Technology Analysis & Strategic Management, Vol. 12, No. 2, 2000

Technological Discontinuities and the Nature of Competition

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ABSTRACT *We revisit the Schumpeterian model of competition driven by the perennial gale of creative destruction. Not every innovation must necessarily lead to the destruction of incumbent firms. In many high-technology industries we observe a symbiotic coexistence between new entrant and incumbent firms. This phenomenon warrants more attention. We build upon the innovation and strategic alliance literature to develop the notion of 'complementary innovation.' We advance propositions with respect to the following questions: What impact will a complementary innovation have on firm entry, interfirm cooperation, and the nature of competition? Based on the propositions advanced, we develop a cyclical model of industry dynamics initiated by a complementary innovation. The propositions and the cyclical model of industry dynamics are illustrated in a case study of the biopharmaceutical industry.*

Introduction

A generation ago, companies like Compaq or Nucor either did not exist or were fringe competitors. However, technological discontinuities such as the microprocessor and the electric arc furnace have reshaped existing industries in dramatic ways to create entirely new industries. These technological discontinuities had a tremendous impact on the nature of competition and firm performance in the computer and steel industries, among others, and subsequently Compaq and Nucor rose to be superior performers in their respective industries.

These examples illustrate the Schumpeterian process of 'creative destruction'.[1] Underlying capitalism is an evolutionary process that follows a characteristic pattern. In periods of market equilibrium, established firms extract monopoly rents based on innovative products or processes. These equilibria are transient. It is only a question of time before they are punctuated by a new round of innovations in which the prevailing competitive advantages of incumbents are overthrown. Schumpeter ascertains that this perennial gale of creative destruction is the driving force behind the market system: 'The process of Creative Destruction is the essential fact about capitalism ... it is not [price] competition which counts but the competition from ... *the new technology*, ... competition which strikes not at the margins of the profits ... of existing firms but at their foundations and their very lives'.[2]

However, not every innovation must necessarily lead to a Schumpeterian process of

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creative destruction, with a subsequent demise of incumbent firms while new entrants rise to dominance. For example, the emergence of biotechnology since the mid-1970s can be understood as a process innovation in the way drugs are discovered, developed, and manufactured for firms within the traditional, chemical-based pharmaceutical framework. In the biopharmaceutical industry—meaning the combination of the traditional pharmaceutical companies with new biotechnology firms (NBFs)—we do not observe a Schumpeterian process of creative destruction. Instead, incumbent firms have adapted to the emergence of biotechnology through collaboration with new entrants and building in-house competencies. On the other hand, the NBFs have also utilized extensive cooperation with incumbents to commercialize biotechnology. The cooperation of Genentech and Eli Lilly is a case in point, as Genentech has preferred to license Humulin, a human insulin based on recombinant DNA, to Eli Lilly instead of commercializing it on its own.[3] Subsequently, we observe a symbiotic coexistence between incumbent firms and new entrants in the biopharmaceutical industry.[4]

A similar situation can be found in the telecommunications industry after the emergence of cellular telephony. Cellular telephony can be interpreted as a technological discontinuity in the way telephone communication is provided from the user's telephone set to the switching network. Cellular telephone services differ from regular wire services in that signals are carried from the user's telephone to the telephone switching network by radio transmission, rather than by traditional wire. The incumbent firms can be identified as the public and private switching companies, and the new entrants as the firms providing radio-based technologies for cellular telephony. The telephone switching companies are in need of radio technology while the radio-communication companies are in need of access to the switching network. Subsequently, providers of the radio technology on which cellular telephony is based have not replaced the incumbent switching providers. Rather, due to the complementarity of their assets, we see extensive firm cooperation between new entrants and incumbents in the telecommunications industry.[5]

