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Complementary assets, strategic alliances, and the incumbent's advantage: an empirical study of industry and firm effects in the biopharmaceutical industry

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Abstract

We argue that incumbents may be in a position to adapt to radical technological change via interfirm cooperation with new entrants when the incumbents have complementary assets within their firm boundaries that are critical to commercializing the new technology. We study 889 strategic alliances of pharmaceutical companies with new biotechnology firms. We find that an incumbent's alliances with providers of the new technology are positively associated with the incumbent's new product development and, in turn, new product development is positively associated with firm performance. At the industry-level, we show that incumbents exhibit a preference towards alliances that leverage complementary assets (exploitation alliances) over alliances that focus on building new technological competencies (exploration alliances). In addition, the cooperation between incumbents and new entrants may contribute to an improvement in incumbent industry performance.

Keywords: Complementary assets; Strategic alliances; Radical technological change; Biopharmaceutical industry

1. Introduction

Incumbent firms often face severe difficulties in adapting to radical technological change. For example, the Swiss watchmaking industry was almost entirely destroyed by one of its own inventions — the quartz. New entrants, such as Seiko and Timex, were extraordinarily successful in commercializing this new energy source for clockworks (Glasmeier, 1991). Radical innovations often initiate a Schumpeterian process of 'creative destruction', frequently leading to the replacement of incumbents by new entrants. Schumpeter asserts 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 ... *new technology* ... competition which strikes not at the margins of profits of existing firms but at their foundations and their very lives" (Schumpeter, 1942, pp. 83–84; italics added).

Not every radical technological breakthrough must necessarily lead, however, to a process of creative destruction in which new entrants rise to dominance as incumbent firms fail. Incumbent firms may be in an advantageous position to adapt to radical technological change if they have within their firm

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boundaries the necessary financial and managerial resources to master such an adaptation (Christensen and Rosenbloom, 1995). For example, the emergence of biotechnology since the mid-1970s can be understood as a technological discontinuity in the way drugs are discovered, developed, and manufactured relative to the traditional, chemical-based pharmaceutical framework (Tushman and Anderson, 1986). The new biotechnology firms (NBFs), however, have not replaced incumbent pharmaceutical firms. Instead, the incumbents have adapted to biotechnology through strategic alliances with new entrants (Greis et al., 1995), and by building in-house competencies (Zucker and Darby, 1997). In turn, the new biotechnology firms have used extensive cooperation with incumbents to commercialize the new technology (Shan, 1990). The cooperation between Genentech and Eli Lilly is a case in point, as Genentech has preferred to license its human insulin based on recombinant DNA (Humulin) to Eli Lilly instead of commercializing it on its own (Lee and Burrill, 1994). We seem to observe a symbiotic coexistence between incumbent firms and new entrants in the biopharmaceutical industry following radical technological change.

This phenomenon of symbiosis between incumbent and new entrant firms warrants more attention. Incumbent survival in the face of radical technological change has been explained by the persistence of market capabilities (Abernathy and Clark, 1985), prior collaborative relationships (Mitchell and Singh, 1996), and complementary assets held by incumbents (Tripsas, 1997). In addition, it has been pointed out that incumbents are able to thrive on technological change as long as it is competence enhancing (Tushman and Anderson, 1986) or sustaining in nature (Christensen and Rosenbloom, 1995).

In this paper, we attempt to show how incumbents that focus on leveraging complementary assets via interfirm cooperation with new entrants can successfully adapt to radical technological change. We suggest that such a response may lead to an improvement in firm and, on the aggregate, industry performance. More specifically, the contribution of this paper lies in the creation of links among interfirm cooperation as a mechanism for adaptation to radical technological change, new product development, and industry and firm performance in the post-innovation time period.

2. Radical technological change, strategic alliances, and incumbent performance

The effect of radical technological change on incumbent firms has been a topic of great interest in prior literature. For example, in his neo-Schumpeterian analysis of discontinuities, Foster (1986) focuses on knowledge creation in combination with physical limits of technologies when explaining the 'attacker's advantage'. In emphasizing the importance of complementary assets when commercializing an innovation, Teece (1986) challenges the notion that being the innovator is necessarily advantageous. He views the fully integrated incumbent as the firm best positioned to benefit from innovation through exploitation of existing complementary assets. The commercialization of the CAT scan highlights this view. GE did not invent the CAT scan, but it soon became the market leader since it possessed the requisite complementary assets necessary to succeed in this new market. On the other hand, the innovator, EMI, was unable to acquire or develop the needed complementary assets to commercialize the CAT scan. This deficiency eventually led EMI to exit the market. The ownership of complementary assets, in particular when they are specialized to the commercialization of the innovation, determines who benefits from that innovation. Therefore, incumbents with competencies in manufacturing or marketing are often well positioned to benefit from radical technological change (Teece, 1986).

Others argue that dynamic networks allow firms to focus on their core competencies and to partner with other firms along the industry value chain (Miles and Snow, 1986). Strategic alliances are viewed as a vehicle for the diffusion of technological knowledge that can contribute to firm success (Mowery et al., 1998), as firms embedded in a network of interfirm relations may have privileged access to emerging opportunities (Burt, 1992). Further, interfirm cooperation may allow firms to generate relational rents which they would not be able to generate in isolation (Dyer and Singh, 1998).

A firm exposed to radical technological change must assemble the appropriate technological and non-technological assets to commercialize an innovation successfully (Pavitt, 1998). Thus, in order to fully understand the complete impact of radical technological change on incumbent firm and industry performance, it is important to expand our analysis

to include its indirect effect on non-technological, often specialized activities of the value chain such as marketing and distribution (Tripsas, 1997).

Though radical technological change generally leads to the depreciation of incumbents' technological value chain activities (Tushman and Anderson, 1986), the non-technological assets of incumbent firms may become more valuable when they are specialized with respect to commercializing the new technology (Leonard-Barton, 1992). If it is difficult for new entrants providing the new technology to integrate forward, then they will demand what initially only incumbents supply: access to the market. In addition, incumbents may possess other attributes that are attractive to start-ups, such as an established reputation and much needed capital (Stuart et al., 1999). In this case, the value of the non-technological market-related value chain activities of incumbent firms appreciates to the extent that they represent complementary assets needed to commercialize the new technology.

