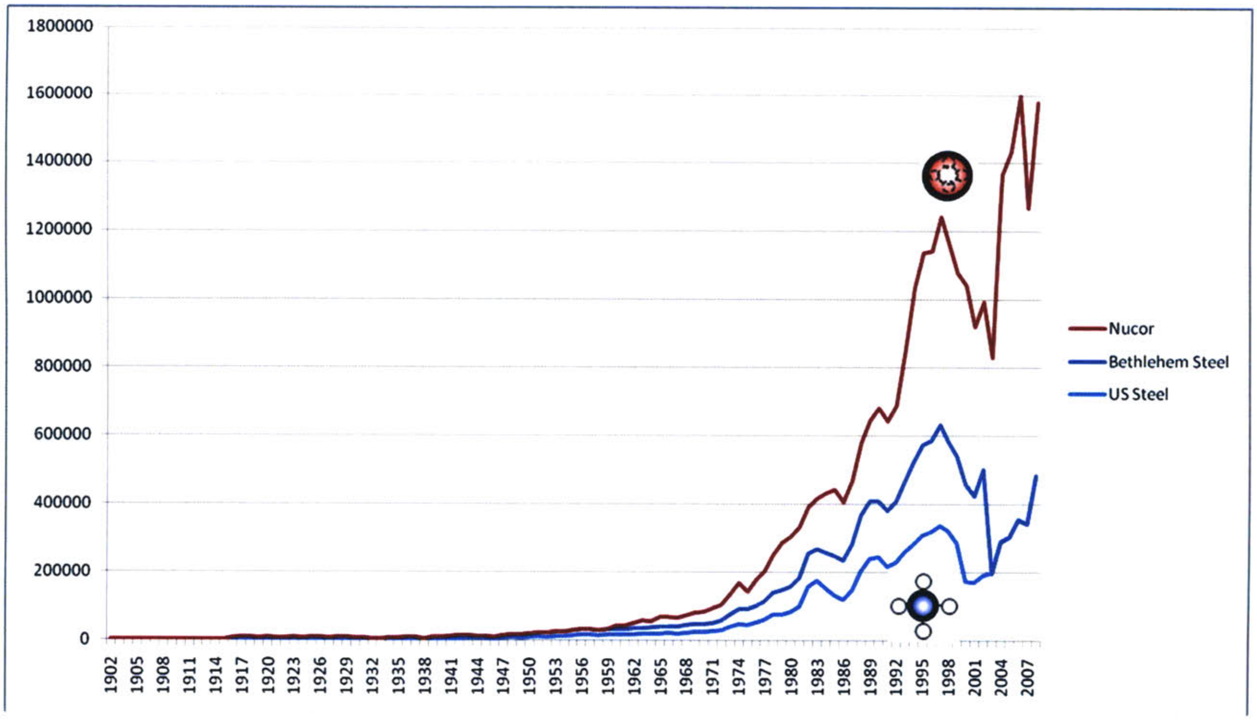

Figure 42: Revenue per Employee ($ per Employee)

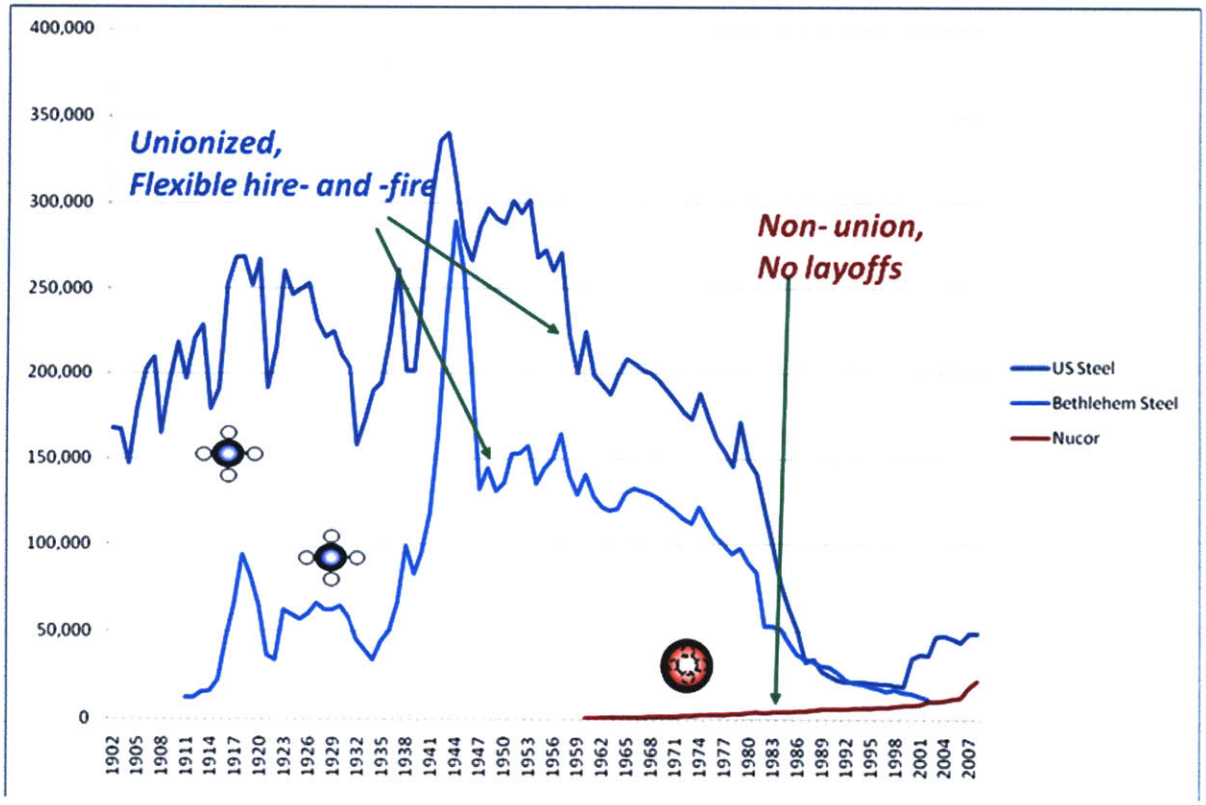

Figure 43: Employees (no. of)

The wide disparity between the incumbents and the challenger on all three measures appears to validate Piepenbrock's Proposition 2b on the quality of firm performance. Fig. 40 (Employees) also further underlines the difference in behavior exhibited by the two architectural forms.

4.1.4 Competitive *Retention*: Performance-Environment Relationship

Piepenbrock's third set of postulates relates firm performance to the *maturity of the environment.*

4.1.4.1 Proposition 3a: *Quantity* of Environment Growth

Proposition 3a: When considering the industry's rates of growth in customer demand, emerging industries, i.e. those that exhibit slow but increasing rates of quantity growth tend to be built by / reward integral enterprise architectures, which specialize in slow (equilibrium) behavior. Transitioning industries, i.e. those that exhibit high rates of quantity growth tend to be built by / reward modular enterprise architectures, which specialize in fast (opportunistic) behavior. Maturing industries, i.e. those that exhibit fast but decreasing rates of quantity growth tend to be built by / reward integral enterprise architectures, which specialize in slow (equilibrium) behavior.

Piepenbrock proposes the following structure for the co-evolution of Firm Performance (Quantity) and the environment:

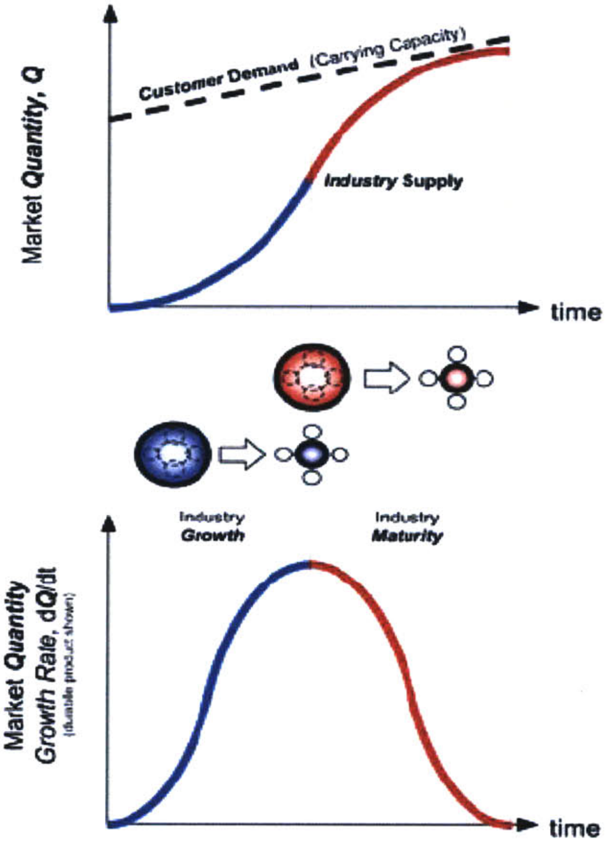

Figure 44: Co-Evolution of Firm Performance and Environment (Quantity), Source: Piepenbrock, 2009

In the context of the Steel industry, it is important to note that there is a wide divergence between the "carrying capacity" of the Global steel industry and the US Steel industry. This is primarily on account of the recent resurgence in global steel demand on account of rapid growth in China and India, markets to which, the US has limited access due to various factors. While the global steel market appeared to have reached its carrying capacity in the mid 1980s (*Fig. 45*), more recent data indicates a resurgence that might be the beginning of a second S-curve (*Fig. 46*).

In contrast, the US steel market reached saturation in the mid-1970s. This was followed by a period of decline until the mid-1990, primarily on account of the "dumping of cheap imports", first from Japan and then from China, and has been stagnant ever since.

The periods of growth, maturity and decline, corresponding to "*blue*" and "*red*" business environments, do however show an excellent correspondence with the entry/ exit of firms with the corresponding "modular" or "integral" architecture.

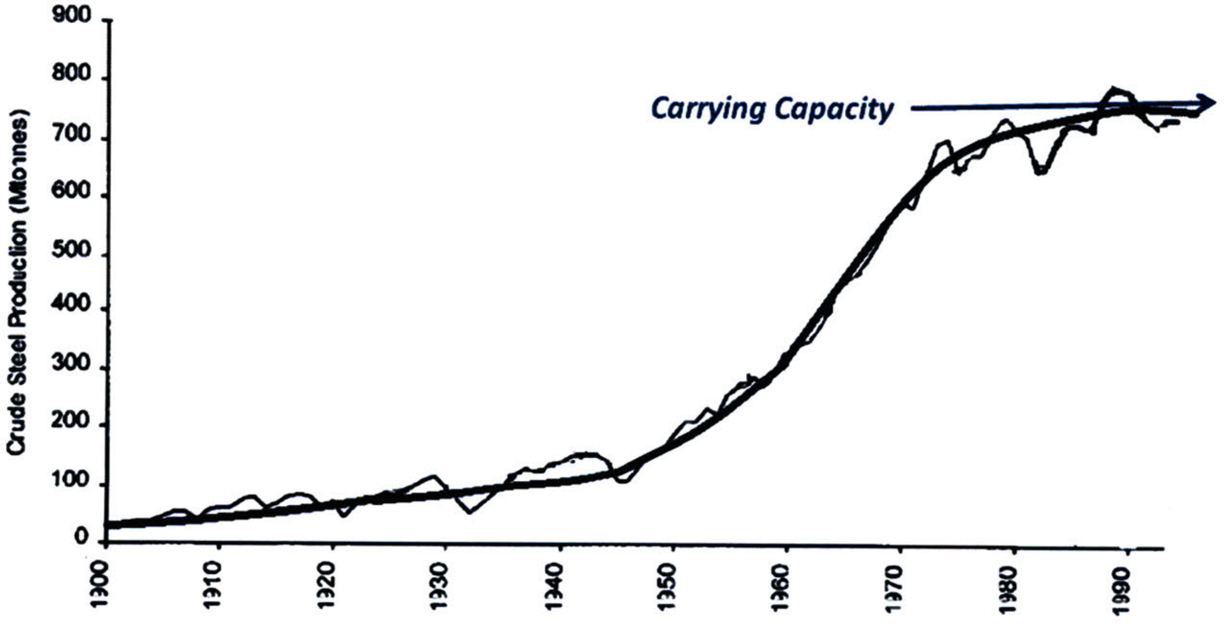

Figure 45: Global Steel Market Evolution (Quantity), 1900 – 1994

Note: The smooth black lines in figures 45 and 46 are schematic trend lines indicating the approximate means of the volumes produced in any given period.