This phenomenon of extensive cooperation between incumbents and new entrants with the goal to commercialize an innovation, which we label 'creative cooperation', is understood with regard to the Schumpeterian notion of creative destruction. Schumpeter defines creative destruction as a process 'that incessantly revolutionizes the economic structure ... incessantly destroying the old one, incessantly creating a new one'.[6] However, an innovation need not lead to the destruction of incumbents. Incumbents may be able to survive, and even thrive, on radical technological change through cooperation with new entrants, as in the biopharmaceutical and telecommunications industries.[7] The term creative cooperation captures the use of extensive cooperation between incumbents and new entrants initiated ('created') by an innovation that leads to a search for mutually complementary assets.[8] Complementary assets such as marketing, manufacturing, and after-sale service are often needed to ensure the successful commercialization of an innovation. Therefore, a 'complementary innovation' destroys the existing industry structure, but instead of destroying the incumbent firms with it as in the Schumpeterian model, it results in an industry structure of extensive cooperation between incumbents and new entrant firms that allows for a symbiotic coexistence in a newly defined industry.

This phenomenon of a symbiosis between incumbent and new entrant firms in the face of a complementary innovation warrants more attention. In particular, this paper brings together the literature streams on innovation and firm cooperation. We advance propositions with respect to the following questions: What impact will a complementary innovation have on firm entry, interfirm cooperation, and the nature of competition? Incumbent survival and adaptation in the face of radical technological change have been

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explained by the persistence of market capabilities[9] and complementary assets.[10] We contribute the notion of interfirm cooperation as a mechanism of incumbent firm adaptation to a discontinuous environment. In the context of a complementary innovation, incumbents will—through strategic alliances with new entrants—not only be able to survive radical technological change, but also thrive as a result.[11]

Complementary Innovation and the Nature of Competition

In order to study the nature of competition following a technological discontinuity, it is important to distinguish between a firm's technological and non-technological competencies.[12] According to the value chain perspective, a firm consists of a chain of activities for transforming inputs into outputs, with each link adding value to the product or service.[13] Some of these activities, product research and development for example, might be highly sensitive to technological change, whereas others, like marketing and distribution, are less so. With respect to the technological core of an industry, however, a technological discontinuity can either destroy or enhance it.[14] We suggest, nevertheless, that it is the combined effect of a technological discontinuity on both ends of the value chain that determines the resulting nature of competition.[15] Hence, in order to understand the effect of a discontinuity on the firm, and the subsequent nature of competition, our analysis must be expanded to incorporate downstream activities.[16]

The nature of competition prior to a technological discontinuity at time T_0 is assumed to be steady-state, most likely based on either price or non-price competition rather than innovation or adaptation to a previous discontinuity. We then assume that this equilibrium is punctuated during the time period T_1 by a technological discontinuity. The technological discontinuity in T_1 will have a moderating effect on the steady-state competition prevalent in T_0. The response of incumbent firms to the impact of the discontinuity will, on the aggregate, determine the nature of competition in the industry in the post-discontinuous time period T_2. This relationship is depicted in Figure 1.

A firm exposed to a technological discontinuity must assemble technological and non-technological assets to successfully commercialize on the technological breakthrough.[17] If a technological discontinuity destroys a firm's technological value chain activities without

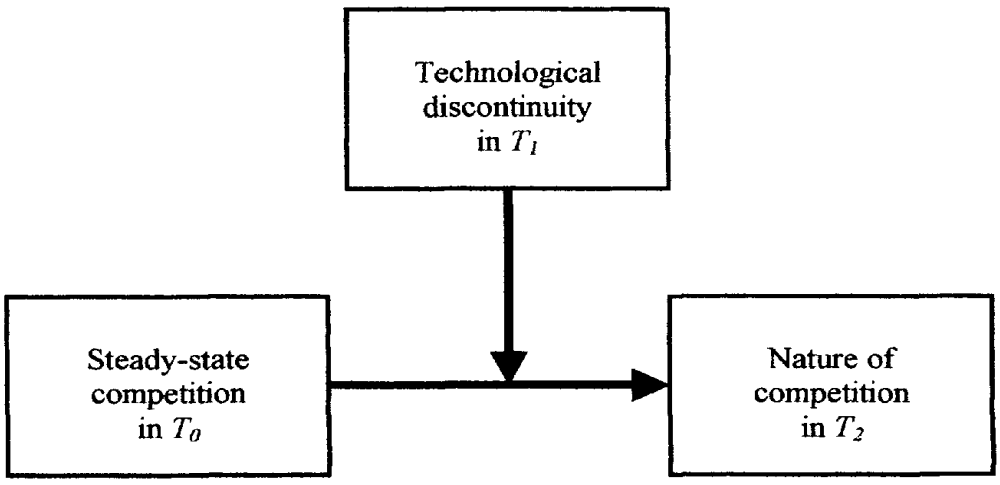

Figure 1. Technical discontinuity as mediator of nature of competition.
Source: Rothaermael (1999), Ref. 11, p. 21.

