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# Connectivity and Performance of Science-based Firms

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ABSTRACT. This paper addresses whether or not there is a relationship between a young science-based firm's patterns of connections and the associated resource flows, and its performance. Hypotheses derived from the literature are tested in relation to three performance indicators: inventiveness, innovativeness and employment. Analyzing a set of firms in Sweden, Ohio and Massachusetts, working with biocompatible materials and related products, the results indicate that firm performance is significantly influenced by the firms' pattern of connectivity. In particular, technology-related connections proved important, where a high diversity in types of sources for technological input, a large number of technological relations and a high amount of technology transfer from the parent organization were related to better performance for this specific group of firms.

## 1. Introduction

The new type of knowledge-based economy that is under evolution, stresses organizations', regions' and nations' ability to create, utilize and diffuse knowledge. In particular, scientific knowledge has amplified its importance for innovation and industrial renewal, and there is an increased appreciation – among academics and firms as well as policy makers – that science and technology are intimately intertwined. In this type of complex innovation processes, *science-based firms* play a significant role, capturing the promises of scientific knowledge, realizing the industrial potential and reaping some of the economic returns.

Such science-based firms evolve and innovate in an interactive course of action with technologies, artefacts, institutions and with other players – research organizations, customers, users, competitors, partners, financiers, etc. (Liebeskind et al., 1996; Orsenigo et al., 2001). Indeed, science-based firms are organizations for which connectivity to other actors and the associated resource flows and learning are crucial for performing their business operations. These connections entail flows of information and knowledge about science, technology, markets, management, institutions, etc., but also, for example, physical resources, financing or intellectual property (Baptista and Swann, 1996, Cooke, 1996).

Certainly, exploiting internal resource and knowledge assets and flows, and tapping into external ones, are crucial capabilities to innovate and grow, supplying the firm with a range of resources and lessons. Such networks of weak as well as strong ties gives access to a wide array of resources, enlarge the opportunity set, secure legitimacy, and reduce risk (Elfring and Hulsink, 2003). Studies within research trajectories such as industrial networks, social networks, firm strategy, and regional clustering, all witness about the importance of appreciating patterns of connections in order to understand innovation and firm development. Indeed, as DeBresson and Amesse (1991, p. 35) have it "The network approach enables us to incorporate … Schumpeterian dynamics, transaction cost analysis… supplier – user linkages…interactive learning … the creation and shaping of markets and organization."

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Importantly, a firm's connections may not only promote its possibilities for innovative activities and success but sometimes also restrict the course of development, by mechanisms of different strategic agendas, information asymmetries, entry barriers, or skewed power relations (see e.g. Lawton-Smith et al., 1991; Saxenian, 1991). Also, even a well-functioning set of connections is likely to contain a significant level of inertia and path-dependency, and the actors may have "… locked their positions, for example as regards the technical solutions to different problems. Instead of trying to break existing system interdependencies, they ignore new opportunities and concentrate on those activities which enforce the existing structure." (Lundgren and Nordenlöw, 1995, p. 174). Thus, a specific set of ties may lock the firm into a disadvantageous path by acting as a "blocking mechanism" to, for example, emerging technologies, products or market opportunities (Glasmeier, 1991).

Evidently, a firm's connectivity, i.e. the firm's patterns of connections over time and the resource and knowledge flows these entail, has a bearing on its innovative activity and development – both in a positive and negative sense – and thereby potentially also on its performance. In accordance, several studies have reported on this importance of a high connectivity (Brüderl and Preisendorfer, 1998; Donckels and Lambert, 1995; Wynarczyk and Watson, 2005). Some examples are that Mitchell and Singh (1996) show that partnering influences the aptitude for survival, Powell et al. (1996) state that the number of collaborations have an effect on growth rates, and Segers (1993) finds that strategic technology partnerships positively influence the growth of new technology-based firms in biotechnology and microelectronics sectors.

