Seldom can an individual entrepreneur alone command the competence, resources, and legitimacy to develop and commercialize an innovation. Entrepreneurship is a collective achievement that resides not only within the parent organization of the innovation but also in the construction of an industrial infrastructure that facilitates and constrains innovation. This infrastructure includes (1) institutional arrangements to legitimize, regulate, and standardize a new technology; (2) public-resource endowments of basic scientific knowledge, financing mechanisms, and a pool of competent labor; (3) development of markets, consumer education, and demand; and (4) proprietary research and development, manufacturing, production, and distribution functions by private entrepreneurial firms to commercialize the innovation for profit.

This chapter takes a macroperspective of the innovation journey and focuses on the issues and events involved in developing an industry infrastructure for innovation. In doing so, we make three contributions to managing the innovation journey:

1. We believe that understanding innovation is deficient if it focuses exclusively on the characteristics and behaviors of individual entrepreneurs and if it treats the social, economic, and political infrastructure for innovation as external factors that cannot be influenced. Popular folklore notwithstanding, the innovation journey is a collective achievement that requires key roles from numerous entrepreneurs in both the public and private sectors.

2. Chapter 6 examines how this infrastructure emerges to commercialize technology and product innovations. This infrastructure emerges through the accretion of numerous institutional, resource, and proprietary events that influence each other over an extended period. Moreover, the very institutional arrangements and resource endowments created to facilitate industry emergence can hinder subsequent technological development and adaptation by proprietary firms. This generative process has a dynamic history that is important to study if we are to understand how novel forms of technologies, organizations, and institutions emerge.

3. We emphasize that the innovation journey is not limited to the for-profit sector; numerous entrepreneurial actors in the public and not-for-profit sectors play crucial roles. By studying the roles and how they interact to develop and commercialize a new technology we can understand how the risk, time, and cost to an individual entrepreneur are significantly influenced by developments in the overall industry. This study also explains why the entrepreneurial firms that run in packs are more successful than those that develop their innovations alone.

The practical implications of this perspective emphasize that innovation managers must not only be concerned with microdevelopments of a proprietary technical device or product within their organization but also with the creation of a macroindustrial system that embodies the social,
economic, and political infrastructure that any technological community needs to sustain its members. We adopt and extend the social-system framework introduced by Van de Ven and Garud (1989) to understand the components of an industrial infrastructure for innovation. Because new-to-the-world technologies typically transcend the boundaries of many individual firms, industries, and populations (Astley, 1985), the framework adopts the interorganizational field as the unit of analysis and focuses on the infrastructure necessary to develop and commercialize technological innovations. This infrastructure includes a variety of institutional arrangements, resource endowments, and proprietary functions that are necessary to develop and transform basic scientific knowledge into commercially viable products or services.

The first part of the chapter elaborates this social-system framework and links it to several current themes in the organizational and economic literature on technological development. The second part, based on study findings of the Minnesota Innovation Research Program (MIRP), develops a set of propositions that explain how this social system emerges to facilitate and constrain the development of innovations.

**Social System for Innovation Development**

The proposition that technological and institutional innovations reciprocally produce each other within the system under investigation is a relatively new development in economic and organization theory (Ruttan and Hayami, 1984). This proposition was central to Marx's (1867/1906) analysis of the dialectical relations between the forces of production (i.e., technology or the equipment and labor processes used in production) and the relations of production (i.e., institutions, especially property rights or ownership of production forces) within the superstructure of cultural and resource endowments of a society. However, perhaps because of ambiguities in Marx's own writings about how the forces and relations of production occur, organizational and economics scholars subsequently formed one-sided theories about technical and institutional change (Bottomore, 1983).

Those who advocated a "technological imperative" perspective treated technological innovation as something that happened to the firm but was not determined within it (Abernathy and Clark, 1985). Technological innovation was viewed as an environmental shock to which organizations or economic systems had to adapt if they were to survive (Ruttan, 1978; Freeman, 1986; Tornatzky and Fleischer, 1990). However, the potency of this "technological imperative" view weakened as the definition of technology expanded from a physical concrete device or artifact to include proprietary design knowledge embodied in the physical artifact (Layton, 1986). This knowledge is socially constructed (Pinch and Bijker, 1987), recognized, and protected as a property right through the institutions of patents or royalties (Nelson, 1982) and imprinted with the economic and cultural endowments of a society (Thirtle and Ruttan, 1986).

A second perspective maintained that institutional rather than technical change was the dynamic source of social and economic development. This "institutional determinism" perspective, as Ruttan (1978) labeled it, emphasized that changes in institutional arrangements precede and constrain
technical change (North and Thomas, 1973; North, 1990). However, as Commons (1950) emphasized, institutional arrangements not only constrain action, they also liberate and expand the freedom of individuals to undertake a wide variety of actions, including due process provisions, to create and change the institutional arrangements. Institutional arrangements are defined as administrative rules, norms, laws, and conventions that society uses to legitimize, regulate, and coordinate the actions and expectations of individuals, which makes them predictable (Ruttan, 1978; Powell and DiMaggio, 1991).

Hurwicz (1993) importantly points out that institutional rules or laws are typically written by specifying (1) the roles (rights and duties) of various institutional actors and (2) their assignment to actors, be they individuals, firms, trade associations, or state agencies. Individuals and organizations become institutional actors by exercising the institutional roles they assume or are assigned. In this way, institutional arrangements have created roles for "artificial persons," such as firms, unions, trade associations, state agencies, and markets, that enable them to act as though they are individuals. Much of the work on institutionalism in organization theory (Powell and DiMaggio, 1991) and political science (March and Olsen, 1989) focuses on the processes by which these institutional arrangements and actors emerge and how this larger exogenous institutionalized environment enables and constrains entrepreneurs and organizations to develop only certain types of technologies and practices.

A third, and older, tradition emphasized that resource endowments of a society create a supply and demand for both technical and institutional innovations (Ruttan, 1978). As exemplified in Rosenberg and Birdzell's (1986) historical examination of "How the West Grew Rich," this perspective maintains that technical and institutional changes occur as a result of advances in the supply of resource endowments (i.e., knowledge about new social and economic possibilities and the financial capital and human competencies available to develop and apply these possibilities). The demand for technical and institutional change, in turn, is brought about by changes in expectations generated by knowledge of new possibilities, as well as the pressure of population growth against relative factor prices or scarcity of land, labor, and capital (Schultz, 1968; Ruttan, 1978).

