Title

Social Networks, Learning, and Flexibility: Sourcing Scientific Knowledge in New Biotechnology Firms

Authors

Liebeskind, Julia Porter
Oliver, Amalya Lumerman
Zucker, Lynne G.
et al.

Publication Date

1994-10-01

Institute for
Social Science **Research**

ISSR

Working Papers

in the

Social Sciences

7994-95, Vol. 6, Number 4

Social Networks, Learning, and Flexibility: Sourcing Scientific Knowledge in New Biotechnology Firms

by

Julia Porter Liebeskind
Amalya Lumerman Oliver
Lynne G. Zucker
Marilynn B. Brewer

October 1994

University of California
Los Angeles

ISSR Working Paper Vol. 6, No. 4
October 1994

Social Networks, Learning, and Flexibility: Sourcing Scientific Knowledge in New Biotechnology Firms

ABSTRACT

This paper examines the organizational arrangements used by New Biotechnology Firms (NBFs) to source scientific knowledge. Using data from two highly successful NBFs, the paper shows that both firms relied principally on hierarchies and networks to source scientific knowledge; market arrangements were insignificant. Most interesting, each firm had a very large, diversified set of boundary-spanning collaborative research arrangements, mostly involving university scientists. It is argued that these external research networks enabled the two firms studied to compete more successfully in a highly turbulent and highly competitive industry environment.

ACKNOWLEDGEMENTS

We thank Paul Adler, Michele Bolton, two anonymous referees, and participants at presentations at the Academy of Management Meetings in Dallas, August 1994, and the Whittemore Conference on Hypercompetition held at the Amos Tuck School, Dartmouth College, September 1994, for useful comments and suggestions. The research reported in this paper was partly funded by a National Science Foundation dissertation improvement grant to Dr. Oliver, and by research grants from the National Science Foundation (SES 90-12925) and from the University of California Systemwide Biotechnology Research Program to Dr. Zucker and Dr. Brewer (principal investigators).

Julia Porter Liebeskind
School of Business Administration
University of Southern California
Los Angeles, CA 90089-1421

Amalya Lumerman Oliver
Department of Sociology & Anthropology
Hebrew University of Jerusalem
Mont Scopus
Jerusalem, 91905, Israel

Lynne G. Zucker
Director, Organizational Research Program
Institute for Social Science Research
University of California, Los Angeles
Los Angeles, CA 90024-l 484

Marilynn B. Brewer
Department of Psychology
Ohio State University
1885 Neil Avenue
Columbus, OH 43210-1222

The ISSR Working Papers in the Social Sciences is a publication series devoted to current research topics undertaken by UCLA academicians and affiliated scholars. Single copies can be ordered for $5 each (check made payable to “UC Regents”) from Professor Lynne G. Zucker, Director, Organizational Research Program, Institute for Social Science Research, University of California, Los Angeles, Los Angeles, CA 90024-1484. Comments or inquiries should be addressed to: The Editor, ISSR Working Papers in the Social Sciences, Institute for Social Science Research, 405 Hilgard Avenue, Los Angeles, California 90024-l 484.

SOCIAL NETWORKS, LEARNING, AND FLEXIBILITY: SOURCING SCIENTIFIC KNOWLEDGE IN NEW BIOTECHNOLOGY FIRMS

1. INTRODUCTION

The biotechnology industry is an archetypical “hypercompetitive” environment There are many competing firms, which face intense time pressure as they race one against the other to obtain patents on new products. Knowledge obsolesces at a rapid rate. Investment capital is scarce and investments are highly risky. The potential for appropriation of valuable knowledge by rivals is high. High quality human capital, essential for competitive success, is scarce. In such a hypercompetitive environment, firms will be pressured to form new innovative organizational forms in order to survive and succeed (D’Aveni, 1994). In this study, we investigate the organizational arrangements used by biotechnology firms to source the input which is critical to their survival and success: scientific knowledge.

A number of prior studies have examined organization in the biotechnology industry. Shan (1990) Kogut, Shan and Walker (1992), Powell and Brantley (1992) and Oliver (1993) examined the inter-organizational exchange arrangements of focal biotechnology firms such as long term contracts, joint ventures, and equity investments Pisano (1990) and Arora and Gambardella (1990) analyzed the exchange arrangements of focal chemical and pharmaceutical firms with biotechnology firms. Barley, Freeman and Hybels (1992) examined the network structure of inter-organizational exchanges in the biotechnology industry using a large sample of biotechnology firms, other firms, universities, hospitals, government agencies, and trade associations. Zucker, Brewer, Oliver and Liebeskind (1991) examined the spatial distribution of founding of new biotechnology firms in relation to their exchanges with universities.

This study differs from these previous studies in both purpose and scope. Rather than concentrating on market exchanges alone, this study examines the relative importance of three different types of exchange – hierarchies, markets and networks -- used by biotechnology firms. Building on transactions-costs theory, we argue that social networks may constitute the most efficient organizational arrangements for exchanges involving scientific knowledge. given the hypercompetitive conditions which pertain in the biotechnology industry. We also restrict our investigation only to exchanges in which biotechnology firms source scientific knowledge. Transaction costs theory suggests that the most efficient form of exchange will be determined by the characteristics of the goods or services being exchanged, and by the organizational options which exist for conducting that exchange (Coase, 1937; Williamson, 1979). We therefore clearly distinguish in this study between exchanges in which biotechnology ftrms source scientific knowledge, and other types of exchange, for which other organizational arrangements may be preferable.

The data we present in this study is based on detailed case studies of two highly successful biotechnology firms. These data include data on scientific collaborations among the firms' own scientists and with external scientists; data on the firms' external exchanges of scientific knowledge through formal contracting, licensing etc.; data on the scientists employed by the two firms; and data on the number, type and geographical scope of institutions with which the firms conduct market or network exchanges. These data show that the two firms studied rely very heavily on sourcing scientific knowledge through the social networks to which their own scientistemployees and other scientists belong. In terms of external exchanges, the number of exchanges which take place through social networks in the two firms vastly outweighs the number of market exchanges sourcing scientific knowledge. In addition, external network exchanges of scientific knowledge extensively supplement the firms' hierarchical exchanges We argue here that social networks have assumed such importance because conducting exchanges of scientific knowledge through social networks overcomes problems of uncertainty, appropriability and human capital immobility which cannot be effectively resolved by conducting such exchanges exclusively through either hierarchies or markets.

This paper proceeds as follows. Section 2 presents some background information on the biotechnology industry, and discusses a number of prior studies on the organ&ion of the industry. Section 3 discusses hypercompetition in the biotechnology industry. Section 4 presents a discussion of the characteristics of markets, hierarchies and networks. and examines their relative costs and benefits in the context of the hypercompetitive environment of the biotechnology industry. Section 5 discusses the case study methods used in this study. Section 6 presents and discusses the findings of the two case studies. Section 7 presents a summary and concluding remarks.

2. THE BIOTECHNOLOGY INDUSTRY AND NEW BIOTECHNOLOGY FIRMS

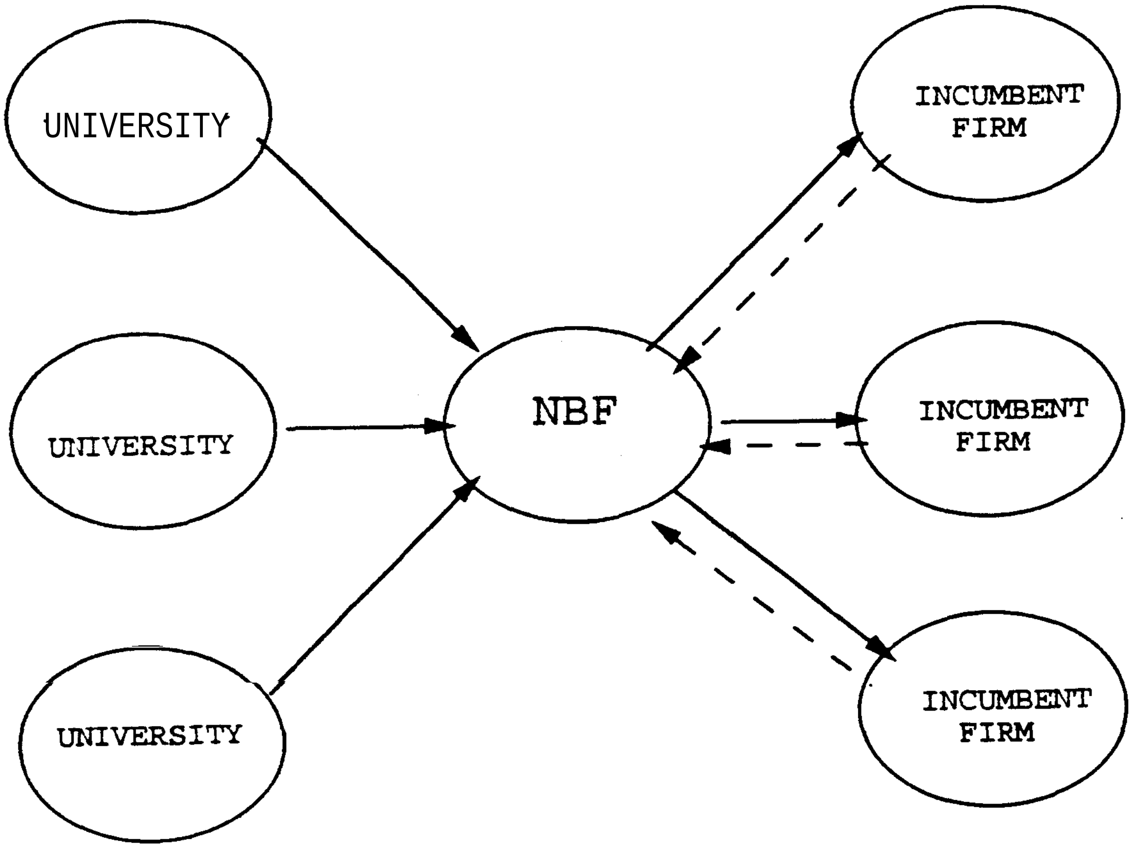
Biotechnology is strictly a technology, not an industry (Powell and Brantley, 1992). In fact, “biotechnology” comprises three different technologies: recombinant DNA technology, or “rDNA” technology, first discovered by Boyer and Cohen in 1973; monoclonal antibody, or “Mabs” technology, first discovered by Kohler and Milstein in 1975; and protein engineering technology, developed during the 1980s. Together, these three technologies offer the prospect of producing a vast array of revolutionary products such as treatments for previously untreatable diseases; fuels and plastics produced directly from plant materials; and substances which can convert toxic and other wastes to useful materials. A number of economically important biotechnology products are already on the market, including human diagnostic and therapeutic products; new plant and animal strains; and new pest control, fertilizer and waste management products. Many of these products are very valuable. For example, the drug Neupogen (produced by Amgen Inc.) which reduces anaemia in chemotherapy patients, had sales of $544 million in 1992 ***(Businessweek,*** April 26,1993, page 86).