In order to commercialize new technology, new entrants may have a need to cooperate with incumbent firms when forward integration and raising capital are difficult (Pisano, 1991). In environments that are characterized by high uncertainty, incumbents will often prefer cooperative arrangements to internalization through acquisition of new entrants in order to maximize the value of their real options (Folta, 1998). Hence, extensive cooperation between incumbent and new entrant firms ensues in such a context as complementary assets provide a basis for a specialization-based division of labor in commercializing a new technology (Garud, 1994).

The biopharmaceutical industry presents an apt illustration of this phenomenon. Many new entrants demand access to the market for pharmaceuticals, which is controlled by a few incumbent pharmaceutical firms. These incumbent pharmaceutical firms have developed path-dependent, firm-specific competencies with respect to certain drug and disease areas that are valuable, rare, and difficult to imitate, and thus may, according to the resource-based view of the firm, form a basis of a competitive advantage (Barney, 1991). For example, Eli Lilly enjoys a dominant position in human insulin and growth hormones (McKelvey, 1996), while Hoffman-La Roche has developed a strong hold in anti-anxiety drugs (Henderson and Cockburn, 1994). This degree of specialization reduces the number of potential strategic alliance partners for new biotechnology firms and further accentuates the value of the incumbents' downstream, market-related value chain activities. Hence, incumbents may be in a position to benefit from the technological breakthrough to the extent that it enables them to create and extract innovation rents based on their specialized complementary assets (Rothaermel, 2000).

Moreover, while the value of upstream activities of incumbent firms may depreciate in an environment of radical technological change, their downstream activities, such as FDA regulatory management as well as marketing and sales, may appreciate in value. A potential appreciation of certain specialized downstream value chain activities held by incumbent pharmaceutical companies can be explained by understanding their importance in commercializing new biotechnology drugs. At the time the new biotechnology firms emerged, existing pharmaceutical companies were the prime candidates for bringing these innovative drugs based on genetic engineering to the market, and their existing value chain activities could be utilized to do so without significant additional investment. Given a standard time horizon of more than 10 years and a cost of up to US$ 500 million for drug development alone (Burrill, 1999), it is understandable that fully integrated new biotechnology firms like Amgen are the exception, rather than the rule.

Not only did the new biotechnology firms lack the necessary complementary downstream value chain activities to commercialize their drug discovery and development research, but they also lacked the capital to finance them. Thus, the new biotechnology firms often approached the traditional pharmaceutical firms for capital to fund their R&D activities, based on the assumption that the incumbents possessed an informational advantage over the capital market in assessing the quality of the NBF's drug discovery and research efforts (Majewski, 1998). As a consequence, traditional pharmaceutical firms and new entrants accessed mutually complementary value chain activities through extensive interfirm cooperation (Rothaermel, 1999). The cooperation between Biogen and Schering-Plough in commercializing Intron A, the first biotech-interferon product approved for cancer treatment, or the cooperation between Chiron and Merck to commercialize the drug Engerix-B for

the prevention of hepatitis B, are examples of these arrangements (Lee and Burrill, 1994). That the strategies of external linkages of the large pharmaceutical companies with the new biotechnology firms are complementary to one another has been empirically corroborated (Arora and Gambardella, 1990).

3. Hypotheses development

3.1. Firm-level hypotheses

Cooperative arrangements between incumbents and new entrants that possess the new technology allow for a beneficial division of labor, assuming a complementarity of their assets (Kogut et al., 1995). In this situation, cooperative arrangements allow participants to focus on their respective comparative advantages (Miles and Snow, 1986), which in turn should enhance new product development for incumbent firms that possess downstream complementary assets relevant to commercializing the new technology (Teece, 1992). It follows that the number of strategic alliances an incumbent firm has formed with providers of the new technology should have a positive effect on the incumbent's new product development. This hypothesis has been empirically corroborated in an analysis of new entrants as the focal firms of the alliances, i.e. it has been shown that there is a positive relationship between the number of strategic alliances in which a new entrant participates and its new product development (Deeds and Hill, 1996; DeCarolis and Deeds, 1999). We propose that this relationship should also hold when we analyze incumbent firms as the focal point of alliances.

Hypothesis 1. There exists a positive relationship between an incumbent firm's strategic alliances with providers of the new technology and the incumbent firm's new product development.

Exploration is understood as "the pursuit of knowledge, of things that might come to be known", and *exploitation* as "the use and development of things already known" (Levinthal and March, 1993, p. 105). Thus, applying March's (1991) dichotomy of exploration and exploitation to a firm's interfirm cooperation, an incumbent firm can theoretically enter two types of alliances with new entrants: *exploration* and *exploitation* alliances.

On the one hand, an incumbent firm can enter into technology-oriented alliances to source the new technology, allowing the incumbent firm to build new upstream value chain activities (Hagedoorn, 1993). This category of alliances can be understood as exploration alliances, i.e. alliances to explore a new technological field and to learn the new technology. An example of an exploration alliance is the cooperation between Eli Lilly and the biotechnology firm Icos with the goal of exploring a class of drugs know as phosphodiestrase 5 to treat male and female sexual dysfunction (Burrill, 1999).

The second class of alliances can be understood as exploitation alliances, in that they allow the incumbent firm to benefit directly from the technological expertise of the new entrant. Exploitation alliances ensue when the new entrants and incumbents have complementary resources that can be accessed via interfirm cooperation. The collaboration between the biotechnology firm Coulter Pharmaceuticals and the chemical-based pharmaceutical company SmithKline Beecham is an example of an exploitation alliance: SmithKline Beecham commercializes Coulter's Bexxar anti-B1 antibody to treat non-Hodgkin's lymphoma (Burrill, 1999). Thus, we propose that the positive relationship between an incumbent's strategic alliances and its new product development also holds when separating the total number of alliances into exploration and exploitation alliances.

Hypothesis 1a. There exists a positive relationship between an incumbent firm's exploration alliances with providers of the new technology and the incumbent firm's new product development.

Hypothesis 1b. There exists a positive relationship between an incumbent firm's exploitation alliances with providers of the new technology and the incumbent firm's new product development.