Arguments over the relative priority of technical, institutional, and resource endowments are generally unproductive. All three endowments are highly interdependent and therefore must be analyzed within a context of continuing interaction. So, also, Ruttan (1978) argues that demand for and supply of technical and institutional change interact with shifts in resource endowments of new knowledge and relative scarcity of land, labor, and capital. Ruttan and Hayami (1984) proposed an induced theory of innovation that provides a more balanced treatment of the reciprocal relationships between technical and institutional innovations and resource endowments. Although developed independently of Marx, their theory echoes Marx's analysis of the reciprocal relationships among changes in technology, institutions, and resource endowments in an economic sector. Ruttan and Hayami argued that in the study of long-term social and economic change, the relationships among these variables must be treated as endogenous, not as givens within a general equilibrium model. "Failure to analyze historical change in a general equilibrium context tends to result in a unidimensional perspective on the relationships bearing on technical and institutional
Ruttan's model emphasizes the role of history in understanding innovation development; that is, the temporal sequence of events and activities that create and transform basic scientific knowledge into commercially viable products or services delivered to customers. Numerous case histories demonstrate that new technologies are seldom developed by a single firm in the vacuum of an institutionalized environment (see, e.g., Usher, 1954; Jewkes, Sawers, and Stillerman, 1958; Constant, 1980; Nelson, 1982; and Chandler, 1990). Many complementary innovations in technical and organizational arrangements are usually required before a particular technology is suitable for commercial application (Binswanger and Ruttan, 1978; Hughes, 1983; Rosenberg, 1983). Research reviews by Mowery (1985), Thirtle and Ruttan (1986), Freeman (1986), and Dosi (1988) show that the commercial success or failure of a technological innovation is, in great measure, a reflection of the institutional arrangements and available resource endowments that an industrial community needs to sustain its members.

Figure 6.1 sketches a social-system framework that incorporates the various components of an industrial infrastructure for technological innovation. This framework, developed initially from MIRP studies of the development of the cochlear implant technology by Van de Ven and Garud (1989, 1993), was extended in subsequent studies of research and development (R&D) communities by Garud and Rappa (1994); of flat-panel display technologies by Murtha, Spencer, and Lenway (1996) and of the health care provider industry by Van de Ven and Lofstrom (1997).

The framework adopts an augmented view of an industry and focuses on relationships among key components of an industrial infrastructure. The framework examines not only an industry, commonly defined as the set of firms producing similar or substitute products (Porter, 1980), but also many other public- and private-sector actors who perform critical functions to develop and commercialize a new technology. The industrial infrastructure includes (1) institutional arrangements to legitimize, regulate, and standardize a new technology; (2) public-resource endowments of basic scientific knowledge, financing mechanisms, and a pool of competent labor; (3) market mechanisms to educate consumers and stimulate demand for a new technology; and (4) proprietary research and development, manufacturing, marketing, and distribution functions by private entrepreneurial firms to commercialize the innovation for profit.

The relevance of each of these system components to the emergence of innovations follows.
Proprietary Functions

The proprietary component of the system incorporates the traditional industrial economics definition of an industry (Porter, 1980), which consists of the set of firms commercializing innovations that are close substitutes for each other. Our focus is on the actions of individual entrepreneurs and firms that typically appropriate basic knowledge from the public domain and transform it into proprietary knowledge through applied research and development in areas related to a technological innovation. If they persist in developing the innovation, they subsequently develop a line of products and gain access to the complementary assets (e.g., manufacturing, marketing, and distribution) necessary to establish an economically viable business.

Williamson (1975) and Teece's (1987) transactions costs theory is useful to understand how
firms organize to perform these proprietary functions. They emphasize that the boundaries of the firm are an important strategic variable for innovation (Teece, 1987). They propose that if proprietary functions and complementary assets necessary for technological development are difficult to protect from imitators (weak appropriability regimes), require specialized investments, or might be difficult to execute, they should be integrated and performed within the innovating firm. If the functions have strong appropriability regimes, entail nonspecialized investments, and have a number of supply sources, they should be licensed or contracted by firms with outside suppliers and vendors.

From a system perspective, these make-or-buy decisions by individual firms produce the aggregate industry channels of raw materials, manufacturing, marketing, and distribution flows (Stern and El-Ansery, 1982; Hakansson, 1988). Shifts in individual firms' make-or-buy decisions over time also determine changes in industry structure. Stigler (1957) examined this issue in terms of the relationship between product life cycle and vertical integration. He argued that early in the product life cycle, vertical integration of functions within firms (i.e., make decisions) predominate because the market has not yet developed. As Smith (1776/1937) indicated, the division of labor among firms is limited by the extent of the market. When the market expands, many of the tasks and functions grow to sufficient size to make it more profitable to buy them from specialized manufacturers or suppliers, as opposed to making them within vertically integrated firms.

**Resource Endowments**

Three kinds of resources are critical to developing most technological innovations: (1) basic scientific or technological research, (2) financing mechanisms, and (3) a pool of competent human resources (Mowery and Rosenberg, 1979). Although private entrepreneurs or firms do engage in developing these resources, typically, public organizations, often viewed as external to an industry, play a major role in creating and providing these "common goods"

1. Basic scientific or technological research provides the foundation of knowledge that underlies technological innovations and makes the commercial births of most industries possible. This basic knowledge is costly to produce relative to its cost of diffusion and imitation (Mansfield, 1985). In addition, it builds in a cumulative fashion, and its generation is inherently an indivisible activity (Metcalfe and Soete, 1983; Garud and Rappa, 1995). For these reasons, Nelson (1982) and Arrow (1962) argued that the social returns to research investment exceed the private returns to entrepreneurs, a condition leading to underinvestment in research. As a consequence, a variety of studies have shown that firms rely on outside sources of knowledge and technical inventions for the majority of their commercially significant new products (Rosenbloom, 1966; Mueller, 1962; Utterback, 1974; Freeman, 1986; Nelson, 1982; Stobaugh, 1985).

However, the private appropriation of basic scientific knowledge is seldom a simple process of information transfer and diffusion because much of that knowledge may be "sticky," or difficult to disembody from its original source and transfer to an applied problem-solving site (von Hippel, 1990). As a consequence, proprietary firms must often engage in a variety of strategies to acquire this knowledge from basic research sites, ranging from simple communications (Allen, 1977) and
personnel transfers (Roberts and Hauptman, 1986) to various licensing arrangements and joint R&D ventures between private firms and basic research centers (Ouchi and Bolton, 1987; Powell, 1990). These strategies appear consistent with von Hippel’s (1990) overall proposition that the location of problem-solving activities shifts over time to the sites or locations of that "sticky" data.

2. Financing mechanisms. Whereas public institutions (e.g., the National Science Foundation or the National Institutes of Health) tend to play the major role in financing the development of basic scientific or technological knowledge, venture capital, in a corporation, or in the market, tends to be the key financial source that supports private firms in transforming basic knowledge into proprietary and commercial applications. In addition, the commercialization of many technological innovations requires unique industrywide financing arrangements. For example, few biomedical innovations would be commercially viable without the health care insurance industry and the creation of thirdparty payment reimbursement systems. Without such a financial infrastructure for a broad array of biomedical and health care innovations, most patients would not be able to pay for many biomedical devices and treatments. But because these insurance systems limit coverage to specifically designated medical devices and treatments, the firms competing to commercialize a specific biomedical device must cooperate to educate and influence third-party payers to include the innovation in their payment reimbursement systems.