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affecting other downstream value chain activities, then we expect a Schumpeterian process of creative destruction to take place.[18] Exclusively competence-destroying technological discontinuities break the existing market structure. Subsequently, barriers to entry will be lowered and new firms will enter the industry by exploiting the competence-destroying technology. Therefore, exclusively competence-destroying discontinuities favor new entrants over incumbents.[19] New entrants based on new competencies commercialize on the new technology and gain thereby market share at the expense of incumbents. The incumbents are often unable to take advantage of the technological breakthrough since they are locked into the old technology in terms of skills, abilities, and expertise. Former core capabilities turn into core rigidities.[20] The performance of incumbent firms declines and eventually incumbent firms will exit the industry while new entrants enter the industry and eventually rise to dominance following a technological discontinuity.[21]

The effect of a technological discontinuity on an individual firm's competence is by definition dichotomous: it is either competence destroying or competence enhancing with respect to the technological core of the incumbent firm.[22] To explain the ultimate impact of the discontinuity, it is therefore necessary to look beyond the technological change alone. For this reason, the analysis should be expanded to include the incumbent firm's non-technological value chain activities.[23]

A theoretically interesting case with respect to the nature of competition in the post-discontinuous time period T_2 arises when a technological discontinuity overturns the upstream technological value chain activities of incumbent firms, but simultaneously enhances their downstream, non-technological value chain activities. We label this phenomenon 'complementary innovation'. The upstream value chain activities of incumbent firms are enhanced when those activities are specialized with respect to commercializing the new technology.[24] Specialized assets, such as manufacturing, marketing, or after sales support, are generally downstream value chain activities that are needed to ensure the successful commercialization of an innovation. Only rarely, however, are those critical value chain activities within the scope of the innovating firm. These specialized complementary assets are, in general, market-oriented value chain activities, however each tends to be industry specific. For example, FDA regulatory management skills in the pharmaceutical industry and ownership of the switching networks in the telecommunications industry are both considered downstream, market-related value chain activities, yet they are unique to their respective industry settings. In addition, innovators generally do not have the capital or the time to build those needed complementary assets in-house. Subsequently, a complementary innovation will break barriers to entry and allow firms that provide the new technology to enter the industry.[25] Thus, a complementary innovation will initiate extensive entry into the industry. Proposition 1 follows.

Proposition 1: *A complementary innovation will initiate extensive entry.*

A complementary innovation overturns the upstream, technology-related value chain activities of incumbent firms while leaving their downstream, market-related value chain activities intact. These downstream value chain activities are enhanced if they are specialized with respect to commercializing the new technology, since they can be used without any significant additional investment. In this situation, new entrants providing the breakthrough technology, and incumbents providing the downstream value chain activities required to commercialize the new technology, will seek out mutually complementary assets through interfirm cooperation. Thus, a complementary innovation will initiate extensive cooperation between incumbents and new entrants. We now derive our second proposition.

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Proposition 2: *A complementary innovation will initiate a process of creative cooperation.*

In the case of a complementary innovation, incumbents are able to adapt to radical technological change by cooperating extensively with organizations that possess the new technology. If an incumbent firm's non-technological assets are specialized or co-specialized with respect to commercializing the technological breakthrough, then it will benefit from that breakthrough, even though it is not the source of the innovation.[26] Not only will the incumbents survive, their specialized assets allow them to extract disproportionately high innovation rents giving them a significant advantage over new entrants. On the aggregate, therefore, the extensive cooperation between incumbents and new entrants should lead to improved incumbent industry performance. The above discussion is summarized in Proposition 3.