Taking this set of literature as a starting point, this paper sets out to further scrutinize the nature and strength of this proposed relation between *firm connectivity* and *performance*. A set of hypotheses will be tested quantitatively on a sample of young science-based firms developing biocompatible materials and related products. We will next continue with an introduction to the challenges facing young bioscience firms, and in particular those within the field of biocompatible materials. Section 3 presents the propositions, while the research model and the empirical data set are laid out in Section 4. The concept of firm performance is operationalized in Section 5, specifying the three indicators used in this study. Then follows the quantitative analysis (Section 6), leading to a discussion of the findings in the final section.

## 2. Challenges for young bioscience firms

Clearly, the issue of firm development and growth has concerned researchers within several disciplines, where studies within the field of economics have contributed to our understanding of aggregated survival and growth patterns, and have – along with research on economics of innovation, strategy, management, organizational issues and entrepreneurship – discussed which factors that help firms to achieve growth. While strong results on factors affecting firm growth have been presented, there is a variance in findings, partly explained by the cross-sectional character of many studies and by methodological differences. Taking this into account, our study dwells on firms within a specific technological field, acknowledging the technology and industry specific nature of innovation processes and firm development.

Thus, empirically the focus rests on a sub-set of science-based firms in the biotech/biomedical sphere, namely those that generate and diffuse products based on *biocompatible materials*, i.e. synthetic or natural materials which are used to treat, enhance or replace human functions. This includes the sub-technologies osseointegration using the material titanium; silicon and other related materials to be used, for example, for orthopedic, dental, hearing and cardiovascular implants; biopolymers, both biodegradable and bioresorbable ones to be used in implants and wound care; as well as the technologies of tissue engineering employing biologic materials to be used in tissue healing and regeneration.

Noticeably, the area of biocompatible materials is an emerging, globally defined, scientific and technological field, with extensive experimenting, and large technological and commercial opportunities. Being science-based, the innovation process is typically long term, with an unclear regulatory domain and therefore costly. The set of technologies of biocompatible materials relate to and transform a number of industries. First, biomaterials products come into the fairly mature industries of devices and medical implants, adding new products as well as new development concepts in orthopedics (e.g. knee repair, artificial joints, hip replacements), dental, or cardiovascular application areas. Second, in the pharmaceutical industry biomaterials are used in products such as drug delivery or surgical procedures for wound care, adhesion and surgical sealants. Third, a range of tissue engineering products and bio-artificial organs are under development, but still only few products have made it to the market. With rather few industrial players so far, tissue engineering firms suffer from an extremely uncertain innovation process, with long time periods in the lab, regulatory vacuum or large uncertainty, a hesitant market, and the need for patient financing. This means that in spite of that the firms analyzed in this study have been active for a number of years, some do not as yet have a product on the market.

Acknowledging that the underlying technological regime influences the character and dynamics of innovation processes (Breschi and Malerba, 1995; Pammolli and Riccaboni, 2002), the features of the regime of biocompatible materials – the high density and many sources of technological opportunities, their pervasiveness, moderate appropriability and low cumulativeness at the firm level – make for a system that favors *extensive innovative activity* and *high entry of firms*. Indeed, the density of technological opportunities – generated by a variety of sources: university researchers, customers (such as medical doctors), incumbent companies, suppliers and new firms – is high. Many biomaterials technologies are pervasive in character, and, as we have seen, fit in a range of applications, and as several are in early phases of development and there is still competition between technological solutions. Even though it is common to patent, scientific results are also diffused through publications and conferences and therefore inventions may not always be easy to protect and, thus, the level of appropriability is moderate. This means that it is important for firms to continuously innovate and build connections to actors with strong resource bases.

Importantly, characteristics of the specific regime of biomaterials also suggest that innovative activity has a tendency to *concentrate in certain locations* in order for actors to be able to reap benefits from spillovers. To be sure, even though the knowledge-base of biomaterials has codifiable and patentable features that are transferable in the form of license agreements, it also has strong tacit features that are not easily conveyed between actors, thereby stressing spatial concentration. Also, being dependent on capital and labor markets as well as producers of scientific knowledge (universities, incumbent companies as well as new entrants) which are not evenly distributed geographically, this enhances the spatial knowledge and actor accumulation.