3. A pool of competent human resources is another essential resource necessary for the emergence of a new industry. New technologies often require new ways to perform essential tasks related to research, manufacturing, or marketing. This pool of competence tends to develop in three ways. First, basic research institutes and proprietary firms recruit and train people in specific skills related to the innovation. Over time, job transfers and mobile professionals among institutes and firms diffuse their skills throughout the industry (Rappa, 1989). Second, educational training programs and accredited degrees at colleges and universities help develop this labor market. In addition, industry conferences, technical committees, trade publications, and technical journals provide opportunities for industry participants to share and learn from each other (Nelson, 1982). Finally, the competence pool is created through "collective invention" (Allen, 1983) among "invisible colleges," or networks of practitioners (often scientists and engineers throughout the world), that support further development or problemsolving activities within a new technological paradigm (Hull, 1988; Dosi, 1988; Rappa, 1989; Garud, 1990). For example, von Hippel (1986) observed extensive trading of proprietary know-how among informal networks of process engineers in rival, and nonrival, firms in the U.S. steel minimill industry and elsewhere.

Institutional Arrangements

The ultimate authorities governing and legitimizing collective action are the rules and norms of the society in which organizations function (Galaskiewicz, 1985; Scott, 1987). The political context is the place to institutionalize and legitimize a social system, which permits firms to operate and gain access to the resources they need (Meyer and Rowan, 1977; Pfeffer and Salancik, 1978). The success or failure of a new industry and firms within it depends on their abilities to achieve institutional isomorphism (Dimaggio and Powell, 1983). To achieve this isomorphism, firms may either adapt to institutional requirements or try to build their goals and procedures directly into
society as institutional rules (Meyer and Rowan, 1977; Garud and Ahlstrom, 1997a). Thus, firms compete not only in the marketplace but also in this political institutional context. Rival firms often cooperate by collectively manipulating their institutional environment to legitimize and gain access to resources necessary for collective survival (Pfeffer and Salancik, 1978; Hirsch 1975; Meyer and Rowan, 1977).

Governance

It is widely recognized that a variety of governmental regulations and institutional arrangements facilitate and inhibit the emergence of new technologies and industries. Mowery (1985) and Nelson (1982), for example, discuss how government funding, by broadening the industrywide knowledge base, can encourage new industry entrance and support a more competitive environment. Thus, also, a more permissive antitrust policy permitting certain kinds of joint research ventures among competitors and requirements by the Department of Defense for licensing and second-sourcing new devices speeds the diffusion of innovation and may aid the operation of competitive forces in an industry (Teece, 1987). However as Ouchi and Bolton (1987) discuss, institutional policies encouraging rapid knowledge diffusion, if pursued too eagerly, may undermine the return to the knowledge producer and thus the incentive to invest in information-producing activities. But another institutional mechanism has been devised: The patent system grants monopoly rights to use knowledge for a limited period. Although these institutional arrangements are often highly imperfect, research shows they exert a profound effect on technological and industry development (Nelson, 1982).

Legitimation

Legitimation is critical for the emergence of a new-to-the-world industry. Garud and Rappa (1994) report how the cochlear implant field lacked the necessary legitimacy to attract a critical mass of researchers to commit themselves to developing this device. It was only after an NIH-sponsored effort reporting the potential of cochlear implants that the field gained some legitimacy. Indeed, Garud and Rappa (1995) demonstrated how NIH's report triggered a series of scientific reports that resulted in attracting many researchers to the cochlear implant field.

Trust, or customer certainty about product quality, is fundamental to the efficient operation of the market institution (Aldrich and Fiol, 1994). Under conditions of high-quality uncertainty, inferior products often drive high-quality products out of the market because of the bad reputation they create for other industry products. Consequently, customers require greater assurances to buy a product in the event it is found after the purchase to be a "lemon" (Akerlof, 1970). The potential for product liability suits and other litigation can significantly dampen the commercialization of an innovation. Creating trust represents a particularly significant entry barrier for product innovations that are costly and technologically sophisticated, and whose purchase entails irreversible health or welfare situations for customers. Numerous mechanisms are often established to counteract this quality-uncertainty entry barrier, including guarantees, licensing practices, industry regulations, and endorsements by other trusted institutions.
The costs to create and maintain these industrywide institutional mechanisms are borne by industry members collectively and by individual firms. The mechanisms are both products of and constraints on the legitimacy of individual entrepreneurs or firms to engage in the commercial introduction of a technological innovation. One of the ways in which these firms collectively create and maintain these institutional legitimizing devices is through industry councils, technical committees, and trade associations (Maitland, 1982). These industry associations, in turn, approach, educate, and negotiate with other institutions and governmental units to obtain endorsements and develop regulatory procedures.

**Technology Standards**

One of the concrete manifestations of industry legitimization is setting technical standards pertaining to component specifications, processes, and performance criteria that new technology designs are expected to achieve (Garud and Rappa, 1994). Such technical standards are powerful institutional mechanisms for selecting dominant designs from among competing technological possibilities and reducing many uncertainties of technological development by channeling the directions of resource investments and technological change. Besen and Saloner (1989), Tushman and Rosenkopf (1990), and Garud and Rappa (1994) describe various ways in which standards develop. In some cases, standards are mandated by governmental regulatory agencies. In others, voluntary standards are established cooperatively, with information exchanged, technologies altered, or side payments made to achieve a consensus among firms in an industry. Finally, setting standards may be left to the market, or de facto standards may be imposed by a dominant producer.

Whatever means are used, the typical process for setting standards is influenced as much by social and political dynamics as it is by technical considerations (David, 1987; Garud and Kumaraswamy, 1994; Garud and Rappa, 1994; Tushman and Rosenkopf, 1990). These sociopolitical dynamics are influenced by the relative benefits to public and private parties for promoting a standard and the extent to which interested parties (producers, consumers, regulators) have different views about the standards chosen (Besen and Saloner, 1989; Garud and Ahlstrom, 1997b), as well as the evaluation complexity of a new technology (Tushman and Rosenkopf, 1990). Inherent in this standard-setting process is the paradox of cooperation and competition (Garud, 1994). Cooperating to set up industry standards clearly benefits all firms, but each firm may try to ensure the standards that suit it best are institutionalized. As Besen and Saloner (1989: 219) state, "standards may be used as tools of competitive strategy as firms promote a standard to gain advantage over rivals." An understanding of this paradox can offer valuable insights about how firms learn to cooperate to sustain themselves collectively while competing to carve out their distinctive positions in an emerging industry.