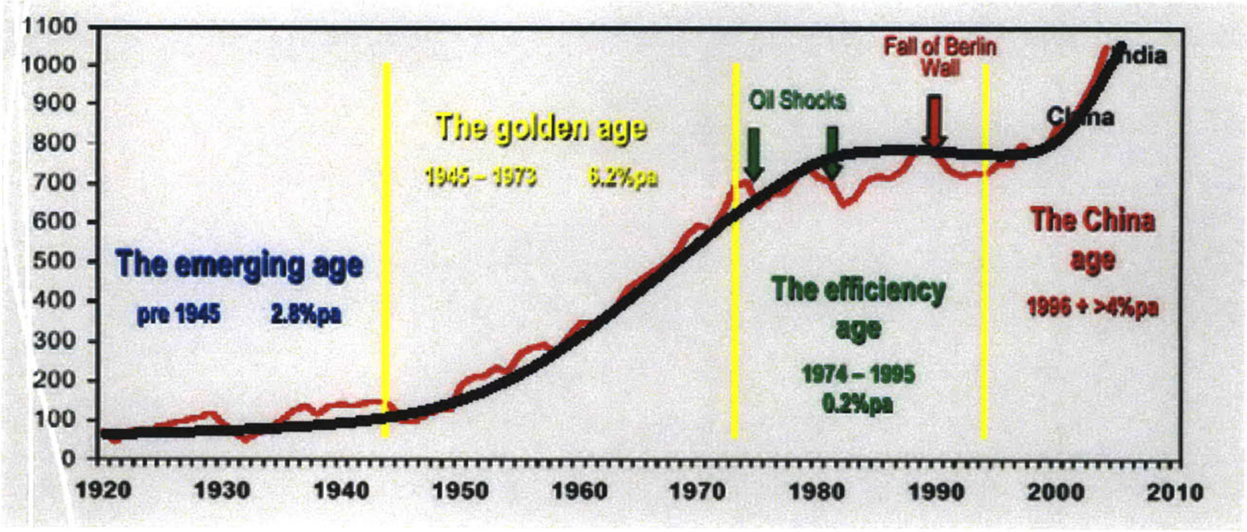

Figure 46: Global Steel Market Evolution (Quantity), 1920 -2007, Source: BHP Billiton

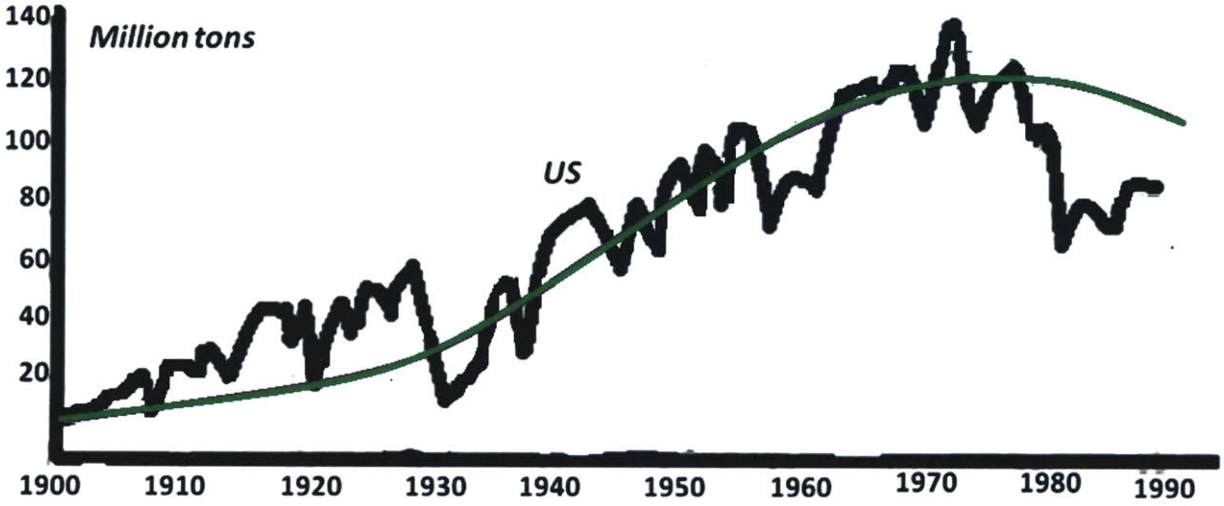

Figure 47: US Steel Market Evolution (Quantity), 1900 - 1994

Note: The smooth green line in the figure above is a schematic trend line indicating the approximate means of the volumes produced in any given period. A downward trend is apparently indicated towards the end of the graph. However, in the saturating *replacement* market into which the US steel market appears to be transforming, and given an average replacement period for steel products of around 50 years, the downtrend is likely to be temporary, with volumes stabilizing around an equilibrium volume in the long run. Actual *apparent consumption* and *domestic shipments* data in the period after 1994 (fig. 29) also appears to confirm this hypothesis.

The evolution of the US Steel market in the *quantity* space can be schematically represented as follows:

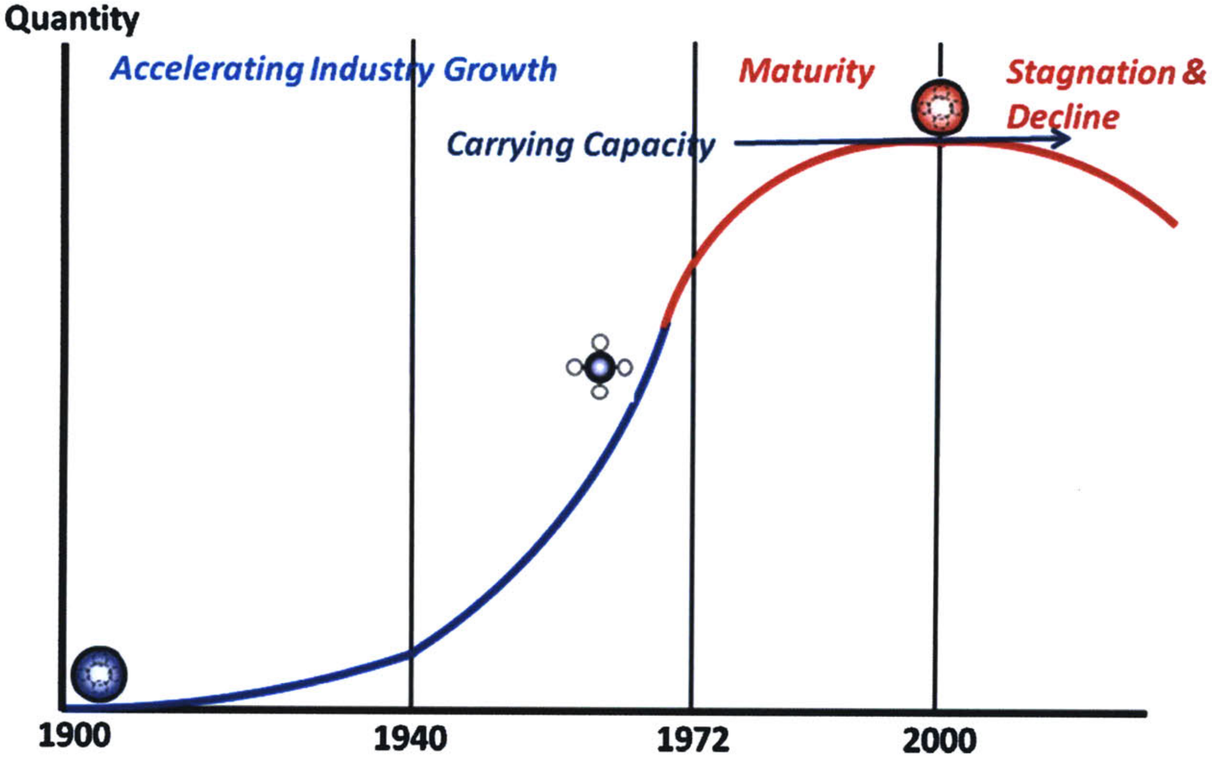

Figure 48: Schematic Representation of US Steel Market Evolution (Quantity)

It is noteworthy that the entry of ***Nucor*** corresponds almost exactly with the beginning of the maturity/ decline phase of the industry. The time of exit of the *blue* incumbent ***Bethlehem Steel*** also corresponds closely with what might be expected, per the *theory of evolution of business ecosystems.*

4.1.4.2 Proposition 3b: *Quality* of Environment Growth

Proposition 3b of the *Theory of Evolution of Business Ecosystems* relates firm growth in the *Quality* space with the business environment.

Proposition 3b: When considering the industry's rates of growth in technological innovation, emerging industries, i.e. those that exhibit slow but increasing rates of quality growth (i.e. under-served markets) tend to be built by and reward integral enterprise architectures, which specialize in radical product innovation (i.e. exploration). Transitioning industries, i.e. those that exhibit high rates of quality growth tend to be built by and reward modular enterprise architectures, which specialize in incremental product and process innovation (i.e. exploitation). Maturing industries, i.e. those that exhibit fast but decreasing rates of quality growth (i.e. over-served markets) tend to be built by and reward integral enterprise architectures, which specialize in radical process innovation (i.e. exploration).