Proposition 3: *A complementary innovation will lead to an overall improvement in incumbent industry performance.*

The improvement in incumbent industry performance following a complementary innovation will lead to further entrenchment of incumbent firms. Thus, the market position of incumbents will be strengthened by a complementary innovation, whereas new entrants will either be acquired by incumbent firms or forced to exit the industry.[27] A few new entrants may be able to integrate forward to bring the missing market-related value chain activities within their firm boundaries.[28] In this case, we would expect to see an inverse relationship between the difficulty of forward integration and the number of successful new entrants. Nevertheless, the industry concentration ratio should eventually approach the pre-complementary innovation level. Thus, the effects of a complementary innovation on incumbent industry performance and the subsequent nature of competition end with industry consolidation. The industry will again enter a phase of steady-state, generally non-price based, competition. A subsequent complementary innovation may start this cycle anew. This discussion is summarized in Proposition 4. In addition, Figure 2 depicts this cyclical model of the expected industry dynamics initiated by a complementary innovation.

Proposition 4: *A complementary innovation will lead to industry consolidation.*

The Case of the Biopharmaceutical Industry

The biopharmaceutical industry is composed of traditional pharmaceutical companies, such as Merck or Pfizer, that apply biotechnology to drug discovery and development, as well as fully dedicated biotechnology firms, such Amgen or Immunex. While biotechnology is perhaps most commonly associated with this relatively young industry, its use can be traced back for millennia, and its reach has been pervasive, extending to fields ranging from agriculture to human therapeutics to waste management. One of the earliest examples of biotechnology is the use of fermentation techniques in beer brewing and bread making. This so-called traditional biotechnology is used to manipulate the external environment of microorganisms. The 'new' biotechnology (recombinant DNA, cell fusion, and novel bioprocessing techniques), on the other hand, enables the manipulation of the inner structure of microorganisms. It is this radical process innovation that has driven the development of the biopharmaceutical industry.

Watson and Crick laid the scientific foundation of the new biotechnology in 1953 when they were able to show that DNA formed a double helix of two spiral strands held together by base pairs. In 1973, a research team lead by Cohen and Boyer published

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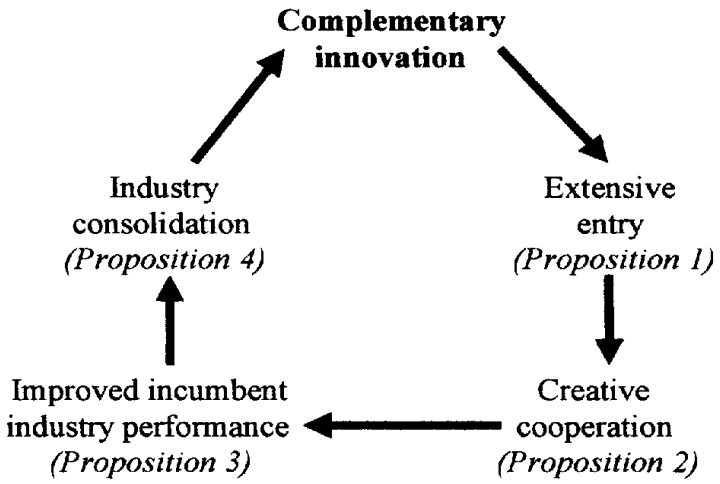

Figure 2. A cyclical model of industry dynamics initiated by a complementary innovation.

their breakthrough on recombinant DNA (genetic engineering). This technique allows 'cutting' DNA out of one cell (e.g. a human cell) and 'pasting' it into a different host cell (e.g. *E-coli* bacteria). If this piece of DNA holds the genetic code for producing insulin, for example, then the host cell will produce insulin external to the human body (in vitro). Subsequently, research in biotechnology prospered, making it one of the stellar sciences of the late 20th century.