**Markets**

The process of translating ideas into commercial products is fraught with difficulties, among them the newness of the products. Debates about the primacy of market pull over technology push notwithstanding, many new-to-the-world innovations have no immediate definable need. New markets have to be created to commercialize many innovations. Potential customers find it difficult,
if not impossible, to compare new products because alternatives embody different merits (Garud and Rappa, 1994; Van de Ven and Garud, 1993; Tushman and Rosenkopf, 1990).

To help customers discriminate, institutional environments for evaluation routines and standards become important. Entrepreneurs clearly try to shape emerging institutional environments but at the same time are shaped by them (Garud and Rappa, 1994; Van de Ven and Garud, 1993). On most occasions, entrepreneurs are only partly successful in shaping these institutional environments to their benefit; more often they adapt their own strategies to connect with customers.

This sociopolitical process is complicated by "interpretive flexibility" (Bijker, Hughes, and Pinch, 1987), which alludes to multiple possible interpretations and uses for products that may be different from those originally intended. To benefit from such interpretive flexibility, firms need to harness learning-by-using processes (Garud, 1997). Failure to do so may result in a disastrous mismatch between what a company creates and what customers value.

Firms use publicity and promotion to create needs and shape customer preferences. Often, in their zeal, firms announce their products to set expectations internally and externally. As Garud and Lampel (1997) observed, such announcements backfire when firms are unable to meet expectations they set.

These discussions point out some of the issues salient in thinking about the social-system framework. It is important to remember that, all too often, entrepreneurs, in their zeal, forget that what they create may not be immediately understandable or acceptable to users. Under these conditions, "acts of critical revision:" as Usher (1954) suggested, may be as important as "acts of insight."
Table 6.1. A social system framework for understanding innovation development and industry emergence

<table>
<thead>
<tr>
<th>Components of community infrastructure for innovation</th>
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<tr>
<td>Proprietary Functions</td>
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<td>Resource Endowments</td>
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<td>Institutional Arrangements</td>
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<td>Market Functions</td>
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Propositions on the Development of the Infrastructure

The social-system framework illustrated in figure 6.1 and outlined in table 6.1 maps a conceptual territory of the essential components of an innovation infrastructure at the interorganizational-community level. Perhaps more than anything else it helps us understand the key elements of an industrial community. While the framework demands a more encompassing perspective of innovation than has often been used, it integrates an eclectic body of literature that has argued that each of the system components is necessary to foster the development and commercialization of technological innovations. Thus, although many of these components have been studied in varying degrees by people in different disciplines, they have been treated as "externalities" (Porter, 1980) to the system under investigation. If we view them as externalities, we are not likely to examine how the functions are interdependent in time and space. Incorporating these different components within an overall systems framework motivates a more systematic study agenda aimed at understanding how various actors and functions interact over time to create an infrastructure that both facilitates and constrains technological innovation.

For innovation managers, this agenda could be motivated with the following overall proposition: The odds of success in developing a technological innovation are primarily influenced
by the extent to which other components of the infrastructure are established at the industrial-community level.

Embedded in this overall proposition are a number of macro- and microissues that are central to the framework. From a macropolicy viewpoint, to understand the process of innovation is to know (1) how and when different components in the system emerge and are organized over time, (2) what actors create and perform these components, and (3) what consequences various arrangements of this community infrastructure have on the time and cost that it takes to develop and commercialize various innovations.

Although we propose that this infrastructure is crucial to an individual firm's success at innovation, a single entrepreneurial firm seldom performs all the functions required to create this system. Thus, from the viewpoint of an individual entrepreneurial firm, three key decisions are necessary: (1) What functions will the entrepreneurial firm perform? (2) What other organizations should the firm link to or contract with to perform other functions? (3) Consequently, what organizations will the firm compete with on certain functions and cooperate with on others? As these questions suggest, one way to understand the implications of the systems framework is to examine the process of innovation at two levels of analysis: (1) the system level looking at the community infrastructure as a whole and the interrelations among its components or functions, and (2) the behavior of individual entrepreneurs and firms within the industrial system.

Emergence of the Community System

The industry infrastructure for an innovation system does not emerge and change all at once by the actions of one or even a few key individuals. Instead, a detailed historical study of the development of the cochlear implant technology indicates that the process involved an accretion of 1,009 institutional, resource, market, and proprietary events involving many actors who transcended boundaries of many public and private-sector organizations. Van de Ven and Garud (1993) provide a graphic breakdown, shown in figure 6.2, by plotting the cumulative number of events observed in the development of specific functions of an industrial system for cochlear implants from 1956 to 1989. They report four qualitatively different periods in the historical development of cochlear implants, as noted on the bottom of figure 6.2:

The first "endowments creation" period began in about 1955 and consisted primarily of advances in basic scientific knowledge of cochlear implants by universities and basic research institutes, supported by a few events to legitimize and finance this research in the public domain. The second period focused on efforts by private firms beginning in 1977 to appropriate this basic research knowledge for launching proprietary commercial activities by entering into relationships with basic research institutes, and by initiating applied research and development, manufacturing, clinical trials, and marketing functions. When these relationships were established, a third "expansion" period is shown in which a rapid growth occurred from 1983 to 1986 in the number of events to develop each component of the emergent industry system. This expansion period was followed by a period of "stabilization" in all system functions, during which a dominant design for cochlear implants
emerged. The very institutional structures that were created in prior periods for industry growth began to constrain subsequent development. (19)
Van de Ven and Garud (1993) also plot the actors involved in these events to develop these system components over time. Figure 6.3 shows that the public sector played the major role during the initial periods of industry emergence beginning in 1955 and that private-sector actors did not become involved in cochlear implant development until twenty-two years later in 1977. However, when private firms became involved, the number of events performed by both private- and public-sector actors increased dramatically.

A breakout of the public-sector actors in figure 6.4 shows that among the public-sector actors, academic-research units played the dominant role, followed by regulatory agencies, particularly the U.S. Food and Drug Administration, funding agencies, principally the National Institutes of Health, and professional or industry associations. For comparative purposes, figure 6.4 provides a breakdown of the involvement of private-sector actors, as well as cochlear implant customers, patients, and otological clinics.

In a parallel set of studies, Garud and Rappa (1994, 1995) and Garud and Ahlstrom (1997) explored the roles of researchers in shaping the institutional and technical facets of cochlear implants. As they report, it is not appropriate to view even researchers as a unitary set of actors.
but, rather, as a set of actors performing different roles depending on their affiliations and motivations. For instance, some researchers create, others regulate, and still others deploy the technology being created. An intense debate among these constituents shapes the rate and direction of advances in the technology.