The U.S. biotechnology industry has evolved in a highly unusual way: its growth and development has been characterized by the founding of large numbers of new biotechnology firms (NBFs) dedicated to researching and developing new biotechnology products. Barley, Freeman and Hybels (1992) report that between 1971 and 1989,525 NBFs were founded, peaking in 1981 when 81 firms were founded. In the late 198Os, as the supply of venture capital dwindled, the rate of founding of new firms slowed somewhat. Nonetheless, NBFs continue to be founded at a rate of about 30 new firms each year.

PowelI and Brantley (1992) attribute the development of NBFs to the fact that biotechnology was a competence-destroying innovation for established firms in client industries such as pharmaceuticals and chemicals. Lacking an understanding of biotechnology, established firms could not invest efficiently in biotechnology research themselves. Instead, they channeled their investments in biotechnology research to NBFs through long term contracts or by forming joint ventures. NBFs, in turn, entered into long term contracts with established firms to supply them with complementary assets such as product testing, production, marketing and distribution capabilities which they lacked at the outset of their development (Teece, 1989; Pisano, 1990; Barley, Freeman and Hybels, 1992; Powell and Brantley,l992). Consequently, the biotechnology industry is chracterized by a network structure of inter-organizational contracts which govern the exchange of complementary assets between NBFs, scientists, and established firms. NBFs are central to these inter-organizational networks of contracts (Barley, Freeman and Hybels, 1992; Powell and Brantley, 1992) because they play a critical intermediary role in biotechnology commercialization between scientists, who make basic discoveries, and large firms which have established capabilities in product testing, production and distribution. This is illustrated in Figure 1. The value of NBFs within this industry network structure therefore depends on their distinctive capability to capture (in the form of patents) the rights to scientific knowledge in the form of commercially valuable discoveries made by scientists.[1] The issue we examine in this paper is how NBFs organize the sourcing of this scientific knowledge, given the hypercompetitive environment of the biotechnology industry.

1 Kogut, Shan and Walker (1992) show that over time, NBFs' interemediary role with regard to incumbent chemical and pharmaceutical firms declines, as they develop their own capabilities in downstream activities such as regulatory approval, production and distribution.

Figure 1
The position of NBFs in the biotechnology industry



Universities supply NBFs with founding scientists and staff scientists; with basic scientific knowledge; and with on-going opportunities for collaborative research in basic and commercially relevent research.

NBFs provide incumbents with access to their intellectual property (i.e. patents on commercially valuable biotechnology products.) Incumbent firms supply NBFs with funds for research, and with complementary assets such as marketing and product testing capabilities.

3. HYPERCOMPETITION IN THE BIOTECHNOLOGY INDUSTRY

The biotechnology industry is hypercompetitive for a number of reasons. These include:

(i) A large number of strategically dedicated competitors

There are over 500 NBFs in the U.S. alone. all of which are dedicated to biotechnology research (Barley, Freeman and Hybels, 1992). There are also many NBFs overseas, particularly in Canada Europe and Japan. In addition to NBFs, many established pharmaceutical, chemical and agribusiness firms are involved in biotechnology research through the formation of strategic alliances, through acquisition, or through direct investment (Arora and Gambardella, 1990; Pisano, 1990; Barley, Freeman and Hybels, 1992; Powell and Brantley, 1992). This large number of competitors can be expected to generate intense competitive rivalry, especially for NBFs, which are strategically dedicated to the biotechnology industry (Porter, 1980; Ghemawat, 1991).

(ii) Extreme payoff structures engendering patent races

Competition in the biotechnology industry is characterized by a “win or lose” payoff structure. A firm which succeeds in being first in terms of patenting a new product or process gets the right to monopoly profits for a period of seventeen years; firms which are followers in the discovery process get nothing in return for their investment. Therefore, firms in the biotechnology industry compete under extreme time pressure as they race to be the first to patent new products and processes. This creates intense competition among firms for access to sources of valuable scientific knowledge--knowledge that might lead to new patentable discoveries.

(ii) Scarce capital

Competitive intensity among NBFs is further exacerbated by shortages of investment capital. Typically, NBFs are funded in their early life by venture capital. However, supplies of venture capital for investment in R&D are limited Jensen (1993) estimates that the total investment in R&D by the US venture capital industry between 1980 and 1990 was $27.8 billion. This sum includes R&D investments in industries other than biotechnology. By comparison, one pharmaceutical firm alone, Merck, (a direct competitor of NBFs) spent $5.4 billion on R&D during the same period NBFs must therefore economize on capital in sourcing scientific knowledge, while at the same time seeking to maximize their chances of obtaining property rights to valuable discoveries which will allow them to raise additional rounds of financing in the future.

(iv) Uncertainty.

Commercially valuable biotechnology products are the result of discoveries made in laboratories by scientists. In this process of research, many uncertainties exist. First of all, NBFs face technological uncertainty: they cannot determine ex ante if any particular research program they invest in will lead to a valuable discovery. For NBFs, **a "valuable' discovery has** a potential market which is large enough to offset the costs of research. Second, NBFs face competitive uncertainty. Rival firms may be first to patent a given new product or process. Other new products developed by rival firms may render earlier biotechnology discoveries immediately obsolete. Process innovations in such areas as protein engineering may also allow some firms to speed up their discovery process at the expense of other firms. In addition, the locus of new and valuable innovations in biotechnology is constantly changing. University-based expertise is diffusing rapidly as new generations of biotechnology scientists are trained and move away from the early centers of innovation such as Stanford and UCSF (Kenney, 1986). Meanwhile, new NBFs continue to be founded, often to capitalize on key discoveries, while existing NBFs are constantly innovating and developing new scientific capabilities AU these sources of technological and competitive uncertainty make it extremely difficult for NBFs to determine which scientific knowledge is potentially valuable, and which is not.

(v) ***Appropriability***

Biotechnology knowledge is potentially very valuable: single discoveries can result in drugs which can generate billions of dollars in sales over their lifetime. This enormous potential value provides a strong incentive for appropriating biotechnology knowledge which is not already protected by patent laws. At the same time, many exchanges of scientific knowledge conducted by NBFs may involve knowledge which is not yet patented. For example. the patent process is lengthy and expensive, so that it may not be efficient to patent knowledge until its value is established. In addition, while some biotechnology knowledge (e.g. discoveries of new chemical entities) can be patented, other knowledge which is contributory to the discovery process (e.g. protein engineering expertise) cannot. Finally, patent coverage may also be too slow and/or too narrow to prevent appropriation of knowledge which can lead to follow-on products (Levin, Klevorik, Nelson and Winter, 1984). NBFs must therefore guard against such appropriation in sourcing scientific knowledge.

(vi) Scarce human capital

Although the number of biotechnology scientists has increased rapidly in the last decade, there are still few “star” researchers--researchers who have made numerous valuable discoveries (Zucker, Brewer, Oliver and Liebeskind, 1991). In addition, many top researchers work in universities, and are not willing to be hired away by firms. Therefore, NBFs are challenged to develop organizational arrangements which can allow them to access human capital resources outside their firms.