## 3. Formulating the hypotheses

Scientific knowledge is often not only the starting point for innovation, but part of an iterative course of action where development of technology and applications go hand in hand, and where a multitude of technological and market opportunities emerge on a global arena, and where competition is fierce and resource intensive and R&D costs are ever increasing. Thereby, science-based firms need to connect to an array of actors to get access to resources and continuously learn. Undoubtedly, such a process of external resource mobilization is an experimental route where the resource transfer, learning or enhanced innovation process hoped for is not always reached, but instead many experiments fail, some give unexpected results and benefits and take the firm on unanticipated paths.

In this, there is a growing number of studies showing how external resource acquisition is beneficial for the firm and how it can be managed. While several relating concepts are used – networks, connections, ties, web of interactions, links, partnerships, alliances, inter-organizational co-operation, seamless web, resource mobilization, etc. – in many instances (but certainly not all) the studies correspond to or are dealing with a similar phenomenon as what we here term *connectivity*, i.e. the firm's patterns of connections over time and the resource and knowledge flows they entail. Several of these studies claim that connections are crucial for a number of aspects of the firm: its knowledge and resource base, its legitimization, its innovative capacity, its economic performance (see e.g. Hagedoorn and Schakenraad, 1994; Havnes and Senneseth, 2001; Mitchell and Singh, 1996; Powell and Smith-Doerr, 1994; Powell et al, 1996; Shan et al, 1994; Yli-Renko and Autio, 1998). Building on this body of literature, the overall proposition in this paper is that there, indeed, is a relation between the connectivity of a science-based firm and its performance, but that this needs to be further scrutinized in order to understand exactly what this relation entails.

As defined here, the concept of connectivity involves four dimensions that specify in detail the type of connection and the resource flow it entails. First, the *type* of connectivity entails the *purpose* of the relationship (e.g. offensive/defensive, transfer of goods/resource acquisition/problem solving), the character of the *partner* (e.g. organization/individual, position in the value-chain, resource profile, geographical location, power structure between partners) as well as the *form* of the exchange (formal/informal, type of agreement). The second dimension, *density,* denotes the *size* of the firm's network, (the number of specific partners), the *diversity* of connections (the number of different types of partners), as well as the *intensity* of connectivity (the number of contacts in a given time period or the time span of relationships). A third dimension is the *degree of flow* of resources that come about through a connection, where one may analyze the flow of each *type of resource*, or the flow to or from each *type of partner*. Inherent in this dimension is that an organization needs to have not only access to resources, but also the capability for evaluating, developing, adapting and exploiting a specific resource transferred. We call this the firm's *receiver capability* (Carlsson and Stankiewicz, 1991), a concept closely related to that of absorptive capacity (Amendola and Bruno, 1990; Cohen and Levinthal, 1990). Forth, the *dynamics* of connectivity involves how connections between different actors come about, are sustained, change over time and come to an end.

Based on these four dimensions of connectivity (type, density, degree of flow and dynamics) a set of hypotheses were formulated and tested in this study. More specifically the focus is set on the type of partner to which the science-based firm connects (Hypotheses A–D), the density of technology-related connections (Hypotheses E, F), and the degree of flow (Hypotheses G–I).

### 3.1. *The type of connectivity: Character of partners*

The characteristics of a partner organization have a bearing on the nature and quality of the resources transferred through the connection: as "alliances are… access relationships" the attributes of the partnering organizations may be crucial for the outcome of collaborations (Stuart, 2000, p. 792). Therefore, as an important subset of its techno-economic competence, that is, its "ability to identify, expand and exploit the opportunity set" (Carlsson and Eliasson, 1995, p. 65), the firm needs to have a selective capability in terms of choosing sources and partners for resources (including, e.g., financing, technological artifacts, knowledge or skilled people).

