Chapter 4

Institutional, Technological, and Strategic Factors in the Global Integrated-Circuit Industry: The Persistence of Organizational Forms

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1 Introduction

Technological change and the globalization of industries are forces fundamentally reshaping relationships among countries. These twin forces also strongly influence the competitive environment in which firms are enmeshed and the role their strategies play in the evolution of economies and industries. Understanding the relational dynamics between technological change and globalization on the one hand and country-based institutional and firm-based strategic responses on the other can provide possible explanations as to why industries have evolved into the structures that exist today, as well as offer insights into how these structures will continue to evolve. In our study we observed recursive ebbs and flows between the technological and globalization factors that conditioned the developmental path of a country's economy, affected the industrial trajectory and competitive environment existing in the integrated-circuit industry, and influenced the survival of firms competing in that industry.

Globalization is made up of many forces—political, social, and economic, among others—that have spun a web of links between countries that is ever tightening. We begin by focusing on one of the forces pushing industries toward globalization. Because of the actions of managers attempting to make their firms more strategically competitive, technological innovation has become a key element driving the process of globalization. Attempts at becoming more competitive within a given national market by introducing new products and processes have resulted in making the two forces of technological innovation and globalization a self-reinforcing process that throughout this chapter we call techno-globalization (Methé, 1992b). The forces of technological change and globalization are inextricably linked. The critical mechanism linking technological change and the globalization of industries is found in the fact that the effort to gain competitive advantage from technological innovation requires substantial and increasing investments in terms of tangible resources, especially human and financial, and intangible resources as well as time. These investments in resources in turn require larger markets to recoup a return, driving firms beyond their own national market to compete in many countries' markets.

As noted, other complex factors separate from technological innovation are at work in the globalization process because as national markets industrialize and develop, the needs of consumers in those separate markets tend to converge and can be satisfied by more standardized products. We will discuss some of these factors below, but a full discussion of them is beyond the scope of this chapter. For now, it is important to recognize that although the degree of convergence varies from country to country because of differences in the macro-environmental and institutional conditions of each country, and the legacies these impart as economies develop and standards of living rise, the demand for various goods converges asymptotically on a global standard.

One outcome of techno-globalization, then, is at the product level. Greater standardization among product attributes is occurring in order to meet converging customer needs, allowing companies to amortize their increasing research and development resource allocations over these markets. Firm managers create organizational forms through the development of strategies. The strategies that are more effective and efficient in accomplishing the tasks associated with the techno-global process result in organizational forms that survive and grow. Over time, the evolutionary mechanisms of variation, selection, and retention are at work on the organizational forms operating in an industry. These mechanisms operate on many levels, and the selection and retention of successful organizational forms is accomplished according to many different criteria.

A key set of environmental selection criteria is applied to the product put forth by the firm. Product selection provides useful informational feedback as well as the necessary revenue for the firm to exist. As a result, another of the outcomes of techno-globalization at the product level is that it often impels firms to confront similar managerial issues concerning resource allocation, creating contexts in which they can adopt similar structures and strategic behaviors—in short, similar organizational forms. The products and applications of high-technology industries, especially the semiconductor industry generally and the integrated-circuit industry more specifically, are fairly standard around the world, and it is possible to talk about a global integrated-circuit industry and global markets for its products.[1] Consequently, if techno-global forces worked unimpeded over time in the semiconductor industry, it could be expected that similar organizational forms would eventually dominate the industry.

Variation has many sources in the broader semiconductor industry and the integrated-circuit industry. The technological innovation process itself is a variation-generating mechanism at both the product and firm levels. However, it can also be expected that the point of origin of a company in terms of the national economy it came from, as well as the timing of entry as the industry evolves along its trajectory of techno-globalization, introduces a set of institutional and strategic differences that modify and enrich the simple homogenization of organizational forms that would be expected from the techno-global forces at work in an industry. Consequently, the institutional environment of the country of origin and the strategic approach taken by firms within that environment at the time of entry into the integrated-circuit industry can introduce variations in the organizational forms that would come to dominate the industry.

The firm as an actor or agent operates in a multileveled macro-environment made up of the techno-global forces at work and the institutional arenas that are generated from the firm's country and time of origin. The strategic approach it selects to meet the challenges of this multileveled environment creates the firm's organizational form. We will return to this discussion in more detail in later sections. For now, it is important to recognize that the organizational form selected by managers at the time of entry and the adjustments in the strategic approach that result in alterations of the organizational form are then selected against by an evolving techno-global and institution-influenced competitive environment. The picture is further complicated because at times the techno-global and institutional forces may be acting in concert, each reinforcing the effects of the other, and at other times working against one another, thus mutating the direct influence of each.

Having discussed, albeit briefly, the techno-global aspect of economic and industrial evolution, we turn our attention to the institutional aspect and its influence on the evolutionary processes. We view institutions as the norms and rules that guide the behavior of individuals and organizations and form the basis for the laws, regulations, and political, economic, and social conventions and habits that govern a society and a national economy. Institutions run the gamut from very macro-societal structures, such as educational or political systems, to the very micro, such as the values and beliefs set inside an individual. They will further range from the tangible, such as codified laws mandating some type of behavior (how to patent an idea, for example), to the intangible, such as attitudes about risk and failure that exist in a societal and psychological milieu (see Methé, 2005, for a discussion of how risk attitudes affect the generation of entrepreneurial ventures in Japan).

Institutions are very firmly embedded in the context of a particular national setting and a particular time and determine the competitive topography of an industry by setting the "rules of the game" for how competition is played in a national economy. For example, companies entering the integrated-circuit industry at various times and from various national economies, as well as incumbent companies adjusting to the changes occurring in the integrated-circuit industry, are presented various options on how to configure their strategic use of resources. The selection they make is strongly influenced by the logic and perspective dominant at that time of how best to use strategic resources to respond to the forces acting on the industry.

These ideas of how a firm should compete, what strategic approach it should take, and how to array its resources to best enhance its chances for survival and growth, in short its organizational form, are often "recipes" or "rules," or, more colloquially, the conventional wisdom of an industry. We will examine the tug and pull of technological change and globalization versus national institutional factors in this chapter. We will also examine the role of a firm's strategy in adjusting to these two forces and its impact on the types of organizational forms in the integrated-circuit industry.

2 Institutions, Strategies, and Technology

2.1 Institutions

Institutions emerge from the interactions of various agents with one another. These agents can be either individuals or organizations, attempting to coexist and meet the challenges of everyday existence. Their rules of behavior are developed to facilitate these interactions. Over time the rules become institutions, or the accepted way of conducting activities, for the agents. Eventually the institutions take on "lives of their own" separate from the agents that generated them and thus become an outside force or factor that agents must contend with in order to carry out their daily activities. An environment is created where agents and institutions exist and interact. Human agents interacting may perceive institutions as "outside" their interaction and consequently constituting their environment, but these institutions are the result of these human interactions.

In examining institutional factors, we find it interesting that several meta-rules or norms can form the lattice on which a large variety of behavioral responses can be generated when individuals confront a situation. So from a simple set of a few rules, very complex behavioral patterns can emerge. An example from the integrated-circuit industry would be Moore's Law, a statement of how the number of transistors on a single silicon chip will increase over time. This simple statement provides guidance for a vast array of decisions concerning technology choices, human and financial resource allocation decisions, and the relationships between various actors in and around the integrated-circuit industry. To the cognoscenti, these meta-rules offer insight into the intricacies of the workings of the techno-global and institutional arenas, but they also can obfuscate because they offer no concrete sets of advice on how to select or adjust an organizational form strategically to those intricacies. Consequently there is as much "art" as "science" to the interpretation of these meta-rules, and experience is often a key ingredient to their proper interpretation.

Meta-rules can operate at the level of the individual, such as a belief that all humans are basically good. They can operate at the level of an organization, which is a collection of individuals operating with a common purpose or goal that they could not accomplish by themselves as individuals, such as a belief in wealth maximization for shareholders. They can operate at the level of an industry, usually a collection of organizations, with a belief, for example, that to service customers properly, vertical integration across the value chain is necessary. They can also operate at the level of a society, a collection of individuals and organizations, with a belief, for example, that democratic processes are good.

We are primarily interested in institutional frameworks or regimens operating at both the macro- and micro-levels; that is, both outside the individuals and organizations and within each.

These institutional frameworks operate at the macro-level of laws and regulations and the mechanisms to enforce them. The institutional frameworks operate inside individuals in the belief and value systems that are inculcated into them through the socialization process (Pascale, 1985). Organizations also exhibit value and belief systems that are often displayed in documents like vision or mission statements and manifest themselves in broader concepts such as "organizational culture," or "organizational ethos" (Sackmann, 1992; Smircich, 1983). This organizational culture, or ethos, is made up of important elements that are infused into the organizational form selected by managers.

In essence, institutional regimens or frameworks help individuals and organizations understand their identity—that is, who or what they are and where they fit into the overall scheme of life. These institutional frameworks also aid in understanding their purpose or their reason for being—simply put, their raison d'etre. The link between identity and purpose at the agent level and the institutional framework is crucial in understanding, for example, the roles that firms are legitimately expected to play and the different concepts of capitalism that exist (Hall and Soskice, 2001).

2.1.1 Strategic Behavior as a Link Between Institutions and Agents

We must draw a distinction between institutions and agents that will assist us in understanding how these two elements are linked. Quoting from Sackmann (1992), "What differentiates collective sense making or cultural cognitions from individual ones is that the former are commonly held by a group of people in a given organization even though members of the same cultural group may not be aware in their daily activities of what they hold in common. In the process of enculturation, cognitions become rooted in the group and ultimately exist independently of any individual group member, even though individuals are the carriers of culture (White, 1959)." Hence the differences observed to exist between the collective sense making of groups (and in this study we can mean groups writ large, such as whole countries) and the sense making of individuals put values, beliefs, conventions, and norms—that is, the elements of institutions—outside of and above individuals.

As noted, institutions are the broader rules that determine the framework within which agents operate. Also as noted, agents can be either individuals or organizations. The issue of which comes first, institutions or agents, is important to address because this linkage gets to the heart of the issue of institutional change. This study views this recursive relationship as one where agents are embedded in institutions, but are not passive (Dacin, Goodstein, and Scott, 2002; Hodgson, 1998). Agents thus embody the rules and norms of an institutional regime, but in reacting to environmental exigencies, they attempt to survive. Their survival may be in accordance with the "rules of the game" as laid out by the institutional regime in which they are embedded—that is, single-loop change. Or they may alter the rules of the institutional game—that is, engage in double-loop change. Over time, then, the institutions themselves can be changed.

At this juncture it may be helpful to draw an analogy between social systems and games (Aoki, 2001). The game of chess as played in the West has an institutional regimen. The rules concerning the movement of the pieces, even the number of pieces and their placement on the board, are given. How many players can play, the order of engagement, and how the endgame stage is reached and a winner determined are also part of the institutional regimen. The behaviors of the various players, agents in our terms, flow from the strategies of each player. This situation is the same for other board games, such as the game of go. The rules are there concerning the number of pieces and their placement, as well as the number of players, types of moves, and the endgame stage of winner determination. Agents, through the use of strategies, operationalize these rules.

2.1.2 Strategic Behavior as a Channel for Institutional Change

The two games are different in terms of the strategies and therefore the behaviors of the players. In chess, it is a good strategy to try to control the center of the board, whereas in go, it is a good strategy to control the edge of the board. For the agents playing these respective games, each understands the institutional framework and the underlying strategy to win the game. As long as each player stays within the same game, the behaviors make sense and the players can be quite creative and display a large variety of behaviors as exhibited in the combinations of moves. This is an example of single-loop change. Exhibiting creative and diverse behavior within the rules of the game in a way further reinforces the rules of the game.

If you understand the game you are playing, you understand the strategies you can employ. If, however, you think you are playing the game of chess when you are actually playing the game of go, you are at a serious disadvantage. Or suppose one player can alter the situation in some way so that the game being played morphs from chess to go. That agent is then engaging in double-loop change, that is, in behavior that attempts to "change the rules of the game" (Buaron, 1981; Foster, 1986; Mann, 1987). We borrow this idea of single-loop and double-loop from the work that Argyris (1976, 1992: 8−12) did on organizational learning and change.

Single-loop learning relates to the detection and correction of an error without bringing into question or altering the underlying values of the system. This type of change operates on one level of the system, similar to the functioning of a thermostat, and we term it homeostatic change, or single-loop change. Double-loop learning occurs when the underlying values of the system are examined and altered as part of the process of correcting an error. This type of learning brings about double-loop change, which occurs at more than one level of a system, and we term it heterodynamic change. The idea of types of change being bipolar also has a long history in the field of organization study (see one early example in Tushman et al., 1986; for an interesting review of change-related studies see Barnett and Carroll, 1995). We will revisit these issues related to bipolar types of change when we discuss technology and technological innovation.

The double-loop type of change often requires that deinstitutionalization occurs before a new institutional regimen can be put in place to replace the first (Dacin et al., 2002). The analogy of board games does break down here somewhat, because it is unlikely that chess players would suddenly start playing the game of go against their opponents. However, in economic, social, or political situations, it is possible to change the rules in certain circumstances. In fact, often the first key to success is determining the game that is being played and understanding when to play within the rules and when to exert force to change the rules. In such a case the debate may move up to a discussion of the rules, about how the rules of the game can be changed. Again we may find ourselves in a self-referential loop, with the institutionalization of rules on how to change them and so on, moving up some never-ending spiral.

This leads us to ask, what are the channels through which change is initiated and sustained? Are these channels outside the institutional framework, or are we forever caught in an ever-spiraling loop upward concerning rules of change? Agents are the conduits by which change is brought about. New laws, regulations, and ways of manufacturing, making decisions, distributing goods, and so on are not generated by the blind force of history, but by agents of change acting in conjunction with other forces or levers of change. Individuals or organizations, either alone or operating in alliances or coalitions, initiate and sustain change either in novel ways that support the rules or by changing the rules themselves.

Researchers have studied these other sources that exert pressure on institutions to change (Oliver, 1997). Three sources of institutional change have been identified: functional pressures resulting from performance gaps, political pressures resulting from shifts in interest or power distribution, and social pressures that emanate from the introduction of divergent or heterogeneous belief and value systems. One important way of characterizing an institutional regimen is the extent to which it tolerates deviation from its fundamental or core conventions. The extent to which it encourages or discourages variety generation is an important element in determining how well the institutional regimen can absorb and respond to the pressures exerted.

Another important way of characterizing an institutional regimen is the selection criteria that it puts in place for determining what is legitimate and what is not. Simply put, these criteria define what is appropriate and therefore encourages and retains behavior, and what is inappropriate and therefore discourages and extinguishes behavior. Consequently, the type (single-loop change or double-loop change), pacing, and amount of change are determined by the mechanisms put into place by an institutional regimen to foster variety and to select, from among those that created variety, that which is legitimate and hence to be retained, and that which is to be discarded (Campbell, 1965).

Why do institutional regimens need to create variety and select among alternatives? For two basic reasons: first, the limited information-processing capabilities of the human mind, and second, the fact that institutions are part of a larger environment. As for the first reason, Herbert Simon noted that human beings make decisions under the condition of bounded rationality. Our ability to comprehend our world and process information about its condition is limited by the cost of searching for that information and the availability of the information itself. We are often not fully aware of the characteristics of the problems we confront, the possible range of alternatives available, and the consequences of these alternatives. Often, we human beings operate in a state of ignorance because of the uncertainty surrounding our lives.

To clear up this "fog of uncertainty," we engage in search patterns to generate information that is then converted into solutions. We tend to limit our search for information because of the cost of that search, and as a result we tend to "satisfice" or accept, the first available alternative that meets some minimal level of evaluation criteria (Simon, 1991). This type of search often results in the exploitation of existing knowledge and ways of solving problems or confronting challenges (March, 1990), thus applying single-loop learning and creating inertia within organizations. It has been shown that this inertia can channel organizations along constrained product development trajectories and thus affect their chances of survival and growth (Methé et al., 1997).

Human beings also have developed numerous ways to cope with decision making under conditions of uncertainty, such as the use of heuristics, emotions, and intuition (Simon, 1987). The proper use of these coping mechanisms is often gained only through the experience of using them. However, historical events, upon which much of our experience is based, are derived from very small sample sizes, often only one. While individuals and organizations have compensatory mechanisms to extract as much information as possible from an event and attempt to accumulate knowledge by pooling that information across diverse contexts (March et al., 1991), faulty information processing often leads to judgments based on biased perceptions (Beyer et al., 1997) and superstition. Often the way in which a choice is framed or interpreted will affect the decision outcome even when the alternatives and their attendant probabilities are known (Tversky and Kahneman, 1991). These interpretations change and evolve with the flow of a historical event and are linked to where the individual is in the change process itself (Isabella, 1990).

There can be many false starts and blind alleys that occur in confronting an environmentally induced change event, especially when the event is precedent-setting or the unfolding of its impact is ill defined and unstructured. It may be that an alternative solution needs to be created de novo because none exists, or it may be that many exist but all are untried and are terra incognita to the individual or organization that must select from them. Consequently, the more variety of search patterns applied in a particular situation, the greater the likelihood of stumbling onto an appropriate solution. Institutional arrangements that foster greater variety may enhance their chances of finding solutions to problems. These types of search patterns often involve the exploration of new knowledge and ways of solving problems (March, 1990) and engage the organization in double-loop learning. This type of activity usually results in the modification of existing organizational forms or the development of new organizational forms (Methé, 1995a, 1995b, 1997; Methé and Penner-Hahn, 1999).

Institutions, and organizations as the agents of institutions engage in search activities to generate a variety of paths to select from when making decisions. As noted above, they do so because institutions are embedded in a larger environment, an extra-institutional environment beyond the boundaries of the one that created the interaction of institutions and organizations. Part of this environment may be made up of other institutional regimens, which may interact in some way to form a meta-institutional regimen. Early on in human existence this may have been limited to the interactions of certain hunter-gatherer groups and later to tribes in a village structure, and still later to cities, until today we talk about the nation-state. Migration, war, trade, and other forms of social intercourse make up the meta-institutional regimen of our globalizing world. The other part of the environment is made up of the physical world around us. Ecological systems (including other living organisms ranging from viruses all the way across to other mammals), climate and weather, natural resource distributions, and such make up our physical world. Disease, inter-species competition for resources, climatic change, and such make up elements of the larger environment with which organizations must contend.

Although few of us who live in post-industrial societies give much daily thought to our survival in the physical world, it is in reality not a benign place to live, as seen by the number of people who die from disease, natural disasters, and weather-related phenomena. The recent problems posed by SARS were but one example of the impact the physical world can have on the economic, social, and political fabric of agent–institution relationships (Bradsher, 2003). This larger world is continuing to change, and to meet the variety that is created, institutional regimens must also create a requisite amount of variety or be overwhelmed (Ashby, 1952). It is becoming recognized that extra-institutional factors such as demographics, global integration, and technological innovation, among others, will influence both types of institutional change (Lewin et al., 1999). One area of particular interest, especially since it can foster functional, political, or social pressures that may result in alterations of institutional regimes, is change in technology (Burke, 1978; Methé, 1991a; Nelson, 1994).