Piepenbrock proposes the following structure for the co-evolution of firm performance in the *quality* space, with the business environment:

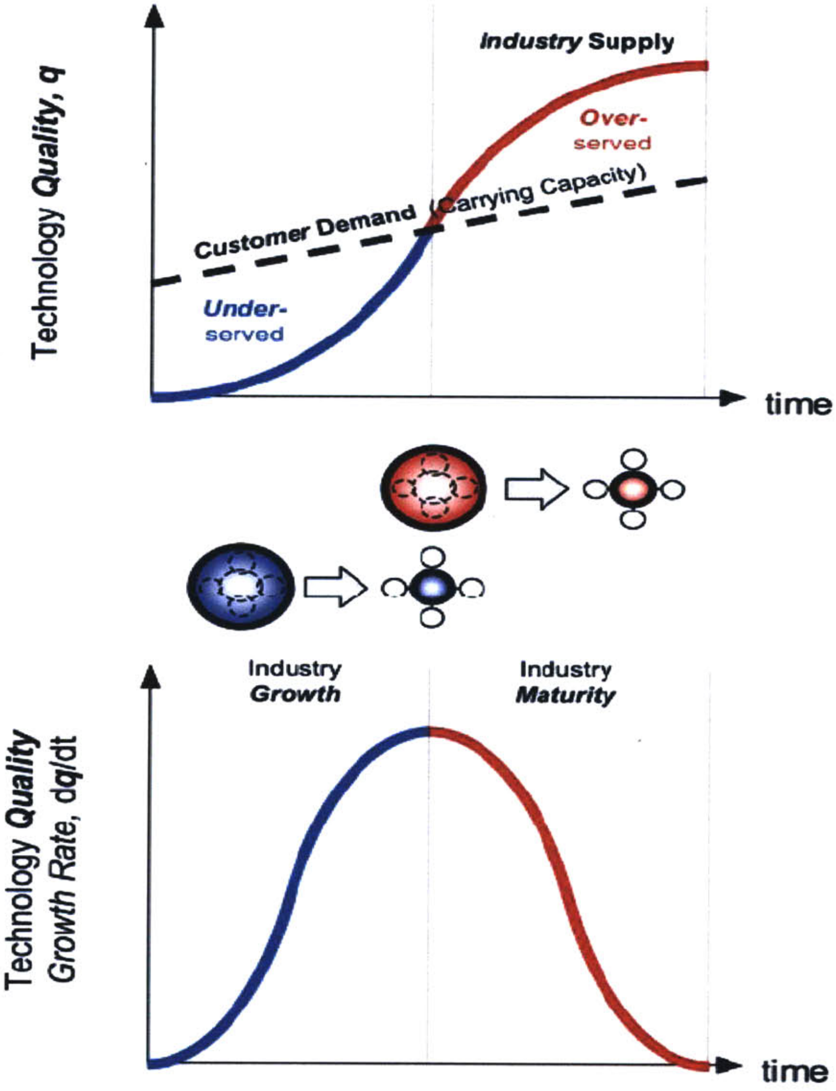

Figure 49: Co-Evolution of Firm Performance and Environment (Quality), Source: Piepenbrock, 2009

In the case of the steel industry, it is somewhat harder to establish the validity of this proposition, since the industry is, and has been for over a century, a *commodity* industry. Most of the most significant technological innovation since the invention of the Bessemer convertor (corresponding to the transition from *Craft* production to *Mass* production), has been in *Process* Technology rather than *Product* Technology.

However, innovation in process technology has coincided with improvements in the quality of steel produced and the capability to produce high grade steels. The quality of steel produced by the Open Hearth furnace was a significant improvement on the quality produced by the Bessemer convertor. The Open Hearth furnace also allowed better control over quality and the capability to produce relatively high grade alloy steels. However the quality produced by the Open Hearth furnace still suffered from defects like blow holes, segregation and poor surface quality. The advent of the Basic Oxygen Furnace and Continuous Casting in the late 1950s resulted in a vast improvement in steel quality and capability for producing high grade steels.

These technologies had achieved a high degree of penetration by the mid- 1970s, and the quality of steel produced was no longer a significant differentiator between firms. The focus on cost achieved high primacy during this period. This period also coincided with the advent of *Nucor* with its focus on mini-mill technology. Until the 1970s, mini-mill technology was a relatively unrefined and incapable of producing high grade steels or flat-rolled steel for use in consumer products. It was not considered a serious option or a threat by the "big steel" manufacturers. However, the mini-mills were capable to producing steel entirely from steel scrap, and afforded much greater process flexibility and agility. *Nucor* can therefore be seen as more of a *process* innovator that its predecessors. As mini-mill technology became progressively more refined in the 1980s, the "big steel" manufacturers were caught unawares and were gradually overtaken and displaced from their own turf.

The ability to produce steel from scrap proved crucial in the context of the *maturing* steel market in the US, as *RW Crandall* explains:

"The minimills of today have their genesis in the 1960s when demand growth slowed in the USA. As scrap prices fell relative to iron ore costs and as the costs of integrated steel companies began to rise in the wake of expensive labor agreements and their inability to build efficient, new plants, steel fabricators began to look for cheaper sources of steel, particularly for construction uses (Barnett and Crandall, 1986). Florida Steel and Nucor, in particular, began to build small, electric furnace plants to produce bar products. By 1970, the minimill revolution was underway..."

"As long as steel demand is growing rapidly, the supply of obsolete scrap is likely to be small relative to current demand for metallic inputs to steel furnaces. But if steel demand slows, as it has since the late 1970s, the return of obsolete scrap grows relative to metallics requirements. As a result, scrap prices fall and compete more intensively with the pig iron produced by blast furnaces, depressing steel prices and integrated steelmaker profits. This effect has been magnified by the rush of new capacity to the market in the 1970s in Europe, Japan and even North America. Integrated steel companies reacted to the superheated market of the early 1970s, when steel spot prices rose astronomically, by expanding capacity at existing plants and building new ones."[35]

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[35] Crandall, Robert W., 1996, "*From competitiveness to competition : The threat of minimills to large national steel companies*"

The following schematic clarifies the relationship between product quality and the transition between enterprise architectures:

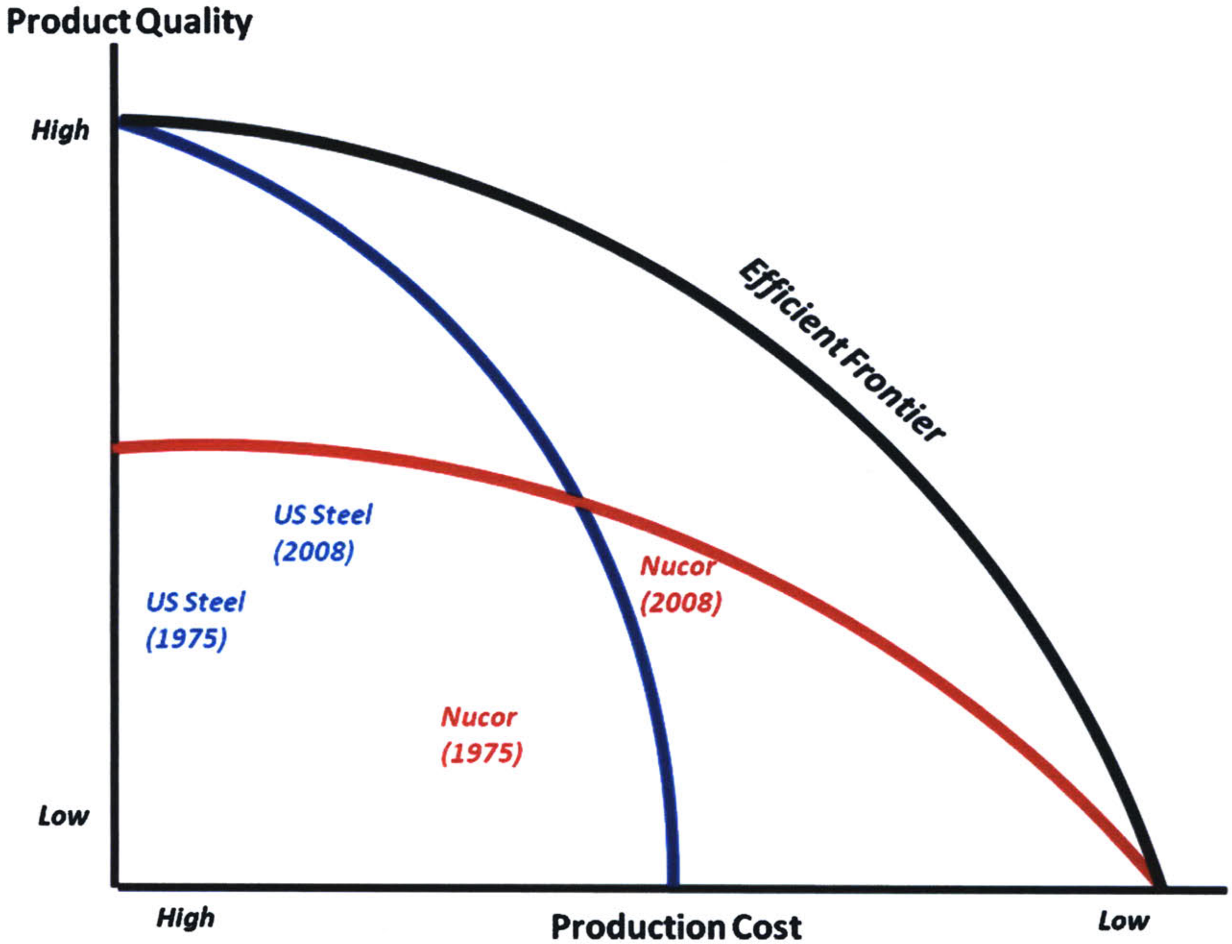

Figure 50: Product Quality vs. Cost of competing Enterprise architectures

In the light of the above, Proposition 3b appears to be validated in the steel industry.

Mini-mill technology is an example of *Disruptive innovation* in process technology, displaying typical characteristics of *Low-end disruption*[36] . Characteristically, minimills started out as a relatively unrefined, but low-cost technology, but through progressive innovations, were able to upstage their established counterparts in quality, while retaining the low-cost structure.

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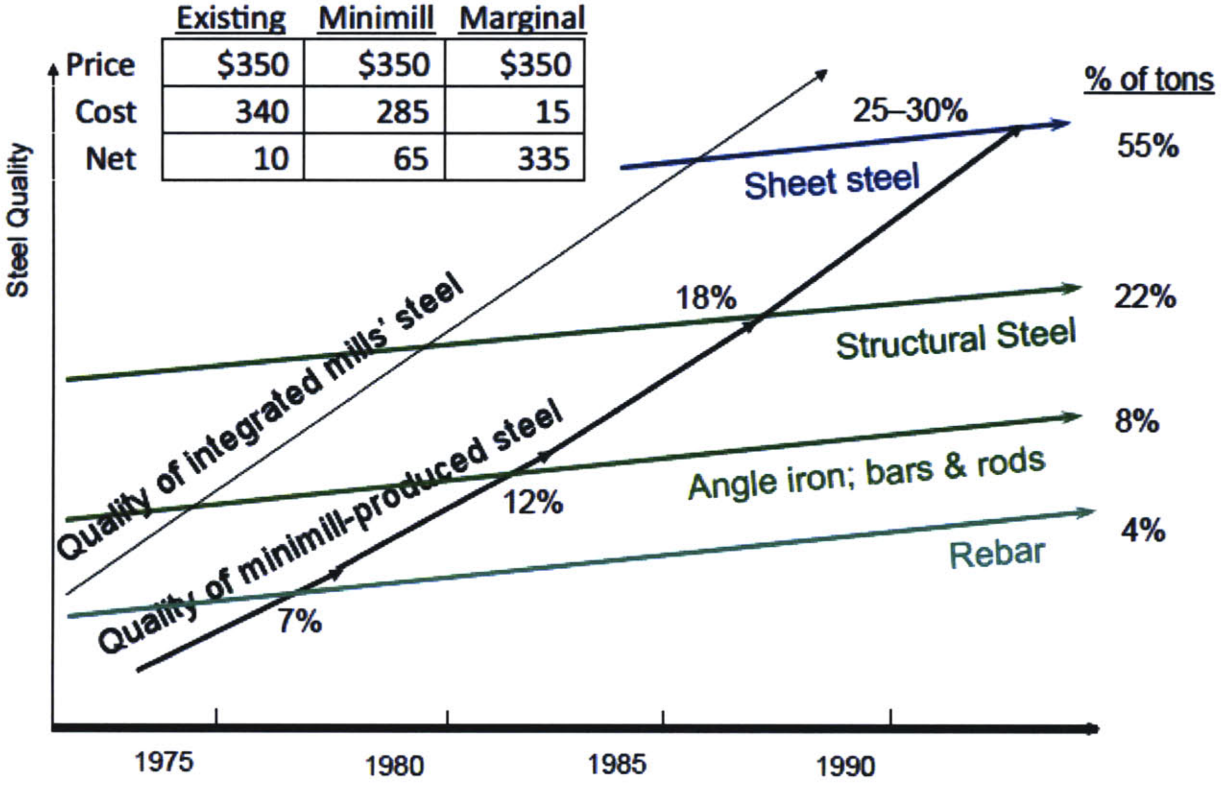
[36] Christenson Clayton M., Raynor Michael E., 2003, "*The Innovator's Solution*"

Christenson explains the disruption of Integrated Steel Mills by Minimills in the schematic below:



	Existing	Minimill	Marginal
Price	$350	$350	$350
Cost	340	285	15
Net	10	65	335

Figure 51: Minimills Disruptive Innovation, Source: Clayton M Christenson, MIT Lecture Series, 2008

Minimill technology quality is seen to lag the quality of integrated steel mills for all products, but eventually matches that of integrated mills for all products, including the largest market segment, Sheet Steel.