These studies are consistent with many other detailed historical studies of technological development. Usher (1954) insisted that the history of mechanical inventions in the nineteenth century is not the history of single inventors or random chance events. Gilfillan (1935) observed a perpetual accretion of little details—having no clear beginnings, completions or definable limits—in the gradual evolution of shipbuilding. Constant (1980) found that advances in aircraft propulsion emerged not from flashes of disembodied inspiration but from many incremental changes and recombinations of existing technology and organizational arrangements, which add up to what might be called a technological revolution.

Moreover, there is a systemic nature to technological advances, as demonstrated in studies by
Hughes (1983) of electrical power, Ruttan and Hayami (1984) of agricultural innovations, and Kuhn (1982) and Hull (1988) of science in general. In their study of cochlear implants, Van de Ven and Garud (1993) provide clear statistical evidence that the institutional arrangements, resource endowments, and proprietary events were reciprocally related and coproduced each other over time. Developments in other complementary technologies, institutions, and resource endowments often explain bottlenecks and breakthroughs in the development of a given technology. Thus, as Rosenberg (1983) says, "What is really involved is a process of cumulative accretion of useful knowledge, to which many people make essential contributions, even though the prizes and recognition are usually accorded to the one actor who happens to have been on the stage at a critical moment" (49).

Discontinuities are inherent to the numerous events in developing the institutional arrangements, resource endowments, and proprietary functions, particularly because they require the involvement of many actors from public and private organizations over an extended period. Individual events are often not made known to other actors, and various "acts of insights" pertaining to technical, resource, and institutional capabilities are often required to overcome bottlenecks. These acts or events accumulate probabilistically; they do not proceed deterministically under the stress of necessity or progress (Rosenberg, 1983). They are possible for only a limited number of individuals and organizations which, by virtue of their different roles, competencies, and available resources, become exposed to conditions that bring both awareness of problems and elements of solutions within their frame of reference. Thus, Usher (1954) said "emergent novelty becomes truly significant only through accumulation" (67) of many interrelated events of technical and institutional change.

These historical studies suggest that an explanation of how innovations develop should focus on the numerous microscopic events by which components of the infrastructure emerge over time. This system emerges as a partially cumulative progression of numerous events involving many actors in the public and private sectors who invest resources and perform different roles to develop an innovation.

Specifically, our proposition on the process of innovation emergence follows: Technological innovations emerge through accretions of many interrelated institutional, resource, and proprietary events involving many actors in the public and private sectors over an extended period of time.

To determine the relative contributions of various actors in developing each function of the cochlear implant infrastructure, Van de Ven and Garud (1993) report the results (table 6.2) of multiple regressions for each system function, the dependent variables in the rows, on the involvements of six kinds of actors, the independent variables in the columns. The table shows that statistically significant contributions were made by at least two or more different types of actors in the development of each system function of the cochlear implant infrastructure. These results lend clear support for the proposition that numerous public and private actors played key roles in the development of each component of the infrastructure for cochlear implants.

The process by which actors become engaged in the development of an industrial infrastructure
can begin any number of ways. It varies with the technology being developed. For example, it can begin with purposeful intentions and inventive ideas of entrepreneurs, who undertake a stream of activities to gain the resources, competence, and endorsements necessary to develop an economically viable enterprise. As they undertake these activities, the paths of independent entrepreneurs, acting out their own diverse intentions and ideas, intersect. These intersections provide occasions for interaction and recognizing areas for establishing cooperative and competitive relationships (Garud, 1994).

Cooperative relationships emerge among the actors who can achieve complementary benefits by integrating their functional specializations. Competitive relationships emerge as alternative technological paths become evident and different entrepreneurs or firms "place their bets on" and pursue alternative paths. We must emphasize that, during this initial period, applied research and development is highly uncertain and often dependent on basic science and technology. Depending on the technological alternative chosen by an entrepreneurial individual or firm, it becomes highly dependent on different clusters of basic research institutions, such as universities, laboratories, and disciplines, that have been producing and directing the accumulation of basic knowledge, techniques, and experience associated with a given technological alternative.

By engaging in cooperative and competitive relationships and by interacting in the same networks, groups of entrepreneurs in the public and private sectors increasingly isolate themselves from traditional industries by virtue of their interdependencies and growing commitments to and unique knowledge of a new technology. Isolation frees an emerging system from institutional constraints of existing technologies and industries (Astley, 1985) and permits it to develop its own distinctive structural form (Rappa, 1987). Coordination among actors takes place not so much by a central plan, organizational hierarchy, or price mechanism but mostly through interactions (Mattsson, 1987) and partisan mutual adjustments among actors (Astley and Van de Ven, 1983).
Table 6.2. Results of time series regression analysis of the contributions of various actors in developing cochlear implant industry functions

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>Constant</th>
<th>Professional associations</th>
<th>Regulator agencies</th>
<th>Funding agencies</th>
<th>Academic research</th>
<th>Customer’s clinics</th>
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Note: regression coefficients are unstandardized betas.

* = Beta coefficient is at least 1 1/2 its standard error.

** = Beta coefficient is at least 2 its standard error.
As the number of organizational units and actors gains a critical mass, a complex network of cooperative and competitive relationships begins to accumulate. This network itself becomes recognized as a new "industrial sector" and takes the form of a hierarchical, loosely coupled system. We view this emerging system as consisting of the key entrepreneurs and firms that govern, integrate, and perform all the functions required to transform a technological innovation into a commercially viable line of products or services delivered to customers. The structure of this system, when fully developed, consists of the institutional and market arrangements, resource endowments, and proprietary functions illustrated in table 6.1.

1. Of course, hierarchy in an industry system is a matter of degree, and some industry systems may be only minimally, if at all, hierarchical. Hierarchy is often a consequence of institutional constraints imposed by political and governmental regulatory bodies. Hierarchy also emerges in relationships with key linking-pin organizations which either become dominant industry leaders or control access to critical resources (money, competence, technology) needed by other firms in the industry.

Loose coupling promotes both flexibility and stability to the structure of an industry. Links between subsystems are only as rich or tight as is necessary to ensure the survival of the system (Aldrich and Whetten, 1981). Based on Simon's (1962) architecture of complexity, Aldrich and Whetten discuss how a loosely joined system provides short-run independence of subsystems and long-run dependence only in an aggregate way. The overall social system can be fairly stable, due to the absence of strong ties or links between elements and subsystems, but individual subsystems can be free to adapt quickly to local environmental conditions. Thus, in a complex, heterogeneous, and changing environment, a loosely joined system is highly adaptive.

Interactions among System Components

It is generally recognized that resource endowments often precede the development of market and institutional system functions because basic research, the search for a fundamental understanding of natural phenomena, provides the foundation of knowledge that makes possible the commercial birth of a technology (Abernathy, 1978; Rosenberg, 1983; Garud and Van de Ven, 1987). What is less well understood is the process by which a common pool of basic scientific or technological knowledge is appropriated and transformed by private firms into proprietary innovations that can become commercial monopolies.