2.1.3 Technology and Institutions

It is important to pick a starting point because the relationship between technology, institutions, and firm strategy is recursive and nonlinear. Over time, through feedback loops, each of these factors affects the others. This is a process that has no doubt been going on since before written records. Hence the choice of where to start the discussion is as much a philosophical question as it is an empirical one, and it is somewhat arbitrary. The progress of humankind has been inextricably linked to the development and use of tools—that is, technology (Burke, 1978).

It has been asserted that change in a social system begins with technological invention: the trigger effect (Burke, 1978: 1). The technological invention precedes changes in the social system that in turn supports further changes in technology. The movements from hunter-gatherer-based societies to ones based on villages were possible because of agricultural technology. The further movements to towns and cities were predicated on the development of ceramic and metallurgical technologies (Burke, 1978: 7–13). The role that technology and technological innovation plays in the development of modern society and as a wellspring of economic growth has been recognized for some time (Mensch, 1979; Solow, 1957; Schumpeter, 1936).

In its modern manifestation, the relationship between technology, institutions, and strategy has been characterized as a co-evolutionary one (Nelson, 1994). Institutional conventions will set up various incentives and disciplinary constraints, which firms will incorporate into the strategic decisions they make concerning resource acquisition and allocation among products and markets. These strategic decisions by firms on product-market combinations affect choices concerning the technologies used to design and produce the products. These choices alter the technological options available, since some technologies are chosen for further development and others are not. Those chosen for development open up alternative paths for economies and societies to follow. The paths that a society moves along in turn guide the decisions that institutions make concerning incentives and disciplinary constraints.

2.2 Technology

Before proceeding further with the dynamics of this relationship, it is important to understand what technology means in this study (this section draws on the works of Methé, 1985, 1991a, and the collected works cited within these two studies). Technology is the way in which uncertainty is reduced through the application of knowledge concerning the design, development, and use of tools that meet a particular need or solve some particular problem for an individual or group. As such, technology is both a process and a state.

The state is often represented by the set of tools that exists, and the processes are the understanding of how to develop, build, and use the tools. Thus technology is made up of a stock of tools and a stock of knowledge. The tools are often embodied in the capital equipment or products that make up a modern capitalist economy. The stock of knowledge is often found embodied in engineers and scientists. These two stocks are enhanced through flows of finance and information. Flows of finance or money are used to add to the capital stock of tools. Flows of information, in the form of learning, are used to add to the stock of knowledge and understanding of engineers and scientists about the tools.

From the perspective of the user, then, technology is a matching process between a set of problems or opportunities and a set of solutions embodied in tools. How well the tool reduces the uncertainty caused by the problem or opportunity will determine the usefulness of the tool. This may seem like a straightforward system, but in modern capitalist societies the designers and builders of the tools are not often those with the problem or opportunity that are creating a heightened level of uncertainty.

It is also often the case that the designers of the tools and the builders of the tools also make up two separate communities (Cross, 1986; Freeman, 1986). The producers of the tools and the users of the tools must communicate in order to develop a set of tools that will actually meet the latter's needs. Each set of agents, i.e., a community, has a mindset based on a similar but not identical set of institutional conventions. This mindset is derived from their respective knowledge and experience in using the technology to solve problems and confront challenges. We will return to this issue of mindsets and communities when we explore the distinction between industries and markets.

2.2.1 Technology and Knowledge

Technology incorporates knowledge applied to problem solving through the use of tools, which are usually in some material form. It is easiest to think of this in terms of a hammer, a simple tool. In the hands of a skilled craftsperson, the hammer can be used to build complicated structures to live in. In the hands of a two-year-old, the hammer can be a very destructive and dangerous object. The difference, in this case, is the rules or the knowledge of how the hammer can be used. The relationship between the tool (usually something physical or material) and the knowledge governing its design, development, and use exists for all technologies, even software programs.

The combination of the physical tool and the knowledge component makes technology a quasi-public good. This means that it is subject to market failures because externalities exist. For a public good, the consumption of the good by one person does not prohibit it from being resold by that consumer to another consumer; that is, there is joint consumption and non-exclusion. In terms of technology, it is usually the knowledge part, the rules concerning the design, development, and use of the physical tool, rather than the tool itself, that fall prey to externalities. In other words, once someone learns the design, development, or use rules for a tool, that knowledge can be simultaneously passed on to many others and used by all without the original inventor's permission; that is, there is joint consumption and non-exclusion of the knowledge related to the physical tool. A market for knowledge cannot develop without the introduction of some extra-market institutions that define how to appropriate the rights to that knowledge. As an institutional regimen, these are called intellectual property rights (IPR) in the modern capitalist system.

The key distinction among IPR regimens is the extent to which they favor the invention or the spread of technology—that is, the creation of a new technology versus the diffusion of the technology. These issues are often phrased in terms of questions as to the extent IPR regimens provide "strong" protection or "weak" protection for the inventor. IPR regimens make up only one element of the variety-generating aspect of technology. It is also the case that there are often multiple technical or engineering routes to the same end product or tool. This allows for cloning to occur through the process of reverse engineering.

Technological variety generation, then, is affected by the IPR regimen and by the imitability, through reverse engineering, of the original design. Cloning strategies are obviously easier under weak IPR regimens, but not impossible under strong IPR regimens. Cloning becomes a matter of how many other resources an organization is willing to devote to the process. Other resource elements include the availability of financing and people who have expertise in the technology.

The access to financing is crucial in securing the buildings, equipment, and other "capital goods" necessary to carry out business activities. Access to capital is particularly difficult for newly entering firms, or start-ups, and the special needs of these firms require special capital arrangements, often called venture capital (OECD, 2003; JSBRI, 2002). Access to people, particularly engineers and technical staff for a technology-intensive start-up, is also of crucial importance. The type and philosophy of educational system as well as the expectations of workers entering the workforce determine the potential pool of recruits for a start-up (OECD, 2003; JSBRI, 2002). These taken together make up the instructional predisposition toward institutional entrepreneurship (Garudet al., 2002).

Some institutional frameworks are more benign toward technology-induced institutional change, and others are more hostile. The greater the access to financial resources and qualified people, the more easily start-ups are able to enter. This, in turn, creates opportunities for new types of organizational forms to enter, and with these the introduction of new agent–institution relationships. The importance of the entry of new organizational forms is that economic and social progress derives not only from the technology itself, but also from the new agent–institution relationships that emerge from attempts to improve the technological base. Certain organizational forms are more likely to generate certain kinds of technological improvements that range from radical to incremental. New organizational forms are more closely associated with radical types of innovations that redefine existing relationships and are more likely to come from entrepreneurial start-ups than from incumbent firms (Methé et al., 1996). We will turn our attention to issues concerning organizational forms below. For now, suffice it to say that the introduction of new forms of organizations becomes an important, albeit not the only, element in determining the sources of variety generation that an institutional regimen needs for creating the variety necessary to match the changes in its environment.

2.2.2 Invention and Innovation

Technology changes through the process of invention and innovation (Schumpeter, 1936; Sahal, 1979). Simply put, invention is the development of a new concept or machine. Innovation is the putting to use of the invention in society. The impact of the innovation depends on the diffusion of the invention throughout an economy or society. The importance of these distinctions can be simply illustrated by the example of the facsimile machine (see Flatow, 1992, for a more detailed and colorful description). The actual invention of the fax machine occurred in 1843, when the first patents for the basic principles and a working model were introduced, and innovation occurred when a fax transmission system was introduced between Lyon and Paris, France in 1865–70. The diffusion of the innovation was slow, since its use was discontinued after several years. It took more than 100 years and continuing refinement and improvement on the basic principles to arrive at the modern facsimile that we use today.

Invention can take on a number of levels in terms of the disruption that it causes to the status quo. Studies examining technological innovation have spawned numerous typologies concerning technical change, including references to competence-destroying/competence-enhancing change, frame-breaking/frame-bending change, radical and incremental change, modular and architectural change, and references to technological paradigms, technological trajectories, innovation envelopes, and dominant designs (Sahal, 1979, 1981a, 1981b; Adler, 1989; Methé, 1985, 1991a: 6–7; Henderson and Clark, 1990). In this study, for the sake of simplicity, we will adopt the convention of terming these disruptions as radical or incremental.

Depending on the degree of disruption, invention-innovation can lead to the creation of whole new industries when it is radical, to new products or product classes when it is architectural, or to changes in existing products through improvements in the processes of making these products when it is incremental. The special nature of these process improvements will be discussed below in terms of the innovation envelope. For now, it is important to consider what impact these types of invention-innovation categories can have on the existing relationships between agents and institutions and what changes in these relationships can lead to the rise or fall of organizations. Previous research has indicated that the greater the probability of radical technological change, the greater the potential for change in the relationship between the relevant agents, which in turn leads to a greater likelihood of the emergence of new organizational forms (Tushman and Anderson, 1986; Henderson and Clark, 1990; Methé et al., 1996). These new forms in turn generate new agent–institution interactions that may put pressure on existing organizational forms. The degree of coexistence between the new and incumbent forms is affected not only by the amount of environmental munificence, but also by the institutional rules governing the legitimacy of new forms. This issue will be taken up in more detail when we discuss the role of firms in industry settings.

2.2.3 The Innovation Envelope: On Industry, Markets, and Organizational Forms

The social/economic space where the diffusion of both technological innovation and organizational forms takes place is what is termed an industry or market. Recall our discussion above of mindsets and the matching that must take place between the knowledge of the needs of the technology users and the solution or technical knowledge of the producers of that technology. One standard definition of an industry is that of a group of firms producing roughly similar products so that these products are more or less substitutable for each other. For example, the makers of refrigerators have a wide variety of products with the similar function of keeping food cool or frozen in order to preserve it. This corresponds to the consumers' perspective that the various types of refrigerators all have common attributes, the most important of which is to keep food fresh. These common attributes make up the demand side of the economic equation. Often this is referred to as a market.

The producers of refrigerators, however, may also produce air conditioners, humidifiers, washing machines, clothes dryers, convection ovens, and microwave ranges. This may be because these items share some similar technical characteristics either in their design, the materials they use, or the way in which they are manufactured or perhaps even distributed and maintained after sales. This is the supply side of the economic equation. Often this is referred to as an industry. The firm is at the nexus of these two sides of the equation. The consumer would be highly unlikely to attempt to substitute a washing machine for a refrigerator, but the firm may decide to do so by exiting the refrigerator industry and entering the washing machine industry.

Since the firm is at the nexus of these two definitions, some scholars have argued that these conceptualizations of an industry or market make little sense (Freeman, 1995). Rather, they see firms' competition for a common set of resources as more important. In Freeman's words:

> Many firms are not in a single industry, nor are they participating broadly in any industry.... Business firms, even small ones, operate in a resource space that includes a conventional market, but also includes political support, information, and access to social networks. Securing the resources that are needed at any moment in time is the fundamental strategic issue for all firms.... By examining the pattern of availability of these critical resources over time, we can identify the resource levels at which a particular kind of organization prospers (Freeman, 1995: 224–225).

According to this research, the firm is a member of a population's resource niche—that is, the combination of these market-political-information-social networks that provide the resources needed to survive. In essence, the combination of resources necessary for a firm's survival and the firm's ability to acquire them defines the niche and thus the industry that the firm competes in for those resources. The term "resources" covers a wide range of elements that the firm needs to exist. In this view, customers are considered a resource because they buy the firm's products. As we noted above, resources are also the human and financial inputs needed to conduct research and development as well as production and sales. Beyond these tangible resources, other more intangible elements, such as access to political, social, and educational networks and the firm's legitimacy and reputation, would also be included. Consequently, not only the techno-global environment, but also the institutional environment will directly affect the availability and necessity of many of the resources the firm will seek to acquire. This is particularly true of technology and the resources necessary to carry out invention-innovation (hereafter referred to simply as innovation).

The firm is also at the nexus of the technological innovation process, since it must match the technical characteristics of a product to the desired attributes of the product required to fulfill the needs of customers. Changing the technical characteristics of the product to better meet the required attributes of the customers is a function of altering various elements of the product, such as its design, materials, and manufacturing processes. Changes in one of the elements that go into a product may require and/or stimulate changes in other elements. For example, changing the design of the product to add new features may require the addition of new materials and thus the development of new manufacturing equipment. Thus innovation in one focal product is often the result of innovations in the inputs going into that product. The technology trajectory of the focal product forms an innovation envelope for the elements needed to design and make that focal product. Further, the potential for innovation in the focal product is a function of the cumulative potentials of the elements that make up the innovation envelope for that product (Methé, 1985, 1991a; Sahal, 1981a).

Securing access to innovations in the input elements of a particular product that make up one of the critical resource networks that comprise a firm's population niche is fundamental to a firm's strategy and thus to its organizational form. However, these resources often reside in firms that are in different industries, in the traditional sense of that term, from the one producing the product in question. So, for example, steel, aluminum, and chemical firms supply not only critical inputs, but also innovations in those inputs to automobile makers and other users of those materials. The inputs allow for current production of automobiles as a product, but innovation in the inputs allows for potential innovation in the automobiles as a technology. How a firm arranges the links among the various technologies that make up a focal product's innovation envelope can impact the pace and direction of the focal product's technology trajectory. A firm's organizational form is directly affected by how it arranges its relationship to these resources in the innovation envelope.

2.2.4 Strategy, Firms, and Organizational Forms

A firm is a bundle of resources focused to accomplish a goal (Grant, 1991). The adopted strategy shapes the resource requirements and also their configuration within the firm. Since firms may operate in any of several industry/market combinations (hereafter referred to as product/market; we will view this as a defining element of the resource niche that a firm occupies), it is easier to classify them by the organizational form they adopt (Freeman, 1995; Carroll, 1993). These organizational forms are usually classified in terms of their degree of specialization within a population's resource niche and range from very specialized types to generalist types (Carroll, 1985). The degree of specialization is a strategic choice that guides the firm in terms of what resources it will acquire and how it will structure these resources to survive in the environment. The concept of organizational form also argues that firms adhering to a similar strategy that is often shaped at founding (Stinchcombe, 1965; Tucker et al., 1990; Eisenhardt and Schoonhoven, 1990) will often suffer a common or shared fate.

The environmental conditions at founding, and most important the institutional conditions, have a direct effect on the form the organization will take. It is very difficult for the firm to change form over its lifetime (Boeker, 1989; Amburgey et al., 1993). Firms changing their strategy and consequently altering their organizational form, which means altering the way they utilize resources or their organizational routines, often become uncompetitive and have to exit a niche (Delacroix and Swaminathan, 1991). Other researchers have argued, however, that organizations do change and adapt to their environment and continue to survive (Brown and Eisenhardt, 1997; Romanelli and Tushman, 1994; Greve, 1995).

The type of change, environmental conditions at the time of the change, and institutional support for the change are all factors that can alter the draconian rule that change leads to a diminution of survival chances and, in the extreme, to exit. It has been shown that the degree of change in the organizational routines, and hence the necessity of unlearning the old while simultaneously learning the new and carrying out competition against organizational forms that are already using the new routines, has an impact on survival. The pacing of the change is also important. The longer an incumbent must adjust, either because of slow entry and diffusion of the new routines or because it has many resources it can expend in adjusting, the less likely it will be for the incumbent to have to exit (Hrebiniak and Joyce, 1985; Burgelman, 1994; Levinthal and Myatt, 1994; March, 1996; Peng and Heath, 1996).

3 Technology, Innovation, and Organizational Forms in the Integrated-Circuit Industry

Sales volume in the integrated-circuit industry was $140.5 billion in 2002. This was down from its peak of $204.4 billion in 2000 (McClean, 2003). The integrated circuit (IC) is a device that is a type of semiconductor. A semiconductor is an element, such as silicon or germanium, whose electrical conductivity lies between a conductor, such as copper, and an insulator, such as glass. It has the property to either hold an electrical charge or let it pass through. As such it can act as a switch by being on or off. From our discussion of technology it is important to remember that this technical characteristic of being an electrical switch must be matched with various customer needs for the technology to be embodied into a product.

The need for switches is quite large; hence the demand for integrated-circuit products has been growing. The semiconductor industry we know today began with the invention of the solid-state transistor on December 23, 1947, at AT&T Bell Laboratories. The integrated circuit industry that exists today began with the invention of the integrated circuit in 1958. Both of these inventions are considered radical inventions because they created whole new industries that opened up the opportunity for the entry of collections of firms sharing common organizational forms different from those used by incumbent firms. Although not as radical as the two previous inventions, the invention of two particular types of integrated circuit—the dynamic random access memory (DRAM) device in 1970 and the microprocessor in 1974 by Intel—also fundamentally shaped the competitive topography of the integrated-circuit industry.

Both of these devices became industries in and of themselves within the broader integrated circuit industry, again creating the dynamics necessary for the entry of new firms into the industry for each integrated-circuit device. Furthermore, and perhaps more remarkably, both devices have been important initiation points and test beds for the development of innovations in the process and design aspects of integrated-circuit technology. The innovations in these two devices, and in the family of memory and logic devices related to them, have been fundamental in powering the dynamics of the techno-global forces shaping the integrated-circuit industry because these two devices give material expression to Moore's law. This has created an innovation dynamic that is both predictable in its timing and vexingly complex in the combination of design and process technologies necessary to carry it out. We will discuss in detail the dynamics of this type of techno-global innovation in a later section.

3.1 Technology

The switching function that integrated circuits perform has allowed these devices to be used in almost every conceivable electrical product. The market for these products is vast in terms of the scope of applications, ranging from telecommunications to automobile control systems, to consumer electronics that range from games to entertainment systems such as televisions, and to computers. The fate of the integrated-circuit industry is directly tied to the fate of the electronic-systems industry. As this industry grows, so does its need for integrated-circuit devices. The electronic-systems industry stood at $972 billion in the year 2000 and fell to $790 billion in 2002 (McClean, 2003). There are two drivers of the relationship between the electronic-systems industry and the integrated-circuit industry.

The first is simply that the growth rate in one industry, electronic systems, affects the growth rate in the integrated-circuit industry. The second driver is a substitution effect. Integrated-circuit switches have been replacing switches based on other types of technology in products ranging from consumer electronics, computers and telecommunications, to automobiles. The percentage of the value of an electronic system that is derived from semiconductors increased from about 5% in 1974 to a peak of 21% in 1995. It had fallen back to about 18% in 2002. This works out roughly to about half a percentage point a year of growth related to substitution over the 1974–2002 period (McClean, 2003).

3.2 The Invention/Innovation Trajectory

This substitution effect has taken place because the applications that integrated circuits can carry out have been increasing. This is a result of the underlying technological dynamic of the innovation process of the integrated circuit. This dynamic has been termed Moore's law, after Gordon Moore, who first articulated it in the 1960s. At the time he first talked about it, Moore stated that the number of components (now often measured in terms of the number of transistors) on a single integrated-circuit chip would double every year. The rate of this doubling began to slow in the mid-1970s, but has held constant since then at about a doubling of components every 18–24 months. It is projected that Moore's law will continue to be valid for at least the next 15 years.

As the number of transistors on an integrated-circuit device increases, the functions that the device can perform also increase. Since the semiconductor can be either on or off, it can take a 0 or 1 state, which is the underlying Boolean logic of programmable computers. These devices can thus not only do simple tasks such as store information, they can be programmed to carry out very complex tasks such as adjusting the fuel-air mixture for an automobile's internal combustion engine in real time (see Methé, 1992a, for a more detailed discussion of the impact of these relationships on one particular device type, the DRAM).