4.1.5 Environmental *Variation*: Environment-Architecture Relationship

In his fourth set of postulates, Piepenbrock relates the emergence of *dominant designs* and the *entry/ exit of Enterprise Architectures* with the evolution of the business ecosystem.

4.1.5.1 Proposition 4a: *Dominant Designs* in Enterprise Architectures

Proposition 4a: Dominant designs in enterprise architectures at the ecosystem level tend to oscillate between integral and modular states throughout the lifecycle of the industry.

Piepenbrock proposes, and validates the following structure of Enterprise architecture dominance over the industry lifecycle:

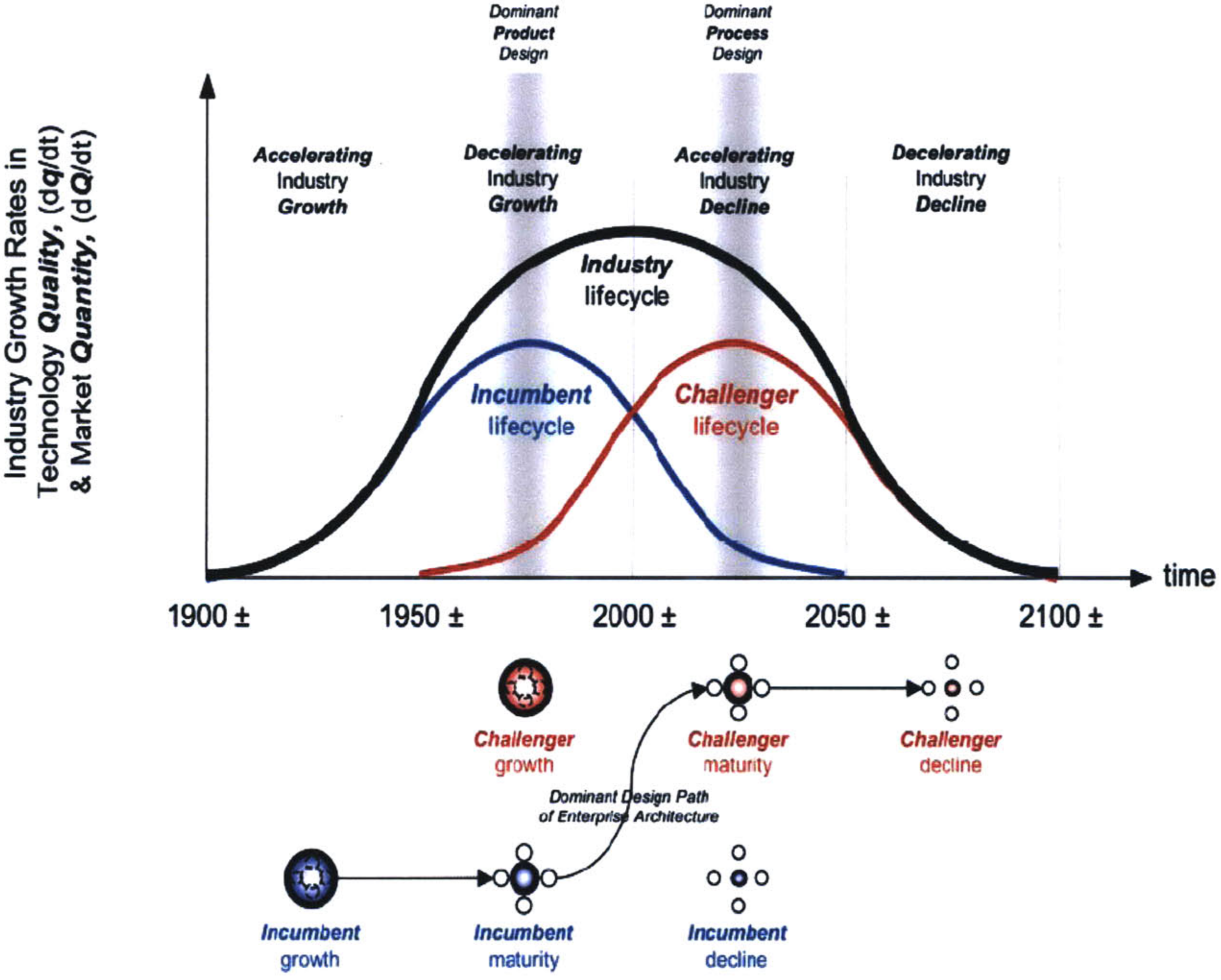


Figure 52: Stylized Co-Evolution of Enterprises and Ecosystem, Source: Piepenbrock, 2009

The firms under study in the steel industry can be seen to undergo the above architectural transitions in the expected sequence, with the evolution of the steel industry ecosystem. Both *US Steel* and *Bethlehem* started out integral in the late 19th century. The increasing size and scale of operations in the early 20th century saw an ever-increasing distance between headquarters and individual plants, between management and labor and between the firm and its investors. The first major labor strike in the 1920s was a manifestation of this increasing distance, and the transition to a modular enterprise architecture.

Nucor entered the industry in the late 1960s with a distinctly integral enterprise architecture, which has persisted to the present time.

The integral architectural form of *Nucor* can be discerned from the core values *practiced* by the company:

Core Values *practiced* by *Nucor*[37]:

- *Treating employees fairly and with respect*
- *Employees should feel confident that if they do their job properly, they will have their job tomorrow*
- *Humility, specially within management*
- *Management Belief that "spontaneous order" will produce superior results compared to "controlled order"*
- *Trust among employees and within employees and management*
- *Intellectual honesty*
- *Continuous Improvement*
- *Openness*
- *Freedom to make mistakes as long as you learn from them*
- *Flat management structure, streamlined chain of command*
- *Employees should have the opportunity to earn according to their productivity*
- *Employees should expect a safe work environment*
- *Uncompromising quality, responsive service and competitive pricing*
- *Integrity in pricing*
- *Simplicity*

Schematically, the architecture transition epochs in the US Steel industry can be represented as below:

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[37] Bill Nobles and Judy Redpath, 1995, "*Market-based Management- A key to Nucor's success*"

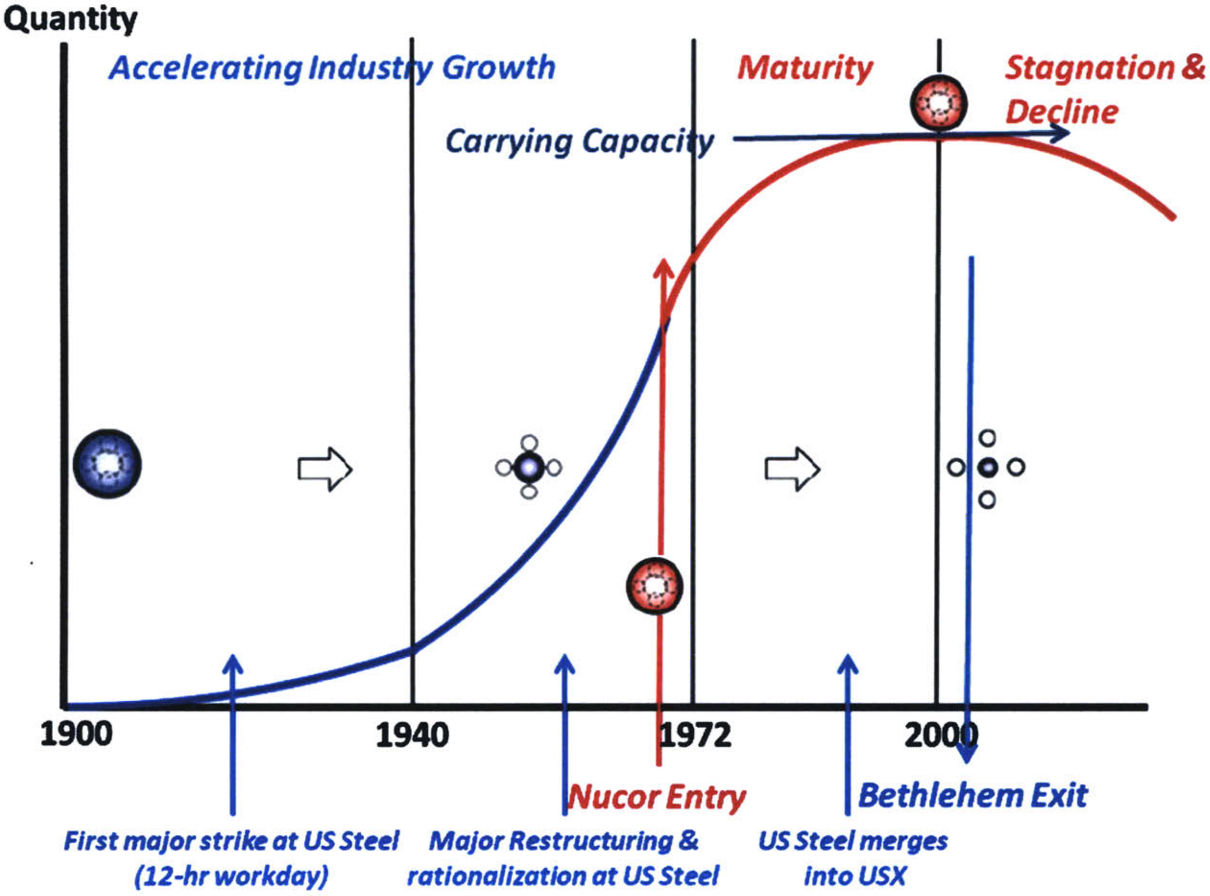


Figure 53: Schematic representation of architectural transitions in the steel industry

4.1.5.2 Proposition 4b: *Entry and Exit* of Enterprise Architectures

This proposition relates the maturity of the business environment with the entry and exit of dominant enterprise architectures.

Proposition 4b: Early entrant (incumbent) enterprise architectures tend toward monotonic disintegration, with increasing levels of architectural inertia inhibiting their reintegration. Thus it is easier for the environment to produce a new species of late entrant (challenger) enterprise architectures.