In environments of radical technological change, a premium is placed on a firm's capability to innovate and subsequently introduce new products or services into the marketplace (Franko, 1989). Continued product introductions are particularly important in hyper-competitive environments (D'Aveni, 1994). We argue that an incumbent's strategic alliances with new

entrants are a way for the incumbent to adapt to radical technological change and subsequently improve its performance through successful commercialization of new products. New product introductions may allow the firm to establish first mover advantages and enjoy a temporary monopoly (Lieberman and Montgomery, 1988). This is particularly true in industries where standards or effective patent protection create winner-take-all scenarios (Hill, 1997). Accordingly, we propose that an incumbent's new product development is positively associated with its performance.

Hypothesis 2. There exists a positive relationship between an incumbent firm's new product development and its performance.

3.2. Industry-level hypotheses

In this paper we analyze alliances along the entire value chain, i.e. alliances focused on upstream technology-oriented value chain activities (exploration alliances) as well as those focused on downstream market-oriented value chain activities (exploitation alliances). Conducting an industry-level study of strategic alliances, Hagedoorn (1993) calculated the ratio of the number of technology-oriented alliances over the number of market-oriented alliances (*T*/*M* ratio) for several high-technology industries and found that the alliances in his sample were more motivated by technology than market considerations. When evaluating Hagedoorn's results, two things are important to note. First, he focused exclusively on technology alliances and classified them as either motivated by basic and applied research (technology-oriented) or motivated by market access considerations (market-oriented). Second, he did not distinguish between incumbents and new entrants as the focal point of analysis.

We augment Hagedoorn's (1993) study by focusing on strategic alliances along the entire industry value chain. In our analysis, exploration alliances encompass upstream, technology-based value chain activities, such as R&D and manufacturing, while exploitation alliances encompass downstream non-technological value chain activities such as marketing and sales. In addition, we examine exclusively alliances formed by incumbent firms with providers of the new technology, with the incumbent firm serving as the focal firm of the analysis. In contrast, most studies in this area have used the new entrant as the focal point of analysis (cf. Shan et al., 1994; Deeds and Hill, 1996; Stuart et al., 1999).

Radical technological change that undermines incumbent firms' upstream value chain activities will cause those firms to seek out a new source of competitive advantage within the redefined technological framework (Dosi, 1982). Assuming that the incumbents hold complementary assets necessary to the commercialization of the new technology, we expect that incumbents will initially structure their strategic alliances to focus more on leveraging their market-oriented value activities than on rebuilding their technology-oriented value chain activities. Hence, they will initially exhibit a greater tendency towards exploitation than exploration alliances. In other words, exploitation alliances will drive out exploration alliances (Levinthal and March, 1993). Thus, we predict an overall tendency at the industry-level towards exploitation rather than exploration alliances following radical technological change.

Hypothesis 3. In the context of radical technological change, incumbent firms will focus more on exploitation than on exploration alliances in their strategic alliances with providers of the new technology, assuming the incumbent firms hold complementary assets necessary to commercialize the new technology.

At the firm-level we hypothesize that incumbent firms that engage in strategic alliances with new entrants are able to create and subsequently extract innovation rents, even though the new entrants are the source of the innovation. For incumbents, the gain of accessing the new technology via interfirm cooperation with new entrants may outweigh their loss due to an obsolescence of their exiting technological value chain activities. This holds true in particular if the 'old' technology coexists with the 'new' technology for a long time, i.e. a technology substitution effect is taking place only very slowly. At the industry-level, the ensuing extensive cooperation between incumbents and new entrants should then be associated with improved incumbent industry performance in the post-discontinuity time period, assuming that the market-related value chain activities of incumbents are specialized with respect to the commercialization of the innovation.

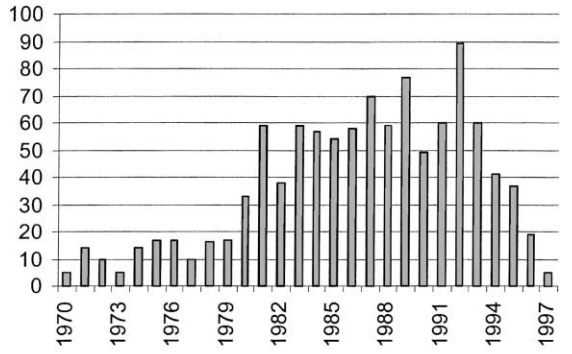
Hypothesis 4. Extensive interfirm cooperation between incumbents and new entrants following radical technological change is positively associated with an improvement in incumbent industry performance in the post-innovation time period, assuming the incumbent firms hold complementary assets necessary to commercialize the new technology.

4. Methodology

4.1. Research setting

The research setting is the biopharmaceutical industry. This term describes the industry composed of traditional pharmaceutical companies, such as Merck or Eli Lilly, that utilize biotechnology for drug discovery and development, as well as fully dedicated biotechnology firms such Amgen or Genentech, and non-profit research institutions and universities engaged in biotechnology research. The 'new' biotechnology (primarily recombinant DNA) allows the manipulation of the inner structure of microorganisms. In 1973, a research team led by Cohen and Boyer published their breakthrough on recombinant DNA. This technique involves 'cutting' DNA out of one cell (e.g. a human cell) and 'pasting' it into a different host cell (e.g. an *E. coli* bacterium). If this piece of DNA holds the genetic code for producing insulin, for example, then the host cell will produce human insulin external to the human body (in vitro). In 1975, cell fusion techniques for producing highly purified proteins (*monoclonal antibodies*) were developed by Milstein and Köhler. Subsequently, research in biotechnology has prospered, making it one of the stellar sciences of the late 20th century.