This study addresses four aspects of how the type of partner may influence performance. First, there is a question about the global or local character of the partners. Clearly, science, technology and technology-based products and services develop in a global arena, and such ties are of crucial relevance (Donckels and Lambert, 1995). On the other hand, and even strengthened by the trends of globalization, there is clear evidence that networks – and in particular technology-related ties – often are spatially skewed. This is due to, for example, tacitness of knowledge, trust relations, clustering of resources such as pooled labor markets, institutional peculiarities or path dependency of networks (Acs, 1996; Almeida and Kogut, 1999; Audretsch and Feldman, 1996; Markusen, 1996). It may even be so that some types of firms increase their relative local or regional connectivity over time (Schutjens and Stam, 2003). In our study of the field of biomaterials, the technological knowledge base has a tacit component, stressing the importance of connections in geographical proximity to the firm. Taken together, one may suspect that the firm needs to be connected not *only* to technology suppliers and partners within relatively close geographical range, but also to the global technology development processes. Therefore, this study proposes that firms that manage to have both types of technological relations ought to be more successful: *Firms that have local as well as national and foreign technology-related connections perform better* (Hypothesis A).

Second, one type of partner assumed to be of particular importance is the parent organization – be it, e.g., a university, a research institute, a military unit, a large, incumbent company or a small, young firm. Perceivably, the type of parent organization matters, giving access to different volume and character of initial resources. No doubt, the initial resources with which firms set out their operations – be it ideas, intellectual property, financial resources, contracts, people, etc. – vary greatly. Where some firms may begin with nothing but an idea and a team of skilled people, others are richly endowed in their start-up phases,[1] embarking with, e.g., a patented technology, secured financing or an agreement with an incumbent company. Such differences in initial resources are here perceived to influence the development of the firm, and with time even have an impact on performance. Specifically, research has shown that a corporate parent enhances success rates, as compared to a university parent (Lindholm, 1994), which may partly depend on a broader initial resource and knowledge base in corporate spin-offs (Grandi and Grimaldi, 2003). In line with this we propose that *firms that have a corporate parent (i.e. are corporate spin-offs) perform better than those that stem from a university setting (i.e. are university spin-offs)* (Hypothesis B).

Third, there are quandaries if the size and age of a partner matter. Here we will focus only on the role of one particular type of firm, the incumbent company, as this is perceived to be a particularly important partner for the set of firms analyzed. Indeed, as Stuart (2000, p. 808) points out, for many young science-based firms "both from a resource access and reputation standpoint, large and innovative firms are likely to be the most valuable associates". In particular, with respect to management and market-based resources, several studies point to the disadvantage of small or young firms (e.g. Rothwell, 1991; Teece, 1986) and, not least in the field of biomedicine and biotech, these are areas where incumbent companies often have an advantage as regards extensive distribution arrangements, market goodwill and management experience. There is thus a possibility of significant gain for the young firm in collaborating with established (often larger) companies on these issues, where for example dedicated biotechnology firms often have extensive agreements with large pharmaceutical firms (Pisano, 1991; Powell et al., 1996).

In particular, in relation to market knowledge and market-related resources it is important to state that markets are formed in a process that is endogenous to the technological field, and to the firm and its network (Fligstein, 2001). Indeed, the understanding of what market that can be created, and how this shaping may come about, is "historically constructed by the interaction among economic actors' strategies" (Glimstedt et al., 2005, p. 8) and the underlying institutions. In this, for young bioscience firms the larger incumbent firms play a very important role (McKelvey, 1997; McKelvey et al., 2004; Orsenigo, 1989; Orsenigo et al., 2001). Based on this reasoning we hypothesize that *firms that have connections with well-established companies for acquiring market-based resources perform better* (Hypothesis C).

Fourth, being in need of patient and often large scale monetary resources, the type of financier may be of importance. While Roberts (1991) found that the source of financing carried less importance, other studies have suggested that financing from a venture capital company is preferable and that it may have an impact on performance depending on the top management team and the type of VC coaching (e.g., Baum and Silverman, 2003; Florin, 2005). Our hypothesis is formulated as: *Firms that source financing from a venture capital company partner perform better* (Hypothesis D).