Qualitative data tabulated below reveals a pattern of architectural inertia that prevented the modular incumbents from re-integrating to adapt to the changed business environment in the 1970s:

Table 5: Summary of Qualitative data supporting Proposition 4b

Firm	Quotation/ Anecdote with Source
US Steel (Modular)	*There were not only too many plants, widely scattered, but there were also divisions and often disagreements between a* ***distant, finance-dominated headquarters*** *and a system of production units made up of formerly independent companies and of product divisions, resulting in a rather* ***clumsy corporate structure****."* *-Kenneth Warren , Big Steel, The first century of the United States Steel Corporation* *From Carnegie forward, American steel companies had designed each of their plants to function as a single operation; from ore refinement to blast furnace to casting, steel manufacturing was one integrated operation. As such, Big Steel in its heyday made big profits. Until those big profits became a big draw for every looter who could somehow get his hands into the till of the American steel companies--and until the U.S. government sanctioned that looting, putting itself first in what would become a long line of thieves.* - Steven Brockerman, 2006, "*Ken Iverson: Man of Steel, Part II*"
Bethlehem (Modular)	"*The characteristic that each department had in common was that they were* ***fiefdoms****, going way back. The turf was inviolable and prizes did not go for objective intelligence or academic training. Rarely were promotions based on merit*" *- John F. Heinz, former Bethlehem employee*
Nucor (Integral)	*"Only four layers of management exist: Chairman, Vice Chairman and President; Vice President-General Manager; Department Managers; supervisor/Professional; and hourly employees. Only 22 employees eight managers and 14 administrative employees work in the corporate headquarters. Senior executives do not have company cars, dining rooms, executive parking spaces or corporate jets. Everyone from the janitors to the CEO has the same basic but generous benefits plan".* -Gregory P. Smith, *"How Nucor rewards Performance and Productivity", 2001* *"We call what we do "Nucorizing" — we say, "listen guys, we have two choices. You can deal with this issue by working together as a team or we can centralize this back at corporate. Which way do you want it?" With the entrepreneurial type of people we hire, you know what the answer is"* -Dan Dimicco, Chairman of *Nucor Corporation*

The above data, while not conclusive, certainly appears to validate Proposition 4b.

Piepenbrock proposes the following schematic conceptualization of the entry and exit of incumbent and challenger species:

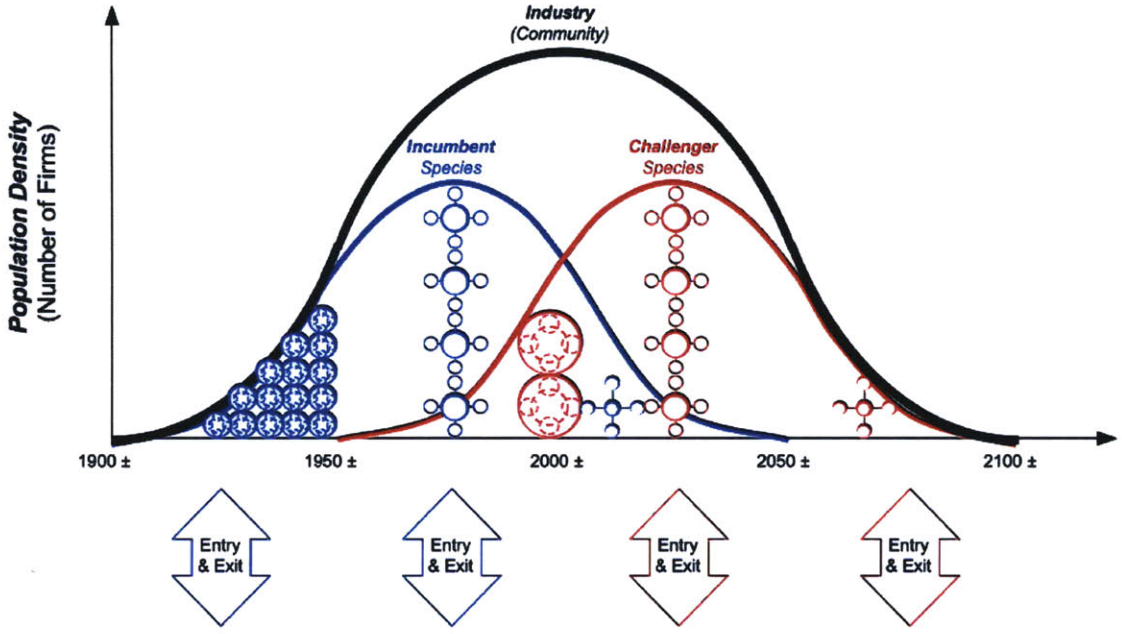


Figure 54: Entry/ Exit of Enterprise architectures, Source: Piepenbrock, 2009

This appears to correspond closely with the actual observed dates of entry and exit of incumbent and challenger species in the steel industry, schematically conceptualized below (future projections are based on anticipated limits to growth on account of carrying capacity of the earth, as well as the possibility of substitution/ obsolescence):

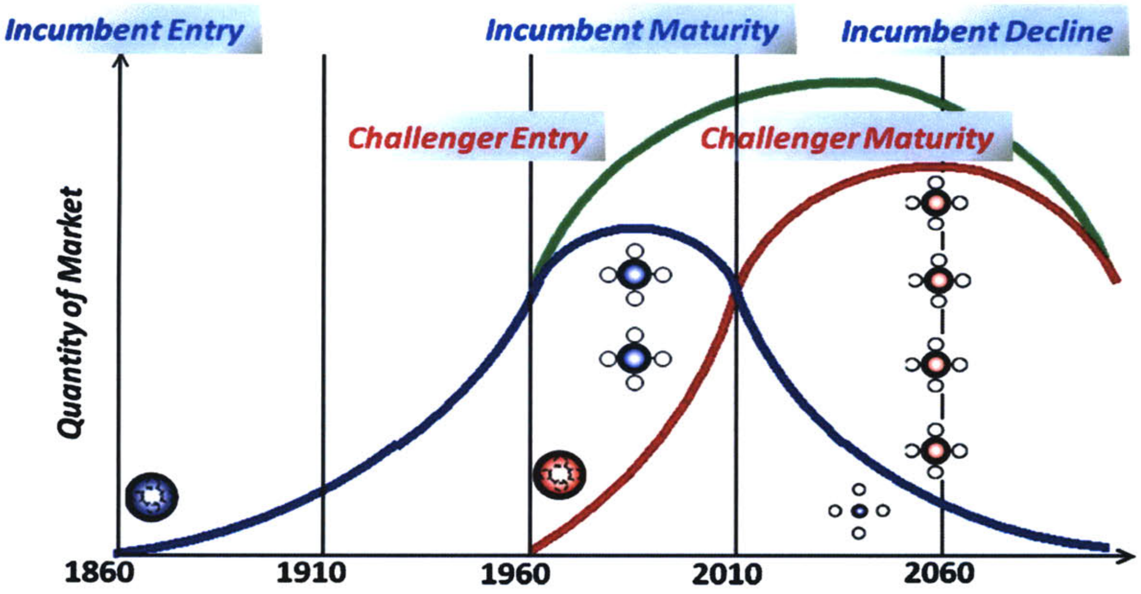


Figure 55: Evolution of Species in the steel industry: Schematic visualization

4.2 Formal Model Validation and Extensions

While the general propositions of the theory of evolution of business ecosystems are seen to be validated by qualitative and quantitative data from the steel industry, it is also useful to examine the degree of correspondence between the steel industry data and the simulation results of Piepenbrock's System Dynamics model. As is revealed in the above analysis, of the different *types* of markets modeled by Piepenbrock, the steel market conforms to the classification of a "*diffusing*, *commoditizing* market", with the possible difference that the *commoditization rate* for the steel industry is higher than that of the cases simulated by Piepenbrock.

Piepenbrock proposes the following model structure for comparing *diffusion* and *commoditization* rates in a given industry/ business environment:

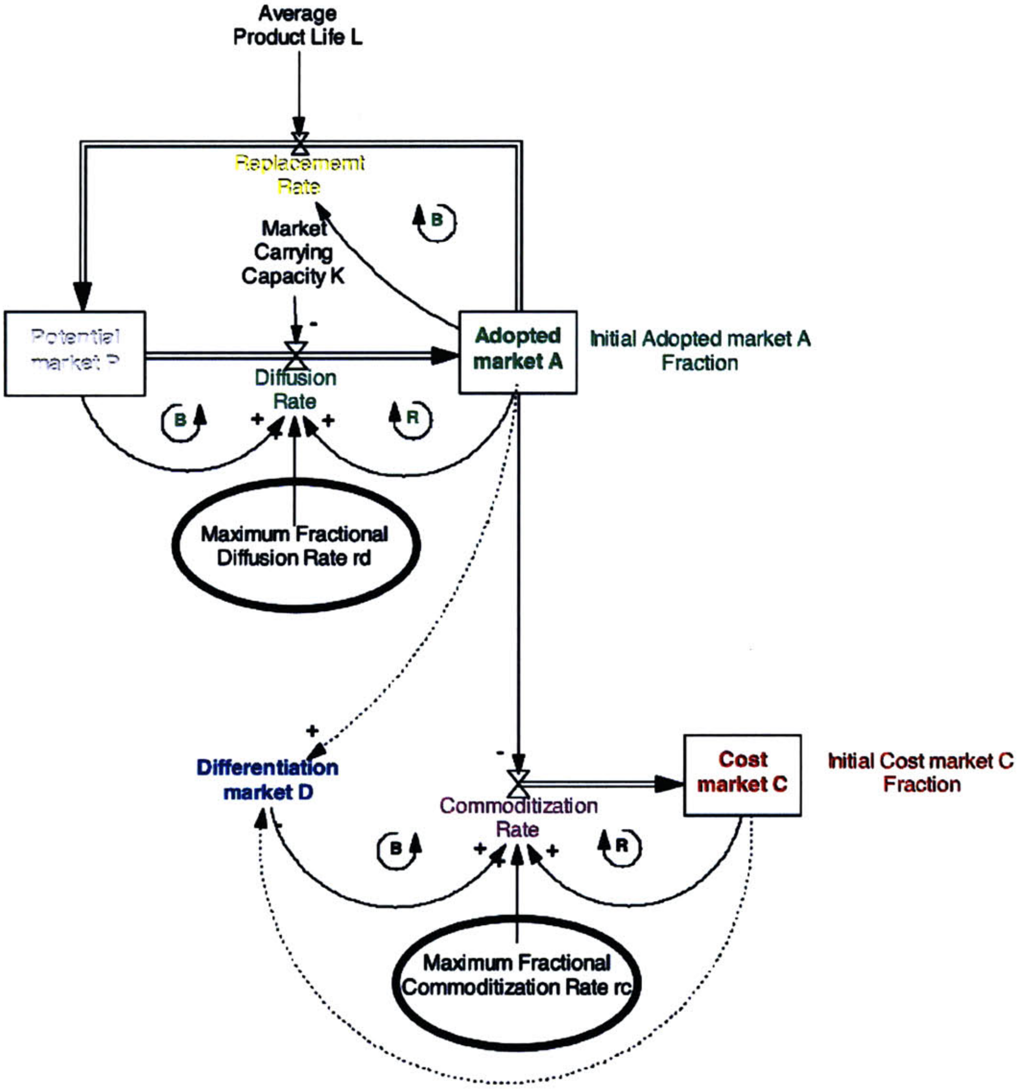


Figure 56: Model structure comparing market *Diffusion* vs. *Commoditization* rates, Source: Piepenbrock, 2009