In all, the biotechnology industry represents an extremely challenging hypercompetitive environment for NBFs. In order to succeed, these firms must devise organizational arrangements which allow them to source their critical input – patentable scientific knowledge -- in ways which allows them to resolve technological uncertainty and overcome problems of appropriability and scarce human capital. At the same time, NBFs are extremely capital constrained. Consequently, NBFs are under intense competitive pressure to devise optimal arrangements for sourcing for the scientific knowledge they need to survive and succeed

4. ORGANIZATIONAL OPTIONS SOURCING SCIENTIFC KNOWLEDGE: HIERARCHIES, MARKETS AND NETWORKS

In this study we examine the use by NBFs of three alternative types of organizational arrangements for sourcing scientific knowledge: Markets, hierarchies and networks.

Transaction costs economics has traditionally distinguished between only two types of organizational arrangements for conducting exchanges: markets and hierarchies (Coase, 1937; Williamson, 1979,199l; Masten, 1988). Markets organize the external exchanges of the firm; hierarchy organizes its internal exchanges (Teece, 1986,1989; Camagni, 1989; Reve, 1990). In markets, exchanges take place between legally distinct entities, be they individuals or firms, and fairness in exchange is assured by price competition or by contract. Price competition provides each buyer or seller with numerous valuations for a given good or service, thereby ensuring that the price they ultimately pay or receive is fair in the sense that there is social consensus about its value. Because price competition cannot always ensure fairness, market exchange may also involve writing legally binding contracts specifying the terms and conditions of exchange (Williamson, 1979). In contrast to market exchanges, exchange within hierarchies does not depend on pricing or contracting, but on rules set by managers and enforced by managerial authority down through the hierarchy of the firm. According to this theoretical framework, the boundaries of the firm are determined by the relative costs and benefits of conducting exchanges through markets or hierarchies (Coase, 1937; Williamson, 1979,199l). If exchanges are frequent and are characterized by high levels of investment in specific assets and by uncertainty, it may be more efficient to conduct these exchanges within a firm than across markets (Williamson, 1979, 1991; Joskow, 1985). This is because asset specificity and uncertainty can generate benefits or costs which are difficult to allocate fairly through price competition or through ex ante contracting. Firms can avoid these costs by using managerial authority to determine the terms and conditions of exchange.

A common critique of this traditional transactions costs explanation of the organization of economic activity is that it ignores the importance of social values in the exchange process

(Granovetter, 1985). Sociologists, anthropologists and historians have long recognized that both "markets" and "hierarchies" are social constructions whose existence and efficacy depend on broad social consensus about norms of behavior. (See, for example, Belshaw (1965) and Geertz (1978)). Thus, exchanges in both markets and hierarchies can be understood to be both supported, and shaped by, the norms of the social groups involved (Dore 1983; Granovetter, 1985). In some situations, social norms may actually substitute for markets or hierarchies in the organization of exchange. For example, Ouchi (1980) identifies three distinct types of organization for conducting exchanges: markets, bureaucracies, and "clans". In clans, shared norms and values serve to ensure fairness in exchange, without resort to market pricing, contracts, or managerial authority. In a similar vein, Bradach and Eccles (1988) define price, authority, and "trust" as the alternative methods of supporting exchange, where trust is engendered by shared norms. Powell (1990) also argues that exchanges through social networks constitute a separate and distinct form of organization in which exchange is predicated on trust. According to these definitions, and following the theoretical frameworks of Cease (1937), Masten (1988) and Williamson (199 l), social networks can be distinguished from markets or hierarchies as follows:

(i) Unlike hierarchies, but like markets, social networks involve exchanges ***between legally distinct entities.*** Network exchanges, like market exchanges, are external to the firm (Reve, 1990). Therefore, these exchanges are not formally excluded from the rule of law, as are exchanges which take place within hierarchies (Masten, 1988; Williamson, 1991).

(ii) Unlike markets, but like hierarchies, ***social networks support exchanges without using competitive pricing or legal contracting. Specifically, exchanges between*** individuals or organizations which are conducted through social networks have no need for price competition or legal contracting because the shared norms of the exchange partners alone will ensure that outcomes are fair.

Shared norms which provide high enough levels of trust to support network exchanges may be instilled in a number of different ways. Norms of trustworthy behavior may be instilled through socialization and tradition among members of a specific social **group** such as a tribe, social class. region, profession, religion, industry or organization (Ross. 1906; Evans-Pritchard, 1940; Brusco, 1982; Dorfman, 1983; Dore, 1983; Zucker, 1986; Elster, 1989). Norms of trustworthy behavior may also evolve over time as exchanges are repeated between friends or members of the same social group (Axelrod, 1984; Kreps, 1990; Zucker , 1986, 199 1). Trustworthy behavior may also be elicited by mechanisms such as posting a bond, testing, or performance monitoring, all of which are commonly used conditions of membership of professional or social groups (Wiiiamson, 1979; Klein and Leffler, 1981).

Analysis of the comparative efficiency of social network exchanges is still in its infancy. One detailed discussion of this issue is provided by Powell (1990), who argues that networks are the most efficient method of exchanging *information because* information is difficult to price and is hard to communicate through a hierarchical structure:

> "Networks are particularly apt for circumstances in which there is a need for efficient, reliable information. The most useful [valuable] information is rarely that which flows down the formal chain of command in an organization, or that which can be inferred from price signals. Rather, it is that which is obtained from someone you have dealt with in the past and found to be reliable. You trust information that comes from someone you know well." (1990, page 304)

Powell's argument here, then, is that personal relationships engender the supply of reliable information. However, Powell does not address the issue of the relationship between such social networks, and the boundaries of the firm. According to his theory, social networks may be within the firm, external to the firm, or transcend its boundaries. However, Zucker (1991) suggests that most network exchanges of information will be external to the firm because, in many situations, bureaucracies (i.e. hierarchies) lack critical information. Specifically, when the information needed must be supplied by "experts", external sourcing of information may be more efficient than internal sourcing:

> While bureaucratic authority is by definition located within the firm's boundaries, expert authority depends on the information resources available to an individual, and not on the authority of office. Thus, authority may be located within the organization......
> but when an external [expert] authority market can provide information that leads to greater effectiveness, then [expert] authority tends to migrate into the market [from the firm] (1991, page 164).

One question here is why hierarchies cannot themselves become “experts” over time. In response, Teece (1986. 1989) and Camagni (1989) all argue that hierarchies become less efficient as technological uncertainty increases because firms may simply not have the time to internalize and institutionalize the appropriate information. For example, Teece (1989) argues that it may not be optimal for a firm (i.e. hierarchy) to seek to internalize numerous exchanges when technology is changing rapidly because the value of internalizing those exchanges may change rapidly under conditions of technological uncertainty, resulting in excess sunk costs from intemalization. Camagni (1989) argues that, when technology is changing rapidly, firms lose their ability to asses the value of information accurately, because they cannot learn and institutionalize appropriate assessment routines in short periods of time. According to Camagni and to Zucker (1991), this problem of uncertainty can be partially resolved when a firm participates in an external “informational network” of experts who have more appropriate information than its own managers. These experts can provide the firm with multiple evaluations of the value of its own information and knowhow, increasing its efficiency in searching for valuable information, in screening information, in codifying information for managerial use, in selecting appropriate investments, and in the task of managerial control.

These arguments all serve to explain why firms might elect to source knowledge external. However, these arguments do not provide a detailed explanation of why networks may be preferable to markets for organizing such external exchanges. One possible explanation is that markets for information are subject to failure, because an efficient price cannot be established for knowledge without revealing its contents (Arrow, 1962). Once the knowledge is revealed, its value is lost to the seller because it can be appropriated by the buyer. Even legal contracting may not be able to prevent misappropriation by buyers in such exchanges (Levin, Klevorick, Nelson and Winter, 1987). However, social networks, in which exchange is supported by norms of trustworthy behavior, may be able to prevent appropriation and thereby support exchange of valuable knowledge.

Networks may also outperform markets when expert information or knowledge is produced by individuals who are not willing to work within the hierarchy of a firm, nor are they willing or able to sell their services to the firm across a market. For instance, some firms may be unable to attract certain desirable employees because they cannot provide a sufficiently attractive menu of incentives. Similarly, firms may not be able to induce certain individuals to sell them their knowledge, or employees of other institutions may be prohibited from selling information to outsiders. However, the same individuals who are not willing to be either employees of a firm, or a market supplier of knowledge to the firm, may be willing or able to provide knowledge to the firm through social networking.

In summary, this discussion suggests that firms may prefer to use social networks, rather than markets or their own hierarchies (i) for governing exchanges of information or knowledge which (ii) is potentially but uncertainly valuable, (iii) which is appropriable, and (iv) whose production is characterized by human capital immobility. These arguments, or course, will only be relevant if a social network form of contracting is an available option. If such networks are not available, then a firm will not be able to use them to conduct its external exchanges, no matter how desirable that may be.