### 3.2. *Density of technological connectivity*

Even though the total number of general collaborations a firm has (over time or at any specific moment in time) seems to be an insufficient indicator to account for differences in performance, we have reasons to believe that the density of *technology-related* partnerships – i.e. those connections that provide the firm with scientific and technological input – are of importance to science-based firms. Undeniably, given the focus on science, technology and application development, such firms need an array of ties to deal with technological uncertainties and multi-technological system features (Baba and Imai, 1993; Liebeskind et al., 1996; Orsenigo et al., 2001). Hence, our hypothesis is that *firms that have many external relationships through which it acquires technological knowledge and resources perform better* (Hypothesis E).

Moreover, science and technology are developed not only inside the firm but within various types of organizations. Indeed, S&T development takes place at the interface with customers, suppliers, competitors, research organizations, and even venture capitalists. Such development may mirror partly different approaches and paths, and in order for the young firm to not lose out on the multiplicity of creative solutions there are for resolving technological and application oriented uncertainties, it ought to be relevant to obtain technology from a diversity of sources. Thus, in addition to the absolute number of technology-related connections as discussed above, we hypothesize that *firms acquiring technology through connections with several different types of organizations perform better* because of an increased diversity in the technological input (Hypothesis F).

### 3.3. *Degree of flow*

In this study we formulate three hypotheses regarding the degree of flow. First, with regard to the firm's initial technology acquisition, Roberts (1991) states in his research on high-technology entrepreneurial firms that the degree of initial transfer from a parent organization is an important contributor to success, and this is verified in several subsequent studies (e.g. Doutriaux, 1992; Feeser and Willard, 1989; Sapienza et al., 2004). We therefore hypothesize that *firms with a high degree of flow of technology-related resources from a parent organization perform better than other firms* (Hypothesis G).

Second, for resource mobilization to be successful the firm needs to have the ability to seize the resource or piece of knowledge, transform and use it within the organization for the benefit of innovation and firm development, i.e. the firm needs to have absorptive capacity or receiver capability as discussed above. In this vein there are two hypotheses on the relation between receiver capability and firm success, where the receiver capability is operationalized by – or approximated by – the founders' experience. Surely, in the case of biomaterials firms, high receiver capability could be assured by founders (and employees) with scientific and technological knowledge, with experience in the particular industry or in other industries with similar characteristics, as well as with experience from firm formation, management and marketing. Previous research supports this proposition, where, for example, Roberts (1991) showed that new firms started by a larger founding team had significantly better firm performance, presumably due to the broader experience in science, technology, management and marketing that a larger team would have as opposed to that of a single founder (see also Almus and Nerlinger, 1999; Eisenhardt and Schoonhoven, 1990; Storey, 1994). Moreover, Utterback and Reitberger (1982) found a correlation between management competencies of the founders and growth of the firm. Accordingly, we hypothesize that *firms that have more than one founder (i.e. a founding team) perform better* (Hypothesis H), and that *firms that have a founding team with experience from research activities as well as from industrial operations perform better* (Hypothesis I).

## 4. Research Design

### 4.1. *Research model and variables*

The research design of this study involves a statistical analysis of whether or not the hypothesized explanatory variables influence the performance of a set of science-based firms, and we solve the equation: $P = f\ (x_1, x_2, x_3, \ldots, x_n)$, where P denotes firm performance, and $xi$ are the explanatory variables (including control variables). The drivers of success are analyzed using linear regression, and for this analysis a linear model of type: $\beta_1 v_1 + \ldots + \beta_{11} v_{11} + \varepsilon$, is assumed where ε is supposed to be random and normally distributed. Based on the hypotheses posed, the general model is as follows: Success = $f$ (CSO, PARENT, GEOG, LTBF, VC, NRTECH, DIV, TEAM, EXP, AGE, REG, APPL). The regression analyses were performed by three complementary methods in order to get stable models.[2] The hypotheses presented above are seen as independent, and the study draws conclusions for only one hypothesis at a time. The resulting variables in Table I are assumed to contribute to the explanation of a high value in one or several of the three performance indicators. To get a better understanding of the data, we used a Spearman's correlation to test whether there was any correlation between the explanatory variables. While the variables were correlated, it was not to the extent that the variable set could be reduced.