Simulating this model structure for a control *diffusion rate* with 3 different *commoditization rate* scenarios, ranging from low to high, Piepenbrock obtains the following simulation results:

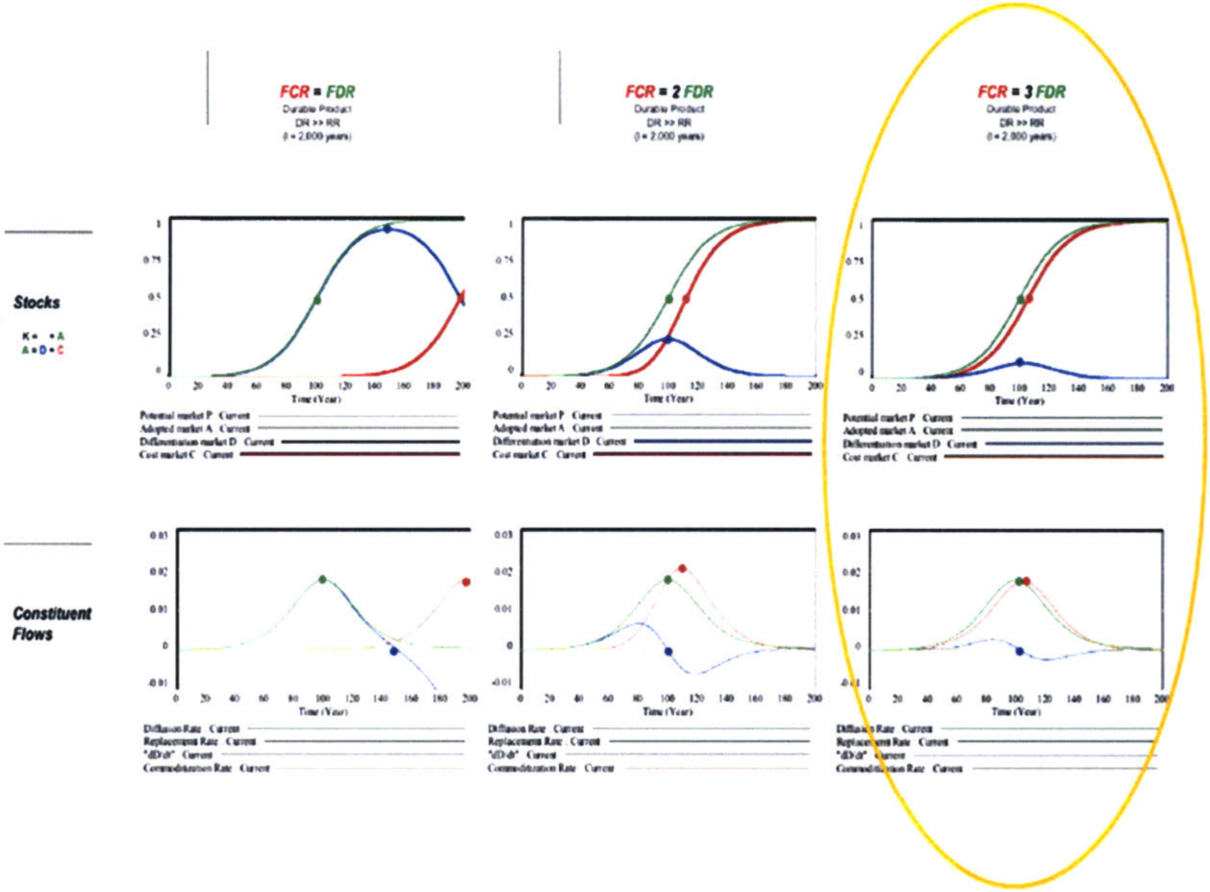


Figure 57: Dynamic behavior of *Diffusion* vs. *Commoditization* rates, Source: Piepenbrock, 2009

In the first scenario, which simulates a low *commoditization* rate, the *cost market* is seen to overtake the *differentiated market* very late in the industry lifecycle in around year 140, and the *differentiated market* is seen to dominate the major portion of the industry's lifecycle. In the middle scenario, a medium *commoditization* rate yields a *cost market* that overtakes the *differentiated market* in the middle of the industry lifecycle, and in volume terms, dominates the *differentiated market* over the course of the industry lifecycle. The last scenario simulates a high *commoditization* rate, where the *cost market* is seen to dominate almost the entire lifecycle of the industry, with the *commoditization* rate closely matching the *diffusion* rate.

It is clear that the last (high *commoditization* rate) scenario is the one that most closely matched the actual dynamics in the steel industry. A qualifier that might be added here is the fact that steel is not necessarily or uniformly a *durable* product, with some categories of steel qualifying as *consumables* or *replacement* products.

Further, simulating an *inter-species* competition scenario in a *diffusing*, *commoditizing* market, Piepenbrock proposes the following model structure:

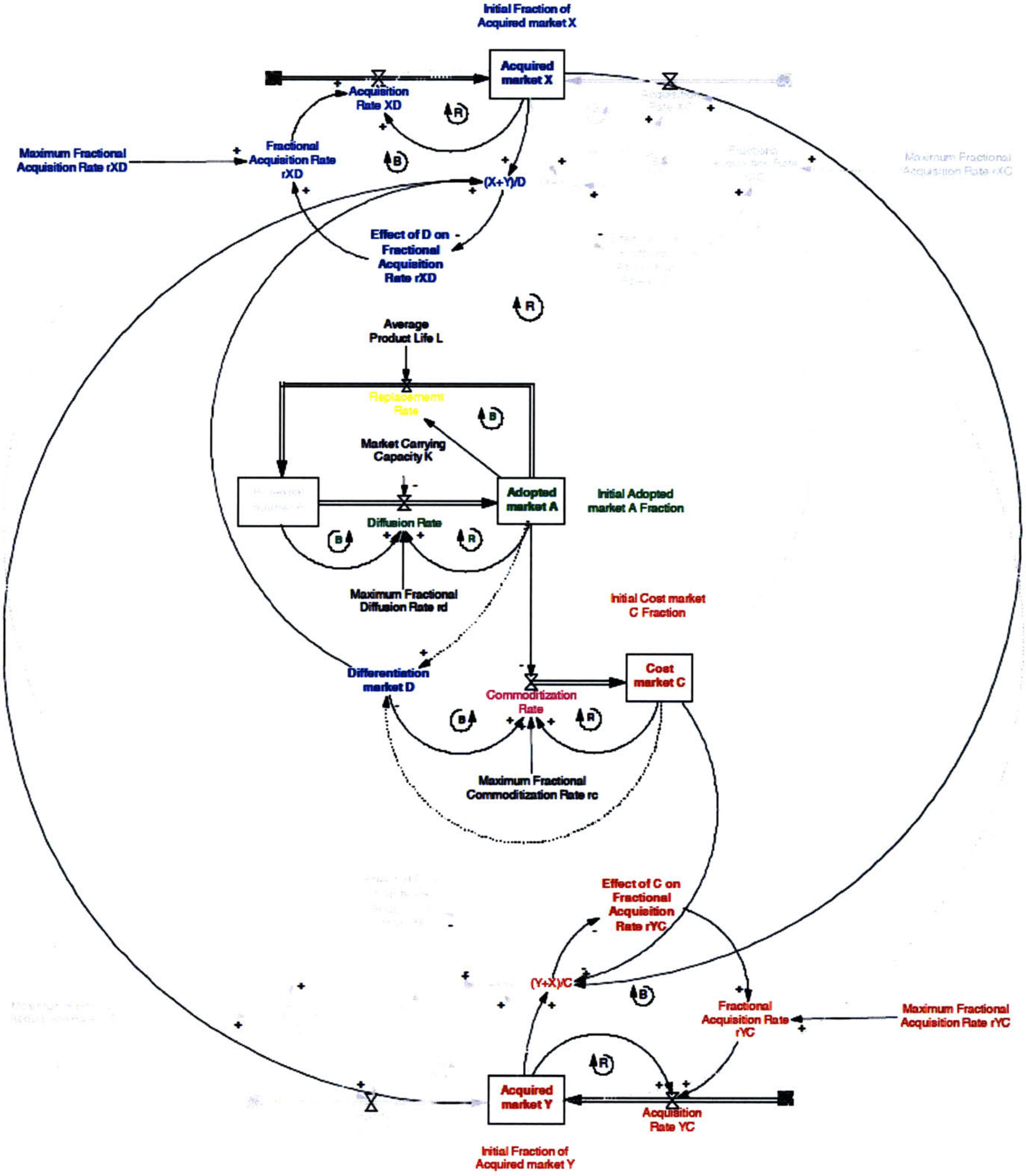


Figure 58: Model Structure of Inter-species "Competition" in a *Diffusing, Commoditizing* Market, Source: Piepenbrock, 2009

Of the many simulation runs performed by Piepenbrock on the above model, simulating different combinations of *diffusion* and *commoditization* rate scenarios for the incumbent and challenger *species*, the following appear to be the ones most relevant to the context of the steel industry:

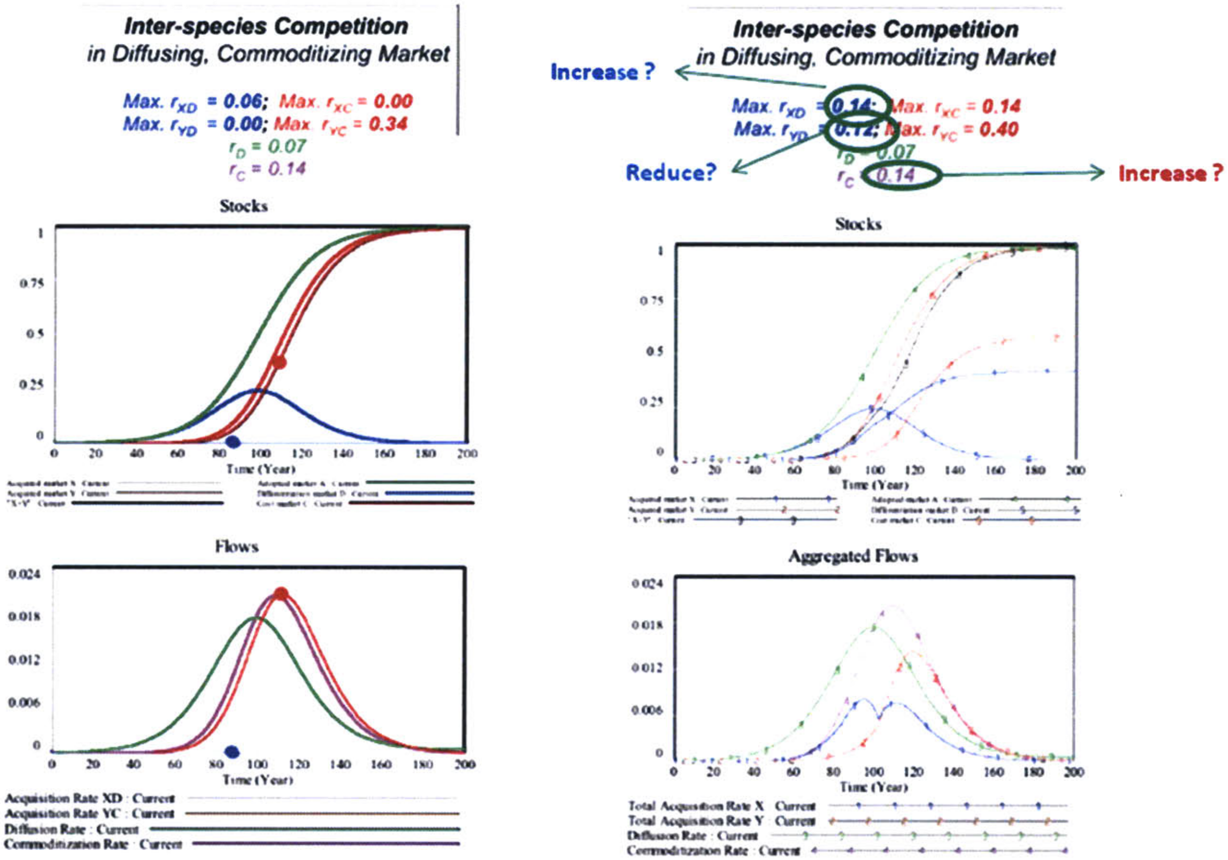


Figure 59: Dynamic Behavior of *Inter-species* Competition in a *Diffusing, Commoditizing* Market, Source: Piepenbrock, 2009

In both scenarios simulated above, the *commoditization* rate of the market as a whole is twice the *diffusion* rate. In the scenario on the left, the *incumbent* (X) species has limited capabilities in the *differentiated* market, and none at all in the *cost* market. On the other hand, the *challenger* (Y) species has no capabilities in the *differentiated* market but significant capabilities in the *cost* market. As a result, the *challenger* species is seen to dominate almost the entire lifecycle, with the *incumbent* making no headway at all.