The ability of integrated-circuit firms to put more transistors on an integrated-circuit device is driven by the technologies that go into the design and manufacture, or fabrication, of these devices. The driving goal has been and continues to be to put more and more components onto the integrated-circuit device. This can be accomplished in a number of ways. One is to increase the size, referred to as the die area, of the device. There are limits to this, of course, since to increase the die area continually would result in the world's biggest microchip. If you cannot increase the die size of the device, you must reduce the size of the components that go onto it. This has been the fundamental approach to increasing the number of components on an integrated-circuit device. One way that this size has been measured is by calculating the width of the circuits on the device. A DRAM device, in the late 1980s, that could store about 1 million bits (1 megabit, or 1 Mb) of information had a circuit width of just less than 1 micron. The current DRAM devices that can store about 1 billion bits (1 gigabit, or 1 Gb) of information have circuit widths of about 0.13 micron.

3.3 The Semiconductor Equipment Technology Trajectory

The requirement to continually reduce circuit width drives the need to innovate new equipment for making the integrated-circuit device. There are many types of equipment used in fabricating an integrated-circuit device. A key type is photolithographic equipment, which is needed to project the circuit design onto the silicon material of the device itself. This width reduction has required changes in the types of photolithographic equipment used in the integrated-circuit fabrication process (Methé, 1985, 1991a). While this has had a tremendous impact on the photolithographic industry in terms of the organizational forms of the firms that represent it (see Methé, 1985, 1991a; Henderson and Clark, 1990), from the perspective of the integrated-circuit device makers, what is important about these changes in the photolithographic technology base is that the cost of the machines keeps increasing. When added up, the cost of fabricating integrated circuits has increased from about \$50 million per facility in the mid-1970s to about \$100 million in the mid-1980s to about \$1 billion in the mid-1990s (Methé, 1985, 1991a). It was expected that the cost of a state-of-the-art fabrication facility would be about \$2.4 billion by 2005 (McClean, 2003). Most of the cost for these fabrication facilities, about 70%–80%, comes from the cost of equipment that goes into the facilities, the rest being the cost of the land and the building.

3.4 The Integrated-Circuit Innovation Envelope

To support the capital investment necessary for these fabrication facilities, The sales of integrated-circuit devices must continue to grow. Likewise, the firms themselves must continue to grow. If the market for devices grows fast enough, the number and the types of firms in terms of their organizational forms remain stable (Methé, 1992a). The relatively fast growth of the integrated-circuit industry, about 14% per year during the period from 1981 until 1991, has been enough to support an increasing number of firms. The growth rate has begun to slow in recent years, however, with the average annual growth rate for the period 1991–2001 at about 10% (McClean, 2003). As noted above, the growth rate has been negative over the period from 2000 to 2002.

More important, the volatility of the growth rate has changed. Four of the past six downturns in the semiconductor industry have occurred in the past 14 years, in 1991, 1996, 1998, and 2001. Making the situation even more difficult has been the fact that the 2001 downturn was the worst decline in the recorded history of the semiconductor industry. The decline in the market value of semiconductors in 2001 as measured in dollars was 32%, far surpassing the 1985 downturn of 17% (McClean, 2003).

The industry has become more costly because of the continued innovation drive in its technology base. This is related to links between the electronic systems industry as users of integrated-circuit technology and the semiconductor equipment manufacturers as suppliers to the integrated-circuit technology base. This relationship forms an innovation envelope for the integrated-circuit industry (Methé, 1985, 1991a). This innovation envelope describes the innovative potential of the integrated-circuit industry in terms of the underlying changes in the electronic systems technology base and the semiconductor equipment technology base. The changes in the innovation envelope of the integrated-circuit industry have strong implications for the organizational forms that can be supported in the various integrated-circuit resource niches (Methé, 1991b).

3.5 Integrated-Circuit Industry Organizational Forms

It is important to begin this discussion with a brief outline of the types of organizational forms that exist in the integrated-circuit industry. We will work from a more generic description of these forms to one more suitable to the integrated-circuit industry. In all industries, the breadth of a firm's involvement in the focal industry and other industries can array the types of organizational forms that a firm can take. The firms with the most breadth that also may have involvement in other industries would be classified as generalists and those that concentrate their resources and strategic attention on the single focal industry would be classified as specialists (see Carroll, 1993 for a more detailed discussion of these classifications).

Thus a firm like Hynix, a Korean integrated-circuit firm that makes and sells logic and memory devices and also provides foundry services, would be a generalist compared to one such as LSI Logic, a U.S. firm that makes only logic devices, or Taiwan Semiconductor Manufacturing Company (TSMC), a Taiwanese firm that provides only foundry services; the latter two would be considered specialist firms. Furthermore, a company like LSI Logic, which designs, makes, and sells a wide range of logic devices, is less of a specialist than one like Nvidia, a U.S. start-up, which only designs and sells logic devices for communication applications.

In classifying firms by their degree of specialty, we will adopt the term "system houses" to describe those integrated circuit firms that are strongly linked to the electronic systems industry; "integrated device manufacturers (IDMs)" for those integrated-circuit firms that design, make, and sell integrated circuits; "fabless" design integrated-circuit firms for those that only design and sell integrated-circuit devices; and dedicated "foundries" for those integrated-circuit firms that provide fabrication services by manufacturing integrated-circuit devices but do not design or sell devices of their own. We must make a further distinction within the foundry category between pure-play foundries, those integrated-circuit firms that provide only foundry services, and IDM foundries, those that are IDMs or system houses and that also provide foundry services. For example, IBM Microelectronics, another U.S. firm, makes logic and memory devices and provides foundry services as well as being linked through the parent company IBM to electronic systems. We can also classify the organizational forms selected by firms according to their geographical origin, the U.S., Japan, Korea, Taiwan, or Europe.

Another way of classifying these firms is in terms of how long they have been in the industry. We describe established firms—those already in the industry at a given time—as incumbents and those just coming into the industry at that time as new entrants. We also classify how the new entrants entered, that is, whether they just started up to make and sell integrated circuits, or whether they diversified in from some other industry (see Methé et al., 1996 for further elaborations of these concepts). We can combine these two types of classification systems to understand change in the integrated-circuit industry. Thus we can observe whether a generalist or specialist firm is newly entered or an incumbent, and whether these firms were start-ups or diversifying entrants.

We will now examine what types of firms exist in the integrated-circuit industry and what impact the changes in the innovation envelope have had on the composition of these firms' organizational forms. We begin our examination of the integrated-circuit industry by looking at the top 10 rankings of integrated-circuit firms in terms of their sales worldwide at about the midpoint of each decade beginning with the 1970s. We are interested in those firms and their respective organizational forms that occupy the center of the industry. In this sense we are not attempting to understand the complete population dynamics of birth, change, and exit. We are interested in the entry, change, and exit of firms at the center of the industry.

The firms that occupy the center are those with the largest amount of sales, with the top 10 firms holding a market concentration of 60%–90%, depending on the category of semiconductor and the country's market under discussion. These firms often dominate not only in sales, but also in research and development expenditures, employment, and impact on financial markets. They also have a strong influence on the institutional arrangements that exist for the industry. As we trace the evolution of the industry, we are concerned with the entry, change, and exit of firms at the center of the industry rather than at its periphery. As such we are concerned more with issues of selection and retention than with issues of variety generation per se. For the convenience of data presentation, we initially divide up the integrated-circuit industry roughly by decades, from the 1970s until today, using selected years to represent the presence of various organizational forms in the industry. We then examine the type of organizational form that was dominant in terms of sales in the industry in each of those years. Data are available for more years than are presented in this chapter, but for the convenience of presentation only selected years are shown.

4 Organizational Forms in the Integrated-Circuit Industry

4.1 The Global Integrated-Circuit Industry[2]

As seen in Table 4.1, in the mid-1970s the leading firms worldwide in terms of sales were Texas Instruments (TI), Fairchild, Signetics, National, Intel, Motorola, NEC, Hitachi, Rockwell, and RCA. Six of these firms—TI, Hitachi, Motorola, NEC, Rockwell, and RCA—were electronic systems houses, and two others, Fairchild and Signetics, were transitioning from being system house-connected to becoming a more IDM-type organizational form. Those having entered with the IDM organizational form were National and Intel. By the mid-1980s the top firms were TI, NEC, Hitachi, Motorola, Fujitsu, Intel, National, Toshiba, AMD, and Matsushita. Again, system houses predominated among the top 10 firms, with 7 using this organizational form, and 5 of the top 10 were Japanese firms.

Table 4.1 Top 10 Semiconductor Firms in the World Industry for Selected Years

Rank	1976	1985	1990	1995	2000	2002
1	**TI**	**TI**	**NEC**	*Intel*	*Intel*	*Intel*
2	*National*	**NEC**	**Toshiba**	**NEC**	**Samsung**	**Samsung**
3	***Fairchild***	**Hitachi**	**Hitachi**	**Hitachi**	**TI**	**TI**
4	**Motorola**	**Motorola**	*Intel*	**Toshiba**	**NEC**	***STMicro***
5	*Intel*	**Fujitsu**	**Motorola**	**Samsung**	**Toshiba**	TSMC
6	**NEC**	*Intel*	**Fujitsu**	**TI**	**Motorola**	**Motorola**
7	***Signetics***	*National*	**TI**	**Motorola**	***STMicro***	***Infineon***
8	**Hitachi**	**Toshiba**	**Mitsubishi**	***IBM***	**Hyundai**	**NEC**
9	**RCA**	*AMD*	**Philips**	**Mitsubishi**	**Hitachi**	**Toshiba**
10	**Rockwell**	**Matsushita**	**Matsushita**	**Hyundai**	***Infineon***	**Hitachi**

Key:
BOLD: Diversifying Entrant with Electronic Systems Connection
ITALICS: Start-up as an Integrated Device Manufacturer
STANDARD: Start-up as a Fabless Design Firm or Foundry
BOLD ITALIC S: Shifting from Electronic Systems to Integrated Device Manufacturer
Sources: Foster, 1986; ICE Status, various issues; ICE Profiles, various issues; IC Insights Strategic Reviews, various issues

Three IDMs were extant at this time: Intel, AMD, and National. The importance here is not just that the predominant firms are Japanese, thus indicating the increasing internationalization of the industry, but that they had very special relationships not only with electronic-systems products, but also with equipment suppliers, many of whom were Japanese (Methé, 1985, 1991b; also see Okada, 2002). As shown in these other works, one of the main reasons for the ascendancy of Japanese system houses during this period was their vertical linkage back into the equipment industry (Methé, 1985, 1991b).

Again, as seen in Table 4.1, by the mid-1990s the top 10 firms were Intel, NEC, Hitachi, Toshiba, Samsung, TI, Motorola, IBM, Mitsubishi, and Hyundai, and the dominance of system houses is quite evident. The emergence of two Korean companies signals a change, however. The most obvious implication of these two companies' appearance is that a set of players from a new national institutional setting has emerged. These two companies were in competition for some time before entering the top 10 worldwide, and their emergence signals a shift in the competitive topography of the globalizing integrated-circuit industry. A more subtle implication is that the two Korean companies, Samsung and Hyundai, are system houses because they are linked forward into the electronic systems industry, but neither has linkages back to semiconductor equipment manufacturers in the way that the Japanese firms did and still do (see Okada in this book and Wakabayashi and Sumita, 1993). A change had occurred in the relationship between the equipment industry and the integrated-circuit industry. We will return to this in the next section.

Again, as seen in Table 4.1, by 2002 the top 10 firms were Intel, Samsung, TI, STMicro, TSMC, Motorola, Infineon, NEC, Toshiba, and Hitachi. By this time, about 5 of the firms—Intel, TI, STMicro, TSMC, and Infineon—were IDMs, and the other five were still system houses. It is important to note that we see the reemergence of European firms back into the top 10 slots. One of these firms is a spinoff from its system house; Siemens spun off Infineon in April 1999. The other, STMicro, is the result of merger activity between two European system houses (IC Insights Strategic Reviews, 2003; Fisher, 2002). This occurred in June 1987 when Thomson Semiconducteurs, part of the microelectronics business of the French state-controlled company Thomson-CSF, and SGS Microelettronica, the microelectronics business of STET-Societa Finanziaria Telefonica, the Italian state-controlled telephone company, were spun out of their respective companies and merged to form SGS-Thomson Microelectronics. It was renamed STMicroelectronics (STMicro) in May 1998. The other important change is the emergence of a Taiwanese firm, TSMC. This is important not only because it is in Taiwan, but also because it is a pure-play foundry firm. TSMC was founded in 1987 as one of the first pure-play foundries in the semiconductor industry and reportedly held 56% of the 2002 pure-play foundry market. It is the largest semiconductor foundry company worldwide. TSMC was created as a joint venture between the Taiwan government (21%), Philips Electronics (28%), and other private investors. As of March 31, 2002, Philips continued to own 22% of TSMC, with the ROC Development Fund owning 10%. Private investors, including employees through stock option plans, owned the remainder (IC Insights Strategic Reviews, 2003).

The legacy of the past is quite obvious in this analysis of the firms entering the worldwide top 10 as presented in Table 4.1. In spite of the changes occurring at the national institutional level and at the techno-global level, system houses, which were diversifying entrants when they entered the integrated-circuit industry, are the most powerful agents in terms of sales. It is only recently, as readily seen in the 2002 data, that we see the IDM form take over half the slots in the top 10. However, we can see indications that change is occurring at a number of different levels.

First, the emergence of U.S. and European, and then Japanese, Korean, and Taiwanese, firms indicates that the technology of this industry and its innovation envelope has been driving the globalization process and that the growth in sales has been able to support that globalization process. Each emergence of firms based on a given national institutional setting was conditioned on the techno-global phase of the industry and had implications for the competitive dynamics of the integrated-circuit industry. The competitive topography of the integrated-circuit industry also influenced upstream and downstream industries and set the conditions for the next set of firms to emerge.

Second, the agent–institution relationships that each of these economies developed created firms that had organizational forms that could cope with entry into an industry already populated with very strong incumbents. In the case of the Japanese firms, these were system houses coming in as diversifying entrants with strong backward links to Japanese semiconductor equipment suppliers. The Korean firms were also system houses coming in as diversifying entrants, but without the strong vertical links backward into equipment suppliers. It is with the entrance of the Taiwanese firms that we notice a deviation from the system house trend. Most Taiwanese firms entered as IDMs. Furthermore, the Taiwanese firm TSMC entered as a start-up, albeit a different form of start-up from the organizational form most often associated with Silicon Valley. Rather than entering as a venture capital-based start-up, it entered with the backing of the Taiwanese government and a major system house firm. Still, the emergence of TSMC is a further deviation from the trend of system house domination because it is a pure-play foundry.

Third, the reemergence of the two European firms indicates also that the momentum toward specialization is becoming stronger. Both were more strongly linked into system houses throughout the entire period. Their reemergence as specialized IDMs further supports suggestions that the direction of change is toward specialization. Although not shown in this data set, when the breakdown is done according to each economy—U.S., Japan, Korea, Taiwan, Europe—this trend is even more pronounced. This indicates that incumbents can under certain conditions readjust their strategic resource configuration or organizational form to meet the changes brought about by the interaction of techno-global and institutional forces.

Another important point that emerges from the analysis presented above concerns the relationship between the semiconductor equipment industry and the integrated-circuit industry. As noted earlier, the continued advance of the integrated circuit along its technology trajectory is largely dependent upon the technological advances made in semiconductor equipment, such as photolithography. As discussed in other works (Methé, 1985, 1991a), the rise of the Japanese integrated-circuit industry was closely supported by the development of a home-grown semiconductor equipment industry. These two industries' fortunes moved in tandem. Japanese firms' replacement of the U.S. and European integrated-circuit firms was mirrored in the replacement of the U.S. and European semiconductor equipment firms by Japanese firms (Methé, 1991a). The special relationship among the Japanese firms led to a strongly idiosyncratic form of technological innovation in integrated circuits. Each semiconductor firm, for example NEC or Hitachi, worked very closely with a specific set of equipment firms, with the resulting equipment highly customized to that semiconductor firm's fabrication process. Unless one was a member of the club, it was difficult to receive the most advanced semiconductor equipment. Confronted with this situation, the U.S. agent–institution relationship changed with the founding of SEMATECH.

It is important to note that the founding of SEMATECH was a result of the pressures exerted by the techno-global environment on the agent–institution relationship concerning cooperative research among U.S. integrated-circuit firms. In this case, changes in technology and the globalization process, especially the emergence of Japanese firms and their subsequent domination of the DRAM industry, led to the establishment of SEMATECH. Its original purpose was as a way of enhancing the survival of U.S. firms. Although this original purpose for the establishment of SEMATECH was essentially conceived of in the context of the bipolar competition between the U.S. and Japan, its actions set in motion a number of important agent–institution relationship changes in other country settings. Flowing from its original purpose, an important accomplishment of SEMATECH was to begin standardizing the development of semiconductor equipment technology and to make progress along the various technology trajectories that make the equipment industry more transparent and open. An unintended consequence of this more transparent and open equipment development was that it facilitated the emergence of the Korean firms in the integrated-circuit industry, allowing them to acquire state-of-the-art equipment even without the parallel development of Korean equipment makers. As the Korean integrated-circuit firms grew, they became more important customers for European and U.S. equipment makers, allowing these firms to survive through the late 1980s and early 1990s. This process continued with the emergence of the Taiwanese firms in the early to mid-1990s. Again, Taiwanese firms were able to gain access to leading-edge semiconductor equipment technology as they needed it. This access became vital to the development of dedicated foundries, which, as we will discuss below, had an effect on the fate of U.S. fabless design firms.

The relationships described above show the importance of serendipity in the co-evolution of the agent–institution relationship in response to changes in the extra-institutional environment. It is a given that the combination of technological opportunities that open with each new generation of integrated-circuit device allows new entrants using new organizational forms the chance to enter the industry. However, as noted in the creation of SEMATECH, the alteration of competitive strategy among U.S. firms in response to the entrance of Japanese firms, and the subsequent alterations in the agent–institution relationship that existed in the U.S., had implications beyond the U.S. firms. It allowed for the growth of new forms in Korea and Taiwan and for a greater variety of relationships among those forms. One part of that variety was across industry boundaries as first Korean and then Taiwanese integrated-circuit firms became customers for U.S. and European equipment firms. Another part relates to the connections among fabless firms and foundries.

The U.S.-based LSI Computer Systems entered as the first fabless firm in 1969. Although the initiation of the fabless organizational form occurred early in the life history of the integrated-circuit industry, few firms adopted it as a legitimate mode of entry, since the conventional wisdom prevailing in the industry was for firms to design and make ICs. Not until the early 1980s, when fabless firms began entering the integrated-circuit industry in large numbers, did the conventional wisdom concerning this agent–institution relationship change. The period 1982–1983 marks the beginning of the period when multiple entries of fabless firms occurred annually.