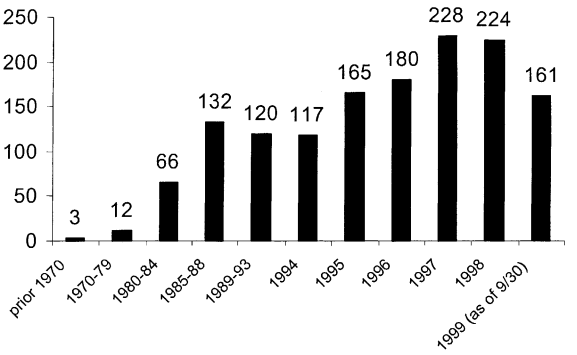
The emergence of biotechnology can be interpreted as a technological discontinuity that broke the barriers to entry into the pharmaceutical industry (Tushman and Anderson, 1986). Consequently, many new biotechnology firms emerged to commercialize this technological breakthrough. Between 1970 and 1997 alone, 1049 companies entered the industry to commercialize biotechnology. On an average, 37 companies entered the industry per year in this time period, with 89 entries in 1992 alone (BioScan, 1997). This wave of entry is depicted in Fig. 1.



Source: Rothaermel (1999).

Fig. 1. Firm entry into the biotechnology industry, 1970–1997.

The commercialization of biotechnology is characterized by extensive cooperative arrangements. Biotechnology is the industry with the highest absolute number of strategic alliances and accounts for 20% of all strategic alliances (Hagedoorn, 1993). This represents more than twice the share of the next largest industry in utilizing strategic alliances and is without precedent in business history (Harrigan, 1985). Thus, the biopharmaceutical industry provides an ideal research setting to study interfirm cooperation and its effect on industry and firm performance. Fig. 2 depicts the number of cooperative arrangements per year between incumbent pharmaceutical firms and biotechnology start-ups.



Source: Greis, et al. (1995) and Burrill (1999).

Fig. 2. Number of alliances between pharmaceutical companies and NBFs, 1970–1997.

4.2. Data and sample

We constructed a database containing 889 strategic alliances between traditional pharmaceutical companies and new biotechnology firms based on the following sources: BioScan industry directory, Scrip's Yearbooks on the global pharmaceutical industry, the biotechnology industry reports published by Ernst & Young as well as Burrill & Company, and Standard & Poor's monthly industry reports. In addition, the Standard & Poor's Compustat and DRI databases as well as Bloomberg's database were used to obtain data to construct firm and industry-level performance measures. BioScan was the main source of our strategic alliance data. This industry directory is the most comprehensive, publicly available source covering the global biopharmaceutical industry. It has been used in a number of different studies (cf. Arora and Gambardella, 1990; Shan et al., 1994; Deeds and Hill, 1996).

We identified the chemical-based, traditional pharmaceutical firms active in biotechnology listed under Standard Industrial Classification (SIC) code 2834 'Pharmaceutical Preparations'. We then cross-referenced and complemented the SIC-2834 industry sample with the Scrip's Yearbooks on the global pharmaceutical industry and BioScan. The final sample comprises 32 large international pharmaceutical firms, which participated in 889 strategic alliances in the biotechnology field. The industry sample is a good representation of the global pharmaceutical industry since the industry is oligopolistic and thus fairly concentrated, with only a dozen or so important firms.

4.3. Firm-level measures

4.3.1. New product development

One direct measure of how well an incumbent firm performs within a new technological paradigm is its new product development. We operationalized an incumbent pharmaceutical firm's new product development by the number of new biotechnology products it had introduced into the market up until December 1997, which marks the publication date of the BioScan industry directory used for this study. Examples of new biotechnology products are drugs like Hoffman-La Roche's Roferon-A for chronic myelogenous leukemia or Bristol-Myers Squibb's Zerit for HIV, and in vivo diagnostics. The number of new biotechnology products on the market is the dependent variable for testing Hypotheses 1, 1a and 1b.

The therapeutics representing the dependent variable are placed inside the human body (in vivo) as opposed to in vitro drugs that are used outside the human body and other applications of biotechnology such as in diagnostics, animals, plants, or industrial processes. We chose to limit the sample to in vivo therapeutics, as the firms engaged in this segment of biotechnology are subject to strict regulatory requirements which demand detailed reporting about each specific drug or diagnostic.

4.3.2. Firm performance

We constructed a financial performance index for each firm based on the average of firm ROE for 1998 and 1999. This is the dependent variable to test Hypothesis 3. Financial performance indices are common measures for firm performance (Zahra and Covin, 1995). We controlled for a potential specification bias due to unobserved heterogeneity through the inclusion of 1997 firm ROE as independent variable ('lagged firm performance') when testing Hypothesis 3 (Jacobson, 1990).

4.3.3. Number of strategic alliances

The number of strategic alliances is a count variable of the strategic alliances a traditional pharmaceutical firm has entered into with providers of biotechnology. In total, we analyzed 889 strategic alliances.

4.3.4. Exploration versus exploitation alliances

This variable discriminates between exploration and exploitation alliances of incumbent pharmaceutical companies with providers of biotechnology. BioScan has a qualitative section for each firm describing its alliances in detail. Each alliance is classified along the value chain of a fully integrated biopharmaceutical company. We coded technology-oriented alliances that focus on drug discovery and development, as well as clinical and commercial manufacturing, as exploration alliances. Market-oriented alliances that focus on clinical trials, FDA regulatory management, and marketing and sales, were coded as exploitation alliances.

4.3.5. Age of strategic alliances

We calculated the average age in months of the total number of alliances and their subcategories

(exploration and exploitation alliances) to control for age dependency.

4.3.6. Equity versus non-equity alliances

We controlled for equity alliances (strong ties) versus non-equity alliances (weak ties) through inclusion of the ratio of equity alliances over non-equity alliances for each firm.

4.3.7. Patents

We controlled for a firm's innovativeness through inclusion of a count variable representing the number of patents issued to the respective pharmaceutical company in 1997. These data were obtained from the US Patent and Trademark Office.

4.3.8. Firm size

We controlled for incumbent firm size by applying the logarithm ($\log_{10}$) to 1997 firm revenues.

4.3.9. Economies of scope

We controlled for economies of scope of incumbent pharmaceutical firms through a count variable representing the number of biotechnology subfields in which the firm participated as of December 1997.

4.3.10. Country

We controlled for institutional differences by including an indicator variable distinguishing between US and non-US pharmaceutical companies.

4.4. Industry-level measures

4.4.1. Technology/market (T/M) ratio

The *T/M* ratio is calculated as the logarithm ($\log_{10}$) of the ratio of the number of technology-oriented (exploration) strategic alliances divided by the number of market-oriented (exploitation) strategic alliances. If the $\log_{10}$ of the *T/M* ratio is positive, then the industry's collaborative preference is focused more towards exploration alliances, whereas a negative value indicates a greater focus towards exploitation alliances. This variable is used to test Hypothesis 3.