Biotechnology can be seen as a complementary innovation for existing pharmaceutical firms. Their core technology in drug discovery and development is based on chemical screening. This method has, for the most part, been replaced by novel drug discovery and development methods based on biotechnology, rendering it obsolete. However, the downstream, market-oriented activities of the incumbent pharmaceutical firms are still intact, and have even been enhanced as a result of biotechnology. The emergence of biotechnology represents a radical process innovations, reducing barriers to entry in the pharmaceutical industry, and paving the way for the emergence of new biotechnology firms (NBFs). The period extending from World War II to the arrival of the new biotechnology saw only one significant entry into the pharmaceutical industry (Syntex, with the breakthrough of its oral contraceptive), but its structure changed dramatically in the years that followed. The year 1976 is often referred to as the start of commercialized biotechnology, as it marks the founding of the first NBF—Genentech—by scientist Boyer and venture capitalist Swanson. Between 1970 and 1997, 1049 companies entered the industry to commercialize biotechnology. On average, 37 companies entered the industry per year during this time period, with 89 entries in 1992 alone. These new entrants represented a little more than 85% of all firms participating in biotechnology. Those numbers related to all sectors of biotechnology, nevertheless, the majority of firms were engaged in pharmaceuticals. This wave of entry following a complementary innovation (Proposition 1) is depicted in Figure 3.

The technological paradigm embodied in the new biotechnology had a strong influence on the relationship between newly emergent biotechnology firms and established firms. It constituted a radical process innovation for traditional pharmaceuticals,[29] making their upstream, chemical-based value chain activities in research and drug discovery, as well as in drug development, virtually obsolete. Whereas these activities had traditionally been grounded in synthetic organic chemistry, their basis within the new biotechnological framework shifted toward molecular biology.[30] However, downstream value chain activi-

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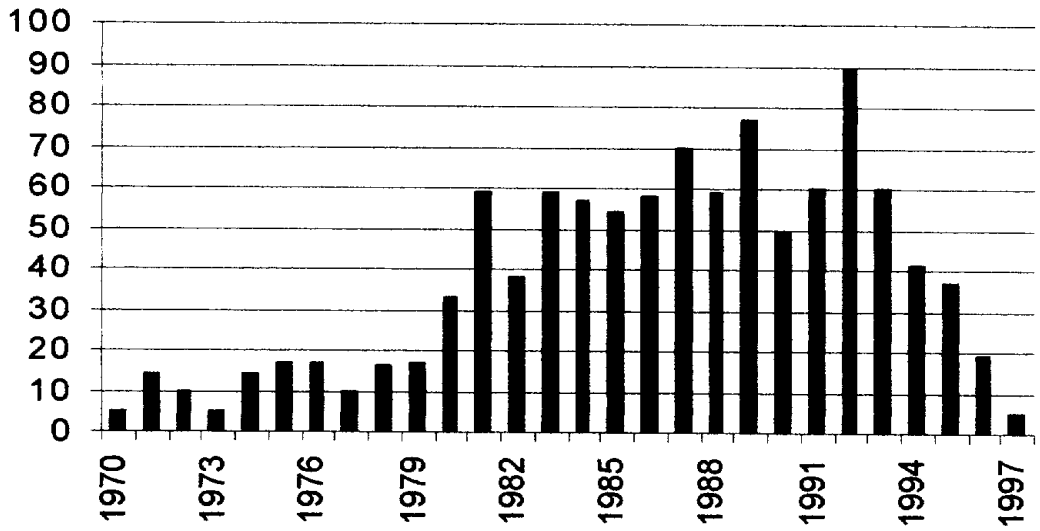

Figure 3. Firm entry into the biotechnology industry, 1970–1997.
Source: Rothaermel (1999), Ref. 11, p. 45.

ties such as FDA regulatory management, as well as marketing and sales, were still valuable. The challenge for the traditional pharmaceutical firms was to fit these new technologies based on recombinant DNA into their existing value chain activities.