5 HYPOTHESES

Academic scientists belong to a social network where exchanges of information are governed by well defined and socially enforced norms, including norms of reciprocity, respect for individuals' intellectual property rights and norms of honesty in research (Crane, 1972; Blau, 1973; Nelkin, 1984). For example, individual scientists' intellectual property rights are protected through presentations and authorship on published research. Norms of honesty in research are instilled through long and rigorous training and are enforced through research which seeks to replicate and validate the findings of other scientists. Reputations for trustworthy behavior can be established because academic scientists conduct repeated exchanges of information through shared research programs, attendance at meetings, presentations. and reviewing and refereeing written work (Zucker. 199 1). This system of repeated exchange allows detection and punishment of plagiarism and falsification (Klein and Leffler, 1982). Finally, scientists who do not conform to accepted norms can be excluded from exchanges of information (such as participation in research teams and access to the latest research findings) which will severely damage their future careers (Crane, 1972). In extreme cases, plagiarism or falsifying research will lead directly to job loss. In sum, trustworthy behavior among academic scientists is instilled, motivated and maintained through a variety of mechanisms. This trustworthy behavior facilitates both the sharing of information, and expert assessment of its value. Information sharing is facilitated because the social network provides numerous protections against appropriation; once shared, the information's value can be assessed by review or by validation. In turn, this process of sharing and evaluating information allows the frontier of knowledge to progress as quickly and cheaply as possible, because unnecessary replication of effort is avoided.

NBFs have access to the information-sharing social network of academic scientists because, typically, NBFs are founded by university scientists. Indeed many NBF founding scientists belong to the scientific elite. For example, Herbert Bayer, one of the discoverers of gene-splicing and a renowned scientist, was the key founder of Genentech, one of the largest and most successful NBFs (Kenney, 1986). Similarly, Hybritech, Amgen, Biogen, Genetic Systems, Chiron, and Genex were all founded by highly successful university scientists. Because some members of the social network of academic scientists are situated within the hierarchy of NBFs, these firms have access to the network for the purpose of conducting exchanges of scientific knowledge. In particular, because of their individual elite status, founding NBF scientists can potentially attract many external scientists who would like to collaborate with them in research. The question remains, however, of whether it would be optimal for NBFs to conduct exchanges of scientific knowledge through this social network In what follows, we argue that exchanges of scientific knowledge do fit the conditions under which social networks are considered to be an optimal form of exchange governance, as discussed earlier. That is. these exchanges involve (i) information or knowledge which (ii) is potentially but uncertainly valuable. (iii) which is potentially appropriable. and (iv) whose production is characterized by **human capital immobility.**

5.1 Uncertainty as a determinant of the organization of exchanges of scientific knowledge in new biotechnology firms

As outlined in **Section 3. many uncertainties exist in the biotechnology research process. in particular,** NBFs face uncertainty regarding the value of the knowledge that they are dedicated to sourcing and commercializing. By seeking out expert evaluations of research findings as they progress, NBFs can minimize the possibility that they are engaging in fruitless research, and learn whether or not they are engaging in research in which rival NBFs may have an advantage. These expert evaluations of research content and progress **relative to rivals may** not be available within the hierarchy of the NBF (Zucker, 1991), impelling the firm to seek research evaluations from external experts. Typically, the external experts used by NBFs to evaluate their research will be scientists who are conducting similar research themselves. NBF scientists can ask these external expert scientists to review and evaluate their findings. More **important,** NBF scientists can conduct collaborative research with external scientists, allowing their expert information to be applied to the NBFs research programs **from the outset.**

Hypothesis 1:

NBFs will conduct external exchanges of scientific knowledge, including collaborative research

In addition, NBFs face uncertainty over the loci of innovation. For example, an NBF may face uncertainty concerning which external research teams working on **a particular scientific** problem may be successful in developing knowledge which is important to the NBFs own survival and success. An NBF can overcome some of this uncertainty by entering into a large number of external exchanges. In this way, the NBF “diversifies” its research program. increasing the likelihood that it will be the first to gain access to any new discoveries-in a particular area Therefore, we expect that the external exchanges of scientific knowledge of NBFs will be conducted with numerous exchange partners.

Hypothesis 2:

NBFs will conduct external exchanges of scientific knowledge with numerous exchange partners.

An additional consideration here is whether the number of external exchanges conducted by NBFs will change over time. If NBFs' uncertainty over the value of their biotechnology knowledge becomes resolved over time, their need to conduct external exchanges will diminish. On the other hand, if their uncertainty continues, they will continue to need to conduct external exchanges. We discuss this issue further in Section 5.3 below.

5.2 Appropriability as a determinant of the organization of exchanges of scientific knowledge in new biotechnology firms

As discussed in Section **3, the** enormous potential value of biotechnology knowledge provides a strong incentive for appropriating knowledge which is not protected by patent laws. Appropriation is particularly a concern of external exchanges of knowledge, because, as we discuss above, it is uncertainly valuable and therefore unpatented knowledge which is most likely to be involved in NBFs' external exchanges. Following Arrow's (1962) arguments, market exchanges may not be able to prevent the appropriation of such potentially valuable and unpatented knowledge. In contrast, conducting exchanges of such knowledge through networks of academic scientists may resolve the appropriability problem. If an external scientist collaborates with NBF scientists on a specified research project, the exchange of valuable knowledge becomes embedded in a social network where behavior is governed by the norms of academic science, which are strongly protective of intellectual property rights. These norms may therefore be able to prevent expropriation of the intellectual property rights of the firm by external scientists.

Hypothesis 3:

NBFs will conduct the majority of their external exchanges of scientific knowledge through social networks rather than through markets.

Appropriability concerns may also impel NBFs to govern certain knowledge exchanges exclusively through their own hierarchies, if the returns to appropriation are so high as to render any external exchange risky. In particular, as research programs progress, their value becomes more certain, reducing the marginal value of external inputs of scientific knowledge. while the incentive for appropriation increases. By internalizing exchanges of more certainly valuable knowledge, an NBF can use managerial fiat to restrict the flow of this knowledge beyond its boundaries. For example, the NBF can prevent its scientists from revealing certain valuable research findings to their external colleagues.

An additional consideration which may mandate internalizing certain exchanges is the NBFs incentive to establish undisputed property rights. As the commercial value of biotechnology discoveries has become manifest, many universities have established intellectual property rights policies which grant ownership of all discoveries made by university scientists to the university itself. Therefore, an NBF may not be able to obtain clear and undisputed patent rights to discoveries, unless it is the undisputed locus of discovery.[2]

---

2 An alternative explanation for NBFs' external exchanges to the ones presented here is that NBFs *free ride" on university research. However, this explanation ignores the risks NBFs face of losing unencumbered and undisputed patent rights to discoveries when they collaborate with external scientists in research. Universities and other research institutions which receive public funding may not be able to enter into formal contracts which grant exclusive intellectual property rights to certain firms and not to others. For example, in 1992 the Scripps Research Institute was the subject of a Congressional hearing after it granted exclusive *first peek" rights to its scientific discoveries to Sandoz corporation. Later, Scripps was forced to renegotiate the agreement, substantially reducing Sandoz' exclusive access to preliminary research findings. Much of the furor surrounding the initial agreement arose in response to the fact that, while much of Scripps' research was funded by U.S. taxpayers, the agreement precluded the use of its research findings by scientists at other institutions and firms. Bernadine Healy, head of NIH at the time, described the Scripps-Sandoz agreement as "contrary to the spirit of science, and possibly, illegal." Similar concerns have been voiced regarding Hitachi's agreement with the University of California, Irvine.

These considerations suggest that it may be more efficient for an NBF to internalize those exchanges which involve knowledge which has a high probability of being valuable, and which is not already patented. Therefore, while we expect that NBFs will conduct many exchanges of (uncertainly valuable) scientific knowledge externally, we also expect that many other exchanges of (more certainly valuable) scientific knowledge will be governed exclusively by the hierarchy of the firm.

Hypothesis 4:

NBFs will conduct a substantial proportion of their exchanges of scientific knowledge through their own hierarchies.

5.3 Human capital immobility as a determinant of the organization of exchanges of scientific knowledge in new biotechnology firms

A third factor which may influence the organization of exchanges of scientific knowledge by NBFs is human capital immobility. This would not be a concern to NBFs if valuable human capital--in the form of high quality biotechnology scientists-were not scarce. Given that it is scarce, immobility becomes a concern, as firms must seek every possible way to access new scientific knowledge from scientists who are not willing to work for the firm. The options available to NBFs for conducting such external exchanges are markets or networks. However, market exchanges may not be a feasible option for university scientists. For example, many universities restrict the amount of time their employees can work for other institutions, and the amount of income they can receive from outside sources (Giamatti, 1982; Kennedy, 1982). (These restrictions do not, of course, apply to scientists working for other firms. These firms can enter into any market contract they wish, and are unlikely to allow their scientists to collaborate without formal agreements being in place, because of appropriability concerns) The problems of human capital immobility and the infeasibility of market contracting with university scientists can be resolved by conducting network exchanges of scientific knowledge. University scientists may be willing to provide knowledge services to an NBF through scientific collaboration, even though they are unwilling to work directly for an NBF, because the scientists may receive valuable materials, technologies. or research findings in return (Zucker, 199 1).

Hypothesis 5:

NBFs will conduct more network exchanges with scientists in universities and other non-profit institutions, than they will with scientists in other firms.