4.4.2. Industry performance

The dependent variables for testing Hypothesis 4 are quarterly industry return on equity (ROE), return on assets (ROA), and net income. For each variable, we obtained a time series spanning approximately 25 years.

4.4.3. Industry concentration

Industry concentration tends to change over time as firms merge, incumbents exit, and new entrants enter the industry, which in turn affects industry performance. We controlled for industry concentration through inclusion of a time series of Herfindahl–Hirschman indexes (HHI). The HHI equals the sum of the squared market shares of each firm in the industry for the respective time period (Carlton and Perloff, 1994).

4.4.4. Quarterly GDP

We controlled for exogenous effects, such as business cycles and other macroeconomic factors that can influence industry performance over time through the inclusion of a time series of the growth rate of quarterly real US GDP.

4.5. Model specification

The firm-level hypotheses were tested using multivariate regression models. Since the dependent variable ('biotechnology products on the market') for Hypotheses 1, 1a and 1b is an integer count variable, OLS estimates of regression coefficients are asymptotically biased and inconsistent (Greene, 1997). Therefore, we chose a negative binomial regression model with a maximum likelihood estimation procedure to test these hypotheses. The negative binomial regression model was preferred over the Poisson model since equality of mean and variance is not present in the sample. Hypothesis 2 was tested using OLS.

Hypothesis 3 states that incumbent firms will focus more on exploitation than on exploration alliances in their cooperation with providers of the new technology. We calculated the $\log_{10}$ of the *T/M* ratio for the research sample, which is expected to be negative. The hypothesis was tested using a one-sided *t*-test.

Hypothesis 4 states that extensive interfirm cooperation between incumbents and new entrants following radical technological change is positively associated with an improvement in incumbent industry performance in the post-innovation time period. To inspect this hypothesis, we estimated the following regression

model to test for a structural break in the respective industry performance time series, assuming a deterministic trending process:

$$y_t = \alpha + \beta t + \delta \, \mathrm{DT}_t + \phi \, \mathrm{HHI}_t + \gamma g_{Yt} + \mu_t \qquad (1)$$

where y_t represents industry performance, t is a time trend, and DT_t is an indicator variable depending on the date of the structural break, or T_B, where $\mathrm{DT}_t = t - T_\mathrm{B}$ if $t > T_\mathrm{B}$, 0 otherwise. The Herfindahl–Hirschman index variable HHI_t controls for industry concentration, while g_{Yt} controls for other exogenous effects that could have caused a structural break in the time series. The null hypothesis states that $\delta = 0$, meaning industry performance, y_t, is governed by a deterministically trending process without an exogenous shock leading to a structural shift in the deterministic time trend. The research hypothesis states that $\delta \neq 0$, implying that industry performance is trend stationary, with a one-time break in the deterministic trend function.

We estimated the regression model sequentially and identified the year of a structural break in the univariate time series of quarterly industry performance by applying a maximum Chow test on the indicator variable 'year' (Quandt, 1960). Since the exact break date T_B is unknown ex ante, we adjusted the critical values using Vogelsang's (1997) method of Wald-type tests for detecting breaks in the trend function of dynamic time series.[1] Hypothesis 4 implies that each time series of industry performance should exhibit a statistically significant structural break sometime after the first products based on the new biotechnology were introduced to the market. In addition, the sign of the indicator variable for the break date, δ, is expected to be positive since we hypothesize a subsequent improvement of incumbent industry performance.

[1] Applying this method raises the level for significance of the t-statistics considerably. In particular, the t-statistic for the indicator variable 'year' representing the break date of the structural break in the industry performance time series must be greater than 3.93 for the usual significance level of $P < 0.05$ and greater than 4.46 for a significance level of $P < 0.01$. This Wald-type test ensures statistical validity and has been empirically employed to detect structural breaks in the growth rate of real GDP for a number of countries (Ben-David and Papell, 1995).

5. Results

5.1. Firm-level results

Descriptive statistics of the variables and a correlation matrix can be found in Table 1, while Tables 2 and 3 depict the firm-level regression results.

The descriptive statistics reveal that the average incumbent pharmaceutical firm in the sample has introduced about 12 new biotechnology products and entered a total of 28 alliances, consisting of 10 exploration and 18 exploitation alliances. The average alliance is more than 3 years old and 87% of them are non-equity alliances. Non-US firms make up 50% of the sample. The univariate correlations between the dependent variable and the independent variables provide preliminary evidence for Hypotheses 1, 1a, 1b and 2. In Table 1, the independent variables 'total number of strategic alliances', 'exploration alliances', and 'exploitation alliances' are positively correlated with the dependent variable 'new product development' and are statistically significant at $P < 0.001$. The dependent variable for Hypothesis 2, 'firm performance', is positively correlated with the independent variable 'new product development' and is significant at $P < 0.05$.

The 889 strategic alliances in our sample split into 317 exploration and 589 exploitation alliances. Only 17 alliances were targeted towards both. The small number of alliances (1.9%) that span the entire industry value chain lends support to March's (1991) view of exploration and exploitation as relatively distinct and separate firm activities. All 589 exploitation alliances were non-equity alliances, while the 317 exploration alliances split into 234 non-equity and 83 equity alliances.

