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THE IMPACT OF NETWORKING ON INNOVATIVE PERFORMANCE OF NEW BIOTECHNOLOGY FIRMS: A COMBINED ECONOMETRIC AND SCIENTOMETRIC ANALYSIS

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ABSTRACT

This paper examines the impact of firm resources and network capabilities on innovative performance in a population of 117 biotech companies. After controlling for the traditional size and scope effects, the managerial focus of the firms' R&D activities and their collaboration activities with external partners (in majority universities) become the central variables in our study. A (unbalanced) panel analysis of the firms over a twenty-year period shows the highly significant impact of research focus and networking activities on innovative performance.

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INTRODUCTION

For many new technology based firms, innovative productivity is directly related to their competitive position in the industry. Firms with a larger innovative output enhance their reputation and may hence be better able to compete for resources in the financial, scientific and corporate community. An extensive body of empirical research on the determinants of innovative output at the firm level exists in industrial economics (Cohen and Levin, 1988). In the wake of Schumpeter (1939), this stream of research has mainly focused on the question whether size influences innovative output. This research has shown that innovative output increases with size below a certain "threshold" (Cohen, Levin and Mowery, 1987; Scherer, 1980). In other words, companies should obtain a "critical mass" before they can innovate efficiently.

More recently, the resource-based theory of the firm (Dierickx and Cool, 1989; Wernerfelt, 1984) as well as the dynamic capabilities framework (Amit and Shoemaker, 1993; Teece and Pisano, 1994; Teece, Pisano and Shuen, 1994), have offered a new theoretical perspective on how companies develop competitive advantages. The former perspective emphasizes the competitive impact of accumulated stock of non-imitable or non-transferable resources; the latter points to the firm's capabilities to deploy these resources and develop new ones as sources of competitive advantage.

This paper starts from the resource-based and dynamic capability concepts to explain innovative performance of new technology firms in the U.S. biotech industry. The biotech industry offers a particularly interesting area to study these issues since innovative productivity is directly linked to economic returns for most biotech companies. Even in 1995, very few biotech companies created value through own product sales (Ernst & Young, 1995). Hence, instead of marketing or manufacturing capabilities, research competencies determine the competitive advantage of these dedicated biotech firms. A unique database was constructed which represents an unbalanced panel of US biotech firms that could be identified in biopharmaceutical research with more than fifty employees during the period 1982-1994. Data was collected from various sources such as ISI, U.S. Patent Office, BioScan, the NDA-pipeline, Compustat, 10-K reports, American Hospital and Healthcare Index, and Dibner's Guide to biotech companies.

HYPOTHETICAL FRAMEWORK

Following Henderson and Cockburn's research (1994), we measure the stock of knowledge in each of these firms as the cumulated number of patents and the cumulated number of research dollars invested, both net of depreciation. Innovative performance is measured as the number of filed US patents during each year of observation. Consistent with the literature on economies of scale in pharmaceutical research, the flow of knowledge is measured as the annual level of research expenditures (Jensen, 1987; Graves and Langowitz, 1993). Dynamic capabilities are elaborated in two ways. First, we look at how research is organized internally. First, we distinguish between companies that are focused or not. It has been argued in the R&D management literature that research focus enhances performance (Woiceshyn, 1995). Second, we distinguish between those firms that organize their research in a functional way and those that use a market-based approach (based on Allen's input- and output-orientation in R&D matrices, 1986).

Following previous work on knowledge spill-overs, we also include the location in the model by distinguishing between those companies that are located in the Route 128 Boston area or San Francisco Bay and those that are not (Saxenian, 1994).

In addition, we focus on the ability that research organizations have developed to collaborate (on research) with external partners (mainly universities and other biotech firms). This hypothesis is derived from the large literature which has focused on the emergence of research networks in biotechnology (della Valle and Gambardella, 1993; Freeman, 1991; Pisano, Shan and Teece, 1988; Powell and Brantley, 1992).