An NBF may also be able to attenuate human capital immobility by changing its own employment policies. An NBF may be able to attract and retain more talented scientists as employees if it permits its scientist-employees to continue to participate in external exchanges of scientific knowledge. These exchanges will enable scientist employees to continue to gain prestige and friendships from their professional social network, while also gaining benefits from their employment at the NBF. Such external exchanges may involve not only collaborative research, but also the publication of some of the scientistemployees' own non-collaborative research findings. These continuing exchanges by scientistemployees will also allow the NBF to maximize the number of external network exchanges it can enter into, thereby reducing uncertainty in its competitive environment. Therefore, it can be expected that an NBF will continue to permit and support exchanges of scientific knowledge between its own scientists and scientists working at other institutions so long as the total benefits of reduced uncertainty and attenuated factor immobility continue to be greater than the expected costs of appropriation.

Hypothesis 6:

NBFs' external network exchanges of scientific knowledge will not diminish over time.

6. METHODS

6.1 Sample

The evidence we present in this study on the use of hierarchies. markets and networks to govern exchanges of scientific knowledge is based on detailed case studies of two NBFs. We used the case study method for two reasons. First, we wanted to obtain as detailed a picture as we possibly could of how NBFs source the scientific knowledge which is their critical input. This would not have been possible using public data; it required that we conduct detailed interviews with managers and scientists, and that we collect data on a wide variety of exchanges. We therefore made a conscious decision to favor depth over breadth in our research design. Second, we also wanted to explore patterns of exchange of scientific knowledge beyond the scope of our study hypotheses. For instance, we also gathered data on the internal organization of the research process at Firm X, and tracked the progress of one particular research program for more than a year. These additional findings are not reported here, but they provided us with a wealth of supporting information and insights which have substantially informed the findings we do report. In summary, we chose to conduct an exploratory, open-ended study of exchanges of scientific knowledge in NBFs, using very detailed and precise information, in preference to conducting a more structured but less wide-ranging investigation, using less detailed and accurate information. However, because we have chosen a case study design, we are not able to test our hypotheses statistically; we can only observe whether or not the data we present from the two firms are consistent with the study hypotheses.

Both firms involved in the case studies requested anonymity. Therefore, we refer hereafter to the two firms studied as Fii X and Firm Y. Both Firm X and Firm Y are well established and successful NBFs which have been in existence for nine or more years. We chose to study successful NBFs because these firms are most likely to have developed an optimal set of contractual arrangements for sourcing their critical input, scientific knowledge. Both firms were founded during the period of peak founding of NBFs, 1976-81 (Barley, Freeman and Hybels, 1992). However, in order to preserve the two firms' anonymity, we cannot reveal the exact year of each firm's founding. Therefore, we refer to the data presented here by the number of years elapsed since the date of founding of each firm, which is designated as Year 1 in each case.

Firms X and Y are both involved in the most profitable area of biotechnology: human diagnostic and therapeutic products. Indeed, some of the products of the two firms are head-to-head competitors. In addition, the two firms are diversified into similar numbers of different product areas, within the diagnostic and therapeutic categories. Each firm also operates under identical regulatory and property rights regimes. For example, the products of both firms are biomedical products which are governed by FDA regulations, and most of their products are patentable under U.S. intellectual property laws. We chose to study two firms with such similar sets of transactions to provide some verification of our findings. If we had studied only one firm, or if we had studied two firms with very different types of transactions, or if we had studied firms operating under different regulatory regimes, we would not be able to compare our findings in any way.

The data we present detail each firm's organizational arrangements for its supply of scientific knowledge for the ten year period following its founding. We restricted the periods of observation in this way so that we can compare and contrast different patterns of contracting in each firm as it evolves. Although Firm X and Firm Y are conducting highly similar exchanges in terms of products, regulation and intellectual property rights regimes, it is nonetheless possible that the two firms might have different competencies and capabilities in terms of governing their exchanges. These can be highlighted by comparing their contracting arrangements over similar periods of time. Since the two firms were founded within a relatively short period of time, we do not expect that the firm's organizational development will be differentially influenced by changes in their competitive environment during the study period.

6.2 Data

The case study data were collected between 1989 and 1992. and were obtained from a variety of sources including interviews with scientists and managers in the two firms studied; proprietary information from corporate records; and information obtained from public data sources.

We measure hierarchical exchanges of scientific knowledge in terms of the number of scientists in Firms X and Y. Because managers have the legally vested power to set the terms and conditions of exchange within the firm, even exchanges which take place among social networks within firms must ultimately be considered to be hierarchical in nature (Masten, 1988). Because scientific knowledge is produced by scientists (rather than, for example, by machines), the number of scientists who are employed by each firm represents an appropriate measure of the extent of each firm's hierarchical exchanges of scientific knowledge. Details of the number of scientists employed in each firm in each year were obtained from company records.

Following previous studies (Shan, 1990; Kogut, Shan and Walker, 1992; Powell and Brantley, 1992; Pisano, 199O;.Arora and Gambaredello, 1990; Barley, Freeman and Hybels, 1992) we measure the extent and nature of market exchanges of scientific knowledge in each firm using details of each firm's formal agreements with external organizations and/or individuals. These formal agreements include long term contracts, licensing agreements, joint ventures and equity investments (Williamson, 1979,199 1). Details of these market exchanges were obtained from corporate reports and from public data sources such as the ***North Carolina Biotechnology Database, BioScan, the Wall Street Journal Index,*** and various reports on ***the*** biotechnology industry published by investment firms such as Ernst & Young, Kidder Peabody, and Shearson.

We measure the extent of each firm's network exchanges of scientific knowledge using output data in the form of scholarly publications on which scientists from the two NBFs were named as authors in collaboration with scientists from other institutions Scholarly publications measure the production of valuable scientific knowledge because research findings are only published if they are considered to contain information of value to other scientists. In addition, Camagni (1989) and Zucker (1991) have argued that networks serve the principal purpose of allowing a firm to obtain outside evaluations of the value of its knowledge. Submitting work for publication in a scholarly journal is an excellent way for firms to achieve this goal, since the review process provides just such an external evaluation. Both Firms X and Y keep proprietary records of scholarly publications in which their scientists are authors. Using these records, we looked up the original articles in libraries and recorded each institution of origin of each external author as listed on each article. We were then able to compile data on the number, identity and type of institutions at which external collaborating scientists worked. We also recorded the number of scholarly publications in which scientists at Firms X and Y did not collaborate with outside scientists. Altogether, these publication data allow us to examine each firm's external network research exchanges in terms of the total number of external institutions involved; the type of institutions involved; the frequency of collaborative research endeavors with specific institutions; the degree to which each firm's external exchange network overlaps with the other's; the degree to which scientists at Firms X and Y collaborate with external scientists in published research; and the evolution of such collaboration over time. We recognize that using publication data provides an incomplete measure of the two firms' network exchanges of scientific information. For example, these data exclude information on collaborations which did not result in any publishable results, even though this outcome may provide valuable information to a firm (e.g. a line of research is not worth continuing). In addition, a collaboration may have provided data so valuable that the firm may have resisted their publication.[3] This may be increasingly the case in recent years, as competition has intensified in the biotechnology industry.

---

3 Normally scientists in NBFs and their external collaborators must agree to allow the firm "first peek" at their research results so that the firm can file patent requests on any potentially valuable discoveries before publication. This usually involves a delay in publication of about one month. However, it is possible that scientists in highly competitive and/or

7 EVIDENCE

The analyses of the organizational arrangements used by Firm X and Firm Y to govern their exchanges of scientific knowledge are presented in two sections. The first section presents the evidence which directly tests the study hypotheses. The second section presents and discusses additional evidence on the importance of uncertainty and appropriability to the organization of the two firms' exchanges.

7.1 The relative importance of markets, networks and hierarchies in the organization of exchanges of scientific knowledge

The relative importance of markets, networks and hierarchies in governing exchanges of scientific knowledge by Firms X and Y is illustrated in Tables 1 through 5.

Table I shows the extent of external exchanges of scientific knowledge at Firms X and Y which are conducted through collaborative research. The table shows that both firms were heavily involved in collaborative research with external scientists during the ten years following their founding: Firm X was involved in 257 collaborative research projects with scientists at 144 different external institutions, while Firm Y was involved in 254 collaborations with external scientists at 147 different institutions. This evidence supports Hypothesis 1, that NBFs will conduct external exchanges of scientific knowledge, and supports Hypothesis 2, that NBFs will conduct external exchanges of scientific knowledge with numerous exchange partners. In all, this evidence suggests that the uncertainty surrounding the process of sourcing scientific knowledge impelled the two NBFs studied to seek out numerous sources of external expertise in conducting their research programs.

Tables 2,3 and 4 show that very few of the external research collaborations reported in Table I were governed by market contracting, supporting Hypothesis 3. First, Panel A of Table 2 shows that Firms X and Y entered in very few formal market exchange agreements for

---

highly valuable research programs may be restricted from publishing their findings altogether.

Table 1:
Collaborations between scientists in Firms X and Y with scientists at external institutions in published research.

Firm:	# of publications involving collaborative research produced by scientists at:	# of institutions in the collaborative research networks of:
Firm X:	257	144
Firm Y:	256	147
Both firms:	513	291

Sources: Corporate records of Firms X and Y; journal references.

Table 2:
Market and quasi-market exchanges for sourcing scientific research at firms X and Y.