In Table 2, Model 1 represents the base model, which includes the control variables but none of the independent variables. An incumbent firm's economies of scope are significant at $P < 0.05$, with the expected positive sign. None of the other control variables are significant. Hypotheses 1, 1a and 1b state that there exists a positive relationship between an incumbent's strategic alliances (total number of alliances, exploration, and exploitation alliances) with providers of the new technology and the incumbent's new product development. We find support for these three hypotheses at $P < 0.01$ (Models 2–4). All three models

Table 1
Descriptive statistics and correlation matrix[a]

	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13
1 New product development	12.34	8.30													
2 Firm performance	21.49	12.07	0.41												
3 Total SAs	27.78	16.65	0.71	0.60											
4 Exploration SAs	9.91	7.64	0.65	0.51	0.93										
5 Exploitation SAs	18.41	9.81	0.63	0.67	0.90	0.73									
6 Age total SAs	38.65	19.10	−0.31	−0.03	−0.35	−0.31	−0.30								
7 Age exploration SAs	46.24	42.38	−0.06	−0.19	−0.11	−0.10	−0.10	0.05							
8 Age exploitation SAs	46.76	22.49	−0.38	−0.19	−0.40	−0.36	−0.40	0.88	−0.04						
9 Equity vs. non-equity SAs	0.13	0.20	−0.21	−0.21	−0.18	−0.06	−0.25	0.05	0.13	−0.09					
10 Patents	64.13	69.45	0.17	0.17	0.24	0.25	0.30	0.17	−0.11	0.01	−0.01				
11 Size	3.48	1.09	0.31	0.32	0.34	0.32	0.32	−0.10	0.04	−0.02	−0.43	0.03			
12 Economies of scope	21.31	11.00	0.25	0.25	0.53	0.63	0.36	0.08	−0.26	0.09	−0.17	0.25	0.27		
13 Country	0.50	0.50	0.39	0.39	0.19	0.13	0.30	0.13	−0.08	−0.03	−0.15	0.11	0.36	0.17	
14 Lagged firm performance	21.71	29.12	0.14	0.54	0.24	0.30	0.16	−0.02	−0.09	−0.04	−0.12	0.01	0.41	0.07	0.12

[a] Correlations greater than or equal to 0.35 are significant ($P < 0.05$); $N = 32$.

Table 2
Firm-level regression results[a,b]

Independent variables	Model 1 (base)	Model 2 (base)	Model 3 (base)	Model 4 (base)
Intercept	1.9144** (0.4467)	2.2024*** (0.4711)	2.2424*** (0.4310)	2.2404*** (0.4758)
Equity vs. non-equity SAs	−0.7276 (0.7391)	−0.6356 (0.6017)	−1.0128 (0.6624)	0.5386 (0.5830)
Patents	0.0001 (0.0015)	0.0002 (0.0013)	−0.0001 (0.0014)	−0.0001 (0.0012)
Size	0.0238 (0.1095)	−0.0974 (0.1084)	0.0024 (0.0127)	−0.0673 (0.0895)
Economies of scope	0.0256* (0.0107)	0.0056 (0.0108)	0.0024 (0.0127)	0.0171 (0.0092)
Country	−0.0610 (0.2392)	0.0664 (0.2072)	0.0493 (0.2158)	−0.1069 (0.1901)
Age total SAs		−0.0070 (0.0067)		
Age exploration SAs			0.0007 (0.0024)	
Age exploitation SAs				−0.0116 (0.0054)
Total SAs		0.0255** (0.0084)		
Exploration SAs			0.0550** (0.0194)	
Exploitation SAs				0.0378** (0.0127)
Likelihood ratio test	97.04***	111.15***	104.70***	115.25***
Pseudo-R^2	0.31	0.36	0.34	0.37
Improvement over base		14.01***	7.66*	18.21***

[a] Dependent variable: new product development.
[b] Standard errors are in parentheses.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

represent a significant improvement over the base model (at $P < 0.05$ and $P < 0.001$, respectively).

Hypothesis 2 posits that there exists a positive relationship between an incumbent firm's new product development and its performance. In Table 3, Model 5 depicts the base model for testing Hypothesis 2. As expected, the control variable 'lagged firm performance' is significant ($P < 0.01$). In Model 6, the variable 'new product development' was added and is significant ($P < 0.05$). Further, Model 6 presents a significant improvement over Model 5 ($P < 0.05$). Thus, we find support for Hypothesis 2.

5.2. Industry-level results

Hypothesis 3 states that incumbent firms will focus more on exploitation than on exploration alliances in their cooperation with providers of the new techno-

Table 3
Firm-level regression results[a,b]

Independent variables	Model 5 (base)	Model 6
Intercept	9.1172* (4.1307)	7.0499† (4.0389)
Patents	0.0166 (0.0260)	0.0157 (0.0246)
Economies of scope	0.1560 (0.1659)	−0.0004 (0.1747)
Country	7.0568† (3.5137)	7.2713* (3.3269)
Lagged firm performance	0.2053** (0.0604)	0.1911** (0.0576)
New product development		0.4587* (0.2253)
F-statistic	5.26**	5.53**
Adjusted-R^2	0.35	0.42
Improvement over base (ΔR^2)		0.07*

[a] Dependent variable: firm performance.
[b] Standard errors are in parentheses.
† $P < 0.1$.
* $P < 0.05$.
** $P < 0.01$.

logy. To test this hypothesis we calculated the $\log_{10}$ of the *T*/*M* ratio for the research sample. The industry average of the $\log_{10}(T/M)$ ratio for pharmaceutical companies participating in biotechnology is −0.27. The number is negative, as expected, indicating that traditional pharmaceutical firms focus more on exploitation than on exploration alliances when adapting to biotechnology. The result of the one-sided *t*-test indicates that the sample mean (−0.27) is significantly smaller than the reference value ($\mu = 0$) at $P < 0.001$.

Hypothesis 4 posits that extensive interfirm cooperation between incumbents and new entrants following radical technological change is positively associated with an improvement in incumbent industry performance. We find statistical support for this hypothesis as industry performance increases shortly *after* the introduction of the first successful biotechnology drugs to the market in 1982. The results depicted in Table 4 indicate that the year identified for a structural break in the ROE and net income time series is 1986, and for the ROA time series it is 1985. In all three regression models, the sign of the indicator variable 'break date' is positive and significant ($P < 0.001$ for ROE and net income; $P < 0.05$ for ROA), indicating an improvement in incumbent industry performance. The statistical evidence supports Hypothesis 4. Fig. 3 depicts a panel of the residuals, actual and fitted values of quarterly industry ROE, ROA, and net income, as well as the respective break dates obtained from the regression analyses.