These firms came in as fabless design firms because of three overriding techno-global environmental factors. The first was the continuing increase in the cost of fabrication. For an IDM to enter at that time, the cost was around $55 million, whereas entry as a fabless firm it was closer to $2 million or $3 million. Entry as an IDM required an investment in fabrication facilities and capabilities, which at that time required about $50 million. Entry as a fabless firm required only an investment in design and marketing capabilities. This illustrates the shift in techno-globally driven selection choices between organizational forms that came into being in the early 1980s.

Until the early 1980s, as noted above, the conventional wisdom was to enter as a company that fully integrated the value chain functions—that is, either as a diversifying system house organizational form or as a start-up IDM organizational form. Emanating first from the U.S. institutional environment, the fabless design IC organizational form was initially a response to the increasing cost of investment needed to enter the semiconductor industry. This phenomenon arises entirely out of the innovation process of the integrated-circuit industry, as described above. Many entrepreneurs had ideas about meeting emerging market needs or birthing some pioneering semiconductor process or design technology, but the investment necessary to both design and to fabricate the devices was growing beyond the initial carrying capacity of these specialized markets. Even though the entrepreneurial impulse was strong and strongly supported within the U.S. institutional regimen, without access to the greater cash flow available in broader-based markets, the "burn rate" of entering with the IDM organizational form was becoming prohibitive.

The second techno-global influence was the emergence of the Japanese firms. As very powerful competitors in the mainstream memory markets, especially in DRAMs, Japanese firms made it difficult to follow a broad-based IDM-type strategy for newly entering firms. Many established U.S. firms were already in the process of exiting the DRAM segment of the integrated-circuit industry in the early 1980s, and this process accelerated with the entrance of Japanese system house IC firms (Methé, 1985, 1992a, 1992b). Firms that could find product-market niches in small areas such as mobile telecommunications, digital signal processors, or analog-to-digital processors could enter with less fear of immediate head-to-head competition with the large Japanese incumbents. However, these market segments were usually small and would not generate the sales revenue volume needed to maintain a continuous investment in fabrication facility capabilities.

The third techno-global influence was the recessions that occurred in the integrated-circuit industry in 1981 and again in 1985, which freed up a lot of manufacturing space among the system house IC and IDM IC manufacturers. With newly created fabrication facilities lying idle, the fabless entrants could find enough fabrication capacity to meet their needs. The system house IC and IDM IC firms were happy to fill in their capacity needs at the margin with the demand from the fabless firms, at least while they had idle fabrication capacity. The constant ebb and flow of demand for the IC devices produced by these system house IC and IDM IC makers often put the fabless design houses in a pinch for fabrication capacity, however. When times were bad for the system/IDM IC makers in the mainstream memory and logic IC markets, fabrication capacity was freed up for the fabless design firms, but when demand for the system/IDM IC firms' products rose in these mainstream markets, the fabless firms found themselves in a squeeze for fabrication capacity.

It took until 1987, with the founding of TSMC as the first pure-play foundry, to fully legitimize the fabless design organizational form and with it the dedicated foundry organizational form. With the founding of TSMC, a firm for the first time created fabrication space dedicated to the needs of the fabless IC firms. Emanating from the Taiwanese institutional environment, the dedicated foundry organizational form benefited from a strong link with the U.S. institutionally based fabless design house organizational form and from the more open and transparent process of semiconductor equipment development, fostered by SEMATECH, which was then taking hold. The relationship between the fabless organizational form and the dedicated foundry organizational form grew and developed over a 15-year period after the emergence of TSMC. It was not until 2002, when TSMC entered into the top 10 global IC firms, that the fabless and foundry relationship became a mainstream sustainable strategy and, with symbiotically organized resource sharing, simultaneously legitimized both the fabless and the foundry as organizational forms. Prior to the founding of TSMC, a fabless design house was limited in its growth potential in sales and profits unless it transitioned into an IDM organizational form.

After the founding of TSMC, fabless firms were no longer on the margin in terms of fabrication capacity considerations. The dedicated foundry organizational form likewise has no meaning if fabless firms shift to an IDM type organizational form. The emergence of the dedicated foundry organizational form gained momentum as several other firms, first in Taiwan and later in other institutional environments, entered as foundries or shifted over to dedicated foundry applications in order to meet the needs of fabless design firms. We will examine these trends more closely as we look in more detail at the emergence of organizational forms in each of the national institutional settings.

4.2 The U.S. Integrated-Circuit Industry[3]

It is not surprising that the American domestic semiconductor industry has been the dominant single-country market for the world semiconductor industry since its beginnings. This is because the industry began essentially with the invention of the transistor at Bell Laboratories and with the pioneering work on integrated-circuit design at both Intel and Texas Instruments as well as the pioneering processing technology work at Fairchild. It was that pioneering work with respect to both product and process technology development that wrested industry momentum away from the early vacuum tube manufacturers who had diversified into the emerging semiconductor transistor industry in the mid-1950s, as can be seen in Table 4.2. By the late 1960s, the firms that would come to

Table 4.2 Top 10 Semiconductor Firms in the U.S. Industry for Selected Years

Rank	2002	1995	1992	1989	1985	1980	1975	1969	1968
1	*Intel*	*Intel*	*Intel*	**TI**	**TI**	**TI**	**TI**	**TI**	**TI**
2	**TI**	**TI**	**Motorola**	**Motorola**	**Motorola**	*National*	*National*	**Motorola**	**Motorola**
3	**Motorola**	**Motorola**	**TI**	*Intel*	*National*	**Motorola**	***Fairchild***	**Fairchild**	**Fairchild**
4	***IBM***	**IBM**	*National*	*National*	*Intel*	Intel	**Motorola**	*Signetics*	*Signetics*
5	*Micron*	*Micron*	*AMD*	*AMD*	*AMD*	***Fairchild***	*Intel*	*National*	*National*
6	*AMD*	*AMD*	**AT&T**	**AT&T**	***Signetics***	***Signetics***	***Signetics***	*AMI*	**Raytheon**
7	***Agere***	*National*	***Harris***	***Harris***	***Fairchild***	***Mostek***	**RCA**	**Raytheon**	**Sylvania**
8	Nvidia	***AT&T***	*LSI Logic*	*LSI Logic*	***Mostek***	*AMD*	*Mostek*	**NRMEC**	**RCA**
9	Qualcomm	*LSI Logic*	*Analog*	***Western Digital***	**RCA**	**RCA**	*AMD*	**Sylvania**	**ITT**
10	*Analog*	*Cirrus Logic*	*Micron*	*Micron*	**Harris**	**Harris/GI**	**GI**	**RCA**	**General Motors**
11								**Philco-Ford**	**GI**
12								Sprague	***Amelco***
13								**ITT**	**Radiation**
14								**GI**	**Philco-Ford**
15								**Radiation**	*Transitron*

Rank	1955 (Vacuum Tube)	1955 (Transistor)
1	**RCA**	**Hughes**
2	**Sylvania**	*Transitron*
3	**GE**	**Philco**
4	**Raytheon**	**Sylvania**
5	**Westinghouse**	**TI**

Key:
BOLD: Diversifying Entrant with Electronic Systems Connection
ITALICS: Start-up as an Integrated Device Manufacturer
STANDARD: Start-up as a Fabless Design Firm or Foundry
BOLD ITALIC S: Shifting from Electronic Systems to Integrated Device Manufacturer
Sources: ICE Status, various issues; ICE Profiles, various issues; IC Insights Strategic Reviews, various issues; Foster, 1986

dominate the semiconductor industry had already begun to enter. Even though at one level there was continuity in terms of the organizational form of both the diversifying entrants and the start-ups, the older vacuum tube companies were being replaced by a new breed of diversifying entrants and start-ups.

The new diversifying entrants, Motorola, Texas Instruments (TI), and

Fairchild, were all companies that had some connection to the electronic systems industry and as such followed closely behind the vacuum tube manufacturers who also had such ties. The emergence of another set of firms, however—start-ups dedicated to the design and fabrication of semiconductors—introduced a new organizational form, the integrated device manufacturer (IDM). The earliest was Transitron, a company started up in 1952 in Melrose, Massachusetts, to sell transistors. Later companies, such as Fairchild Semiconductor (founded in 1957), National Semiconductor (1959), Signetics (1961), AMI (1966), Intel (1968), AMD (1969), and many others were started up as IDMs dedicated to the design, development, fabrication, and sale of semiconductors, especially integrated-circuit devices.

Most, of these firms, but not all, were founded in the San Jose region of northern California, which is now called Silicon Valley. The firms founded there, initially with the IDM start-up organizational form and later the fabless design house organizational form, are the result of an extraordinary mixture of human, financial, and other tangible and intangible resources that has not been duplicated elsewhere in the world. This story is all the more remarkable, since it was accomplished in as close to a self-organizing system as one could expect to find. Government played no direct overarching or orchestrating role in the creation of the Silicon Valley phenomenon, although government policies on procurement, R&D funding, IPR protection, and such did influence aspects of firm strategy (Methé, 1985; Tilton, 1971). This extraordinary entrepreneurial milieu is still actively generating new start-up firms even today after having sustained several boom and bust cycles in its existence.

As can be seen in the table, in the late 1960s and early 1970s the dominant organizational form was the diversifying entrant with system house connections, some of which were even the older vacuum tube manufacturers. Firms like TI and Motorola represented the newer diversifiers, and Raytheon, Sylvania, RCA, and North American Rockwell Micro Electronics (NRMEC) represented the older diversifying entrants. Signetics and National were IDM start-ups. Fairchild Semiconductor, which originated as an IDM form, in 1965 had been purchased by its main investor, Fairchild Camera and Instrument, for $3 million and was transitioning from the IDM form to the system house form. By 1975, the situation had further shifted in favor of the IDM start-ups. From the table it can be seen that 4 of the top 10 companies were using the IDM organizational form, and 4 were using the system house diversifying organizational form. Joining National were Intel, Mostek (founded in 1969), and AMD. TI, Motorola, RCA, and General Instrument (GI) followed the system house form. One other firm, Signetics, joined Fairchild in transitioning from the IDM form to the system house form. Signetics, which had started as an IDM form, had been acquired by North American Philips and as such came under the system house organizational form. Fairchild Camera and Instrument, with the Fairchild Semiconductor division, was bought by Schlumberger in 1979 and continued as an IDM within a system house organizational form.

Change again can be seen in the 1980s portion of the table. In 1980, 4 firms, TI, Motorola, RCA, and Harris/GI, were following the system house organizational form, and 2 firms, Intel and AMD, were following the IDM form. Mostek was acquired by United Technologies in 1980 and sold to SGS-Ates in 1981; thus it was a transitioning organizational form going from an IDM to a system house form. In 1985, TI, Motorola, RCA, and Harris were system house organizational form companies. Signetics, Fairchild, and Mostek were transitional organizational forms. Intel and AMD were the only companies of the IDM organizational form to remain in the top 10 companies for the U.S. semiconductor industry in 1985.

In 1989, the U.S. semiconductor industry had changed yet again. TI, Motorola, and Harris still remained in the top 10 as system house organizational forms, but AT&T had joined them. AT&T had had substantial captive semiconductor capacity and had turned into a merchant company by selling its semiconductor devices in the open market. Western Digital, which had started out in 1970 making chips that controlled computer drives, had now diversified into making the drives themselves and is represented as a transitioning organizational form, but one that was doing so through internal organic growth rather than through acquisitions. Intel and National, which had acquired the semiconductor operations of Fairchild in 1987, AMD, LSI Logic (founded in 1981), and Micron (founded in 1978) joined the IDM organizational form. At the end of the decade of the 1980s, the competitive topology of the U.S. domestic semiconductor industry looked like this: 4 system house organizational form companies led the top 10, followed by 5 IDM organizational form companies and one transitioning organizational form company.

By 1992, the domestic industry had begun to change again. Motorola, TI, Harris, and AT&T were representing the older system house organizational form. But for the first time, a firm representing the IDM organizational form, Intel, had become the leading company in the top 10; with the addition of National, AMD, LSI Logic, Analog Devices, and Micron, the IDMs now made up the majority of the top 10 companies. Intel occupied the top spot in 1990 and has hung onto it since. The previous transitioning company organizational forms were no longer present on the top 10 companies list. By 1995 TI and Motorola were still representing the system house organizational form. IBM had joined them much in the same way that AT&T had entered the merchant market in 1988. IBM had been producing semiconductors going back to the early years of the industry, but had done so only for internal use and as such had remained a captive company. It began selling its IC devices in 1992, turning from its captive position into a merchant company using the system house organizational form. Intel remained the leading company in 1995 and along with Micron, AMD, LSI Logic, and Cirrus Logic, which was founded in 1984, rounded out the top 10 companies utilizing the IDM form.

In 2002, the domestic industry was again undergoing change with the introduction, for the first time, of a new organizational form into the top 10 positions. TI, Motorola, and IBM represented the older system house organizational form. The dominant form once again was the IDM form represented by Intel, Micron, AMD, and Analog Devices. AT&T had become Lucent Technologies in 1996 and still maintained a system house organizational form. Agere was a transitioning company, having been spun out of Lucent Technologies in 2002 and taking on a more IDM-type organizational form because its product focus was on semiconductor devices. The listings of Nvidia and Qualcomm represent the emergence of a new organizational form on the top 10 list: the fabless semiconductor organizational form. As noted above, this form was initiated in the late 1960s and began entry in earnest in the early 1980s. Firms have been entering the U.S. domestic semiconductor industry using this form ever since. However, it took some 20 years for this form to move into the top 10 listing for the U.S. domestic semiconductor industry.

There are several trends that are apparent from the above analysis. First is the persistence and resilience of the system house organizational form. From the very inception of the semiconductor industry until the present time, organizations that have adopted this form, albeit not the same companies, have been present in the semiconductor industry in the U.S. Second, the IDM form, while quickly establishing itself as a viable alternative organizational form, did not come to dominate the industry until the late 1980s, more than 30 years after its first appearance. Third, the newest organizational form to emerge into the top 10 list of companies in the U.S. institutional setting, the fabless semiconductor design firm, has taken about 30 years from its first appearance to even enter this area of dominance. Fourth, in the earlier years firms were transitioning from the IDM form to the system house form, often because of difficulties that a company had in the market with an IDM form, as with the Philips acquisition of Signetics and the Schlumberger acquisition of Fairchild, or because a company with a system house form was looking for a quick entry into the semiconductor industry, as with the United Technology acquisition of Mostek. Fifth, the most recent trend in transitioning appears to be the movement from a system house organizational form to an IDM form, as in the case of Agere and to a lesser extent IBM Microelectronics and Motorola, which have all spun out their semiconductor operations into separate divisions with more autonomy, if not into separate companies.

The sixth trend concerns the innovation envelope relationship between equipment suppliers and semiconductor firms in the U.S. The basic relationship was governed by market forces of price, delivery, and quality and was organized as a loose network of these market-based contracting relationships. The origin for this configuration of the innovation envelope is found in the self-organizing processes at work in the early development of the semiconductor industry in the U.S. Like most of the semiconductor industry, the equipment supplier firms began as spinoffs and start-ups. The relationship was important, since advances in semiconductors could only be made if equipment was available to mass-produce the devices. In the early years, the center of process innovation lay more closely with the semiconductor companies. Robert Noyce's development of the Planar process for fabrication while at Fairchild is perhaps the best example of this. This put the equipment companies in a less than advantageous position relative to the semiconductor companies, which led to a less than cordial relationship from time to time.

Add to the above the ordering practices that existed between the electronic systems users of ICs and the semiconductor firms, and between the semiconductor firms and the equipment suppliers, and at times the relationship could be downright hostile. Electronics firms would often double- or triple-book semiconductor orders in order to be assured an adequate supply during good times. This would lead to overestimations of demand by the semiconductor companies and over-ordering of equipment from equipment makers. When demand for electronic systems slowed, the double orders were dropped and the demand for semiconductors evaporated, causing the semiconductor companies to cancel their orders for equipment. Since the semiconductor equipment was expensive and not many units were sold, the loss of even a few orders would cause the equipment companies to have difficult times maintaining technology development momentum. It was once remarked that if the electronics companies got the sniffles, the semiconductor companies caught cold and the equipment companies suffered pneumonia.

This market-contract-based, loosely governed network worked until the mid-1970s to late 1970s, when it began to compete against the more tightly linked relation-based club arrangement that existed in Japan. U.S. equipment suppliers were slower in developing the latest equipment needed to produce high-quality semiconductors in volume, especially DRAMs. The DRAM was special because it was a commodity semiconductor device, so its design was similar within each generation, and it was produced in such volume that it literally drove advancements in the processing technology needed to fabricate it and any other semiconductor device. The Japanese semiconductor companies were able to dominate in DRAMs, partly because of the closer ties that existed between the equipment suppliers and the semiconductor companies. These closer ties allowed for a more efficient use of resources in developing each new generation of DRAM (Methé, 1985, 1991, 1992a). It is not surprising that as U.S. semiconductor companies began to exit the DRAM segment of the semiconductor industry, so too did U.S. equipment suppliers. The sense of crisis that this generated spurred the various actors connected to the semiconductor industry to act.

The establishment of SEMATECH was part of the U.S.'s institutional answer to the crisis. The impact of SEMATECH and various other initiatives related to semiconductors that sprang from the government or from the semiconductor industry itself—such as the Semiconductor Research Corporation (SRC), which helped foster better university-industry relationships—was not just in reviving the U.S. equipment firms and IC firms, but also in enhancing the technological forces that were globalizing the semiconductor industry.

These techno-global forces lay in the increasing capital cost of semiconductor equipment accompanied by the decreasing unit cost of the semiconductor devices themselves. The decreasing unit cost meant that semiconductor devices were finding their way into myriad applications because of the cost advantages they gave over other non-electronic switching devices. As such, any electronic systems company needed a supply of semiconductor devices in order to compete in its respective market. As the electronics industry globalized, especially to other parts of Asia, this need spread as well. SEMATECH's work on equipment technology facilitated the growth of Korean and Taiwanese firms by providing better information about equipment technologies. Although the cost of equipment continues to rise, the greater information on the direction and pacing of innovation along various equipment trajectories allowed for market-based transactions to occur and reduced uncertainty in evaluating the alternatives offered for new equipment innovation. The changes in the semiconductor industry wrought by these techno-global dynamics have come full circle in their influence on institutional responses such as SEMATECH, which recently lost its U.S. government financial backing and has evolved into International SEMATECH (ISEMATECH) and begun to accept non-U.S. firm participation. We will discuss these issues in the final sections of this chapter.

The U.S. equipment suppliers were aided, then, by two market-related developments. The first was the emergence of the microprocessor and later other logic devices, such as application-specific integrated circuits (ASICs) that could be made in enough volume to drive processing technology. The second was the breaking of the bipolar orientation of the global semiconductor industry away from a U.S.–Japan axis with the emergence of South Korean and later Taiwanese semiconductor companies. Both of these developments created virtuous cycles between the non-Japanese equipment suppliers and the non-Japanese semiconductor companies. The standardization of equipment technology and the more open and transparent evaluations that could be performed on it made it more readily available to new entrants. The emergence of new customers for the non-Japanese equipment suppliers drove their gradual reascendance in the market.

4.3 The European Integrated-Circuit Industry[4]

System houses that have diversified into the technology by setting up divisions or subsidiaries, some as joint ventures with U.S. companies and some entirely on their own, have dominated the European semiconductor industry. Rather than take this year by year, as we did in examining the U.S. semiconductor industry, we will examine the European industry on a firm-by-firm basis.