Adding control variables, our analysis asks: given that the control variables *age* of firm, *location*, and *application* make a difference, what else matters for success? The first control variable, the age of the firm (see Table I), was added to our models of what drives inventiveness and innovativeness (see below), where we can expect that the older a firm is the better it will perform. The second variable is the firm's choice of location. The evidence for whether or not location matters for firm success is inconclusive, and varies depending on the success measure chosen, as well as for different populations (e.g. Enright, 1994; Popkin et al., 1991). In this paper, location is included as a control variable in all models tested, and acknowledging its history of successful firm establishment and growth (as compared to the other two regions) we expect Massachusetts to be the most favorable region to be located in. Finally, given that different applications have different market potential, we perceive it to be important which focus the firm has, and the type of application is taken into consideration as a control variable. The population was divided into three groups, where group I includes applications related to bio-artificial organs (such as liver, kidney, pancreas, skin, blood) and tissue engineering, matrixes and cell growth (such as tissue, bone and cartilage healing, protection and regeneration, surgical sealant and wound care). Group II includes applications based on biopolymers (e.g., various types of soft-tissue implants, wound dressing), drug delivery applications, cardiac assist systems and vascular grafts. Finally, group III relates to hard-tissue implants for dental or orthopedic use (based on osseointegration and other technologies), biocompatible surfaces, coating, and micro-texturing.

TABLE I
Explanatory variables and control variables

| Hypothesis | Name | Explanatory variables | Coding | Type |
|---|---|---|---|---|
| A | GEOG | Regional as well as national and foreign technology-related connections | Yes/no | Binary |
| B | CSO | Corporate spin-off company as opposed to a university spin-off company | Yes/no | Binary |
| C | LTBF | Connections to larger, established firms to acquire market-based competencies | Yes/no | Binary |
| D | VC | Financing from a venture capital company | Yes/no | Binary |
| E | NRTECH | Number of specific external relations through which the firm acquires technological competencies | Number of technological relations | Cont. |
| F | DIV | Diversity in types of external relations through which the firm acquires technological competencies | Number of types | Cont. |
| G | PARENT | Amount of technology transfer from the parent organization | None, low, medium, high | Category |
| H | TEAM | More than one founder (i.e. a founding team) | Number of founders | Discrete |
| I | EXP | Founding team with experience from research and industry | Yes/no | Binary |
| Control variables | | | | |
| Age of firm | AGE | Number of years | | Discrete |
| Location | REG | Massachusetts (M), Ohio (O), Sweden (S) | | Category |
| Application | APP | I, II, III | | Category |

### 4.2. *Data collection*

So as to capture the richness of connectivity as specified in the hypotheses above, this involves extensive qualitative data collection through interviews complemented with ample secondary data sources. While a substantial number of cases was deemed necessary for the comparison, data also had to be detailed and longitudinal in character, resulting in an analysis of a set 73 of science-based firms within the field of biocompatible materials, and located in Sweden, Ohio, and Massachusetts, respectively.[3] These three regions all have a strong scientific base in biomaterials-related fields, and one could expect a considerable number of firms to have been established. The aim has been to identify all such firms established within the period 1975–1998 – whether independently started or spin-outs from universities or companies – in any of the three regions. Thus, the paper deals with a population of firms – as given for these three regions – rather than a sample. Notably, while several of the firms have been in operations for quite a few years, they are still considered fairly young as it takes a long time to reach the market and to move into a growth phase.[4]

The firms were identified in a triangulated approach by matching all firms with product profiles potentially involving biomaterials, with their competence based as mirrored in the patent profile and supplementing with comments from technology and industry experts. As regards data collection, the firm's connections to all types of actors (VCCs, companies, customers, universities, other organizations, and so forth) were traced over time for several development projects within each company, and each connection was characterized, and the type and extent of flow of resources and knowledge were assessed. We included both informal and formal connections in one-directional flows, customer–supplier relations, agreements on technology exchange, joint development of R&D or market as well as direct investment.