Success at creating a monopoly by commercializing a new technology does not rest on a unique command of basic research or on the control of all the competencies and resources relevant to innovation. Instead, as Stobaugh (1985) and Mowery (1985) discuss, it rests on orchestrating a highly uncertain journey by linking with numerous organizations and actors and appropriating the competencies and resources relevant to developing and commercializing the innovation. This journey consists of an interactive search process involving parallel developments in building: basic research, financing mechanism, competence capabilities (the resource endowments), institutional arrangements, market demand, and proprietary commercial activities.
Different search and linking patterns should be expected for innovations in different industrial sectors. As Nelson and Winter (1977) discuss, in many sectors many R&D organizations—some profit-oriented, some governmental, some academic—do different things but interact in synergistic ways. In particular, in medicine, agriculture, and several other sectors, private for-profit organizations do the bulk of R&D that leads to marketing products, but academic institutions play a major role in creating basic knowledge and data used in the more applied work.

Most people understand that R&D is an uncertain business. Uncertainty resides at the level of an entrepreneurial firm, where the "best" way to proceed is seldom apparent and the individuals involved have to be satisfied with finding a potentially promising technological path. Less often understood is that the source of much of this uncertainty confronting individual entrepreneurs and investors resides at the system or community level. As the system framework highlights, if institutional arrangements and resource endowments have not yet emerged for an innovation, proprietary entrepreneurs are exposed to high uncertainties and risks in not knowing what kinds of institutional regulations, technical standards, financing arrangements, and specialized competencies will emerge for the innovation. Uncertainties are reduced as these institutional arrangements and resource endowments become established and embodied in a dominant technological design for the innovation.

This leads to our third proposition about interactions between proprietary, resource, and institutional components of the system framework: The time, cost, and risk incurred by proprietary firms in developing an innovation are inversely related to the developmental progress of building institutional arrangements and resource endowments for the new technology.

A concrete example of this proposition emerged from one MIRP study of the development of gallium arsenide integrated circuits in the United States, Japan, and Western Europe from 1983 to 1987 (Rappa, 1989). Although far more firms and scientists were engaged in the development of this technology in the United States than in Japan, by 1985, Japan was judged to be several years ahead of the United States in commercial developments and applications of the technology. One possible reason for the more rapid advancement of the technology with fewer scientists and engineers is that in Japan, a system infrastructure was already well established through MITI (Japan's Ministry of Trade and Industry), which encouraged firms that were competing on proprietary technical developments to cooperate with one another and many other actors in various industry and trade committees. The Japanese were meeting to develop commercial applications for the technology, to influence industrial governance policies, and to create a competence pool through training programs and informal information sharing. In the United States, no comparable industry infrastructure was in place in 1985. Instead, it appeared that many U.S. firms, while investing heavily in their own proprietary R&D projects, were "sitting on the fence" waiting for others to build the industry infrastructure for collective advancement.

Of course, the degree of system change varies with the novelty of the innovation being developed and commercialized. Some innovations change the entire order of things, making obsolete the old ways and spawning a cycle of creative destruction (Schumpeter, 1942). Most innovations simply build on what is already there, requiring modifications in existing system
functions and practices. We expect that innovations of different levels of novelty will require different degrees of change in system functions. For new technologies within established industries, some of the functions, such as governance institutions, may be established and may change in only subtle, nearly invisible ways. That, however, does not deny their importance, but it does explain why radical new-to-the-world innovations are far more difficult to develop and commercialize than incremental innovations within established industries.

Specifically, we propose the following: More novel innovations require greater change in all system functions and, therefore, greater development time and greater chance of failure.

Radical or revolutionary innovations not only represent new-to-the-world technologies but also represent vast departures from existing industrial systems. Although development and commercialization of certain radical innovations may require starting from scratch to construct an industry de novo, more often genuinely new industries emerge by relying on metaphors and adapting institutional arrangements that are carried over from other industries. But, as a study by Leblebici, Salancik, Copay, and King (1991) of the institutional evolution of radio broadcasting indicated, the use of more metaphors and arrangements that are borrowed from other industries makes building an integrated infrastructure for institutional scaffolding in the new industry more difficult because the components of an industrial system do not emerge independent of each other; they are highly interdependent. Many convergent and divergent events become bottlenecks that delay the overall development of the system.

For example, in the development and commercialization of cochlear implants, Garud and Van de Ven (1989) identified numerous temporal interdependencies in the creation of different system functions:

Basic scientific knowledge first had to ensure safety and efficacy of the technology for use in humans before business firms would become involved. The presence of firms wanting to commercialize cochlear implants was necessary as a thrust for the creation of the FDA panel for cochlear devices. The FDA's approval of cochlear devices was necessary for Medicare to extend its coverage for cochlear implants, which in turn is necessary for accessing a wider patient base. (516)

The rate of success for entrepreneurial firms is significantly influenced by the length of time it takes for the system to become established. For an individual entrepreneur, start-up funding for a venture represents an initial stock of assets that provides the entrepreneurial unit a "honeymoon" period to develop and commercialize its innovation (Fichman and Levinthal, 1988; Venkataraman and Van de Ven, 1998). These assets reduce the risk of terminating the innovation during its honeymoon period when setbacks arise and initial outcomes are judged unfavorable. The likelihood of replenishing these assets is highly influenced by the duration of the change process: Interest and commitment wane with time. Thus, after the honeymoon period, proprietary efforts at innovation terminate at disproportionately higher rates, in proportion to the time needed to develop institutional arrangements and resource endowments for the innovation.
Innovation uncertainty decreases over time as system functions that define key technical and institutional parameters for the innovation emerge. In addition, transitions from development to commercialization activities often entail shifts from radical to incremental and from divergent to convergent progressions as system functions develop. Analogous patterns of innovation processes within organizations, which become more highly structured and stabilized in their patterns and less differentiated from other organizational arrangements when innovations are implemented, have been observed (Tornatzky and Fleischer, 1990; Zaltman et al., 1973). Thus, at different periods of technological development, we should expect that different functional arrangements are needed to foster innovation and that different components of the system become the limiting factors that serve as "bottlenecks" to sustained innovation development.

This developmental pattern often culminates in the selection of a dominant design for the technology from among competing alternatives. As Van de Ven and Garud (1993) observed in cochlear implants, this selection process is produced primarily by a convergence in developments of institutional, resource endowments, market, and proprietary system functions that emerged to embody preferences for the dominant design. As this dominant design emerges, there is a leveling off in further developments of system functions. When primarily established, the system infrastructure systematically channels and constrains further technological advances in the direction of the dominant design.

This leads to our proposition on the temporal dynamics of system development: The very institutional mechanisms and resource endowments that initially develop to facilitate proprietary innovation development become inertial forces that constrain subsequent development in the direction of a chosen dominant design.