In 1978 the dominant companies were Philips and Siemens. Their semiconductor operations were company divisions and had begun early; Philips started in 1964 with its Components Division. In 1991 a separate product division, Philips Semiconductor, was created out of the Components Division in order to focus activities on semiconductors. Siemens began research on semiconductors in 1949 and was producing integrated circuits in 1963. In 1988 the Siemens Semiconductor Group was established as a self-standing unit within Siemens AG. In 1999 this group was spun out as Infineon.

ITT Semiconductor was a subsidiary of the ITT Corporation in the U.S. that was formed in 1952 in Germany as Intermetall GmbH to sell germanium transistors and diodes. SGS-Ates was the merger of Ates, a subsidiary of the Italian

Table 4.3 Top 10 Semiconductor Firms in the European Industry for Selected Years

Rank	2002	1995	1992	1989	1985	1983	1978
1	***STMicro***	***SGS-Thomson***	**Philips**	**Philips**	**Siemens**	**Philips**	**Philips**
2	***Infineon***	**Philips**	***SGS-Thomson***	***SGS-Thomson***	**SGS-Ates**	**Siemens**	**Siemens**
3	**Philips**	**Siemens**	**Siemens**	**Siemens**	**Philips**	**SGS-Ates**	**ITT**
4	**Bosch**	***TEMIC***	**GEC Plessey**	**Plessey-Ferranti**	**Thomson**	**ITT**	**SGS-Ates**
5	*Micronas*	**GEC Plessey**	**ITT**	**ITT**	***Inmos***	**Thomson**	**Thomson-CSF**
6	**Alcatel**	**Ericsson**	**Ericsson**	**Telefunken**	**ITT**	**Ferranti**	**Plessey**
7	***AMS***	**Alcatel Mietec**	**MHS Semi**	**Matra Harris**	**Ferranti**	**Inmos**	**Ferranti**
8	**Ericsson**	***Austria Mikro***	**Telefunken**	***Austria Mikro***	**Plessey**	**Plessey Telefunken**	
9	X-Fab	**ITT Semi**	**Mietec**	**ABB Hafo**			
10	Melexis	***EM Micro Elec***	***Austria Mikro***	**Marconi**			

Key:
BOLD: Diversifying Entrant with Electronic Systems Connection
ITALICS: Start-up as an Integrated Device Manufacturer
STANDARD: Start-up as a Fabless Design Firm or Foundry
BOLD ITALIC S: Shifting from Electronic Systems to Integrated Device Manufacturer
Sources: ICE Status, various issues; ICE Profiles, various issues; IC Insights Strategic Reviews, various issues

telecommunication company STET (Societa Finanziara Telefonica) that was set up in the 1950s, and SGS, which was set up by Olivetti also in the 1950s. SGS had entered the semiconductor industry through a joint venture with Fairchild in 1960. Fairchild withdrew from the joint venture in 1968, and it reverted back to SGS. In 1971 SGS-Ates was formed through the merger of the two companies by the Italian government. In 1981 SGS-Ates acquired Mostek from United Technologies Corporation, and in 1987 it was merged into Thomson to form SGS-Thomson. Thomson-CSF is the parent company of Thomson Semiconducteur and is part of the larger Thomson SA group in France. The Thomson group has continued to develop semiconductors for the military.

Plessey Semiconductors began in 1966 as a part of Plessey, Inc., an electronic systems house. It was merged with Marconi and acquired by GEC in 1990. Ferranti Semiconductor was a part of Ferranti, Ltd., an electronic systems house that was one of the first companies to build computers in the 1950s. It was merged with Plessey in 1988. Ferranti developed the gate array, 10 years before LSI Logic in the U.S. exploited it commercially. AEG-Telefunken, or simply Telefunken, was part of the Daimler-Benz group when it entered the semiconductor industry. Telefunken acquired 50% of Matra Harris Semiconductor (MHS) in 1989. Telefunken was itself folded into TEMIC, which was formed in 1992 when the Daimler group and Deutsche Aerospace set up a joint venture.

Inmos, which joined the top semiconductor vendors in 1983, was established in 1977 through a $50 million investment from the UK government. It developed some unique microprocessor designs such as the Transputer. Inmos was sold to Thorn EMI in 1984 and later sold to SGS-Thomson in 1988. Matra Harris Semiconductor, later just MHS, was formed in 1979 as a joint venture between Matra SA of France and Harris Semiconductor of the U.S. This joint venture was set up as one of several the French government encouraged to bring in semiconductor technology from abroad through a program called Plan Circuits Intégrés. The French government at the time owned Matra SA, and it was privatized in 1988. The company became a subsidiary in 1992 of the TEMIC organization, and is responsible for semiconductor operations in France. Austria Micro Systems (AMS) was established in 1981 as Austria GmbH. It was originally a joint venture between American Micro-Systems Inc. (AMI) and VOEST-Alpine AG. In 1987 it changed its name to Austria Mikro Systeme as AMI was withdrawing. It changed its name to Austria Micro Systems in 2001 and has become a privately held company with Aspern Industrie Beteiligungs AG holding 98% of the company's stock.

ABB Hafo was originally established in 1934 as a private research institute; it began to focus on semiconductor research in 1954 and was part of the ASEA group. It became a part of the Asea Brown Boveri Group in 1987. A Canadian firm, Mitel, acquired ABB Hafo in 1996. Mietec was formed in 1983 as a joint venture between Bell Telephone Manufacturing Co., a subsidiary owned by ITT, and GIMV, a Flanders regional investment company. In 1987 the telecommunications activities of ITT were merged into Alcatel's operations and Mietec went with them. In 1990 Alcatel purchased all the remaining shares of Mietec, and the name of the company was changed to Alcatel Mietec. In 2002 Alcatel sold its semiconductor operations to STMicro.

EM Microelectronic-Marin was founded in 1975 as a division of the Swiss Ebauches Electronics SA, which was part of ASUAG, a larger group of Swiss watchmaking companies. Ericsson Microelectronics was the semiconductor division of the Ericsson electronics company. It began operations in the early 1970s, and much of its activity was captive. It moved into the merchant market more in the 1990s. In 2002 it sold off much of its semiconductor operations to Infineon, which was the semiconductor operations unit of Siemens. As noted above, Infineon was spun off from Siemens in 1999, but it is still majority-owned by Siemens at about 19%. It is, however, seen as a system house organizational form transitioning into an IDM form.

Micronas has a more complex history, since part of it was founded in 1980 as a subsidiary of Nokia, and then in 1989 Crosstec Engineering AG acquired it. The Micronas name was kept, and in 1992 it became an independent company. Micronas acquired the semiconductor operations of ITT Semiconductor in 1997, and then went through a restructuring in 1998, selling off the remains of the old Nokia division; therefore we are classifying this as an IDM start-up. X-Fab is a pure-play foundry company formed in 1999 when Belgium's Elex NV combined three of its semiconductor facilities into one company. Melexis is also part of the Elex NV organization and a major customer of X-Fab. We classify X-Fab as a foundry start-up. Melexis Microelectronic Integrated Systems originally was established in 1988 and produced primarily ASICs. It is part of the Elex NV holding company along with X-Fab and Thesys Mikroelektronik GmbH. We have classified this company as an IDM start-up.

Several trends can be identified from the analysis presented above. First, the role of the large system houses in establishing semiconductor operations in Europe dominates all other organizational forms. IDM start-up forms did occur, but few became large or remained independent in the European institutional environment. The system house organizational form has dominated from the beginning of the European semiconductor industry. This industry was highly fragmented by national markets throughout much of its history, and much of the European demand for semiconductors—more than 60% in many years—was filled either by Japanese or U.S. firms. Even if generous amounts of venture capital had been available, it would have been difficult to support these newly entering firms.

Second, governments played a much more direct role in establishing and shaping the topography of the European semiconductor industry. This is seen in the active participation of various national governments in the establishment of semiconductor companies. This governmental activity went further when it was recognized that national markets would not sustain the operations of national champions. Cross-border mergers were set up between various national champions. Many began occurring in the late 1980s in preparation for the 1992 unification of European markets. Governments also played a more traditional role. The various governments comprising Europe established research institutes and funded research consortia concerning semiconductors and electronic systems. BRITE and ESPRIT were two formed during the 1980s, and Interuniversity MicroElectronics Center (IMEC) is a current research consortium. Unlike previous consortia that focused on a limited set of objectives, IMEC is an ongoing consortium of university, business, and government researchers carrying out midterm research focused on advancing semiconductor fabrication technology.

Third, when start-up companies began as IDM organizational forms or later as fabless/foundry organizational forms, these companies often drew their financial resources from either holding companies or regional development companies, or from the participation of system houses. The line demarcating the IDM start-up and system house organizational forms is less clear in the European institutional setting than in the U.S. institutional setting. Philips and Siemens were true system houses because these two companies were connected to multiple electronics markets. Many of the European system houses were diversifying entrants from the military or industrial electronics/computer markets. The domination of the system house form also had an impact on the human resources necessary for starting up a firm. Moreover, most of the downstream customers of the semiconductors produced in Europe were the very same system houses.

Fourth, merger and acquisition activity took place in the U.S., but in Europe the effect was more marked because the industry has been experiencing consolidation throughout its history. According to some estimates, the top 2 firms accounted for 87% of the semiconductor output in Europe in 2003. This high level of concentration was exhibited throughout the history of the European market, where the top 2 or 3 firms controlled anywhere from 70% to 90% of the market. In the U.S. the continued entry of new firms has muted the consolidation effect of mergers and acquisitions. This consolidation around a few large firms and the lack of continual renewal through start-up entry is one explanation why some years have fewer than 10 firms in the top list.

The fifth trend is seen emerging in the last year of the data: movement to the independent IDM organizational form with STMicro, Infineon, and the emergence of companies like Micronas and Melexis and the foundry X-Fab into the top list. The European semiconductor topology is beginning to resemble that of the U.S. in its mix of organizational forms, with system houses, IDMs, and foundry organizational forms coexisting. Two caveats need to be interjected concerning this recent trend. It is just appearing, and in its nascent form may be blunted or redirected by other environmental or institutional factors; also, the level of concentration, as noted, is higher in Europe than in the U.S., which has a substantial impact on the distribution of the resources necessary for a firm representing a particular organizational form to get established and survive.

The sixth trend concerns the configuration of the innovation envelope for the European semiconductor industry. Most of the semiconductor industry equipment firms in Europe were spun off from semiconductor companies, but the connection was tighter than in the U.S. case because of the connection of the semiconductor companies to the larger system houses, which in turn were often connected to larger industrial groups. Furthermore, because the European semiconductor companies often served small fragmented markets and supplied mainly domestic electronics firms, few process innovations originated in Europe relative to the U.S. and Japan. The European manufacturers were slow to move from bipolar process technology to MOS process technology and often lagged by as much as six months to a year behind their U.S. and Japanese counterparts. Because of the techno-global forces driving the semiconductor industry, those equipment firms that became competitive, such as Kulicke & Soffa and Schlumberger, did so in the less technologically advanced equipment areas and established their presence early in the U.S. or Japanese markets.

4.4 The Japanese Integrated-Circuit Industry[5]

In the Japanese situation, as in Europe, the dominance of large diversifying system houses is evident. Unlike the European situation, the Japanese system houses were more like Philips and Siemens with connections to multiple downstream electronics markets. Although the Japanese semiconductor industry has been well covered in this volume (see Okada's chapters) as well as in other works (see Methé, various works), several key trends should be given additional attention. The first is that the Japanese semiconductor system houses were not all equal in terms of access to resources. There is an important distinction that

Table 4.4 Top 10 Semiconductor Firms in the Japanese Industry for Selected Years

Rank	2003	2002	1995	1992	1989	1985	1983	1978
1	***Renesas***	**NEC**	**NEC**	**Toshiba**	**NEC**	**NEC**	**NEC**	**NEC**
2	**Toshiba**	**Toshiba**	**Hitachi**	**NEC**	**Toshiba**	**Hitachi**	**Hitachi**	**Hitachi**
3	***NEC Elec***	**Hitachi**	**Toshiba**	**Hitachi**	**Hitachi**	**Toshiba**	**Toshiba**	**Toshiba**
4	**Sony**	**Fujitsu**	**Mitsubishi**	**Fujitsu**	**Mitsubishi**	**Fujitsu**	**Fujitsu**	**Mitsubishi**
5	**Fujitsu**	**Mitsubishi**	**Fujitsu**	**Mitsubishi**	**Fujitsu**	**Matsushita**	**Matsushita**	**Fujitsu**
6	**Matsushita**	**Matsushita**	**Matsushita**	**Matsushita**	**Matsushita**	**Mitsubishi**	**Mitsubishi**	**Matsushita**
7	**Sharp**	**Sony**	**Sanyo**	**Sharp**	**Sharp**	**Sanyo**	**Sanyo**	**Sanyo**
8	*Rohm*	**Sharp**	**Oki**	**Sony**	**Sanyo**	**Oki**	**Oki**	**Sharp**
9	**Sanyo**	**Sanyo**	**Sharp**	**Sanyo**	**Oki**	**Sharp**	**Sharp**	**Oki**
10	**Oki**	*Rohm*	**Sony**	**Oki**	**Sony**	**Sony**	**Sony**	**Sony**

Key:
BOLD: Diversifying Entrant with Electronic Systems Connection
ITALICS: Start-up as an Integrated Device Manufacturer
STANDARD: Start-up as a Fabless Design Firm or Foundry
BOLD ITALIC S: Shifting from Electronic Systems to Integrated Device Manufacturer
Sources: ICE Status, various issues; ICE Profiles, various issues; IC Insights Strategic Reviews, various issues

must be made between system houses like NEC, Hitachi, Toshiba, Fujitsu, Oki, and Mitsubishi Electric, the *sogo denki* makers, who made industrial electronics and computers as well as consumer electronics, and companies like Matsushita, Sony, Sharp, and Sanyo, who focused on consumer electronics. Further, it was the *sogo denki* makers of semiconductors who were included in government-sponsored research consortia, the most famous of which was the Cho LSI Kenkyu Kumiai (VLSI Research Cooperative) (Methé, 1985).

Second, the institutional environment changed over the history of the Japanese semiconductor industry from one of "catch-up" to one of "integration" and back to "catch-up." This can be seen in the role of the government and the various sponsored consortia that changed as a result of the shift from the bipolar competition between the U.S. and Japan to the multipolar global industry that exists today. The effect of these consortia can be debated, but the VLSI Research Cooperative was credited with much of the success of the Japanese semiconductor companies in overtaking the United States, at least in the minds of U.S. policy makers and the leaders of the various industry associations linked to the U.S. industry. Efforts were made by the U.S. side to open up access to these Japanese government-sponsored research endeavors, and for both policy and practical reasons the Japanese government allowed foreign access to various electronics-related research programs, as seen in the SELETE program. The focus also shifted within these programs away from the more practical aspects of readying the technology to launch the next generation to more long-term or basic research-oriented goals. This process shifted again in the late 1990s as the Japanese firms found themselves behind the Koreans and Taiwanese in memory and fabrication technology and unable to match the U.S. companies in the heavily design- and market-oriented logic areas. Recent research consortia such as ASPLA, ASUKA, and others have attempted to remedy this situation.

Third, many companies in the Japanese semiconductor industry, especially the *sogo denki* makers, were connected not only downstream to various electronics markets, but also upstream to various semiconductor equipment companies through the innovation envelope. These relationships could be as wholly owned subsidiaries or as in-house production units, but more often than not they were the equity relationships known as vertical *keiretsu* ("business group"). The impact of these upstream linkages with equipment companies was important in the early years because they enabled the Japanese semiconductor companies to catch up and then surpass their U.S. counterparts in fabrication process technology (Methé, 1985, 1991a). The relationship between the equipment companies and the semiconductor companies was tighter than in the U.S. or European cases and was relation-based—that is, based on long-term mutual commitments to co-develop fabrication technology and refine it for the primary contractor. The character of this relationship shifted from facilitator to inhibitor as the context of the semiconductor industry began to change around the end of the decade of the 1980s and early 1990s.

During the period when the global semiconductor industry was bipolar in terms of market contenders, from roughly the late 1970s (1978) until the early 1990s (1993), with Japanese and U.S. companies in heavy competition, the strong links between equipment companies and semiconductor companies that existed in Japan helped the Japanese to gain and then maintain their lead in fabrication process technology. This was evident in the DRAM market that drove innovation in this technology, especially in the decades of the 1970s and 1980s. Japanese semiconductor and equipment makers could co-develop new fabrication process technology faster than their U.S. counterparts could.

Furthermore, the Japanese equipment makers would continually fine-tune the equipment after it was in place to the exact specifications of the Japanese semiconductor maker in order to increase the yield from the fabrication line. As noted, U.S. semiconductor companies had more loosely linked network relationships with their equipment suppliers, and these were governed by market-based contracting as opposed to the more relation-based contracting of the Japanese. One outcome of the bipolar competition between the U.S. and Japan was the creation of SEMATECH, which worked to advance and standardize fabrication process technology, thus diffusing advanced process technology more rapidly out into the industry. U.S. equipment suppliers could then add customized software solutions to the technology with the hope of gaining advantages over their equipment rivals.

With the emergence of a multipolar semiconductor industry, the Japanese equipment and semiconductor companies were now faced with an entirely different industry situation. The advantage of closely linked innovation envelope relationships that had been so important in the 1970s and early 1980s began to fade in the late 1980s as equally good or better fabrication technology became available. Further, as Japanese semiconductor companies lost momentum in the DRAM segment of the semiconductor industry to the new Korean competitors, their ability to fund the increasing demand for capital needed for new equipment faltered. This started to drive the Japanese equipment manufacturers to search for new customers. The Achilles' heel of Japanese electronics firms in general has always been in the area of software development and systems integration. With the growing importance of software-controlled fabrication equipment, the Japanese equipment makers were at a disadvantage, and one that could not be compensated for by the sharing of information with Japanese semiconductor firms, which were equally as deficient. The advantage of a tightly linked innovation envelope had now become a disadvantage.

To understand further why the Japanese began to lose momentum in the DRAM industry, we find it important to note a macro-institutional event that occurred in 1985. The Plaza Accord raised the value of the yen substantially against the dollar. This agreement between the Japanese government and the other OECD member governments was not aimed specifically at the semiconductor industry, but it had an impact on it nevertheless. We will discuss the Korean semiconductor industry more fully below, but the Plaza Accord opened the door for the Koreans to come in with lower priced DRAMs, in dollar terms, than the Japanese. The 1985 Plaza Accord put an effective floor under the price of Japanese DRAMs relative to Korean and U.S. companies. The heavy dependence of Japanese semiconductor companies on DRAMs for much of their revenue as well as volume placed a considerable burden on them in terms of financing the further development of new processing technology. This burden was magnified by the slowdown in the growth of the Japanese economy overall after the bursting of the "Economic Bubble" in 1990 and in the slowdown in consumer electronics within Japan.