	Type of institution involved in exchange:				
	Universities: U.S.	Universities: Int'l.	Firms: U.S.	Firms: Int'l.	Total
A. ***Market exchanges sourcing scientific knowledge*** [a]					
Firm X	0	0	***2***	***0***	***2***
Firm Y	1	1	4	0	6
Total	1	1	6	0	8
B. ***Other market exchanges:*** [b]					
Firm X	0	0	**13**	**5**	**18**
FirmY	1	1	**17**	**16**	**35**
Total	1	1	30	21	***53***
C. ***Total* A + *B:***					
Firm X:	0	0	**15**	**5**	***20***
Firm Y:	2	2	**21**	**16**	41
Total total	2	2	36	21	61

[a] Defined as all market and quasi-market types of contracts including long term contracts, license agreements, joint ventures and equity investments in which the NBF is primarily sourcing scientific knowledge from other organizations (Williamson , 199 1). See Table 2 for further details.

[b] Defined as all exchanges in which the NBF is sourcing goods other than scientific knowledge, or is selling scientific knowledge to other organizations, or both.

Sources: Corporate records; *North Carolina Biotechnology Database*; *BioScan* ; *Wall Street Journal Index.*

the supply of scientific knowledge: Firm X entered into only 2 such agreements. while Firm Y entered into 6 agreements. In contrast. Panel B of Table 2 shows that Firms X and Y entered into far more market contracts for other inputs, and/or for the sale of scientific knowledge and other outputs. Firm X entered into 18 other market contracts, while Firm Y entered into 35. This evidence suggests that market exchange is not an efficient mode of contracting for the supply of scientific knowledge, relative to other inputs and outputs.

One reason for this scarcity of market exchanges of scientific knowledge may be because the two NBFs were unable to write binding contracts for the supply of scientific knowledge with universities. Only two of the market contracts for scientific knowledge were with universities; indeed, Firm X had no market exchanges at all with universities. However, the evidence also suggests that appropriability considerations are a cause of the observed scarcity of market exchanges of scientific knowledge. Although Firms X and Y could feasibly contract with other firms for the supply of scientific knowledge, they in fact entered into a total of only 6 such exchanges with other firms, versus 5 1 market exchanges with other firms for other types of goods and services. Furthermore, Table 3 shows that only 5 of the market exchanges of scientific knowledge of the two firms were governed purely by contract while the remaining 3 exchanges were equity investments or joint ventures with other firms in which incentives for appropriation are attenuated (Williamson, 1991).

Second, Table 4 shows that almost none of the research collaborations of Firms X and Y documented in Table 1 were governed by the market agreements reported in Tables 2 and 3. Of the 8 market agreements the two firms entered into for the supply of scientific knowledge, only 2 concerned institutions with which the NBF also conducted collaborative research. Consequently, of the total of 291 institutions with which Firms X and Y conducted exchanges of scientific knowledge through collaborative research, 287 were partners in exchanges which were conducted purely through social networks. That is, these exchanges were governed exclusively by the network of academic scientists. This evidence supports Hypothesis 3, that

Table 3:
Types of market and quasi-market governance mechanisms for exchanges supplying scientific knowledge to Firms X and Y

Type of contract:	FirmX	Fiim Y	Total
Long term research contract [a]	4	1	5
Licensing agreement	1	0	1
Research joint venture	1	0	1
Equity investment in another research-based firm	0	1	1
Total:	6	2	8

[a] Two of these long term research contracts were with universities. Otherwise all exchanges listed were with other firms.

Sources: Corporate records; *Nonh Carolina Biotechnology Database*; *BioScan*; *Wall Street Joumal Index.*

Table 4:
Extent of market governance of external research collaborations at Firms X and Y.

	Universities etc.: U.S.	Int'l.	Firms: U.S.	Int'l.	Total
A. *Total number **of market exchange par-men:** a*					
FirmX	*0*	*0*	2	**0**	**2**
FirmY	1	1	4	**0**	**6**
*B. Number **of market** exchange partners with which NBF also conducts collaborative research: b*					
FirmX	-.-	-.-	**0**	-.-	*0*
Firm Y	**1**	**1**	**0**	-.-	*2*

a See Table 2, Panel A.
b See Tables 1 and 6.

NBFs will conduct their external exchanges of scientific knowledge through networks and not through markets.

The evidence presented in Table 5 shows that hierarchical exchanges are also important in the two NBFs, supporting Hypothesis 4. The number of scientists employed by Firms X and Y during the ten year period following their founding increased steadily, showing that both firms relied to some considerable degree on employee-scientists to conduct research. Firm X had almost 200 scientists working in its laboratories by its tenth year; Firm Y had about 150 scientists by its ninth year. (Data on scientist employees for the tenth year at Firm Y were not available).

Table 6 shows the types of institution of affiliation of the external scientists involved in scientific collaborations with NBF scientists. The table shows that the vast majority of institutions of affiliation of these external exchange partners, 86%, were U.S. and international universities. Only 14% of institutions of affiliation of external exchange partners were other firms. This evidence is consistent with Hypothesis 5. Panel B of Table 6 shows that scientists at Firms X and Y also collaborated more frequently with scientists at universities, than with scientists at other institutions. The rate of collaboration is highest for scientists at U.S. universities, with an average rate of 3.28 collaborations in published research per institution involved, and is lowest for foreign firms, with an average rate of 1.08 collaborations per institution involved.

The evidence presented in Table 6 also shows that the two NBFs built a global network for exchanges of scientific knowledge: 29% of all institutions in the collaborative network of Firm X and 43% of all institutions in the collaborative network of Finn Y were located outside the U.S. This evidence points to the strength of scientific norms in being able to resolve appropriability problems in the exchange of intellectual property far beyond the boundaries of U.S. jurisdiction on intellectual property rights.

Table 7 shows patterns of publication and collaboration with external scientists in Firms X and Y for each of the ten years following each firm's founding. The table shows that scientists

Table 5:
Hierarchical governance of exchanges sourcing scientific knowledge at Firms X and Y.

	Firm X:		Firm Y:	
Year from founding	Total scientists a	Number added per year a	Total scientists a	Number added Per year a
1	26	26	13	13
2	41	15	25	12
3	50	9	38	13
4	67	17	55	17
5	73		61	6
6	94	2:	71	10
7	122	28	113	42
8	154	32	138	25
9	188	34	146	18
10	197	9	na	na

a The number of scientist-employees entering each year is measured as the number of scientists who entered in that year and who remained at Firms X and Y through Years 10 and 9 respectively. The numbers therefore exclude scientist-employees who did not remain with the two firms.

source: corporate records.

Table 6:
Frequency of collaboration **in published research between scientists at Firms X and Y and external scientists by type of institution of affiliation of external scientists.**

	Type of institution: Universities and other non-profit research institutions: U.S.	In t'l.	Firms: U.S.	Intl.	Total
A. Number of ***institutions with which external collaborating scientists are affiliated:***					
Both firms:					
Number:	157	93	28	13	281
% of total:	54%	32%	10%	4%	100%
Firm X:					
Number:	**85**	**36**	**17**	**6**	**144**
% of total:	**59%**	**25%**	**12%**	**4%**	**100%**
Firm Y:					
Number:	**72**	**57**	**11**	**7**	**100**
% of total:	**49%**	**39%**	**8%**	**4%**	**100%**
B. Mean number of collaborations per institution by type:					
FirmX	3.31	2.08	1.88	1.16	
FirmY	3.25	2.03	1.18	1 .00	
X+Y	3.28	2.05	1.53	1.08	

Sources: Corporate records of Firms **X and** Y; joumal references.

Table 7:
Number and proportion of publications involving and not involving the collaboration of external scientists at Firms X and Y by year from founding.

	Firm X:					Firm Y:				
Year from founding	Total # of pubs.	# of pubs. involving external scientists	Proportion of total pubs.	# of pubs. involving only Firm X scientists	Proportion of total pubs.	Total # of pubs.	# of pubs. involving external scientists	Proportion of total pubs.	# of pubs. involving only Firm Y scientists	Proportion of total pubs.
1	0	0		0		0	0		0	
2	0	0		0		0	0		0	
3	18	4	.22	14	.78	13	10	.77	3	.23
4	39	9	.23	30	.77	21	17	.81	4	.19
5	56	25	.45	31	.55	50	43	.86	7	.14
6	56	18	.32	33	.68	56	43	.77	13	.23
7	82	49	.60	33	.40	47	27	.66	20	.34
8	73	42	.58	31	.42	56	38	.68	18	.32
9	82	48	.59	34	.41	60	45	.75	15	.25
10	107	62	.58	40	.42	42a	33a	.80a	9a	.20a
Total:	513	257	.50	246	.50	345	256	.74	89	.26

• **Numbers for Firm Y in Year 10 represent incomplete records due to a number of in press publications.**

at Firms X and Y continued to participate in external exchanges of scientific knowledge over time. consistent with Hypothesis 6. First. the table shows that scientists at Firms X and Y continued to collaborate with external scientists in published research. At Firm X, scientists steadily increased their number of external collaborations over time to a high of 62 collaborations in Year 10. At Firm Y, scientists maintained a rate of about 40 external publications of from Year 5 onwards, although this rate fluctuated quiet considerably from year to year. Therefore, the number of external collaborations in both Firm X and Firm Y did not decline over time, even though each firm was increasing its number of scientistemployees during this period (see Table 5). This suggests that NBFs continued to gain benefits over time from these external collaborations in terms of reducing uncertainty, accessing the knowledge of immobile external scientists, and attracting and retaining scientist-employees. With regard to the latter benefit, Table 7 also shows that scientists at Firms X and Y continued to publish research findings, even when research did not involve collaboration with external scientists. However, there was some difference between the two NBFs in the degree to which they encouraged (or permitted) their employee-scientists to enter into network exchanges of scientific knowledge which did not involve external collaborations The number of publications at Firm Y involving only its own scientists (n = 89) was far lower than the number at Firm X (n = 246), even though the number of external collaborations in published research of the two firms was essentially identical.