An examination of these propositions on the interactions among system components as they develop over time should lead one to examine whether and how learning occurs between functional events, which could provide guidance as to the next paths taken by actors to develop other parts of the system. By examining the outcomes of alternative paths, one could also identify the feasible sets of paths available in the emergence of an industry. Great interindustry differences should be expected (Mowery, 1985), but only by cumulative longitudinal studies of these developmental progressions between system functions will we come to appreciate how system infrastructures emerge for innovation and entrepreneurship (Dosi, 1982).

Roles of Individual Entrepreneurial Firms

The social-system framework emphasizes that any given entrepreneurial firm is but one actor, able to perform only a limited set of roles, and dependent on many other actors to accomplish all the functions for an industry to emerge and survive. As a consequence, an individual firm must make strategic choices concerning the kinds of proprietary resource endowments and institutional functions in which it will engage and what other actors it will engage to achieve self-interest and collective objectives. These strategic choices make clear that the ways entrepreneurial firms choose to allocate their innovation efforts are variables and that the lines separating the firm from its innovation community are not sharply drawn but are fluid and change frequently over time.
These choices and transactions evolve over time, not only as a result of individual firm behavior but, just as important, by the interdependencies that accumulate among firms engaged in numerous components of the emerging industry.

Pragmatically, therefore, firm managers and entrepreneurs should be concerned not only with their own immediate proprietary tasks and transaction modes but also with those of other firms in their resource distribution channel and with the overall social system. Switching involvement among different system functions and proprietary distribution channels is expensive. Influencing one’s own existing channel may be more efficient than switching channels or creating new ones. Also, there is an ongoing tension for each industry participant to organize its own proprietary functions and distribution channels as opposed to contributing to the creation of the industry's resources and institutional arrangements. Although the former may advance the firm's position as a first-mover in the short run, the latter provides the infrastructure that ultimately will influence the collective survival of the emerging industry.

There is an important counterintuitive implication in these decisions for individual entrepreneurs, which is captured in the following proposition: Entrepreneurial firms that run in packs will be more successful than those that develop their innovations alone.

Conventional wisdom is that entrepreneurs act independently and compete to be the first into the market with their new products or services. There are many technologies and industries in which acting alone may lead to successful monopoly profits. However, acting alone may lead to unsuccessful results when the innovation involves a new technology for a new industry. Running in packs means that entrepreneurs simultaneously cooperate and compete with others as they develop and commercialize their innovations. Running in packs is analogous to bicycle racers who cue their pace to one another and take turns breaking wind resistance until the ending sprint.

The argument for running in packs emphasizes that the interests of entrepreneurial actors with a stake in a technological innovation are both intertwined and divergent (Ben-Ner, 1993). The actors seek to maximize both their total surplus and their respective shares in the surplus. The total surplus amounts to creating an industrial infrastructure that makes it collectively possible to develop and commercialize a new technology for a new market. This draws actors together and drives them to cooperate because no one actor has sufficient resources, competence, or legitimacy to do it alone. The goal of maximizing individual shares propels actors to compete with each other to reap monopoly profits that derive from introducing a dominant technology or product. However, enlightened actors realize that the probability of economic survival from reaping monopoly shares of an orphan technology are much lower than from gaining relatively small shares of a larger and growing new industry. This is why population ecology studies are finding that having more competitors in a new organizational niche increases the survival probability of its members until a threshold level is reached where resource scarcity limits the growth of all members of a population (Hannan and Freeman, 1989). Gaining legitimacy is a key problem in the early emergence of a new industry, and the growth of a critical mass of actors is often a prerequisite for legitimacy.

Three corollary propositions elaborate this overall proposition on the self-interested and
Contrary to industrial economists' stress on competitive interfirm relations, the social-system perspective emphasizes that relationships have cooperative and competitive elements (Van de Ven, Emmett, and Koenig, 1974). For example, it is easy to understand that a firm needs to establish cooperative relationships with suppliers, distributors, and customers to make its own activities meaningful. It is also easy to see that other firms that pursue competing technological routes carry out conflicting activities. However, as Mattsson (1987) discusses, there are also important elements of conflict among cooperating firms that have to do with the negotiating and administrating business transactions and adaptation processes. Among proprietary competitors, there are also elements of complementarity, not only when they cooperate to share resources or develop industry institutional functions but also when they are complementary suppliers to the same customers.

Indeed, because firms in an emerging industry are often engaged in multiple issues simultaneously, they create a "multiplexity of ties" (Galaskiewicz, 1985: 296). Thus, Aldrich and Whetten (1981) point out that it is misleading to think of single relations among most firms in an industry. Common forms of multiple links between a given set of firms include exchanging multiple resources, communicating with other firm representatives on industry and trade committees, sharing common pools of knowledge, and acquiring personnel trained and socialized in a common pool of competence, friendship and kinship ties, and overlapping board memberships: As the number of cooperative and competitive ties among firms increases, the inter-firm relationships become more stable and the overall system becomes more flexible.

A rupture in one aspect of a relationship does not sever other ties, and continuing ties are often used to correct or smooth over the severed link. From an industry perspective, stability through redundant functions and activities among actors minimizes the negative impact of the loss of services provided by one industry member on the performance of the total system.

Multiple ties among firms emerge over time and often produce unintended consequences. Prior relationships and transactions among firms in the pursuit of an industry subsystem activity are remembered and become the infrastructure on which subsequent relations are based (Van de Ven and Walker, 1984). Galaskiewicz (1985) nicely summarizes some of these temporal dimensions:

"The networks of resource exchange that already existed among organizations are the infrastructure on which political coalitions are built. In all likelihood, these resource networks were created out of competitive struggle for survival by self-seeking and selfcentered actors, who were seeking to minimize their dependencies on one another. Now these networks are the infrastructure on which coalitions to achieve collective goals are built. In turn, as political coalitions become institutionalized, they impinge on the struggle for dominance in the resource procurement/allocation arena. (299)"

An appreciation of the temporal dimension of interfirm relationships also provides important insight on how competitors emerge in an industry. Generally, the literature tends to assume that competitors are profit-seeking entrepreneurs who somehow recognize and seize commercial
opportunities by entering lucrative markets. Based on their longitudinal study of the emergence of the cochlear implant industry, Van de Ven and Garud (1993) provide quite a different proposition to explain how industrial competitors emerged: Aborted efforts to establish cooperative relationships may become competitive relationships.

In studying the development of cochlear implants, Van de Ven and Garud (1993) observed two instances in which the efforts of the first-mover to initiate cooperative relationships or joint ventures with other research clinics failed, leading to the birth of the firm's competitors. Initial negotiations of possible relationships with a foreign university and a domestic university did not materialize. Otological scientists and clinicians in each of these two universities subsequently entered into licensing arrangements with two other firms, one a new company startup and the other a subsidiary of a large manufacturer, which two years later became the first-mover's major competitors.