The Japanese semiconductor companies were part of the system house operations of the Japanese electronics companies. Much of the volume production of semiconductors was driven by the growth of the consumer electronics industry. Japanese system houses and the *sogo denki* makers in particular were more dependent on the domestic Japanese market than were the other electronics companies, such as Sony, Matsushita, Sharp, and Sanyo. Consequently, as demand for consumer electronics began to wane in the Japanese domestic market, price competition intensified and this affected the margins of all electronics companies. The situation of the PC industry in particular had an impact on the *sogo denki* makers, especially NEC and Fujitsu, after the arrival of viable foreign competitors (Methé et al., 1998a, 1998b).

These broader institutional, economic, and specific consumer electronics industry related factors put differential pressure on the various system house forms that supplied semiconductors and set in motion the fourth trend evident in the table above. The *sogo denki* system house form, as represented by NEC, Hitachi, Toshiba, and Mitsubishi Electric, began to withdraw from segments of the semiconductor industry, such as DRAMs. Hitachi and NEC created a joint venture for their DRAM operations called Elpida, which later absorbed the DRAM operation of Mitsubishi. Toshiba sold off its DRAM operation to Micron, a U.S. IDM. NEC further streamlined its semiconductor operations by spinning off its logic device operation as NEC Electronics in November 2002. NEC Electronics went public in July of 2003, although NEC is still the largest single shareholder after the initial public offering (IPO). This accounts for the system house shifting to the IDM designation as its organizational form in Table 4.4. The same can be said for Renesas, the joint venture for logic devices that is a combination of Hitachi's and Mitsubishi Electric's logic operations. Currently, Hitachi has 55% of the equity and Mitsubishi Electric 45%. Renesas has yet to have its IPO, but one is planned. These two firms, NEC Electronics and Renesas, are concentrating much of their efforts on what has become the system-on-a-chip (SoC) segment of the semiconductor industry, an outgrowth of the older ASIC segment. This trend of shifting to an IDM organizational form with a focus on the SoC will most likely continue as companies like Fujitsu, Toshiba, Matsushita, Sony, and other system house firms that made semiconductors continue to have difficulties competing in the market. It remains to be seen if this strategic approach will be successful or not. As noted above, the Japanese electronics firms have had problems in developing their capabilities in software development and engineering. This is particularly troubling because success in the SoC segment requires, among other capabilities, sophisticated software engineering for embedding the software on the chip itself.

In the DRAM area, only Elpida remains. It is not listed in the table because its operations are not large enough to qualify, but it is also indicative of the movement toward the IDM organizational form that is evident in the cases of NEC Electronics and Renesas. Elpida has had a difficult time of it but was able to move toward a successful IPO on April 28, 2005. Rohm, which first appeared on the top supplier list in 2002, was established in 1958. It began producing integrated circuits in 1981 and has a more focused strategy when confronting the selling of them in the merchant market. Although it is not a semiconductor start-up per se, it is much more akin to the IDM form than to the system house form, since semiconductor devices generate about 85% of its revenue and the company does not produce any electronic systems products, only components. It is a focused operation that has carved out competitive positions in selected segments of the semiconductor industry, such as signal processing and control chips for multimedia applications, and is a leading company in nonvolatile memory devices. It represents an alternative organizational form to the more dominant system house form and appears to be more profitable.

A fifth trend is seen more in its absence because few other companies in Japan have emulated Rohm's success. As a result of the barren environment in terms of human, financial, and other resources necessary for entrepreneurial start-ups to begin and grow, few such start-ups have entered the Japanese market (Methé, 2005; Methé and Bracker, 1994; Bracker and Methé, 1994). This lack of start-up organizational form support is deeply ingrained in the Japanese economic system and has inhibited the birth and growth of even the fabless organizational form. It should be remembered that this form originated in the U.S. as a counter to the high cost of entering with a fabrication facility. There have been no foundry start-ups either. Some of the system house forms have diversified into foundry operations, however. The alliance in 2000 between Hitachi and UMC in creating Tricenti was such a diversification. This alliance ended in 2002, however, because Hitachi bought out its UMC partner and later transferred the Tricenti operations to Renesas in 2003. Renesas has closed down the foundry operation, converting it into a leading-edge production fab for Renesas.

4.5 The Korean Integrated-Circuit Industry[6]

Anam Industrial, one of the Korean *chaebol* (large industrial group), initiated the Korean semiconductor industry with the development of contract services in 1968. Through its connections with Amkor, a U.S. firm that still offers services in the area of packaging and testing, Anam Industrial began offering assembly and testing services in Korea. Throughout the 1970s and into the 1980s, both Anam and Amkor did much of the spadework to promote the front end, or fabrication process, and the back end, or assembly and test process, in Korea. In the 1980s, European and U.S. firms—partly in response to the challenge coming from Japanese producers—availed themselves of the lower labor costs and skilled and increasingly knowledgeable engineering talent in Korea (Kim, 1997). However, the Korean semiconductor industry did not really begin to take off on its own until the early to late 1970s as the government set semiconductor technology as one of the key areas for future growth.

Drawing on the engineering talent that was graduating from the Korean Advanced Institute of Science and Technology (KAIST), the government set forth in its fourth five-year plan the specific target of developing an indigenous semiconductor industry in Korea. In the early 1980s the focus of this development plan became the DRAM segment of the semiconductor industry. Through a combination of government promotion and the astute strategic moves of several of the large Korean *chaebol*, the semiconductor industry grew rapidly throughout the late 1980s and into the 1990s. The *chaebol* were tapped early for the development of semiconductor technology in Korea, and with the entry of Korean *chaebol* firms such as Samsung Electronics in 1983, Hyundai Electronics Industries in 1983, and Goldstar Electron in 1989 (the latter being a combination of the semiconductor operations of Goldstar Company and Goldstar Semiconductor that had begun in the early 1980s), a critical mass of financial and human resources was quickly created.

Of these three *chaebol* players, Goldstar, which changed its name to LG Electronics, was the weakest and would in 1999 lose most of its semiconductor operations to Hyundai. Daewoo, which began its electronic systems operations in 1974, also entered into the semiconductor industry in the early 1980s, but did not develop into a strong enough contender to take its place within the Korean

Table 4.5 Top 10 Semiconductor Firms in the Korean Industry for Selected Years

Rank	2002	1995	1992	1989	1987	1985	1983
1	**Samsung**	**Samsung**	**Samsung**	**Samsung**	**Samsung**	**Samsung**	(LITTLE sophisticated semiconductor production done by indigenous Korean firms)
2	***Hynix***	**Hyundai**	**Hyundai**	**Hyundai**	**Hyundai**	**Hyundai**	
3	***Anam/Dongbu***	**LG Semi**	**Goldstar**	**Goldstar**	**Goldstar**	**Goldstar**	
4					**KEC**	**KEC**	

Key:
BOLD: Diversifying Entrant with Electronic Systems Connection
ITALICS: Start-up as an Integrated Device Manufacturer
STANDARD: Start-up as a Fabless Design Firm or Foundry
BOLD ITALIC S: Shifting from Electronic Systems to Integrated Device Manufacturer or Foundry
Sources: ICE Status, various issues; ICE Profiles, various issues; IC Insights Strategic Reviews, various issues

domestic semiconductor industry and then displace Japanese firms in the DRAM industry as Samsung, Hyundai, and Goldstar did. Many of the human, technological, and financial resources of the *chaebol*, as seen in the LG Electronics case, were recirculated among the remaining *chaebol*, rather than out into entrepreneurial start-up firms.

The combination of focused firm strategy and government policies that supplied both financial and human resources helped to shape the Korean semiconductor industry. Korea is a latecomer both to industrialization and to the high-technology world of semiconductors. As such, it has experienced both the benefits and the costs of the techno-global forces that have been driving the global semiconductor industry. The competition between the Japanese and U.S. segments of the semiconductor industry opened up opportunities for the Korean companies to gain valuable technological knowledge, especially as U.S. equipment firms were looking for new markets for their fabrication equipment. Furthermore, the Korean industry's proximity to Japan opened up opportunities to secure technology either through strategic alliances or by paying for moonlighting Japanese engineers to come to Korea periodically to help with various design and production problems. Although Korean semiconductor companies make a wide variety of semiconductor types, both logic devices and memory devices, the focus on DRAM production made the acquisition of knowledge easier.

The Korean semiconductor industry is also a captive of its latecomer industrialization roots in terms of the institutional environment in which it was born and grew up. The government supplied financial resources through various grant and loan programs. These had traditionally gone to members of the *chaebol*, and those aimed at the semiconductor industry were no different. Likewise, the government's efforts to supply good engineering talent were met with the demand from the *chaebol*. The best engineering talent competed for positions with Samsung, Hyundai, LG, and Daewoo. This left little for smaller *chaebol* or companies not fully connected to these industrial giants, let alone anything for entrepreneurial start-ups.

Furthermore, this engineering talent was young and inexperienced in semiconductor fabrication. However, the fact that many Korean nationals had emigrated to the U.S. and had worked in the U.S. semiconductor industry helped to bring seasoned talent into the companies in areas such as project management. Again, the larger *chaebol* members were able to attract the best overseas talent to return to Korea in order to work for them. Many of these returnees ended up managing critical elements of each *chaebol*'s entry into sophisticated integrated-circuit production. They provided the necessary managerial and project experience that was lacking with the younger homegrown engineers, and this enabled these companies to grow rapidly.

These factors explain why only 3 or at most 4 firms are listed as the top companies for the various years in Korea. It also explains why most of these are essentially of the diversifying system house organizational form. Each of the companies occupying a top position—and the concentration ratio in the Korean semiconductor industry is around 80%–90% of production with these top 3 or 4—is a member of one of the large industrial groups that still dominate the Korean economy. Only in the past few years, beginning with the financial crisis of 1997 and followed by the collapse of the semiconductor industry in 2001, have we seen the emergence of different types of organizational forms.

The Korean government's attempts to reign in the power of the *chaebol* took a serious turn after the financial crisis of 1997. The recognition that the Korean economy was very top-heavy with the *chaebol* occupying the best positions in many industries, coupled with the sudden loss of economic growth that followed the Asian financial crisis, brought about a different policy environment concerning the future activities of the *chaebol*. Furthermore, the *chaebol* were not always run with the best of managerial decision-making algorithms. Samsung's move into the automobile industry was not based on sound economic and financial reckoning, but more on the chairman's interest in the auto industry in general and automobiles in particular. Daewoo's drive to become large in terms of market share often left it with a lot of debt and not the most efficient operations. As a result the government ordered that the *chaebol* members rationalize their operations. This had an impact on the semiconductor industry because LG's semiconductor operation, LG Semicon, was sold to Hyundai in October 1999. In taking over the LG semiconductor operation, the Hyundai group also had to assume the debts of LG. The new company was called Hynix.

The creation of Hynix came when the DRAM segment of the semiconductor industry was moving through a rapid series of peaks and troughs, culminating with the worst downturn in the industry's history in 2001. Hynix has been in near bankruptcy since then and has been under considerable pressure to separate its memory from its non-memory operations. This saga still continues today with no clear end in sight. Although Hynix is more focused—having spun off its telecommunications and liquid crystal display (LCD) operations—than its predecessor, conforming more closely to an IDM organizational form, it is still an open question, given the ownership issues to be determined, whether it will adopt a true IDM form. The role of the Korean government became an issue with Hynix as well because the company was hit with 57% tariffs by the U.S. for receiving subsidies from the Korean government. These subsidies kept the company afloat during 2001 and 2002 by allowing Hynix to sell its DRAMs below cost.

Several important trends can be observed from the Korean semiconductor case. First is the role of the techno-global aspects of the semiconductor industry. Knowledge and skills were gained because of the industry's globalization through the flow of people and equipment. Further the bipolar axis of the industry between the U.S. and Japan during much of the 1980s opened up opportunities for the diversifying Korean entrants to gain access to knowledge from both contenders. Second, as noted above, the broader institutional factor of the Plaza Accord in 1985 created a price floor below which the Japanese producers of DRAMs could not go. This allowed the Korean suppliers of DRAMs to compete on price at a time when they were still untested as suppliers of this important commodity device. Third, the institutional latecomer environment clearly shaped the size of the Korean industry and the organizational forms that were able to enter. The diversifying system house organizational form dominated from the industry's inception and throughout the 1980s and 1990s.

Fourth, the very narrow focus of the Korean semiconductor companies on DRAMs facilitated their entry, but put them in a trap. The DRAM industry is a commodity industry and one that is subject to business as well as silicon cycle fluctuations. Furthermore, the drive of the Korean semiconductor companies to outperform the Japanese led them to invest in capacity beyond what would have been economically feasible had the institutional support of the Korean government not been available. As a result, the overcapacity created by the Korean manufacturers and their over-reliance on DRAMs has also led to their being hurt more than others when this industry turns down. Some fabless design houses and IDM organizational form companies have entered in non-memory areas, especially in the middle to late 1990s as the Korean government has attempted to open up the economy to more domestic competition, but none of these firms has achieved any significant global market presence as yet.

Fifth, in terms of the innovation envelope, the volume generated by the focus on DRAMs has created an environment out of proportion to the number of device companies. As a result the equipment segment of the industry includes foreign firms from the U.S., Japan, and Europe as well as the indigenous Korean semiconductor equipment suppliers. Most of the Korean suppliers, however, were established to serve the Korean semiconductor companies and must work harder to develop a global presence. This is especially true because the number of Korean companies in the DRAM industry has declined.

A sixth trend, which is just emerging and is not evident from the table or our discussion to date, but it is quite evident from visiting the Web site of the Korea Semiconductor Industry Association (KSIA) and from discussions with Korean semiconductor engineers and managers, is the recent entry of fabless design house IC firms. Their number is not great, but several of these firms adopting the fabless organizational form have entered since the middle to late 1990s. It is too early to tell if these firms will have a measurable impact on the semiconductor industry in Korea, but they are indicative of the techno-global dynamics of innovation driving the integrated-circuit industry.

4.6 The Taiwanese Integrated-Circuit Industry[7]

The Taiwanese semiconductor industry is also a true latecomer to the global semiconductor industry, but its story, though bearing some resemblance to the Korean one, is remarkably different (Hu, 1997). As a latecomer, it features the same agents, or players, but they are configured differently. The regular players were the government, indigenous companies, emigrants returning from the U.S., foreign semiconductor companies, and foreign semiconductor equipment companies. The beginnings of the semiconductor industry in Taiwan go back to action taken by the Taiwanese government in setting up the Industrial Technology Research Institute (ITRI) in 1971. Concern for electronics first manifested itself within the ITRI organization with the establishment of the Electronics Research Service Organization (ERSO). The activities within ERSO resulted in the spin-out of the United Microelectronics Corporation (UMC) in 1979. This event set the difference in tone between Taiwanese semiconductor industry efforts and those of either Japan or Korea.

UMC began in 1980 as an IDM start-up and went public with an IPO on the Taiwan Stock Exchange in 1985. It moved from the IDM organizational form to the foundry organizational form in 1995, though it had had some foundry operations after 1982. It was the first semiconductor company to do so. In 1987 another company was spun out of ITRI, Taiwan Semiconductor Manufacturing Company (TSMC). As noted in a previous section, this company had financial support that was about equally divided among the Taiwanese government, Philips, and private investors. TSMC was the first pure foundry start-up in the world. In 1994 another company, Vanguard International Semiconductor Corporation (VIS), started up as an IDM organizational form focusing initially on memory devices, especially DRAMs. Since then, ITRI and even ERSO have largely withdrawn from active support of the semiconductor companies and moved on to other emerging technological areas.

These companies were nestled in a newly created science park in the city of Hsinchu. The park was set up through the National Science Council and has received government funding, but a Park Administration runs it with about 89% of its funding coming from private sources. Foreign companies can set up in the park, and about 53 of the 335 companies currently in the park are from other countries. It is also the home of a wide variety of technology-related companies, not just semiconductor companies. As of 2002 the park had 136 companies related to the semiconductor industry. Of these, 75 were fabless design start-ups and 14 were IDM types. The Park Administration offers a variety of services, but one that was important to returning engineers was the establishment of schools within the park. The National Experimental High School was set up in 1983 and runs programs in English and Chinese from kindergarten through high school. This educational service eliminated a major stumbling block for returnee

Table 4.6 Top 10 Semiconductor Firms in the Taiwanese Industry for Selected Years

Rank	2002	1995	1992	1989	1987	1985
1	TSMC	TSMC	UMC	UMC	UMC	(LITTLE sophisticated semiconductor production done by indigenous Taiwanese firms)
2	UMC	UMC	TSMC	TSMC	*Quasel*	
3	*Winbond*	*Winbond*	*Winbond*	**Hualon**	*Mosel*	
4	*Nanya*	**TI-Acer**	**Hualon**	*Winbond*		
5	*Mediatek*	*Mosel-Vitelic*	*Holtek*			
6	VIA	*Macronix*	*Macronix*			
7	ProMOS	Hualon	*Mosel-Vitelic*			
8	*Macronix*	**Acer Labs**				
9	*SiS*	*Holtek*				
10	*Powerchip*					

Key:
BOLD: Diversifying Entrant with Electronic Systems Connection
ITALICS: Start-up as an Integrated Device Manufacturer
STANDARD: Start-up as a Fabless Design Firm or Foundry
BOLD ITALIC S: Shifting from Electronic Systems to Integrated Device Manufacturer
Sources: ICE Status, various issues; ICE Profiles, various issues; IC Insights Strategic Reviews, various issues

engineers and managers from the U.S., many of whose children had been educated in U.S. school systems.

Other companies have been established in and around the Hsinchu Science Park. Companies such as Winbond and Macronix began as IDM start-ups in 1987 and 1989, respectively, and Mosel and Vitelic, two privately held companies, began in 1983 as IDM start-ups and later merged. Mosel or MOS Electronics Taiwan was a Taiwanese start-up, and Vitelic was a U.S.-based start-up. Some were fabless start-ups such as VIA Technologies and SiS, both of which began in 1987. Others were diversifying entrants such as Hualon Microelectronics, which was established in 1984 as an assembly operation and began fabrication operations in 1987. It was part of the Hualon Group, a multibillion-dollar conglomerate at the time.

Another diversifying entrant was Acer Laboratories Inc., which began as an independent research and development company for the Acer Group in 1987 and became a fabless design house called ALi in 1999. Nanya Technology was founded in 1995 as a diversifying entry for the Formosa Plastics Group. Foreign companies have also been involved. TI set up a joint venture with Acer called TI-Acer in 1989 and Mitsubishi Electric set one up with Taiwan's Umax-Elite Group called Powerchip Semiconductor in 1994. Another, ProMOS Technologies, was initially a joint venture between an existing Taiwanese semiconductor company, Mosel-Vitelic, and Infineon. In a different entry pattern, the company

Holtek began as a fabless design form in 1983 and added a fabrication facility in 1989, but reverted back to its fabless organizational form in 1998. The variety of organizational forms entering and moving into the top listing of semiconductor companies in the Taiwan semiconductor industry is seen in only one other region, the United States. In some respects the Taiwanese industry is dominated more by the IDM and fabless/foundry start-up organizational forms than is any other region, including the U.S.

Several trends can be seen in this latecomer to the semiconductor industry. First, although the role of government was important in the formative years of developing a critical mass of semiconductor-related technology and knowledge, this role changed in terms of how that knowledge was diffused. The government chose to spin out companies as venture operations and then basically withdrew. Market forces were allowed to shape the development of the semiconductor industry in Taiwan. This is not to say that the Taiwanese government plays no continuing role in the semiconductor industry. This role, however, is not the direct role of subsidies and funding, but of tax incentives and the education of engineering and managerial talent. The Taiwanese government has not directly stepped in to rescue a failing company.