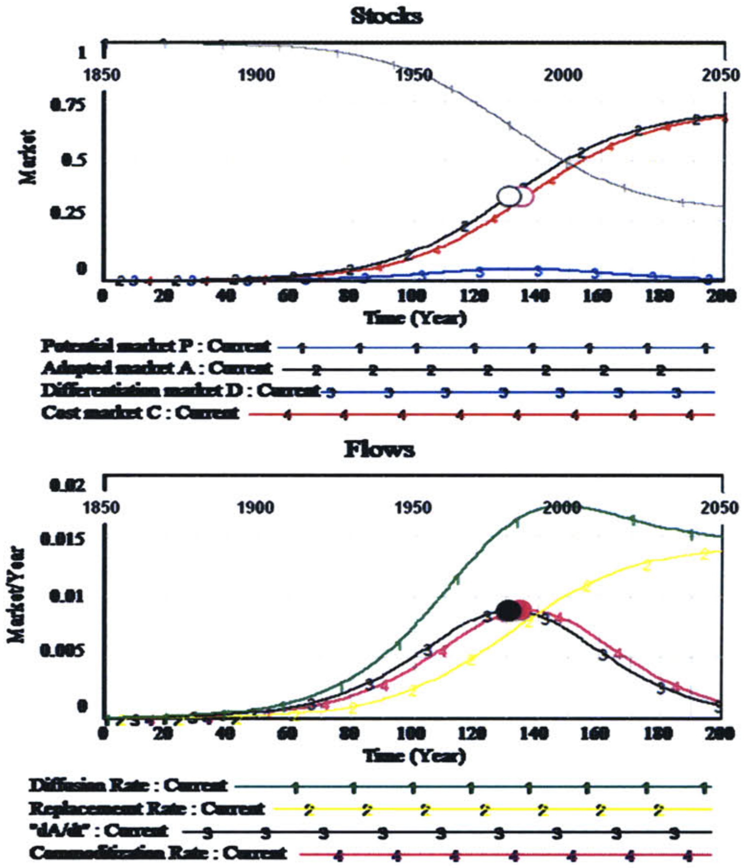
In the scenario on the right, the capabilities of the *challenger* species are marginally lower than those of the *incumbent* species in the *differentiated* market, but are significantly higher in the *cost* market. As a result, the *challenger* species is seen to overtake the *incumbent* species in around the 120th year of the industry lifecycle (assumed to last a total of 200 years).

If we look at the data from the steel industry, assuming the industry lifecycle to start in the late 1800s with the invention and subsequent diffusion of the Bessemer Convertor, we can see a very close correspondence between the steel industry and the second scenario simulated above. The early 21st century, corresponding to approximately 120 years of the industry lifecycle, was indeed the time when the challengers (*Nucor*/ *Arcelor Mittal*) overtook the incumbents (*US Steel*/ *Bethlehem*) in volume terms.

The actual dynamics of the steel industry can be visualized as being somewhere between the two scenarios above, although significantly closer to the second scenario than the first. The commoditization rate of the market itself is expected to be higher in the steel industry. Also, the capabilities of Nucor in the *differentiated* market in its early years (the 1970s), were *significantly* lower than those of the *incumbents*, since the use of minimill technology did not afford it access to the premium *sheet steel* segment. In the *cost market*, however, its capabilities were *significantly* higher than those of the incumbents, giving it a significant advantage in that market. Hence, if the second simulation above uses a higher value of $\boldsymbol{r_C}$, a lower value of $\boldsymbol{r_{YD}}$, and a higher value of $\boldsymbol{r_{XD}}$, it can be expected to simulate the steel industry scenario with even greater accuracy.

Simulating the steel industry scenario for a value of $\boldsymbol{r_C}$ equal to three times the diffusion rate ($\boldsymbol{r_D} = 0.07$, $\boldsymbol{r_C} = 0.21$), and assuming the mean *replacement rate* of steel products to be 50 years (*semi-durable* product rather than *durable* product), we obtain the following simulation results for the dynamic behavior of *diffusion* and *commoditization* rates in the evolution of the business environment in the steel industry:

Note: In fig. 60 and fig. 61 below, the flows represent **change** *in growth rates rather than growth rates themselves, and the stocks represent accumulation of* **growth** *rather than cumulative production volumes. The adopted market is seen, in 200 years, to stabilize at around 70% of the initial potential market. This reflects the fact that the replacement market represents a significant fraction of the initial potential market. In the flows, the black line (dA/dt) represents the difference between the diffusion rate and the replacement rate.*



US Steel Industry

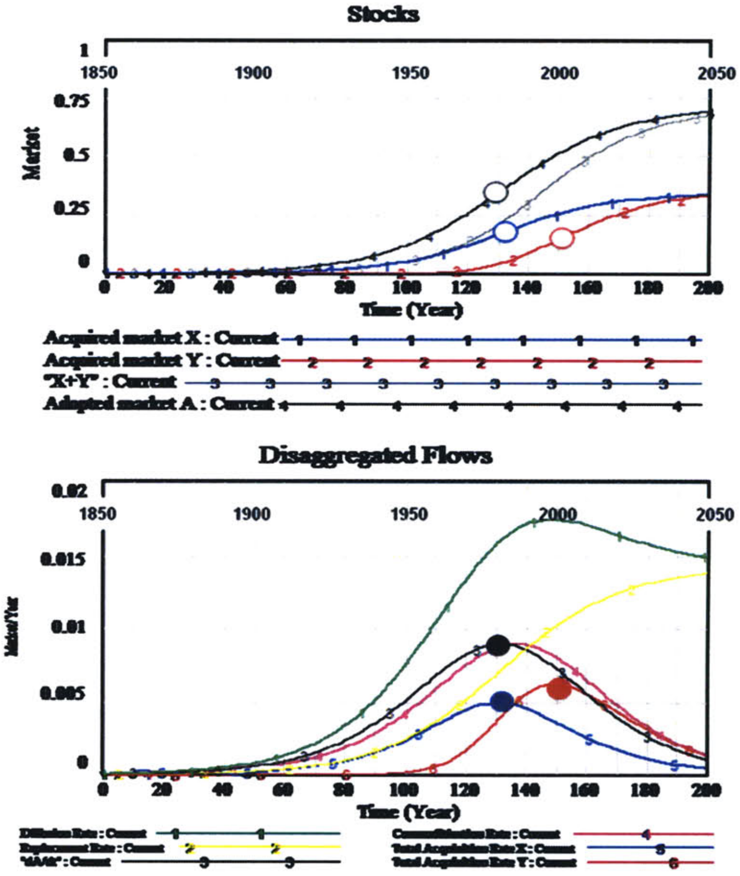
Market:
$r_d = 0.07$
L = 50 years
$r_c = 0.21$

Figure 60: Dynamic Behavior of *Diffusion* and *Commoditization* rates in the Steel industry

The correspondence between these results and the actual dynamics evidenced in the evolution of the steel industry is striking. The steel industry is seen to be a *cost market* since almost the very onset of the industry. This is indeed true, since the invention and rapid diffusion of the Bessemer convertor in the early 1850s led to cost being a primary source of competitive advantage in the steel industry, very early on in the industry lifecycle. *Commoditization* rates are seen to closely match the *diffusion* rates.

Both *diffusion* and *commoditization* rates are seen to peak in around year 130, and then taper off. Correspondingly, the early 1980s were the time when the US Steel market reached saturation, with *replacement* replacing *growth* as the primary dynamic. The early 1980s were also the time when *minimill technology* caught up with *integrated steel plant technology* in terms of quality, and *cost* and *process* capabilities decisively replaced *product quality* capabilities as a source of competitive advantage.

Further, simulating the model for *inter-species* competition dynamics, using conditions specific to the US steel industry, using a higher value of r_{XD} (0.6) and a lower value of r_{YD} (0.0), we obtain the following results:



US Steel Industry

Market:
$r_d = 0.07$
L = 50 years
$r_c = 0.21$

Interspecies Competition:
$r_{XD} = 0.6$; $r_{XC} = 0.1$
$r_{YD} = 0.0$; $r_{YC} = 0.3$

Figure 61: Dynamic Behavior of *Inter-Species* Competition in the Steel Industry

These simulation results can be seen to correspond very closely to the actual dynamics of *inter-species* competition in the steel industry. Volume growth for the *challenger* species is seen to commence in approximately the 120th year. This corresponds to the early 1970s, which saw the emergence of *Nucor*, and other process focused firms in the steel industry.

Also, the output growth of the *incumbent* species is seen to peak shortly after the 130th year (the early 1980s), after which they enter a period of decline. This is seen to correspond almost exactly to the actual data for both US Steel as well as Bethlehem Steel (Fig. 62 below):

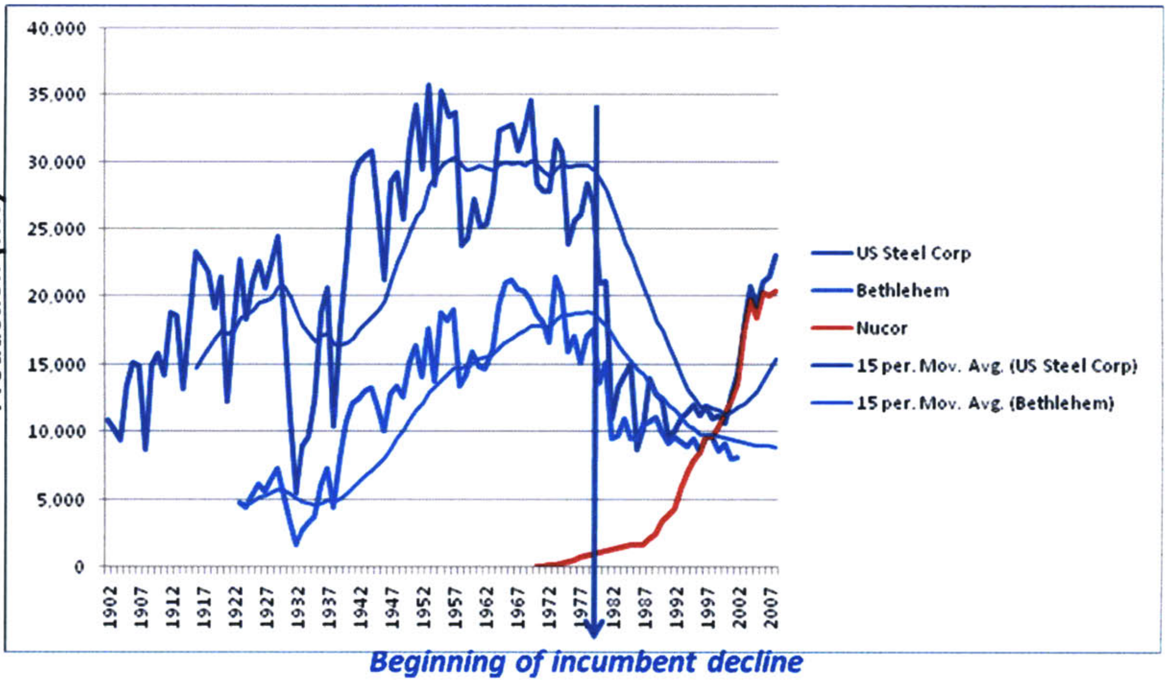


Figure 62: Production Output with trendlines

Based on the above analysis, it can be concluded that Piepenbrock's System Dynamics model is robust across industry types, and is able to model business environments and competitive dynamics across diverse industries, including commodity industries such as the steel industry, with a reasonably high degree of accuracy.