Industrial organization and innovative productivity. A first hypothesis is derived from the extensive body of literature on industrial economics which has concentrated on the relationship between innovation and size (e.g. Acs and Audretsch, 1990; Cohen and Levin, 1988; Kamien and Schwartz, 1982). Although inconclusive on Schumpeter's hypothesis, this stream of research converges on the idea that innovative productivity increases with size up to a certain threshold (Cohen et al., 1987; Graves and Langowitz, 1993; Scherer, 1965). Scherer (1980) concluded that the firms which foster innovation ideally should obtain a critical mass of about 250-400 million dollar (1978-dollars) in sales, a revenue range where most biotech companies only can dream of. Hence, we hypothesize that:

Hypothesis 1: Innovative productivity in new biotech firms is a positive function of firm size.

A second hypothesis, concerns the marginal productivity or elasticity of R&D expenditures (Hausman, Hall and Griliches, 1984; Henderson and Cockburn, 1995; Jensen, 1987). The main question of interest in these studies has been to determine the elasticity of patents with respect to R&D expenditures. Most studies find that there are economies of scale at the research level, though most probably at a decreasing rate.

Graves and Langowitz (1993: 603) find that the expected elasticity does not differ significantly from 1 for pharmaceutical firms that report an R&D expenditure which is minimum 25% below the mean. The average biotech R&D expenditures are well below Graves and Langowitz' average industry mean of 1443 million dollars (in constant 1994 $). Hence:

Hypothesis 2: After controlling for firm size, a positive influence of annual R&D expenditure on innovative productivity with an elasticity which does not differ from 1, is hypothesized.

The resource-based theory of the firm. The resource based tradition goes back to Penrose's analysis of firm growth (1959). Rumelt (1974) was an early adopter of her pioneering ideas and has implemented them in a theory of differentiation. Wernerfelt (1984) redirected the attention towards Penrose's original resource based explanation of firm growth. He added the imperfect working of markets as a critical element in explaining how resources generate competitive advantage. Resources are only valuable if they are difficult to trade or imitate on the spot market. Subsequent contributions have made a further distinction between "resources" and "capabilities" (Amit and Schoemaker, 1993; Foss and Eriksen, 1995; Henderson and Cockburn, 1994; Nelson, 1991; Teece, Pisano and Schuen, 1991). Resources are the "strategic assets" which companies have accumulated in the past while capabilities represent their ability to deploy and rebuild these resources.

We follow Amit and Schoemaker's definition of resources (1993) as "stocks of available factors owned or controlled by the firm". One factor of tremendous importance for a new technology based firm is its stock of knowledge. In many instances, a new technology based startup's only valuable asset is its knowledge stock. The value of knowledge in biotech and, more generally, in modern pharmaceutical research has been documented by many studies (Henderson and Cockburn, 1994 ; della Valle and Gamberdella, 1993). Hence hypothesis 3 is formulated as follows:

Hypothesis 3: After controlling for firm size and annual R&D expenditures, innovative productivity is hypothesized to be an increasing function of the knowledge that a company has accumulated.

However, it would be too optimistic to attribute all differences in innovative productivity to the stock of knowledge which has been built up in-house. The increasingly complex process of drug discovery has forced many organizations to enter collaborations with partners which have complementary research strengths or strategies (IMS Market Letter, 1992). Especially in the biotech industry, the emergence of research collaborations is prominent and well-documented (Arora and Gambardella, 1990; Barley et al., 1992; Debackere et al., 1996; Pisano et al., 1988; Powell et al., 1995). Though, organizations should learn how to deal with external partners and to develop "routines" which make them efficient participants in a research network. These learned patterns of inter-firm collaborations coincide with Nelson and Winter's (1982) evolutionary theory of organizational routines. Hence, hypothesis 4 is stated as follows:

Hypothesis 4: After controlling for firm size and annual R&D expenditure, innovative productivity is an increasing function of the routines the firm has developed to deal with external partners.