7.2 Additional **evidence**

Table 8 provides additional evidence on the importance of uncertainty to exchanges of scientific knowledge. It shows that the majority of collaborations in extemal research collaborations by scientists at Firms X and Y were short term. In Firm X, 130 out of a total of I44 (90%) collaborative research relationships by institution involved 5 or fewer research publications; in Firm Y, 134 out of 147 (91%) collaborative relationships involved 5 or fewer publications. In no instance did either NBF conduct long term collaborative research with

Table 8:
Frequency of collaboration in published research by scientists at Firm X and Firm Y by type of institution of external scientists' affiliation for the ten years following firm founding,

	Firm X: Universities: U.S.	Int'l.	Firms: U.S.	Int'l.	Total Firm X	Firm Y: Universities: U.S.	Int'l.	Firms: U.S.	Int'l.	Total Firm Y	Both Firms: All Universities	Both Firms: All collaborations
Number of published research projects per institutional collaboration:												
1-5	**74**	**33**	**17**	**6**	**130**	**60**	**56**	**11**	**7**	**134**	**223**	**264**
6-10	6	3	0	0	9	7	1	0	0	8	17	17
11-15	2	0	0	0	2	3	0	0	0	3	5	5
16-20	1	0	0	0	1	0	0	0	0	0	1	1
21-25	1	0	0	0	1	1	0	0	0	1	2	9
26-30	1	0	0	0	1	0	0	0	0	0	1	1
31 +	0	0	0	0	0	1	0	0	0	1	1	1
Totals:	85	36	17	6	144	72	57	11	7	147	250	291

scientists at other firms; all the collaborations which resulted in more than 5 publications were with university scientists. Overall, these patterns of collaboration show that Firms X and Y by and large "went fishing" for valuable information by conducting numerous short-term collaborations, consistent with the arguments of Camagni (1989) and Zucker (1991); they did not focus on building long term exchange relationships.

One question here is whether this pattern of conducting many, short term relationships led to serious appropriability problems for Firms X and Y. This issue is examine in Tables 9 and 10. Table 9 examines the issue of whether Firms X and Y, which compete head-to-head in certain products, sought to reduce potential appropriability in their external scientific exchanges by forming collaborative relationships at mutually exclusive sets of external institutions. The table shows that the two firms did not form completely exclusive external collaborative networks, out of a total network of 255 institutions, Firms X and Y both had collaborations with scientists at 36 institutions, which comprised 25% of all institutions in both Firm X's and Firm Y's collaborative research networks4 Clearly, for each firm to have collaborative research efforts with scientists at the same institution is likely to increase their risk of information leakage to the competitor firm. Therefore, this evidence indicates that each firm must have considered the benefits of external exchanges with these institutions to outweigh the appropriability risks. Alternatively, it is possible that Firms X and Y were both able to optimize the balance of internal and external exchanges in such a way that their appropriabitity risks were minimized, even when they conducted external exchanges of scientific knowledge with scientists at institutions where their rivals were also actively involved in such exchanges This issue is examined in Table 10, which shows the number and type of patents obtained by Firms X and Y in the ten years following their founding. The data show that both firms were highly successful in obtaining clear property rights to scientific discoveries. Of the 28 patents owned by Firm X, only 3 were shared, none of them with scientists or institutions in their

4 The data presented in Table 9 show only those institutions with'vhich Firms X and Y both have, or do not both have, external network exchanges. It is possible that when other competitor firms are considered, neither firm has any exclusive access to external research.

Table 9:
Extent of **exclusive** and shared networks of external scientists involved in published collaborative research with Firms X and Y measured by number and type of institution of affiliation of external scientists.

Institution Firm type	Number of institutions in collaborative R&D networks of firms which are: Shared	Exclusive to: FirmX	FirmY	Shared insts. as % of total insts. in R&D network of: Firm X	FirmY
Universities and other non-profit research institutions:					
U.S.:	30	55	42	35%	42%
International:	5	31	52	14%	9%
Finns:					
U.S.:	1	16	10	6%	14%
International:	0	6	7	0%	0%
Total	36	108	111	25%	25%

Table **10:**
Exclusive versus shared patent rights of Firms X and 1'.

	Firm X	Firm Y
Total number of patents?	**28**	**21**
Number of exclusive patents:	25	**19**
Number of shared patents:	**3**	**2**
Number of patents shared by NBF with institutions with which NBF has a formal contractual agreement:	3	**2**
Number of patents shared by NBF with institutions with whose scientists NBF scientists have collaborated in published research:	0	2

a Defined as major patents in force at the time of writing; numbers do not include patents applied for and not received and do not include separate claims made under each patent.

Sources: Corporate records: patent records.

collaborative network Of the 2 1 patents owned by Firm Y. 2 were shared with institutions in their collaborative network However, Firm Y also had market agreements with these two institutions which may have specified that intellectual property be shared.

8 DISCUSSION AND CONCLUSION

This paper has investigated the organizational arrangements used by firms in one hypercompetitive industry--the biotechnology industry-to source their most critical input, scientific knowledge. Specifically, we have investigated the degree to which new biotechnology firms, or NBFs, rely on hierarchies, markets and networks to source new scientific knowledge. Building on the arguments of Teece (1986,1988), Powell (1990), Camagni (1989) and Zucker (1991), we have argued that, for reasons of uncertainty, appropxiability and factor immobility, NBFs will find it optimal to (a) conduct a proportion of their exchanges which supply them with scientific knowledge with external exchange partners and (b) to conduct these external exchanges through extensive social networks, rather than across markets. The evidence presented here on the organizational arrangements used by two highly successful NBFs to source scientific knowledge is largely supportive of our major hypotheses. The central result of this study is that the two firms studied relied to a very large degree on collaborative research conducted through extensive external networks of scientists to source scientific knowledge. The importance of these network exchanges of scientific knowledge vastly outweighed the importance of market exchanges in both firms, in terms of the number of exchanges conducted and in terms of their institutional scope. These network exchanges of scientific knowledge also extensively supplemented the two firms' hierarchical exchanges of scientific knowledge conducted by their own scientist-employees. The fact that the two firms studied relied to such a degree on network exchanges of scientific knowledge is consistent with previous arguments that, under conditions of environmental uncertainty, external exchanges may be more efficient than internal exchanges (Teece, 1986,1988; Camagni, 1989; Zucker, 1991). The fact that the two firms undertook most of their external exchanges through networks rather than markets suggests that the norms and values of the social network of research scientists regarding intellectual property rights were sufficiently binding to prevent appropriation, even in circumstances when the returns to appropriation were (and remain) very high. These strong norms therefore permitted the two firms to maximize their chances of obtaining property rights to valuable discoveries while reducing their costs of internalizing research efforts in a technologically uncertain environment.

This study provides some new insights into understanding the relationship between competitive strategy and the boundaries of firms. Recent research has considered the importance of interorganizational exchanges such as joint ventures, licensing arrangements, and long term trading contracts to corporate strategy and efficiency (Auster, 1990; Reve, 1990). In these inter-organizational exchanges, a firm may need to adjust its own hierarchical rules and procedures to accommodate those of its exchange partners, or of the law (Williamson, 1991). In this paper we show that firms can also pursue competitive strategy by promoting and supporting external exchanges which are conducted through the social networks to which their employees belong. In such network exchanges, a fum also may need to adjust its hierarchical rules and procedures in order to accommodate the norms and values of the network in question. For example, in this study we have suggested that NBFs may need to allow publication of research findings by their employee-scientists, even though this increases appropriability risks, so that the norms of these scientistemployees and of their external research collaborators can be accommodated Given the importance of exchanges of scientific knowledge to competitive success in the biotechnology industry, NBFs' ability to adjust their hierarchical rules in order to accommodate external network norms may be vital to their survival.

This paper provides a useful complement to the findings of prior studies on the organization of exchanges in the biotechnology industry. Previous studies have analyzed the formal market and quasi-market arrangements which exist between NBFs and other organizations (Shan, 1990; Pisano, 1990; Arora and Gambaredella, 1990; Barley, Freeman and Hybels. 1992; Kogut. Shan and Walker. 1992: Powell andBrantley. 1992; Oliver 1993 I. These studies have served to illustrate the network structure of the biotechnology industry at the inter-organizational level, and to illustrate the importance of market exchanges to NBFs' survival and success. In this study, we have supplemented these findings to show that NBFs' reliance on formal external contracting for their most critical input, scientific knowledge, is limited. Instead, we find that NBFs rely predominantly on their own hierarchies and on external network exchanges for sourcing scientific knowledge. This finding emphasizes the importance of including all modes of exchange when investigating the scope of the external transactions of the firm.