Second, electronic systems houses did exist, such as Acer and Hualon, but with the exception of these two and later Formosa Plastics, few moved into the semiconductor industry as diversifying entrants. By the time the larger industrial groups, such as Formosa Plastics, took an interest in the semiconductor industry, the IDM and fabless/foundry start-up organizational forms had become well established and difficult to dislodge. Part of the answer may lie in the fact that UMC began essentially as a proving ground for whether semiconductor technology could take root in Taiwan. Much of the technology was imported from the U.S., and many of the people at UMC had had some experience working in the U.S. semiconductor industry. In the early 1980s the semiconductor industry was a risky place for companies that were engaged in relatively simple electronic systems assembly. The investments and the skills and people resources needed were not readily available, and profits could be made by further investment in electronic systems operations.

Third, the Taiwan semiconductor industry has been an active source of new entrepreneurial start-up activity. The growth in the numbers of new entrants and the variety of semiconductor segments has a much broader base than in the growth in Korea. This is reflected in the top listing of semiconductor companies in Taiwan, which includes many fabless, foundry, and IDM companies. The 1987 founding of TSMC using the pure foundry organizational form set in motion forces that have affected both the Taiwan semiconductor industry and the world semiconductor industry. By legitimizing the fabless design house strategy, the yoke of ever-increasing capital investment was lifted from the neck of any engineer who had an idea for a new semiconductor device. This has opened up more opportunities for latecomers and mature countries alike if they have the institutional environment to support such entrepreneurial activities. However, the foundry/fabless nexus has had other impacts on the industry that may not be as beneficial.

Fourth, in the period running from the 1970s through about the early 1990s, there were several downturns. The silicon cycle of boom, overinvestment, bust, and underinvestment followed by a new boom has been repeated throughout each downturn. In the semiconductor industry of the periods throughout 1970–1990, memory and logic market segments were complementarily linked. Semiconductor companies focused on either logic or memory or both, and each used an IDM format even if the company itself was part of a system house. That is, all semiconductor operations were integrated to include design through fabrication and sales. If one company had a difficult time or even if the entire industry was confronted with an economic downturn, the fortunes of individual companies varied. The linking of many previously separated market segments occurs through the fabless/foundry nexus. From about the 1990s through the present, the global semiconductor industry has gone through another series of downturns that have been far more devastating in terms of their troughs than previous cycles and that have occurred closer together. Although it is difficult to establish a clear causal link between the emergence of the fabless/foundry strategy and the worsening of these cycles, the circumstantial evidence asks to be explored further.

Fifth, as with Japan and Korea, the innovation envelope tying the semiconductor industry to the equipment industry is in full activity in Taiwan. The role that equipment companies played and are continuing to play is that of diffusers of fabrication technology. The growth and strength of the Taiwanese semiconductor industry has altered the balance that existed before. Reinforcing the trend begun in Korea, the existence of another market outside the U.S.–Japan axis has freed up equipment companies to compete more on technical and market merit that emphasizes clear and transparent adherence to standards than on a customized approach that depends on intense company-to-company interaction. Although the Taiwanese semiconductor industry supports both indigenous and foreign equipment companies, the leading companies are still either Japan- or U.S.-based semiconductor equipment companies. Further, with the catching up to and surpassing of world semiconductor fabrication standards by Taiwanese companies such as TSMC, another node has been added to the global network of companies and research institutes developing next-generation semiconductor technology.

5 Some Observations on the Change Mechanism Role Played by the Interaction of Institutional and Techno-Global Forces on Organizational Forms

We have examined the theoretical and conceptual literature concerning the relationship of institutions to agents and the potential that this relationship brings for institutional change. We have seen that not only is there an endogenous source of change that can exist between institutions and agents as functional, political and social pressures are exerted, but that extra-institutional elements, in particular technology, can exert considerable influence for change. These change factors we termed techno-global; they are balanced by various institutional regimens that exist within the domestic national markets that were examined. How do these two forces interact in the integrated-circuit industry?

The change mechanisms that work endogenously within a current agent–institution relationship tend to be single-loop changes, that is, those that would continue to support the basic relationship and help buffer it against the extra-institutional environment. The development of SEMATECH was one such example. The founding firms were all U.S. incumbents in the integrated-circuit industry. They represented the already established system house IC and IDM IC organizational forms. The more recently emerging fabless design IC and foundry organizational forms were not part of the original SEMATECH organization. The development of new-process technology helped the established U.S. system house and IDM organizational forms to continue competing against Japanese system house organizational forms.

We also observed that whether intended or not, the combination of continuing extra-institutional change and the adjustments of the agents and institutions within a relationship can bring about a double-loop change. Continuing with the SEMATECH example, this occurred as SEMATECH began to change its original response to the techno-global pressure being exerted, from a response of developing process technologies related to specific integrated products to one of a more generic approach to innovation and standardization of semiconductor process technology. As noted above, this shift facilitated the emergence of both the Korean and Taiwanese semiconductor industries. It also facilitated the legitimization of the fabless and foundry organizational forms.

It is also interesting to note that the relationship between agents and institutions can change in terms of direction. Again as illustrated by the example of SEMATECH in the U.S., the government went from essentially a "let the market adjust" attitude, which it exhibited from the mid-1960s through the 1970s, to one of active government involvement beginning in the early 1980s. The post-SEMATECH era, as that organization has transitioned into International SEMATECH or ISEMATECH, is also a marker for a shift in government policy away from direct involvement in integrated-circuit technology innovation processes. This pattern of changes appears among the Japanese institutions and agents. The period beginning in the 1970s and culminating in the establishment of the VLSI Research Cooperative in the early 1980s marked a time when the Japanese government was actively exerting influence on the techno-global forces driving the innovation process in the integrated-circuit industry. During the later 1980s and into the 1990s the Japanese government had withdrawn from such active participation in the process. With the reemergence of research cooperatives such as SELETE, ASPLA, ASUKA and others, an attempt is being made to duplicate the pattern exhibited earlier with the hope that government involvement will again create conditions conducive to a Japanese semiconductor industry rebirth. The openness of these consortia to international participation may have a telling effect on their success.

It is an open question whether the earlier attempts exhibited by the VLSI Research Cooperative were essential to the emergence of the Japanese as dominant players in the integrated-circuit industry in the 1980s (see Methé, 1985, 1991a, for comments on the success or lack thereof in the activities of the VLSI Research Cooperative). It is also an open question whether the efforts of the newly formed cooperative research consortia will be of much help, or whether the strongest support for any rebirth will emanate from the restructuring of the Japanese companies themselves. Likewise it is still an open question whether the initiation of SEMATECH and its activities can be completely credited with the revival of the U.S. semiconductor industry in the late 1980s and early 1990s. It is well beyond the scope of this chapter to attempt to definitively answer those questions. It is enough to note that the institutional responses to these techno-globally driven changes were similar, in spite of the different institutional histories of the U.S. and Japan. The activities of these consortia and the firms themselves have been to develop vectors that have multiplied the knowledge bases for semiconductor innovation around the world. It is important that we understand the vectors by which techno-global change has exerted its influence on various institutional settings.

The vectors for channeling techno-global forces, as we have seen, in part work through and in part are shaped by the innovation envelope that exists within the semiconductor technology. The relationship between the semiconductor technology and the processing technologies required to fabricate each generation of devices sets up mechanisms for both innovation and diffusion of the innovation across different countries' institutional boundaries. We have observed that the role that equipment firms played in moving the latest technology from its point of origin, whether that was in the U.S., Japan, Europe, or now Korea or Taiwan, to semiconductor firms working in other countries has been in existence from the beginnings of the semiconductor industry through today. The fact that neither Korea nor Taiwan has developed a strong presence in the semiconductor equipment industry has made the "globalization" role of the extant U.S., Japanese and European firms all the more important today.

Another vector for channeling techno-global forces exists in the direct movement of people, especially engineering and managerial talent, from the U.S. institutional environment to other institutional environments. This is not to downplay the indigenous efforts of the Japanese, Europeans, Koreans and Taiwanese in the development of their respective domestic semiconductor industries, which were substantial in scope. But another important element was the training received at U.S. companies in the U.S. by a core group of engineers who later went on to head the domestic development of integrated-circuit technology within their respective countries. Many Japanese engineers who headed the drive towards dominance in the DRAM industry had for a time worked at Bell Labs in the late 1950s and 1960s. Likewise, many of the engineers who headed efforts at Samsung, Hyundai or LG in Korea, or who went on to found firms such as TSMC in Taiwan, had work experience at U.S. firms in the U.S. before taking on leading roles in their current firms.

Another vector observed was the direct movement of companies in entering each other's institutional environments, either through green field establishment of overseas wholly owned subsidiaries, the acquisition of companies, or strategic alliances that included the sharing of financial or knowledge resources through capital and/or technological investment. We observed the intensive use of this vector in Europe, both among European companies from various countries within Europe, and by U.S. companies entering Europe in the early 1960s. This vector also played a role in the early years of the Korean and Taiwanese efforts to develop their domestic semiconductor industries.

The use of mergers and alliances continues as a vector for developing and moving resources to meet the needs generated from the dynamics of techno-global change. Institutional forces have affected the use of these mechanisms, however. Mergers and acquisitions as well as divestitures appear more likely to occur within an institutional regimen, such as Texas Instruments' purchase of Burr-Brown, the creation of Elpida and Renesas in Japan, the folding of LG's semiconductor operations into Hynix in Korea, and the creation of STMicro in Europe. Alliances among firms through the sharing of financial and technological resources are common both within and between institutional regimens. Systematically organized alliances, as seen in research consortia in the early decades of the development of the semiconductor industry, were more likely to be limited to firms within an institutional regimen, such as the VLSI Research Cooperative in Japan, SEMATECH in the U.S., ESPRIT and BRITE in Europe, and the fourth five-year plan in Korea as well as its successor, the HAN project (Methé, 1995b). Although each was successful in some respect, as the semiconductor industry has become more global, limiting membership to firms from one institutional regimen may not be the best way to organize current or future consortia. As illustrated by the more open membership rules of the Hsinchu Science Park, IMEC in Europe, and ISEMATECH in the U.S., participation by international companies may now be a prerequisite for the success of these national-base institutional initiatives. This is because the knowledge bases for innovation have multiplied around the world. Likewise the earlier consortia were limited, either by design or by accident, to specific organizational forms, mostly system house IC organizational forms and some IDMs. The more recent cooperative endeavors are more open to various types of organizational forms. This more open attitude towards membership may in part derive from recognition that the dynamics of techno-global innovation place more emphasis on capability than on institutional or organizational form pedigree.

We found that each individual country began with the same general set of institutional and company actors, but established a different configuration of these respective actors, resulting in differences in the types of firms that have entered and dominated their respective national markets. The effect of institutional forces on the composition of the firms comprising each country's integrated-circuit industry is readily apparent. Although the contrasts among the U.S., Europe, and Japan are stark enough, the disparity between the two latecomer countries, Korea and Taiwan, is profound in illustrating how differences in the configuration of players and policies can result in a differing mix of organizational forms at the time of the founding of the industry in each country.

The difference in institutional regimens between Korea and Taiwan was evident from the beginning in terms of the types of firms that received government assistance to enter their respective integrated-circuit industries. Established system houses diversifying into the IC industry were chosen for Korea, and IDM start-ups were chosen for Taiwan. The initial mix of organizational forms could not have been more different. We have also found that the oldest organizational form, the diversifying electronic systems house, has had remarkable staying power. Although individual firms may have come and gone, the organizational form itself has lasted throughout the entire history of the semiconductor industry and has existed within each country's local institutional context. We have further found that the techno-global forces at work are pushing the global semiconductor industry into a new set of dominating organizational forms.

It appears that at the beginning of the 21st century, the dedicated IDM organizational form and the fabless and foundry organizational forms are about to finally push the venerable system house form out of the top tier of the global semiconductor industry. This is particularly evident in the U.S. and Taiwanese integrated-circuit industries, but is also becoming apparent in the European, Japanese, and Korean industries. First, it is important to point out that some firms will most likely continue with a system house organizational form. In the U.S., IBM appears to be continuing to use this form. In Europe, Philips has continued to keep its integrated-circuit operations closely tied to its systems operations. The same appears to be so with Samsung in Korea. There are strong technological and economic reasons for linking system house and IC operations in one organizational form. Astute management can capture potential economies of scale and scope and can focus research and development efforts to take advantage of both a large internal market as well as the external merchant market.

Second, it is also important to recognize that the exit of the system house organizational form from the top position in the industry is not simply through some blind selection force that has begun to erase this organizational form from existence. Instead, the system house organizational form is declining through the strategic choice of the firms that had adopted it in the first place. Many system houses are spinning out their semiconductor operations to become more standalone companies, albeit with some equity connection back to the parent company. The actions in Japan of Hitachi and NEC in forming Elpida, of Hitachi and Mitsubishi Electric in forming Renesas, and of NEC Electronics and Elpida in becoming more freestanding companies within the NEC group are one set of illustrations of the developing IDM organizational form. In Europe the creation of Infineon and STMicro are also examples of spinouts from system houses of their integrated-circuit operations. The same can be said of Hynix within the Hyundai group; it is more independent than its predecessor Hyundai Electronics was. The same techno-global driving forces are also at work in the move of Motorola to spin out its semiconductor operations into an independent company.

The IDM organizational form is perhaps best suited to respond to the changes in the merchant market and also has sufficient resources and links between design and process activities to continue to pioneer technological innovations. Moreover, the focused strategy of the IDM organizational form may be easier to manage, in tracking both the upswings and the downturns of sales and profit performance in semiconductors, than the more broad-based system house form. However, strategic choices by managers using the IDM form may make the IDM form more of a blended form itself. Many IDM companies are beginning to reduce their commitment to the fabrication aspect of semiconductor technology. Even firms newly adopting the IDM organizational form, like Motorola, NEC Electronics, Elpida, and others, regardless of their country of origin, as well as some system house forms like Philips, are beginning to adopt a "fab-lite" strategy. With the fab-lite strategy, the IDM company devotes some human and financial resources to fabrication technology, but it also begins to rely on the dedicated foundry companies such as UMC and TSMC. IDM companies that adopt this strategic approach may eventually evolve into a collection of fabless design houses under one company name as each of their various IC divisions sheds its fabrication capability and relies on dedicated foundries for production. Or each division may be spun out as a separate fabless company. It remains to be seen if this strategy will be lasting and what direction it will take, but the techno-global forces of increasing resource needs for each succeeding semiconductor generation and the worldwide diffusion of fabrication skills are driving it.

From discussions with senior managerial and engineering personnel at many companies mentioned in this report, it appears that a consensus is forming around the belief that the fabless organizational form is the wave of the future. We have seen that it has been in existence since the late 1960s and came into prominence as a preferred mode of entry in the early 1980s. Its growing importance as a mode of entry emerged in response to certain features of the techno-global innovation dynamics driving the integrated-circuit industry. The emergence of the dedicated foundry legitimized the fabless organizational form. The combination of these two organizational forms into a symbiotic link could be considered a new organizational form in its own right. Whether considered so or not, the fabless/foundry nexus has had a growing impact on the integrated-circuit industry, as is evident from the emergence of TSMC into the global top 10 in 2002[8]. It should be noted, however, that no fabless firm by itself has yet entered the global top 10 semiconductor firms. Some, such as Nvidia and Qualcomm, have entered the top 10 semiconductor producers in the U.S., and there are also VIA and ProMOS among the top 10 companies in the Taiwanese semiconductor industry. It is possible and in fact very likely that some firm that has adopted the fabless organizational form will enter the global semiconductor industry's top 10 rankings. Given the relatively narrower customer focus adopted by these firms, however, the fabless form is by no means the most likely organizational form to have the organizational resources necessary to dominate over the IDM form. It is also an open question whether the new entries into the semiconductor industry from China using the dedicated foundry organizational form will be as successful as the initial firms that adopted that form. The level of concentration of foundry services has been about 80% for the top 3 firms. However, it does appear that the dedicated foundry organizational form, along with its symbiotic partner, the fabless organizational form, is a legitimate form within the global semiconductor industry and one that will not disappear soon.

6 Conclusion

We have examined the influence of techno-global and institutional forces on the birth, development, change, and exit of organizational forms within the global semiconductor industry and within the major country segments of the industry. We have found that the earliest entering organizational form, the system house IC form, has had remarkable staying power. It does appear, however, to finally be on its way out of the global industry, at least as a dominant form occupying the center of the industry. The IDM form, which also entered early in the development of the semiconductor industry, seems also to have remarkable staying power and is poised to become the dominant form for the foreseeable future. However, it will share the stage with the fabless and foundry forms.

It is important to note that these two new forms entered roughly midway through the development of the semiconductor industry, if we measure this from the early 1960s until today. As we observed, all the various organizational forms including the fabless form and then the dedicated foundry form had entered by the 1980s. No new organizational forms have emerged from the techno-global dynamics of the industry since the 1980s. It is possible that after more than 40 years of existence, the techno-global dynamics of the semiconductor industry have entered or are entering a period of maturation of the technological and globalization forces that have given birth to these various organizational forms. The exiting of the system house organizational form from the industry may also be an indicator of this passage into a more mature phase of development. It is quite clear that the competitive dynamics that result in the turnover of individual firms will continue, however. The strategic adjustment by integrated-circuit firms using the system house organizational form to move to an IDM form, and by those firms using the IDM form to move to a “fab-lite” strategy, is indicative of the ability of incumbents to sustain their positions in the industry. Strategic choices, both in terms of the organizational form adopted during entry into the semiconductor industry and in terms of the changes that managers make to that organizational form, are important transmission mechanisms for selection and adaptation to the techno-global and institutional forces at work in the semiconductor industry.

This study has also shed some light on the processes of change and continuity in an industry that is considered a technology-intensive industry and thus one that is characterized by a volatile environment. We do not dispute the characterization of the semiconductor industry’s environment as volatile. It has undergone many recessions, several quite severe, as well as many technological changes both in underlying technology and in product classes, such as DRAMs and MPUs. It is important to note that some changes, such as the development of the semiconductor and the integrated-circuit themselves, were radical (double-loop or heterodynamic changes) and that others, such as the movement along the integrated-circuit technology trajectory, were more moderate and predictable (single-loop or homeostatic changes). Although the radical changes did open up the industry to many new entrants, they did not open it up to many new organizational forms. The commercialization of semiconductor technology resulted in the first two types of organizational form, the system house and the IDM, but it was the more routine technology progression along the IC innovation envelope that created the conditions for the development of the fabless and dedicated foundry types of organizational form. It appears that single-loop change at one level of the system resulted in double-loop change at another level of the system. Likewise, the diminution in the number of firms holding to the system house organizational form in recent years does not appear to be the result of fundamental or double-loop technological change. The tremendous decline in the market that occurred in 2001 does seem to have hastened the decline of the system house form, but it does not appear to have initiated it. The dynamics of the techno-global and institutional forces at work in the semiconductor industry have created an intricate nested system of relationships. We have explored some aspects of those relationships, and it is hoped that this study will stimulate and inform discussions on these important issues. It is obvious, but still needs saying, that further study is warranted in order to develop a deeper understanding of the processes described in this work.