Dynamic capabilities in the management of knowledge stocks. Companies that are able to proceed more quickly in the identification and isolation of lead compounds are most likely to be winners in the biotech industry. Research in such new technology based companies is sometimes organized in a way to increase the speed of product development, regardless the risk factor involved (Christoffersen and Marr, 1995 ; Spilker, 1989). Literature that has focused on the management of drug discovery has described two extremes of organizational approaches: a discipline/technology versus a therapeutic organizational structure (Christoffersen and Marr, 1995:27). A discipline/technology-based organizational structure has been hypothesized to be useful if the discipline/technology is rapidly evolving (Allen, 1986). This organizational approach has been called input-oriented. A second "pure" form of organization is the therapeutic or output focused organization (Allen, 1986). In this type of organization, there is a clear focus on the therapeutic targets of interest. These therapeutic targets are likely to be accomplished through a variety of technologies. Large organizations try to balance both approaches through the matrix structure (Katz and Allen, 1985).

Case study research examining successful and less successful new technology based firms has identified "focus" as a critical success factor, regardless whether this focus is input- or output-oriented (Woiceshyn, 1995). Along these lines of thought, it seems questionable whether the consolidation or merger of different biotechnology firms is beneficial in terms of research productivity. Literature on mergers suggests an increased coordination costs to

direct research efforts off-setting many hypothesized benefits of such mergers (Folta and Leiblein, 1994). Especially if two firms are located in different geographical areas, it might be difficult to obtain the empowered team-spirit which characterizes most successful product development teams (Katz, 1993).

Based on these arguments, we hypothesize that:

Hypothesis 5: After controlling for firm size and annual research expenditure, companies of which the research efforts are focused around a particular technology or disease are more productive than those without focus.

Corollary 5: Given the life-cycle position of most biotechnological developments, input-oriented organization forms will be more productive than output-oriented forms.

Finally, we focus on the implicit or explicit choice which a company makes about its location. Both the economic and management literature has recently focused on the importance of knowledge spillovers in high technology industries (Griliches, 1991; Kenny, 1986; Saxenian, 1994). Jaffe et al. (1993) found that these spillovers are geographically localized. In his analysis of Vertex, Werth (1994) describes how the company founder, Boger, purposefully decided to locate his company in the Boston area close to Harvard, MIT and the Whitehead Institute. Hence:

Hypothesis 6: After controlling for firm size and annual research expenditure, companies located in regions subject to many knowledge spillovers will be more productive than those that are not.

RESEARCH SITE: THE BIOTECH INDUSTRY

We have restricted our study to a new biotechnology firms characterized as biopharmaceutical companies; consistent with the "Center for the Study of Drug Development at Tufts University," biopharmaceuticals are defined as "therapeutic protein drugs or imaging agents, derived either through recombinant DNA techniques (rDNA products) or through hybridoma technology (monoclonal antibodies, Mabs)."

Panel data were collected from 1971 onwards (the founding year of Cetus, generally considered to be the first new biotechnology start-up), using a wide variety of public and bibliographic data sources. Major data sources were: patent and publication data from the U.S. Patent Office and ISI respectively; BioScan (1985-1994); Dibner's Guide to Biotechnology (1988/1991/1993) and, finally, the NDA-pipeline for the period 1982-1994. In line with

previous industrial economics approaches (e.g. Scherer, 1980), the database was limited to companies with at least 50 employees in a given year. This criterion stems from the fact that data on companies with less than 50 employees tends to be highly unreliable and incomplete. The database used in the analyses reported below covers the period 1982-to-1994. It contains 642 observations, representing 118 firms.

Variables. The dependent variable is the number of patent applications filed at the U.S. Patent Office. The Industrial Organization variables are EMPLOYEE and RESEARCH. We use the number of employees as an indicator of size rather than their annual sales or revenue level (Jensen, 1987; Graves and Langowitz, 1993). There are two reasons which favor the use of employees in our case. First, it has been argued that the number of employees as a proxy for size regards size in terms of capacity, while annual sales measure the scale of current operations (Barron et al., 1994). Second, new technology based firms may obtain substantial amounts of funding from sources that are not included in the annual income statement. Therefore, the actual size of a company would be underestimated if the annual revenue level was used. The scale of the firm's research level is measured by its R&D-spending that year. We deflate this variable by using the PPI (Producer's Price Index) for proprietary pharmaceutical preparations.