At the time of the emergence of the first biotechnology firms in the 1970s, the new entrants focused almost entirely on research and drug discovery. Some companies developed diagnostic kits and brought them to the market, but with regard to drug discovery and development, the focus of NBFs could be found in the first two activities of the value chain.[31] The NBFs intended to eventually integrate downstream through the value chain to become fully integrated pharmaceutical companies. After almost 25 years of commercialized biotechnology, however, only a handful biotechnology companies, such as Amgen, Chiron, and Immunex, can be considered stand-alone biopharmaceutical companies that encompass all the necessary value chain activities within their firm boundaries. Almost all NBFs established strategic alliances with existing traditional pharmaceutical companies to gain access to missing downstream activities of the value chain. At the same time, traditional pharmaceutical companies incorporated the new building block based on genetic engineering into their existing upstream activities through cooperative arrangements with new entrants.[32] The pharmaceutical firms not only needed to understand the new technology, they also needed access to the innovative products NBFs could potentially provide. As a result, incumbents and new entrants alike had incentives to search out their mutually complementary assets through the use of cooperative arrangements. The alliance between Biogen and Schering–Plough in commercializing Intron A as the first biotech-interferon product approved for cancer treatment, and the alliance between Chiron and Merck to commercialize the drug Engerix-B for the prevention of hepatitis B, are examples of such agreements. In 1993, six of the top-ten selling biotech drugs were marketed by firms other than the NBFs that had developed them. Those six drugs alone accounted for over $2.5 billion in sales.[33]

Partnership agreements have been critical vehicles for biotechnological innovation. External partnering is used in the biopharmaceutical industry primarily to move a discovery along the value chain through development, manufacturing, and eventually marketing and sales. Prior to 1970, only three biotechnology cooperative agreements

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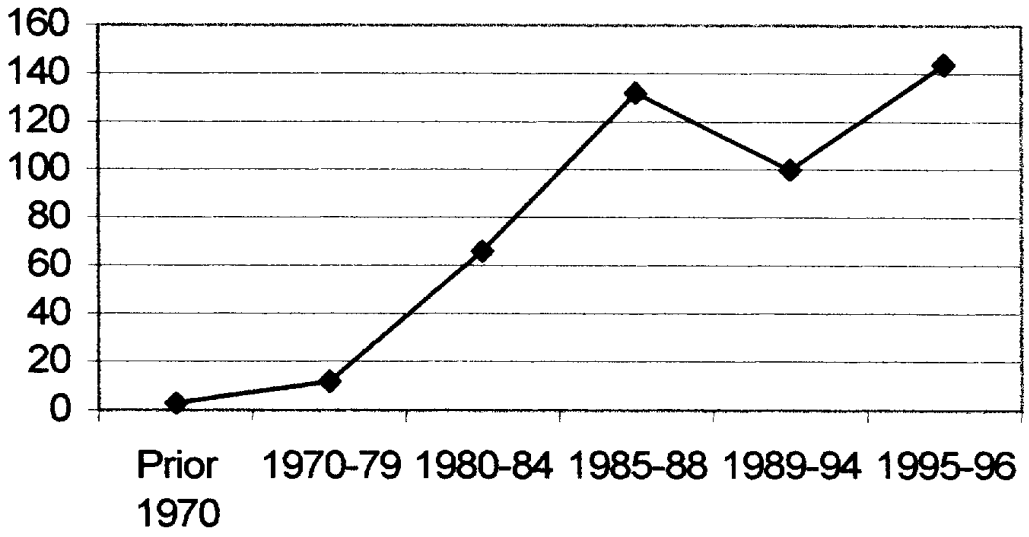

Figure 4. Average number of cooperative arrangements in the biopharmaceutical industry, 1970–1996.
Source: Rothaermel (1999), Ref. 11, p. 47.

were formed, and about 120 agreements were created during the ten years between 1970 and 1979. During the early 1980s there were on average 66 agreements per year, and this number peaked at 132 per year for the period 1985 to 1988. Since 1989, the number has remained at about 100 annually,[34] however in 1995 and 1996, a total of 287 strategic alliances were formed. Almost 70% of CEOs of all publicly traded NBFs and 50% of privately held NBFs anticipated having at least one strategic alliance completed by the end of 1997.[35] Hence, the complementary innovation initiated a process of creative cooperation in the biopharmaceutical industry (Proposition 2). The increase in the average number of cooperative arrangements between pre-1970 and 1996 is depicted in Figure 4.