Notes

1 We recognize that the integrated-circuit industry is part of the semiconductor industry, but that the semiconductor industry includes a broader range of solid-state physics-based products such as discrete transistor smf diodes. In this chapter we are primarily interested in the integrated-circuit industry, but given the time frame involved for the study, i.e., from the 1950s to today, we will refer to the semiconductor industry and integrated-circuit industry interchangeably.

2 Data for this section are derived from various McClean Reports 2002–2003, ICE Status reports 1968–1999, and various ICE Profiles reports and IC Insights Strategic Reviews. Information was also gathered from the Web sites of companies mentioned in the text and organizations related to the semiconductor industry, such as the Semiconductor Industry Association (SIA), Korea SIA (KSIA), Taiwan SIA (TSIA), Fabless Semiconductor Association (FSA), and Semiconductor Equipment and Materials International (SEMI). Additional information was collected at various semiconductor-industry-related meetings, such as the Industry Strategy Symposium (ISS) sponsored by SEMI, and in particular ISS Korea 2001, ISS Taiwan 2002, and ISS Japan 2001–2003. Information was also collected through interviews conducted at these symposia and at other times in Taiwan, Korea, and Japan during the period 2001–2003. Information for Korea was also obtained from annual interviews conducted during the period 1991–1996 through grants

from the University of Michigan's Center for International Business Education and for Japan from interviews conducted periodically from 1983 to 2000.

[3] Data for this section are derived from various McClean Reports 2002–2003, ICE Status reports 1968–1999, and various ICE Profiles reports and IC Insights Strategic Reviews. Information was also gathered from the Web sites of companies mentioned in the text and organizations related to the semiconductor industry, such as SIA, SEMI, Fabless Semiconductor Association, and International SEMATECH (ISEMATECH). Additional information was collected at various semiconductor-industry-related meetings, such as the ISS sponsored by SEMI, in particular ISS Korea 2001, ISS Taiwan 2002, and ISS Japan 2001–2003. Information was also collected through interviews conducted at these symposia and at other times in the U.S. during the period 2001–2003. Information is also used from interviews conducted in the U.S. periodically from 1983 to 2000.

[4] Data for this section are derived from various McClean Reports 2002–2003, ICE Status reports 1968–1999, and various ICE Profiles reports and IC Insights Strategic Reviews. Information was also gathered from the Web sites of companies mentioned in the text and organizations related to the semiconductor industry, such as SIA, SEMI, SEMI Europa, and Interuniversity MicroElectronics Center (IMEC). Additional information was collected at various semiconductor-industry-related meetings, such as the ISS sponsored by SEMI, in particular ISS Korea 2001, ISS Taiwan 2002, and ISS Japan 2001–2003. Information was also collected through interviews of European participants conducted at these symposia during the period 2001–2003.

[5] Data for this section are derived from various McClean Reports 2002–2003, ICE Status reports 1968–1999, and various ICE Profiles reports and IC Insights Strategic Reviews. Information was also gathered from the Web sites of companies mentioned in the text and organizations related to the semiconductor industry, such as SIA, SIA Japan, SEMI, and SEMI Japan. Additional information was collected at various semiconductor-industry-related meetings, such as the ISS sponsored by SEMI, in particular ISS Japan 2001–2003. Information was also collected through interviews conducted at these symposia and at other times in Japan during the period 2001–2003. Further information about Japan was obtained from interviews conducted periodically from 1983 to 2000.

[6] Data for this section is derived from various McClean Reports 2002–2003, ICE Status reports 1968–1999, and various ICE Profiles reports and IC Insights Strategic Reviews. Information was also gathered from the Web sites of companies mentioned in the text and organizations related to the semiconductor industry, such as SIA, KSIA, SEMI, and SEMI Korea. Additional information was collected at various semiconductor-industry-related meetings, such as the ISS sponsored by SEMI, in particular ISS Korea 2001. Information was also collected through interviews conducted at these symposia and at other times in Korea during the period 2001–2003. Information for Korea was also obtained from annual interviews conducted during the period 1991–1996 through grants from the University of Michigan's Center for International Business Education.

[7] Data for this section are derived from various McClean Reports 2002–2003, ICE Status reports 1968–1999, and various ICE Profiles reports and IC Insights Strategic Reviews. Information was also gathered from the Web sites of companies mentioned in the text and organizations related to the semiconductor industry, such as SIA, TSIA, Fabless Semiconductor Association, SEMI, and SEMI Taiwan. Additional information was collected at various semiconductor-industry-related meetings such as the ISS sponsored by SEMI, in particular ISS Taiwan 2002. Information was also collected through interviews conducted at these symposia and at other times in Taiwan during the period 2001–2003.

[8] This issue of whether to consider the fabless/foundry as an organizational form in and of itself or the fabless and foundry companies as separate organizational forms is emerging in a current debate among various market research organizations over how to count the production figures of each. Our use of sources to construct the tables in this chapter should in no way be construed as an endorsement of a particular source in terms of its position on this production-counting debate or its usefulness as a market forecasting tool. Our concern in choosing data sources was to be as consistent as possible over the time frame involved in this study.

Bibliography

Adler, P.S. (1989) "Technology strategy: A guide to the literatures." Research in Technological Innovation, Management, and Policy 4: 25–151.

Amburgey, T.L.; Kelly, D; and Barnett, W. (1993) "Resetting the clock: The dynamics of organizational change and failure." Administrative Science Quarterly 38: 51–73.

Aoki, M. (2001) Toward a Comparative Institutional Analysis. MIT Press, Cambridge, MA.

Argyris, C. (1976) "Single- and double-loop models in research on decision-making." Administrative Science Quarterly 21(3): 363–375.

——— (1992) On Organizational Learning. Blackwell Publishing, Inc., Cambridge, MA.

Ashby, W.R. (1952) Design for a Brain. Wiley, New York.

Barnett, W.P. and Carroll, G.R. (1995) "Modeling internal organizational change." Annual Review of Sociology 21: 217–236.

Beyer, J.M.; Chattopadhyay, P.; George, E.; Glick, W.H.; Ogilvie, D.; and Pugliese, D. (1997) "The selective perceptions of managers revisited." Academy of Management Journal 40: 717–737.

Boeker, W. (1989) "Strategic change: The effects of founding and history." Academy of Management Journal 32(3): 489–515.

Bracker, J. and Methé, D.T. (1994) "A cross-national study of planning characteristics of U.S. and Japanese entrepreneurs." International Journal of Management 11(2): 634–640.

Bradsher, K. (2003) "SARS is disrupting worldwide business: Disease hits wide variety of industries." International Herald Tribune. 4 April, pp. 1 and 4.

Brown, S.L. and Eisenhardt, K.M. (1997) "The art of continuous change: Linking complexity theory and time-paced evolution in relentlessly shifting organizations." Administrative Science Quarterly 42: 1–34.

Buaron, R. (1981) "New-game strategies." McKinsey Quarterly (Spring): 21–40.

Burgelman, R.A. (1994) "Fading memories: A process theory of strategic business exit in dynamic environments." Administrative Science Quarterly 39: 24–56.

Burke, J. (1978) Connections. Little, Brown and Company, Boston.

Campbell, D.T. (1965) "Variation and selective retention in socio-cultural evolution." In: Barringer, H.R.; Blanksten, G.I.; and Macks, R.W. (Eds.) Social Change in Developing Areas: Reinterpretation of Evolutionary Theory. Schenkman, Cambridge, MA, pp. 19–48.

Carroll, G.R. (1985) "Concentration and specialization: Dynamics of niche width in populations of organizations." American Journal of Sociology 90(6): 1262–1283.

——— (1993) "A sociological view on why firms differ." Strategic Management Journal 14: 237–249.

Cross, N. (1986) "The changing design process." In: Roy, R. and Wield, D. (Eds.) Product Design and Technological Innovation: A Reader. Open University, Philadelphia, pp. 36–47.

Dacin, M.T.; Goodstein, J.; and Scott, W.R. (2002) "Institutional theory and institutional change: Introduction to the special research forum." Academy of Management Journal 45(1): 45–57.

Delacroix, J. and Swaminathan, A. (1991) "Cosmetic, speculative, and adaptive organizational change in the wine industry: A longitudinal study." Administrative Science Quarterly 36: 631–661.

Eisenhardt, K.M. and Schoonhoven, C.B. (1990) "Organizational growth: Linking founding team, strategy, environment, and growth among U.S. semiconductor ventures, 1978–1988." Administrative Science Quarterly 35: 504–529.

Fisher, L.A. (2002) "STMicroelectronics: The metaphysics of a metanational pioneer." Strategy+Business, Issue 28. Booz Allen Hamilton, New York.

Flatow, I. (1992) They All Laughed... From Light Bulbs to Lasers: The Fascinating Stories Behind the Great Inventions that Have Changed Our Lives. HarperCollins, New York.

Foster, R.N. (1986) Innovation: The Attacker's Advantage. Summit Books, New York.

Freeman, C. (1986) "Successful industrial innovation." In: Roy, R. and Wield, D. (Eds.) Product Design and Technological Innovation: A Reader. Open University, Philadelphia, pp. 29–33.

Freeman, J. (1995) "Business strategy from the population level." In: Montgomery, C. (Ed.) Resource-Based and Evolutionary Theories of the Firm: Towards a Synthesis. Kluwer Academic Publishers, Boston, pp. 219–250.

Garud, R.; Jain, S.; and Kumaraswamy, A. (2002) "Institutional entrepreneurship in the sponsorship of common technological standards: The case of Sun Microsystems and Java." Academy of Management Journal 45: 196–214.

Grant, R.M. (1991) "The resource-based theory of competitive advantage: Implications for strategy formulation." California Management Review 33(3): 114–135.

Greve, H. (1995) "Jumping ship: Diffusion of strategy abandonment." Administrative Science Quarterly 40: 444–473.

Hall, P.A. and Soskice, D. (Eds.) (2001) Varieties of Capitalism: The Institutional Foundations of Comparative Advantage. Oxford University Press, New York.

Henderson, R.M. and Clark, K.B. (1990) "Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms." Administrative Science Quarterly 35: 9–30.

Hodgson, G. (1998) "The approach of institutional economics." Journal of Economic Literature 36: 166–192.

Hrebiniak, L.G. and Joyce, W.F. (1985) "Organizational adaptation: Strategic choice and environmental determinism." Administrative Science Quarterly 30: 336–349.

Hu, G.J. (1997) "Perspectives of the Taiwan semiconductor industry." Business Briefing ASEAN: Semiconductor Manufacturing Technology. World Market Research Centre, London.

ICE Status (1968–1999) A Report on the Integrated Circuit Industry. Integrated Circuit Engineering Corporation, Scottsdale, AZ.

ICE Profiles (1991–1994, 1996, 2000) A Worldwide Survey of IC Manufacturers and Suppliers. Integrated Circuit Engineering Corporation, Scottsdale, AZ.

IC Insights Strategic Reviews (2000–2003) Extensive Profiles of the World's IC Manufacturers and Fabless Suppliers. IC Insights, Inc., Scottsdale, AZ.

Isabella, L.A. (1990) "Evolving interpretations as a change unfolds: How managers construe key organizational events." Academy of Management Journal 33(1): 7–41.

JSBRI (2002) White Paper on Small and Medium Enterprises in Japan: The Age of the Local Entrepreneur: Birth, Growth, and Revitalization of the National Economy. Japan Small Business Research Institute (JSBRI), Ministry of Economy, Trade and Industry, Tokyo.

Kim, C.L. (1997) "The Korean semiconductor industry." Business Briefing ASEAN: Semiconductor Manufacturing Technology. World Market Research Centre, London.

Levinthal, D. and Myatt, J. (1994) "Co-evolution of capabilities and industry: The evolution of mutual fund processing." Strategic Management Journal 15: 45–62.

Lewin, A.Y.; Long, C.P.; and Carroll, T.N. (1999) "The coevolution of new organizational forms." Organization Science 10(5, Sept.-Oct.): 535–550.

Mann, C. (1987) "Protection and retaliation: Changing the rules of the game." Brooking's Papers on Economic Activity, Issue 1, pp. 311–335.

March, J.G. (1990) "Exploration and exploitation in organizational learning." Organization Science 2(1): 71–87.

——— (1996) "Continuity and change in theories of organizational action." Administrative Science Quarterly 41: 278–287.

March, J.G.; Sproull, L.S.; and Tamuz, M. (1991) "Learning from samples of one or fewer." Organization Science 2(1): 1–13.

McClean, W.J. (Ed.) (2002) The McClean Report 2002. IC Insights, Inc., Scottsdale, AZ.

——— (Ed.) (2003) The McClean Report 2003. IC Insights, Inc., Scottsdale, AZ.

Mensch, G. (1979) Stalemate in Technology: Innovation Overcomes Depression. Ballinger, Cambridge, MA.

Methé, D.T. (1985) Technology, Transaction Costs, and the Diffusion of Innovation: The Evolution of the United States and Japanese DRAM Industries. University of California, Irvine.

——— (1991a) Technological Competition in Global Industries: Marketing and Planning Strategies for American Industry. Quorum Books, New York.

——— (1991b) "The effect of innovation on market structure." Engineering Management Review 19(4): 18–30.

——— (1992a) "The influence of technology and demand factors on firm size and industrial structure in the DRAM market—1973–1988." Research Policy 21: 13–25.

——— (1992b) "Techno-global competition in the integrated circuit industry." In: Foster, L.W. (Ed.) Advances in Applied Business Strategy, Vol. 3. JAI Press, Greenwich, CT, pp. 145–201.

——— (1995a) "Basic research in Japanese electronics companies: An attempt at establishing new organizational routines." In: Liker, J.; Ettlie, J.; and Campbell, J. (Eds.) Engineered in Japan: Organization and Technology. Oxford University Press, Oxford, UK, pp. 17–39.

——— (1995b) "Moving into the technological fast lane: From reverse to forward engineering through the establishment of innovation communities in Korea." Proceedings of the IEEE Engineering Management Conference, Singapore, 28–30 June.

——— (1997) "Living on the edge: Basic research and knowledge creation in Japanese electronics companies." In: McIntyre, J.R. (Ed.) Japan's Technical Standards: Implications for Global Trade and Competitiveness. Quorum Books, Westport, CT, pp. 47–63.

——— (2005) "Continuity through change in Japanese management: Institutional and strategic influences." In: Haak, R. and Padelko, M. (Eds.) Japanese Management—The Search for a New Balance between Continuity and Change. Palgrave, London.

Methé, D.T. and Bracker, J. (1994) "A cross-national study of perceptions of the business environment by U.S. and Japanese entrepreneurs." International Journal of Management 11(1): 599–603.

Methé, D.T.; Miyabe, J.; and Toyama, R. (1997) "Product development strategy and organizational learning: A tale of two PC makers." Journal of Product Innovation Management 14(5): 323–336.

——— (1998a) "A tale of two PC industries: Technology, environment and managerial action in shaping the Japanese and US personal computer industry." RIEB Kobe University Discussion Paper Series No. 89, Kobe University, Kobe, Japan.

——— (1998b) "Overcoming a standard bearer: Challenges to NEC's personal computer in Japan." RIEB Kobe University Discussion Paper Series No. 90, Kobe University, Kobe, Japan.

Methé, D.T. and Penner-Hahn, J. (1999) "Globalization of pharmaceutical research and development in Japanese companies: Learning and the parent-subsidiary relationship." In: Beechler, S. and Bird, A. (Eds.) Japanese Multinationals Abroad: Individual and Organizational Learning. Oxford University Press, Oxford, UK, pp. 1–42.

Methé, D.T.; Swaminathan, S.; and Mitchell, W. (1996) "The underemphasized role of established firms as the sources of major innovations." Industrial and Corporate Change 5(4): 1181–1203.

Nelson, R. (1994) "The co-evolution of technology, industrial structure, and supporting institutions." Industry and Corporate Change 3: 417–419.

OECD (2003) OECD Economic Survey: Japan. Vol. 2002, Supplement No. 2, January. OECD, Paris, France.

Okada, Y. (2002) "Decline of the Japanese semiconductor industry: Institutional restrictions and disintegrated techno-governance." Working Paper, Institute of Comparative Culture, Sophia University, Tokyo.

Oliver, C. (1997) "Sustainable competitive advantage: Combining institutional and resource-based views." Strategic Management Journal 18: 697–713.

Pascale, R. (1985) "The paradox of 'corporate culture': Reconciling ourselves to socialization." California Management Review 27(2): 304–316.

Peng, M.W. and Heath, P.S. (1996) "The growth of the firm in planned economies in transition: Institutions, organizations and strategic choice." Academy of Management Review 21(2): 492–528.

Romanelli, E. and Tushman, M.L. (1994) "Organizational transformation as punctuated equilibrium: An empirical test." Academy of Management Journal 37(5): 1141–1166.

Sackmann, S.Z. (1992) "Culture and subcultures: An analysis of organizational knowledge." Administrative Science Quarterly 37: 1–22.

Sahal, D. (1979) "A theory of evolutionary of technology." International Journal of Systems Science 10(3): 259–274.

——— (1981a) "Alternative conceptions of technology." Research Policy 10(3): 2–24.

——— (1981b) Patterns of Technological Innovation. Addison-Wesley, Reading, MA.

Schumpeter, J.A. (1936) Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalist Process. McGraw-Hill, New York.

Simon, H.A. (1987) "Making management decisions: The role of intuition and emotion." Academy of Management Executive 1(1, February): 57–64.

——— (1991) "Bounded rationality and organizational learning." Organization Science 2(1): 125–134.

Smircich, L. (1983) "Concepts of culture and organizational analysis." Administrative Science Quarterly 28: 339–358.

Stinchcombe, A.L. (1965) "Social structure and organizations." In: March, J.G. (Ed.) Handbook of Organizations. Rand McNally, Chicago, pp. 142–193.

Solow, R.M. (1957) "Technical change and the aggregate production function." Review of Economics and Statistics 36: 312–320.

Tilton, J.E. (1971) International Diffusion of Technology: The Case of Semiconductors. Brookings Institution Press, Washington, DC.

Tucker, D.J.; Singh, J.V.; and Meinhard, A.G. (1990) "Founding characteristics, imprinting and organizational change." In: Singh, J.V. (Ed.) Organizational Evolution: New Directions. Sage Publications, Newbury Park, CA, pp. 182–200.

Tushman, M.L. and Anderson, P. (1986) "Technological discontinuities and organizational environments." Administrative Science Quarterly 31: 439–465.

Tushman, M.L.; Newman, W.H.; and Romanelli, E. (1986) "Convergence and upheaval: managing the unsteady pace of organizational evolution." California Management Review 29: 29–44.

Tversky, A. and Kahneman, D. (1991) "Loss aversion in riskless choice: A reference-dependent model." Quarterly Journal of Economics 106(4): 1039–1061.

Wakabayashi, H. and Sumita, M. (1993) "South Korea's semiconductor industry." NRI Quarterly, Summer. Nomura Research Institute, Tokyo.

White, A. (1959) "The concept of culture." American Anthropologist 61: 227–251.