REFERENCES

Aldrich. H. and Zimmer. 1986. "Entrepreneurship through social networks." In D. Sexton and R. Smiler (eds.) The *Art and Science of Entrepreneurship. New* York, NY.: Ballinger.

Arora. A. and A. Gambardella, 1990. "Complementary and external linkages: The strategies of large firms in biotechnology.' *Journal of Industrial Economics* 38: 361-379.

Arrow, K., 1962. "Economic welfare and the allocation of resources for invention." In The *Rare and Direction of Inventive Activity. National* Bureau of Economic Research, Princeton, NJ: Princeton University Press.

Auster, E, 1990. "The interorganizational environment: Network theory, tools and applications." In F. Williams and D. Gibson (eds.) *Technology Transfer: A Communications Perspective.* Newbury Park, CA.: Sage Publications.

Axelrod, R., 1984. The *Evolution of Cooperation. New* York, NY.: Basic Books.

Barley, S., J. Freeman and R. Hybels, 1992. "Strategic alliances in commercial biotechnology." In N. Nohria and R. Eccles (eds.) *Networks and Organizations.* Boston, MA: Harvard University Press.

Belshaw, C.S., 1965. *Traditional Exchange and Modem Markets. Englewood Cliffs,* NJ: Prentice-Hall.

Blau, P., 1973. The *Organization of Academic Work New York, NY.:* John Wiley and Sons.

J. Bradach and R. Eccles, 1989. 'Markets versus hierarchies: From ideal types to plural forms." In W.R. Scott (ed.) Annual *Review of Sociology,* 15: 97-l 18.

Brusco, S., 1982. The Emilian model: Productive decentralization and social integration." *Cambridge Journal of Economics, 6:* 167- 184.

Burt, R., 1982. *Toward a Structured Theory of* Action. New York, NY: Academic Press.

Camagni, R "Cambiamento technologico, "milieu" locale e rete di imprese: Verso una teoria dinamica dell0 spazio eumomico." Economia e Polifica *Industriale, 64:* 209-236.

Coase, R., 1937. "The Nature of the Firm" *Economica, 4: 386-405.*

________ *1988. "The* Nature of the Firm: Origin, Meaning, Influence." *Journal of Law,* Economics and *Organization, 4(1):* 3-47.

Coser, L., C. Kadushin and W. Powell, 1982. Books: The Culture and *Commerce of Publishing. New York, NY:* Basic Books.

Crane, D.. 1972. Invisible College: *Diffusion of Knowledge in Scientific Communities* Chicago. IL.: University of Chicago Press.

D'Aveni. R. 1993. Hypercompetition: ***The Dynamics of Strategic Maneuvering. New*** York, NY: Free Press.

Dore, R., 1983. "Goodwill and the spirit of market capitalism." ***Brirish Journal** of Sociology,* 33: 459-482.

Dorfman, 1983. "Route 128: The development of a regional high-tech economy." Research *Policy,* 12: 299-316.

Eccles, R. and D. Crane, 1988. *Doing Deals: Investment Banks at work. Boston, MA.:* Harvard Business School Press.

Elster, J., 1989. "Social norms and economic theory." *Journal **of Economic Perspectives,*** 3 ***(4): 99-117.***

Evans-Pritchard E 1940. The *Nuer: A **Description of** the Modes of Livelihood and Political Institutions **of the Nilotic People.*** Oxford, England: Clarendon press.

Geertz, C., 1978. "The bazaar economy: Information and search in peasant marketing." *American Economic **Review, 68 (2): 28-32.***

Gerlach, M., 1993. *Alliance Capitalism: The Social* Organization ***of Japanese Business.*** Berkeley, CA.: University of California Press.

Ghemawat, P., 1992. *Commitment: The Dynamics of Strategy. New York, NY:* Free Press.

Giamatti, B., 1982. "The university, industry, and cooperative research." *Science,* 218 (December ***24): 1278-1289.***

Granovetter, M. "Economic action and social structure: A thoery of embeddedness." ***American Journal of Sociology, 9 1: 48 l-5*** 10.

Jensen, M., 1993. "The modern industrial revolution, exit, and the failure of internal control systems." *Journal of Finance, 48:* 83 l-880.

Joskow, P., 1985. "Vertical integration and long term contracts: the case of coal-burning electric generating plants." Journal *of Law, Economics and Organization 1:* 33-80.

Kennedy, D. "The social sponsorship of innovation." *Technology in Society, 4* (4): 253_ 266.

Kenney, M., 1986. Biotechnology: The *University-Industrial Complex. New Haven, CT: Yale* University Press.

Klein, B. and K. Leffler, 1982. "The role of market forces in assuring cont performance ***Journal of Political** Economy,* 89: 615-641.

Kogut. B.. W. Shan, and G. Walker, 1992. "The make or cooperate decision in the context of an industry network." In N. Nohria and R. Eccles (eds.) Networksz and ***Organizations.*** Boston. MA: Harvard University Press.

Kreps, D., 1990. "Corporate culture and economic theory." In J. Alt and K. Shepsle (eds.) ***Perspectives on Positive Political Economy.*** Cambridge, MA.: Cambridge University Press.

Larson, A., 1992. " Network dyads in entrepreneurial settings: A study of the governance of exchange relationships." Administrative Science Quarterly 37 (1992): 76 104.

Levin, R., R. Klevorick, R. Nelson and S. Winter, 1987. "Appropriating the returns from individual research and development." ***Brookings Papers on Economic Activity,*** 3.

Lorenzoni, G. and 0. Ornati, 1988. "Constellations of firms and new ventures." ***Journal of Business Venturing,*** 3: 41-57.

Masten, S., 1988. "A legal basis for the firm." ***Journal of Law, Economics and Organization, 4*** (1): ***3-47.***

Nelkin, D., 1984. ***Science as Intellectual Property: Who Controls Scientific Research? New York, NY.:*** Macmillan.

Ouchi, W.G., 1982. "Markets, bureaucracies and clans." ***Administrative Science Quarterly, 28: 129- 14 1.***

Oliver, A., 1993. New Biotechnology Firms: A Multilevel Analysis of Inter-Organizational Relations in an Emerging Industry. Unpublished Ph.D. dissertation, University of California, Los Angeles, June 1993.

Pisano, G., 1990. "The R&D boundaries of the firm: An empirical analysis." ***Administrative Science Quarterly,*** 35 153 176.

Powell, W., 1990. "Neither market nor hierarchy: Network forms of organization." Research ***in Organizational Behavior*** 12: 295-336.

1____ and P9 Brantley, 92. "Competitive cooperation in biotechnology: Learning through networks? In N. Nohria and R. Eccies (eds.) Networks and ***Organizations.*** Boston, MA: Harvard University Press.

Reve, T., 1990. " The firm as a nexus of internal and external treaties." In M. Aoki, B. Gustafsson and 0. Williamson (eds.) The ***Firm as a Nexus of Treaties. Los*** Angeles,. CA.: Sage Publications.

Ross, E, 1906. ***Social Control. New*** York, NY: Macmillan.

Shan, W., 1990. "An empirical analysis of organizational strategies by entrepreneurial high-technology firms" ***Strategic Management Journal,*** 11 (2): 129-140.

Shimolcawa, K., 1985. Japan's Keiretsu system: The case of the automobile industry." ***Japanese Economic Studies,*** 13 (4): 3-3 1.

Teece D.. 1986. "Profiting from technological innovation." *Research Policy* 15 (6): 286-305.

______1989. "Concorrenza e cooperazione nelle strategie di sviluppo tecnologico." Economia e *Politica Industraile 64: 17-46.*

Thorelli, H.. 1986. "Networks: Between markets and hierarchies." *Strategic Management Journal, 7:* 37-5 1.

Williamson, O., 1975. *Markets and Heirarchies. New York, N.Y.:* Free Press.

______ 1979. "Transaction cost economics: The governance of contractual relations." *Journal of Law and Economics,* 22 (October): 3-61.

______,199O. "*The* firm as a nexus of treaties: Introduction." In M. Aoki, B. Gustafsson and 0. Williamson (eds.) The *Firm as a Nexus of Treaties. Los* Angles: Sage Publications.

______ 199 1. "Comparative economic organization: The analysis of discrete structural alternatives." *Administrative Science Quarterly, 36:*

Zucker, L, 1986. "Production of trust: Institutional sources of economic structure 1840 to 1920." *Research in Organizational Behavior 8:* 53-l 11.

______ 1991. "Markets for bureaucratic authority and control: Information quality in professions and services." *Research in the Sociology of Organizations, 8: 157-190*

______ M. Brewer, A. Oliver and J. Liebeskind, 1992. "Basic science as intellectual capital in firms: Informational dilemmas in rDNA biotechnology research." Working paper, Institute for Social Science Research, University of California Los Angeles.