4.2.1 *Symbiotic* dynamic in the steel industry

While the adoption of minimill technology is seen as key factor that enabled the *integral* challengers in the steel industry to take over the market from the *modular* incumbents, it is clear that this factor alone is insufficient for them to retain competitive advantage over the incumbents.

Minimills enable the production of steel at a relatively low cost using more agile, flexible and customer-focused processes. However, minimills are crucially dependent on *scrap* as a raw material. The 1970s were an opportune time for the emergence of an industry based on the recycling of steel scrap, with over a century of accumulation of steel scrap, and a consumer society that discarded a large volume of steel products each year.

The dynamic of producing steel from scrap is self-limiting. The conceptual model below of the symbiotic dynamic in the steel industry clarifies this further:

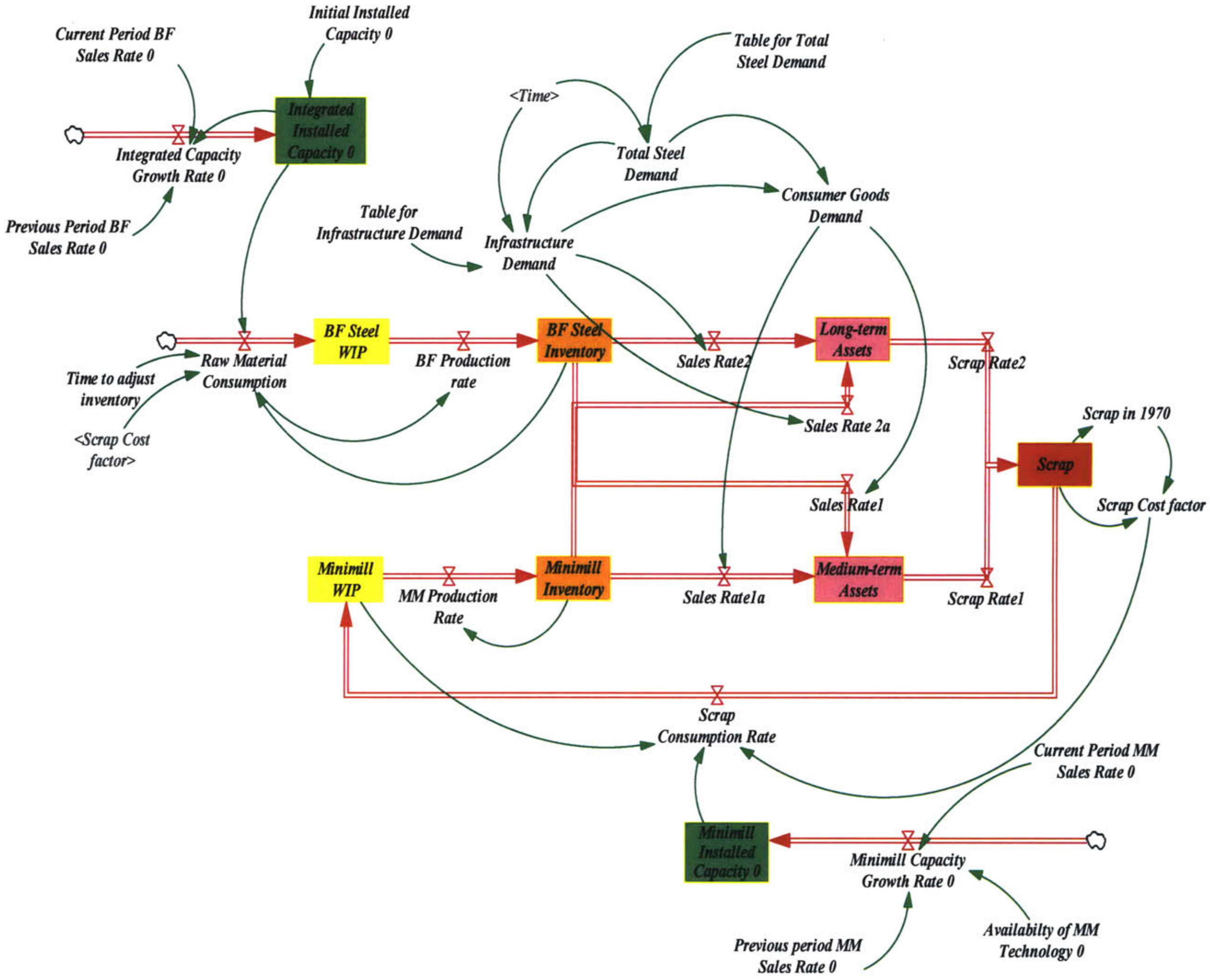


Figure 63: Conceptual model of the dynamic of interdependence and limits to growth in the steel industry

As can be seen from the conceptual model above, if minimill-based production were to entirely replace production through the traditional route, equilibrium will be reached only if annual consumption of steel is equal to or less than the annual generation of scrap. This can be visualized only in a structurally and critically stagnating or declining economy, or if steel is replaced by substitutes for most applications.

visualized only in a structurally and critically stagnating or declining economy, or if steel is replaced by substitutes for most applications.

In a normal, growing global economy however, scrap-based producers will always be critically dependant on the production of new steel from iron ore through the traditional route. This implies that barring a terminal collapse of the global economy, or a very significant substitution of steel with alternative materials, minimills will never entirely replace the traditional route.

Enterprise Architectures are fundamental firm characteristics that are largely independent of the structure of asset-ownership or technology. As is abundantly clear from Piepenbrock's doctoral dissertation, enterprise architectures emerge from much more fundamental aspects of a firms DNA than merely asset ownership, and are largely independent of the physical architecture of a firm or the degree of vertical integration of physical assets in the value chain. Hence this symbiotic dynamic need not have any implications for the *theory of evolution of business ecosystems* itself. However, it does suggest that in order to retain and sustain market dominance, the integral challengers in the steel industry such as *Nucor* would have to adopt/ acquire the technology and/ or assets of the firms they replaced.

5. Discussion and Conclusions

The intent of this thesis is to contribute to the building of a theory of evolution of business ecosystems by establishing the validity and robustness of the theory in a commodity industrial setting, specifically the US Steel industry from 1860 - 2010, in addition to the industries where its robustness has already been established in the original work (Piepenbrock, 2009). This thesis also seeks to explore possible extensions and refinements of the theory that could potentially further enhance its robustness across industries.

On the evidence of qualitative and longitudinal quantitative data, it is reasonably established that the US steel industry is currently in a mature stage, after having undergone over a century of evolutionary dynamics and transitions consistent with the expectation of the theory of evolution of business ecosystems. Comparative historical analyses were performed of the firms studied examining the evolution of their *form*, *function* and *fitness* with specific reference to their organizational architectures, their strategic choices in market quantity and technological quality, and the stage of maturity of the steel industry environment in the quantity and quality space.

This analysis reveals morphology of architectural forms, their periods of dominance and decline, as well as transitional epochs that are consistent with the theory of evolution of business ecosystems. Furthermore, each of the principal propositions of the theory is seen to be consistently supported by qualitative and quantitative data from the steel industry. Tracing the evolution of the firms from the 1860s to the present time, it is seen that the incumbents including *US Steel* and *Bethlehem Steel* started out as relatively small *integral* units in the late 19th century. Their high initial growth and expansion resulted in rapid *modularization* of enterprise architecture in the early 20th century, manifested in several ways including oscillating performance parameters, acrimonious labor relations, and rapid infusion of impatient capital.

Growth in the *product quality* space is seen to peak in the early 1970s, yielding a transition from *product* focus to *process* focus. Consistent with the theory of evolution of business ecosystems, this transition also coincides with the industry environment reaching maturity, and the entry of challenger *integral* architectures (*Nucor*/ *Mittal*). Qualitative data reveals the existence of unwieldy, inflexible and *sticky* structures in the enterprise architecture of the incumbent firms, with a consequent inability to adapt to the changed business environment.

Qualitative data from the *integral* challengers also reveals the application of proactive *architectural leadership* from the leaders of these firms, enabling them to exploit the conditions of the mature business environment to their advantage. Also, consistent with the expectation of the theory of evolution of business ecosystems, the *modular* incumbent architectures are seen to progressively *disintegrate* over time, prominently manifesting as the *merger* of *US Steel* into *USX* in the 1990s and the *bankruptcy* of *Bethlehem Steel* in 2002.

Owing to the wide convergence seen between the findings of this thesis and the evolution of business ecosystems, the theory can be said to be validated in the steel industry within reasonable constraints. The findings demonstrate the evolution of business ecosystems to be a robust theoretical framework that has broad explanatory power, makes reasonably accurate predictions and provides a robust and consistent explanation for systematic variation in performance over time of firms within the same industry.

Further, the degree of correspondence between the simulation results of Piepenbrock's System Dynamics model and the actual dynamics of the steel industry in also examined. The model formulation for *diffusing*, *commoditizing* markets is seen to be capable of simulating the dynamics specific to the steel industry, and commodity industries in general, with a reasonably high degree of accuracy.

Also discussed is the *symbiotic* dynamic specific to the steel industry, which might prevent the *current* challengers from completely replacing the members of the incumbent species.

5.1 Areas for future research

In his doctoral dissertation, Piepenbrock identifies some areas of future research, including validation of the theory using alternative methods including traditional quantitative statistical analysis, as well as exploring the validity of the theory in additional industries, particularly utilizing company pairs, the architectural form of which might be more ambiguous, or which might be closer to the center of the red/ blue spectrum. Firms in this category identified by Piepenbrock include IBM/ Dell, FedEx/ UPS, Walmart/ Costco and Hersheys/ Mars.

Additionally, further robustness can be added to the theory by exploring its validity in industry segments with non-traditional competitive dynamics, such as not-for-profit organizations, NGOs, public service organizations, real estate, research/ academic institutions or governmental organizational. Potential extensions of the theory include strategies for *architectural leadership*, *re-architecting* and overcoming *architectural inertia* and the effects of evolutionary *stasis*.

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