Biotechnology is the industry with the highest absolute number of strategic alliances, accounting overall for 20% of these agreements.[36] This represents more than twice the share of the next largest industry in utilizing strategic alliances. Such an extensive use of interfirm cooperation is without precedent in business history.[37] One general reason for the extensive use of interfirm cooperation is that the new biotechnology is applied to a wide variety of industries. However, where the biopharmaceutical industry is concerned, a more compelling reason explaining such an extensive use of strategic alliances is that cooperative arrangements are necessary in order for incumbents and new entrants to access their mutually complementary assets. That the strategies of external linkages between large pharmaceutical companies and NBFs are complementary to one another has been empirically corroborated.[38]

As mentioned previously, while the upstream, technological value chain activities of traditional pharmaceutical firms are obsolete within the framework of biotechnology, their downstream, market-oriented value chain activities are enhanced. This can be explained by understanding the importance of incumbent firms in commercializing biotechnology drugs. At the time of the emergence of the NBFs, existing pharmaceutical companies were the only firms capable of bringing these innovative drugs to the market. In particular, the NBFs did not have the capital to conduct large-scale clinical trials, nor did they have the skills to master the FDA regulatory process, which commands

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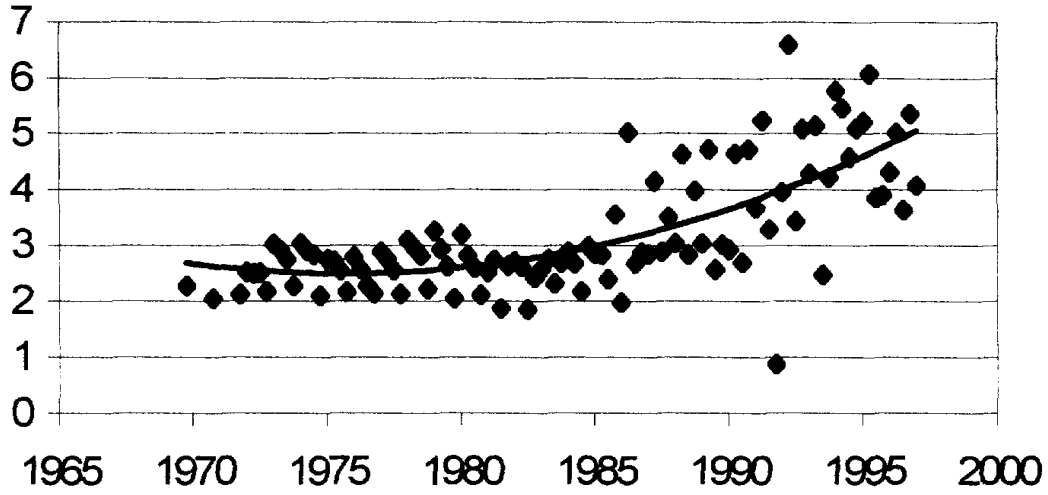

Figure 5. Industry ROE for global pharmaceutical industry, 1969–1997.
Source: Standard & Poor's Compustat (Englewood, Co: McGraw-Hill, 1998).

tremendous managerial and legal resources.[39] The downstream activities of the existing pharmaceutical companies were enhanced by the emergence of biotechnology, since their existing value chain activities could be utilized in commercializing on biotechnology without significant additional investment. This enabled the incumbent pharmaceutical firms to command disproportionately high innovation rents, which led to an overall improvement in incumbent industry performance (Proposition 3). The revenues of biotechnology product sales totaled $14.6 billion in 1997, which amounts to more than approximately 10% of the total sales in the pharmaceutical industry.[40] The relatively large amount of revenue generated by biotechnology drugs indicates the potential of the revenue stream accessed by the incumbent pharmaceutical firms via cooperation with new entrants. Figure 5 depicts the trend in incumbent industry performance in a time series of quarterly industry return on equity (ROE) for the global pharmaceutical industry participating in biotechnology beginning in 1969 through to 1997.