In order to test the resource-based hypotheses, three variables were constructed. CUMPAT stands for the cumulative number of patents, net of depreciation. Whereas CUMPAT is a proxy for the stock of knowledge on the innovative output side, CUMRES stands for the stock of knowledge measured at the input level. Finally, REXP is a proxy for the organizational routines organizations have developed in dealing with external research partners, measured as the number of years a company has been involved in research collaborations, as we could re-construct them from the various bibliographic data sources used.

The variable COLLAB takes on the value of 1 in a given year when the company is involved in a collaboration agreement with another organization. The other dynamic capability variables are MARKET, TECH and MERGER. TECH and MARKET capture the functional (input-oriented) or therapeutic (output-oriented) form of research organization. Information from the NDA-pipeline was used to construct this variable. MERGER is a dummy variable to indicate whether the company is a merged one or not, hence pointing to the potential integration of research teams.

Finally, we define the location of the company. In the initial database, the exact location of each company is included. A dummy was constructed to indicate whether the company was located in the Boston area or in the San Francisco Bay area.

MODEL SPECIFICATION

Consistent with Henderson and Cockburn (1994&1995), we hypothesize that patents are generated by a production function $Y=f(X,b)$, where X is a vector of the drug discovery input variables and b is a vector of parameters.

As the dependent variable is a count measure (i.e., an integer truncated at 0), we model the probability that n patents will be filed by a certain company in a particular year. In line with other studies which have analyzed discrete variables as innovative output variables, we assume that the counts are generated by a Poisson process (Graves and Langowitz, 1993; Hausman et al., 1984; Henderson and Cockburn, 1994&1995; Jensen, 1987). The basic Poisson model for event count data can be described as:

$$\Pr(Y_{jt} = y_{jt}) = e^{-\lambda(x_{jt})} \left[\frac{\lambda(x_{jt})^{y_{jt}}}{y_{jt}!}\right]$$

To incorporate the explanatory variables, Lambda is made a function of the covariates, which generates equation:

$$E(Y_{jt}) = \lambda_{jt} = e^{\sum \beta X_{it}}$$

where b are the coefficients, X are the explanatory variables, i is the i^{th} variable, t is the t^{th} time period and j is the j^{th} company. The Poisson model holds the strong assumption that both the variance and the mean are equal. Because of these potential problems that arise when using the Poisson specification as the only model, we have analyzed the model's robustness by comparing the results obtained in the Poisson model with those in the Negative Binomial.

RESULTS

Table 1 shows the various models tested. Consistent with the Industrial Organization literature, we started with the size and research scale variables and a time trend. This time trend has been included in most of the previous (time series) studies on innovative productivity (e.g. Graves and Langowitz, 1993; Hausman et al., 1984; Henderson and Cockburn, 1994&1995; Jensen, 1987). We find an inverted U-shaped relationship for this time trend, indicating that innovative productivity has started to slow down.

The analyses suggest that there are high, though decreasing, returns to scale to be gained from an increase in absolute size of the company. As a general conclusion, we can state that hypothesis 1, relating size to innovative output, receives full support; with size explaining already 33% of the variance in innovative productivity. The elasticity of R&D expenditures, after controlling for size, is somewhat more difficult to interpret. Since this variable is rather strongly correlated with EMPLOYEE (r=0.76), the results should be treated with some caution. After controlling for firm size, only a small effect of annual research expenditures on innovative productivity remains. To compute the change in slopes, we further divided the sample in four parts, using age quartiles as a cut-off point: the 25% quartile is 4 years, the median age is 6 years and the 75% quartile is 9 years. Interestingly, the magnitude of the slope of LNDERES changed as follows over the subsequent intervals: 0.47 in the first interval, 0.11 in the second quartile, 0.02 in the third quartile and finally 0.01 for the oldest 25% of the companies. This significant drop in slope is surprisingly, at least.