6. Discussion

The emergence of biotechnology can be understood as a radical process innovation in the way drugs are discovered, developed, and manufactured for firms within the traditional, chemical-based pharmaceutical framework (Pisano, 1997). However, the emergence of biotechnology has not led to the destruction of the existing pharmaceutical companies. Rather, we are witnessing a transformation of the traditional, chemical-based pharmaceutical industry into the newly emerging biopharmaceutical industry. This new industry is a combination of traditional pharmaceutical firms, like Merck or Pfizer, and new biotechnology firms, such as Biogen or Immunex. We argue that this transformation through combination is mainly the result of extensive interfirm cooperation between incumbents and new entrants.

The contribution of this paper lies in creating links between interfirm cooperation as a mechanism for incumbents to adapt to radical technological change, firm innovative output, and industry and firm performance in the post-innovation time period. The results of this study lend support to the notion of incumbent survival through complementary assets (Tripsas, 1997), and the importance of differentiating between technological and market-related capabilities when adapting to a new technology (Mitchell, 1992). In addition, this paper reinforces the importance of analyzing the impact of an innovation on incumbents

Table 4
Industry-level regression results[a,b]

Dependent variable	Break date	Constant	Time trend t	Indicator variable 'break date' DT_t	Control variable HHI_t	Control variable g_{Yt}	Adjusted-R^2	F-statistic
ROE	1986	−0.3467 (1.1875)	0.0209** (0.0061)	0.3643*** (0.0500)	0.0041*** (0.0010)	0.02252 (0.0837)	0.71	58.71***
ROA	1985	2.5116*** (0.5697)	−0.0052 (0.0043)	0.1338* (0.0327)	−0.0001 (0.0005)	0.0087 (0.0421)	0.34	9.68***
Net income	1986	1096.44* (417.57)	10.58*** (2.04)	131.98*** (16.04)	−1.0353** (0.3327)	1.3896 (29.45)	0.90	229.51***

[a] Results of the regression model (1).
[b] Standard errors are reported in parentheses.
* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
*** Significant at $P < 0.001$.

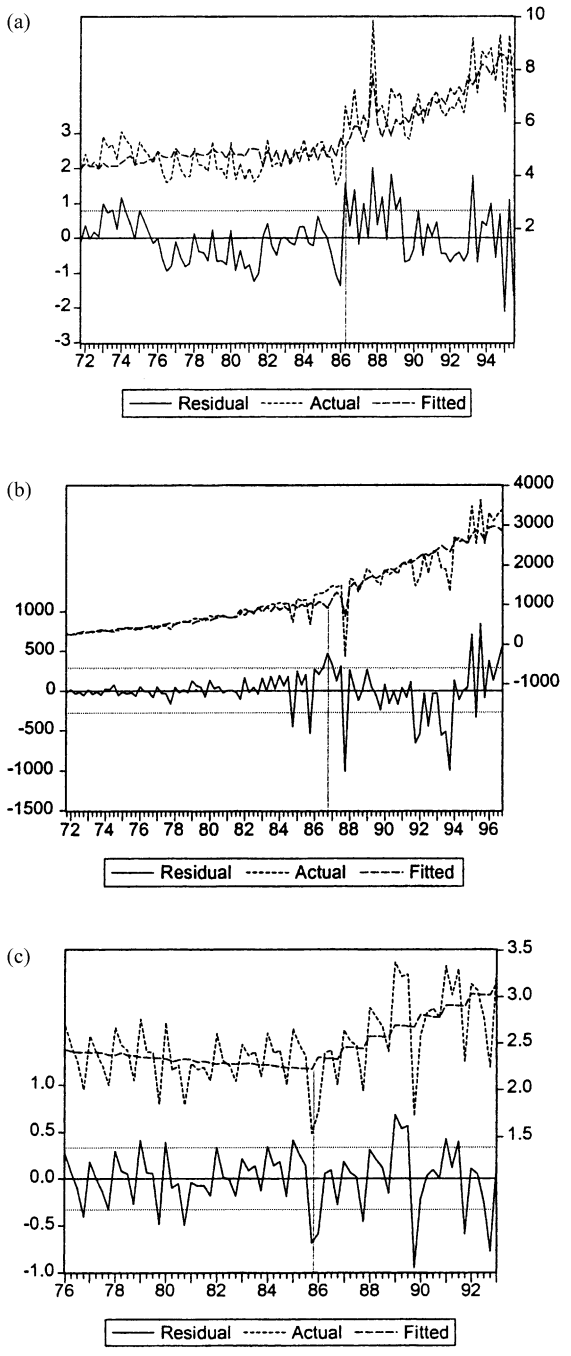


Fig. 3. Residual, actual and fitted values of industry performance for pharmaceutical industry: (a) quarterly industry ROE, 1971–1995; (b) quarterly industry ROA, 1971–1996; (c) quarterly industry net income, 1976–1993. The right axes represent ROE (a), ROA (b), and net income in million US$ (c), while the left axes represent the residuals of the actual values and the fitted model.

in its entirety, including all linkages between different firm activities (Pavitt, 1998). The findings of this study also lend support to the interpretation of biotechnology as a sustaining technological change for incumbents (Christensen and Rosenbloom, 1995). Since mastery of the new technology is important to the incumbents' value network, the incumbent firms will marshal the resources and strategies necessary to adapt.

In particular, our findings support the notion that interfirm cooperation between incumbent pharmaceutical firms and new biotechnology firms is positively associated with an incumbent's new product development. Building on this result, we were able to show that an incumbent's new product development is positively associated with its performance. At the industry-level, we demonstrated that incumbents prefer exploitation alliances over exploration alliances. In addition, we found support for the notion that extensive interfirm cooperation between pharmaceutical firms and dedicated biotechnology firms is associated with an overall improvement in incumbent industry performance.