New entrants have not replaced incumbent firms in the biopharmaceutical industry, nor is this likely to take place in the future. Currently, we see a symbiotic relationship between incumbent and new entrant firms. One distinct feature of this symbiotic relationship is the extensive use of cooperative arrangements. As a complementary innovation, biotechnology initiated a process of creative cooperation. This may, however, only be a temporary phenomenon.[41] Many incumbent firms are very active in building in-house competencies in biotechnology.[42] Besides the extensive use of cooperative arrangements or building in-house competencies, we have also witnessed that many incumbent pharmaceutical firms take substantial equity in new biotechnology firms. For example, most of Immunex's shares are owned by American Home Products, while Roche has an option to outright acquire Genentech.[43] All of this points toward industry consolidation (Proposition 4). We expect to see more takeover activity and an intensified building of in-house competencies by incumbent pharmaceutical firms. Most new entrants will either be acquired by an incumbent firm or exit the industry. Some NBFs will remain independent, however, they will focus on a niche strategy and be the provider of drug discovery research for large pharmaceutical firms. Only a few firms, like Amgen, will develop into stand-alone, fully integrated pharmaceutical firms based on the new technological paradigm of biotechnology. We expect that the concentration ratio of the

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industry will reach its pre-complementary innovation level with a level of industry performance that is higher than the one experienced prior to the emergence of biotechnology. This will close the cycle of industry dynamics initiated by the emergence of the biotechnology.

Discussion and Conclusion

The concept of complementary innovation fits nicely with Abernathy and Clark's notion of 'low transilience' innovation, which points out how incumbent firms may benefit from innovation.[44] An example for a 'low transilience' innovation is a process innovation that requires discontinuous change in product design technology while existing market linkages remain unchanged. Abernathy and Clark find that in this situation, incumbents will not only survive, but experience significant advantages relative to new entrants as well.[45] This paper also reinforces Tripsas' notion of incumbent survival through complementary assets,[46] and Mitchell's differentiation with respect to the importance of technical vs market-related capabilities when adapting to a new technology.[47] In addition, this paper buttresses the importance of analyzing the impact of an innovation on incumbents in total, including all linkages between different firm activities.[48] This paper carries the analysis a step further by including the element of firm collaboration as a way for incumbents to adapt to radical technological change. For example, incumbents may focus on adapting to 'disruptive technologies'[49] through cooperation with new entrants.

We propose that a complementary innovation will break the barriers to entry and induce extensive new entry (Proposition 1). Subsequently, a complementary innovation will lead to a process of creative cooperation between incumbents and new entrants (Proposition 2). Hence, complementary innovations lead to symbiotic relationships between incumbents and new entrants. Further, in such a context incumbents will be able to profit from the innovation provided by the new entrants. Thus, the process of creative cooperation will lead to an overall improvement in industry performance of incumbent firms (Proposition 3). Finally, the industry will consolidate again as incumbents build in-house competencies and/or acquire new entrants. In addition, many new entrants will exit the industry (Proposition 4). This will close the cycle of industry dynamics initiated by a complementary innovation. A subsequent complementary innovation may initiate a new round of extensive entry, creative cooperation, improvement in incumbent industry performance, and subsequent industry consolidation ending in steady-state competition (Figure 2).

The notion of creative cooperation initiated by a complementary innovation is an important expansion of the Schumpeterian notion of competition driven by the perennial gale of creative destruction. This new perspective has important public policy and anti-trust implications. For example, cooperative arrangements in many high-technology industries are aimed towards commercializing an innovation, and not towards distorting competition. Second, incumbents often play a crucial role in commercializing a new technology due to the importance of complementary assets.

This expansion of the Schumpeterian model of competition has important implications for strategic management. For example, managers of incumbent firms in industries experiencing a complementary innovation should strive to gain a competitive advantage by searching out those strategic alliance partners that enhance the incumbent's downstream, market-related value chain activities. This strategy should also enable incumbent firms to 'buy time' in order to build the upstream, technical-related value chain activities. Similarly, new entrants may choose a cooperative strategy as the only possible way to enter an otherwise non-contestable industry.

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Future research should attempt to empirically test the notion of complementary innovation and creative cooperation to enhance its internal and external validity. One limitation of this paper is, however, that we are unable to say anything with respect to interfirm performance differentials. To study interfirm performance differentials in industries experiencing a discontinuous technological change in their environment is a much-needed expansion of this stream of research. We hope that this paper will inspire such efforts.

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