There are a number of explanations which can be given for this observation. First, biotech companies may, early in their life-cycle, pursue patents as a research outcome; later on their R&D expenses turn towards the development of this patented knowledge in products. Second, new biotech companies often are able to attract researchers which bring along "ready-to-patent" knowledge. Third, there may be decreasing marginal returns to patent productivity.

Our findings further confirm the hypothesis that both resource-based explanations and dynamic capabilities play an important role in explaining differences in innovative productivity.

As shown in the models, the cumulative number of research dollars invested (net of depreciation) has some effect on innovative productivity; while the cumulative number of patents does significantly affect innovative productivity, after controlling for the IO-variables. Additional analyses suggest that biotech firms, after controlling for increases in firms size, are very much dependent upon the "quality"of the people whom they hire (which is reflected in the stock of knowledge measured on the output side, but not on the input side). Researchers, who already have a name in the field or are very close to patenting, significantly increase the productivity of those firms.

We further analyze whether the routines the organization has developed to deal with external partners contribute to its research productivity. From the analyses, we can conclude that the routines developed to collaborate with external partners significantly contribute to the innovative productivity of an organization, regardless its size.

Finally, we investigate the hypotheses that dynamic capabilities, or the abilities a firm has to organize its research activities at a certain period in time, influence its innovative productivity. Hypothesis 5 receives full support, indicating that integration of the research activities is a very important explanation of differences in innovative output. Both the MARKET and TECH variables are significantly different from 0, which indicates that having a focus is always better than having no focus (although in 50% of the observations, no focus is available). In order to further test hypothesis 5, we perform a test on the linear combination of the coefficients of TECH and MARKET. As expected, the combination of coefficients was different from 0 at the $p<0.01$.

Taken at face value, the most important variable seems to be TECH, which captures the organization of research activities around one particular technology. The slope of this variable is 0.705, in comparison to 0.368 for the MARKET variable. A t-test on the slope coefficients supported this speculation.

Further elaborating on hypothesis 5, merged companies are significantly less productive than the not-merged ones. Again, this result supports hypothesis 5, stating that research integration is an important factor to foster research productivity. The literature on mergers mostly mentions the high coordination costs which accompany these transactions. Especially in a research environment, where know-how is intangible, mergers may not work very well.

Finally, the LOCATION of the company was entered as a separate variable in the model. Although this is a very rude proxy to capture spillovers, the coefficient was (surprisingly) not significant.

Finally, we explored how sensitive the results are to the Poisson assumption. The results using a Negative Binomial approach were highly comparable to the Poisson model, thus confirming the robustness of the previous findings.

CONCLUSION

After controlling for the traditional Industrial Organization hypotheses, we showed how hypotheses derived from the resource-based theory of the firm and the dynamic capability framework can explain innovative performance. More specific, external collaborations are found to be very important to increase innovative productivity. In this case, there are strong returns to learning. Although about one fourth of our sample is currently involved in a kind of formal research agreement, not all of them have sufficiently developed the organizational structures to successfully exploit these arrangements. The findings on external collaboration

show how organizations should develop certain routines or build up certain resources before they can fully exploit the dynamic capabilities.

Consistent with qualitative research, we find that having a R&D focus is extremely important in reaching an optimal level of innovative productivity. In this stage of the biotech life-cycle, a technology focus still seems more important than a market focus.

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TABLE 1

Results of Poisson Regressions on Patent Productivity

Variables	(1)	(2)	(3)
Intercept	-6.247**	-7.511**	-8.33**
Log(Employees)	0.613**	0.077**	0.324**
Log(Research $)	0.042*	0.085	0.095
CUMPAT		0.004**	0.012**
Log(CumRes $)		-0.029	0.100*
REXP			0.095**
MARKET			0.313**
TECH			0.637**
MERGER			-1.11**
COLLAB			-0.226
LOCATION			0.076
TIME	0.871**	0.705**	1.263**
TIME*TIME	-0.0458**	-0.039**	-0.068**
R^2	0.33	0.36	0.44

*: $p<0.05$ -- **: $p<0.01$ // 117 new biotechnology firms // period of observation: 1982-1994.

Applying a Negative Binomial leads to robust results.