The pharmaceutical industry experienced a structural break in incumbent industry performance in the mid-1980s *after* the introduction of the first successful biotechnology drugs. For example, the first biotechnology drug, Humulin (human insulin), received final FDA approval to be marketed in 1982. The new biotechnology firms are the primary developers of the new biotechnology drugs, while the incumbent pharmaceutical firms carry the drugs through the FDA approval process and subsequently market them. In 1993, 6 of the top 10 selling biotechnology drugs where marketed by incumbent pharmaceutical firms and not by the NBFs that had developed the products. Those six drugs alone accounted for almost 60% of the revenues for the top-10 selling biotechnology drugs (Lee and Burrill, 1994). By 1996 and 1997, the number of top-10 selling biotechnology drugs marketed by incumbent pharmaceutical firms had grown to seven. In 1996, those seven drugs accounted for more than 62% of revenues, and in 1997, the same seven drugs accounted for more than 66% of the revenues for the top-10 selling biotechnology drugs (Morrison and Giovannetti, 1998). Overall revenues from new biotechnology drugs were US$ 22 billion in 1999, about 15% of the total revenues for phar-

maceuticals (Burrill, 1999). Based on this evidence, it seems that the incumbent pharmaceutical firms are in a strong bargaining position — due to their specialized downstream assets — to capture a significant amount of the revenue stream generated by new biotechnology drugs. Thus, an improvement in incumbent industry performance since the mid-1980s seems to be partly explainable by the success of the cooperative strategies pursued by incumbent firms with the goal of partnering with new entrant firms.

Nevertheless, alternative explanations for our findings need to be addressed. Our results at the firm-level seem to be robust. In particular, the relationship between strategic alliances and new product development is well established in the literature when analyzing the new entrants as the focal firm of alliances (cf. Shan et al., 1994; Deeds and Hill, 1996; DeCarolis and Deeds, 1999). We corroborated this result when analyzing the incumbent firm as the focal point of alliances.

Our finding that there exists a positive relationship between new product development and an incumbent firm's performance is much less robust. Even though we find a positive association between new product development and performance, it is important to point out that the performance of new drugs in the biopharmaceutical industry is heavily skewed. Immunex' CEO Fritzky has indicated that the chance that a newly discovered biotechnology molecule will make it from the start through finish in the drug commercialization process is approximately 0.0115% or about 1 in 11,500 (Fritzky, 1998). Thus, one blockbuster drug, like Humulin, must compensate for all of the firm's drugs that do not make it through clinical trials and FDA approval, or do not perform well on the market. Moreover, in vivo diagnostics are generally not as profitable as new biotechnology drugs.

Clearly, some of our measures contain limitations. For example, a count of new product development is only a crude measure of firm performance. In a similar fashion, a count of patents as a control measure for a firm's innovativeness can only be considered a rough approximation. In addition, we were unable to differentiate between the impact of traditional versus biotechnology drugs on firm performance. Therefore, our analysis does not allow for the establishment of a cause and effect relationship between new product development and firm performance. All we can say is that new product development is positively associated with firm performance.

The result that incumbent pharmaceutical firms prefer exploitation alliances over exploration alliances seems to be robust. The number of exploitation alliances (589) is almost twice as large as the number of exploration alliances (317), which seems to indicate that exploitation alliances crowd out exploration alliances (Levinthal and March, 1993). In addition, the literature provides evidence that exploitation alliances are driven by the search for mutually complementary assets (Arora and Gambardella, 1990). This trend might reverse over time as incumbents shift their attention towards exploration alliances or in-house development (Zucker and Darby, 1997).

The finding that interfirm cooperation between incumbents and new entrants is positively associated with an improvement in incumbent industry performance is not very robust because it is based on several contingencies. For example, we assumed that a technology substitution effect could be neglected, or in other words, that the performance loss based on the old technology is not greater than the performance gain due to the new technology. What we could not control for is the possibility that a technology substitution effect does not really take place (at this time), meaning that the old technology continues to perform well or even improves in performance simultaneously to the emergence of the new technology.

This could be viewed as the time period of a discontinuity where the two sigmoid curves, representing the performance trajectory of the respective technologies, overlap (Foster, 1986). In this situation, the new technology has emerged; however, it does not initially perform as well as the old technology. Only over (a long) time will the new technology overtake the old technology in terms of performance. This scenario is even more complicated in the biopharmaceutical industry as the pharmaceutical companies have been able to improve their performance based on traditional, chemical-based drugs, while they simultaneously introduced new biotechnology drugs. This implies that both performance trajectories exhibit a positive slope during the time of discontinuity, which points to an exception to Foster's (1986) framework that should be investigated in future research. The observed improvement in industry performance of pharmaceutical companies participating in biotechnology might be due to

performance gains obtained through the introduction of traditional chemical-based drugs. Our analysis does not allow us to differentiate between these two effects; all we can say is that the industry has performed significantly better since the mid-1980s, which coincides with the introduction of a stream of highly successful biotechnology drugs. In sum, our results for Hypothesis 4 are clearly susceptible to alternative explanations.

Another limitation of the paper is that as a single industry study, its generalizability may be restricted, in particular because the biopharmaceutical industry is a heavily regulated industry. One could argue that the incumbent's advantage stems from the expertise and competence within this regulated environment. However, a similar phenomenon can be observed in the (de-regulated) telecommunications industry. The emergence of cellular telephony can be interpreted as a technological discontinuity in the way telephone communication is provided between the user's telephone and the switching network. Signals are carried by radio transmission to the switching network rather than by wire. The incumbent firms need access to competencies in cellular technology, while the success of the new entrant cellular firms hinges on gaining access to the switching networks held by incumbents. This complementarity of assets has generated extensive interfirm cooperation between new entrants and incumbents (Ehrnberg and Sjöberg, 1995). Thus, the telecommunications industry may provide an ideal setting for future research to clarify some of the findings advanced in this paper.

7. Conclusion

In this paper, we attempted to show that incumbent firms may be in a position not only to survive radical technological change, but also to thrive on it. We argued that the incumbent's advantage will materialize if the incumbent firm has complementary assets within its boundaries that are critical to commercializing the new technology. We showed that incumbents that adapt to the new technology via interfirm cooperation with new entrants can enhance their new product development, which in turn may contribute to superior firm performance. At the industry-level, we attempted to show that the adaptation to radical technological change via interfirm cooperation is mainly executed through exploitation alliances, which are a quick and cost effective way to respond to radical technological change. Finally, interfirm cooperation with new entrants may contribute to an overall improvement in industry performance.

We believe that this study contributes to a better understanding of the commercialization of new technologies. In particular, it focuses on interfirm cooperation as one possible response that incumbents can use to adapt to radical technological change. Nevertheless, much more work needs to be done. For example, the links between new product development and performance at both, the firm- and industry-level, need to be strengthened. We hope that future research will take on some of the challenges confronted in this study.

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