The proposition that aborted cooperative relationships lead to competitive relationships applies primarily to conditions in which a small number of organizations, perhaps the size of an oligopoly, exist with the requisite unique competence or assets necessary for innovation development. Such conditions tend to exist during the early emergence of new-to-the-world technologies, where one can often count on one hand the pioneering firms and inventors worldwide who are pursuing the development of a parallel set of basic research ideas or technological designs. These pioneers make themselves known to one another by reporting results of their inventions through patents, professional publications, and association meetings. They thereby come to recognize opportunities to obtain unique competencies or components needed to advance their own work. If efforts to obtain the needed resources go unconsummated because a cooperative relationship could not be established, the negotiating parties will go their separate ways by entering into cooperative relationships with other parties in this limited set of pioneers who possess the unique competencies or resources. As Van de Ven and Ring (1994) discuss, this implies a shift to a competitive orientation between the parties who failed at each other's initial efforts at cooperation.

Through this and related processes, key first-mover organizations emerge that have extensive and overlapping ties to different components of the emerging technological community and play the key role of integrating the system. Because they have ties to more than one subsystem of a community, these first-movers are the nodes through which a network is loosely joined (Aldrich and Whetten, 1981). They serve as communication channels among industry participants and link third parties by transferring resources, information, or specialties within and outside of the industry. By being linked into multiple-subsystem functions in the industry, these first-movers accumulate a broad base of power to ascend to a dominant position in the industry, which permits them to survive at the expense of peripheral participants.

But these first-movers also experience the greatest conflicts of interest in the emerging industry because they tend also to have the greatest amount of visibility, which limits their abilities to capture significant proprietary advantages. This is because their dominance serves as a model that is imitated by others and diffused throughout the industrial community. Thus, the leading firm that chooses to "go it alone" must bear significant first-mover burdens, which permits free riding by other industry participants. In return for these burdens, first-movers are generally believed to have
the greatest degrees of freedom to shape industry rules, technology standards, and product perceptions in the directions that benefit them the most (Porter, 1985).

However, these first-mover benefits do not appear to be empirically substantiated for technologies with weak appropriability regimes—that is, those that are easy to imitate, reverse engineer, or substitute (Teece, 1987). Anderson and Tushman (1990) found that the original breakthroughs in cement, glass, and minicomputers almost never became the dominant design except where strong patent protection existed. This research leads to the following caveat: The technological design of the first-mover often turns out not to become the dominant design that yields the greatest profits.

While striking out to be the first to introduce a new technology, the first-mover will inevitably make mistakes, and followers who watch can make adjustments in their own technologies. As a result, after the first-mover has introduced the product in the market, the second-, third-, and fourth-movers, who have been carefully following the leader, can often and rapidly introduce a more significant, advanced, and better product or service. These are strong economic motives for first-movers to run in packs, not alone.

Inherent in all the previously discussed relationships among firms engaged in an emerging industry is the paradox of cooperation and competition. Each firm competes to establish its distinctive position in the industry; at the same time, firms must cooperate to establish the industry infrastructure. Olson (1965) summarizes the paradox:

If the firms in an industry are maximizing profits, the profits for the industry as a whole will be less than they might otherwise be. Almost everyone would agree that this theoretical conclusion fits the facts for markets characterized by pure competition. The important point is that this is true because, although all the firms have a common interest in a higher price for the industry's product, it is in the interest of each firm that the other firms pay the cost, in terms of the necessary reduction in output, needed to obtain a higher price. (10)

Another example that pertains to institutional arrangements is that it clearly benefits all firms to cooperate to set up industry standards. However, in doing so, each firm will try to ensure that the industry standards that suit it best get institutionalized.

One of the major reasons for the origin of industry regulation is that it is an institutional means to address these collective action dilemmas in which individual firms do not voluntarily act in a designated way to achieve benefits for all industry participants (Mitnick, 1980). Institutional ways to guarantee such action must be devised to provide the benefits. Otherwise, individual self-interest may lead some members to free-ride on whatever group benefits may have been obtained by others.

**Conclusion**

We believe the social-system perspective and its associated propositions make four contributions to understanding the emergence of technological innovations.
1. The social-system framework provides a holistic perspective to examine both the generative process by which a new-to-the-world technology is developed and commercialized and the roles of public- and private-sector actors, which create an infrastructure that supports technological development. By taking the interorganizational community or network as the relevant unit of analysis, the framework provides a more inclusive perspective of a competitive industry. In addition to this proprietary subsystem, the framework examines the industrial infrastructure that supports and constrains innovation. This infrastructure includes resource endowments of basic knowledge; financing mechanisms; competent labor; the institutional governance structure that legitimizes, regulates, and standardizes the activities of industry members; and market demand from informed consumers. Although an eclectic body of literature and research substantiates the importance of these component functions of a community infrastructure, they have been treated as "externalities" (Porter, 1980). By incorporating these functions within a conceptual framework, one can undertake a systematic research agenda aimed at understanding how various actors and functions interact to create an infrastructure that both facilitates and constrains innovation.

2. The infrastructure for innovation at the macro community level is grounded in a theory of action at microlevels of individuals and firms. We proposed that the odds of a firm successfully developing an innovation are primarily a function of the extent to which this infrastructure is developed at the industrial-community level. This community infrastructure facilitates and constrains entrepreneurial firms, but it is the actions of individuals and firms that construct and change the community infrastructure. But this infrastructure does not emerge and change all at once by the actions of one or even a few key individuals. Instead, we proposed that this infrastructure emerges through the accretion of numerous institutional, resource, and proprietary events, which coproduce each other through the actions of many public- and private-sector actors over an extended period. This generative process has a dynamic history that itself is important to study systematically if we are to understand how novel forms of technologies, organizations, and institutions emerge.

3. We argued that institutional and market arrangements, resource endowments, and proprietary functions are highly interdependent and coproduce each other over time. The framework allows us to examine the dynamic interplay in the progression of the different system components. Indeed, the very institutional arrangements and resource endowments created to facilitate industry emergence can become inertial forces that hinder subsequent technological development and adaptation by proprietary firms. However, even though various system functions coproduce each other, they are not expected to be completely determined. When tracking a highly uncertain generative process, researchers should consider large unexplained components of chance, noise, or error in the process.

4. The social-system perspective emphasizes that the debate on corporate revitalization through innovation is not limited to the for-profit sector; numerous entrepreneurial actors in the public and not-for-profit sectors play crucial roles that enable a new technology to be developed and commercialized. This perspective also enables one to examine the different roles and events of these different actors and how their roles affect the roles of other actors, as well as their joint contributions to the emergence of the entire industry. This, in turn, makes it possible to understand how developments in the overall infrastructure for innovation significantly influence the time, cost,
and direction of proprietary innovation.