In order to build a solid data material five different sources of information were used about the firms and their patterns of connectivity: (a) extensive written company information and external company and industry analysis, (b) all the firms were interviewed,[5] (c) the majority of the inventors of the firms initial technology were interviewed, (d) some of the firms' partners were interviewed, and (e) a directory provided by Recombinant Capital Inc., containing all American biotechnology firms' formal alliances, gave us the possibility to verify and sometimes complement the data on connections for biotech related firms. As regards data analysis, data was codified to be able to perform both quantitative and qualitative analyses.

## 5. Indicators of firm performance

It is clear that the choice of performance indicators on the firm level partly depends on the maturity of the firms, technologies or industries, and partly on the aim with the study and on which interest group that is addressed. One can perceive to analyze interim indicators of success – inventiveness, innovativeness, etc. – to cope with early stages of firm development or fluid industry phases, or to make direct linkages between patterns of connectivity and accomplishment on the market in terms of size of labor force, sales, market share, etc., in absolute levels or in growth terms.

In our case, the biomaterials technologies – as well as several of the corresponding industries – are immature, and there are uncertainties regarding technological and application choices as well as market response. What's more, some firms have not yet reached their growth phase, and may not even have products for sale on the market. Accordingly, sales or sales growth cannot be used as sole indicators, even though these are some of the most common measures of economic performance. Instead we will have to find indicators that can assess performance in earlier phases of firm and industry development. Hence, in this study, we chose to not rely on any single measurement to describe performance, but instead a combination of indicators was used that, from different perspectives, reflect how well the firm has succeeded. Based on previous studies of firm performance, the following three performance indicators are chosen, each of which will be discussed below: (a) inventiveness, (b) innovativeness, and (c) growth in terms of number of employees.

First, the firm's ability to incorporate new knowledge – to learn – or more specifically to generate inventions (inventiveness), may be approximated by the number of patents a particular firm has issued, related to the age of the firm. Pavitt and Patel (1988) discuss merits and shortcomings in the use of patents as an indicator, and it is clear that in this science-based field firms have a high propensity to patent and the indicator is thus useful. The database on U.S. patents was selected as the primary source of information.[6] Interestingly, while the population of biomaterials firms had a mean value of 1.08 patents per firm and year, the variation spans from no patents at all to the highest-performing firm's average of 6 patents issued every year of its life span.[7]

The second performance indicator is that of innovativeness, which seem to go hand in hand with intense networking (De Propris, 2000; Rogers, 2004; Rothwell, 1991; Tether, 2002). Inherently, innovativeness is a measure of how well the company has succeeded in their development process, acknowledging that they struggle with a lengthy period of technology and product development in tandem with clinical trials before regulatory approval is granted and a product can reach the market. Innovativeness was assessed by the number of products the firm has developed and either introduced on the market or for which they have an agreement with another company for co-development and distribution.[8] Data on the number of products, their development stage and collaborative agreements were given in interviews and by written company material. Innovativeness, as indicated by the mean number of products per year, was 0.30, with a standard deviation of 0.39. While some firms had not developed any products that had reached the market or resulted in distribution licenses, the maximum value was 2.4 products developed per year.

As a proxy for growth our third indicator is that of *the size of the stock of employees as related to the age of the firm*. Employment growth has been associated with connectivity in a number of studies of, for example, Canadian biotech firms (Niosi, 2000) or small and medium-sized firms' collaborations with suppliers (Robson and Bennett, 2000). In our case, because the firms analyzed deal with medical technologies and pharmaceuticals, the products need to go through clinical trials to gain regulatory acceptance which is a long-term process, postponing sales. However, the number of employees may have grown considerably before growth in sales takes off, for example, because the trial process itself often requires production. Therefore, the growth in number of employees reflects that economic activity is taking place and that there are possibilities for sales, but sales may not yet have taken place (or may be small).

Growth is uncontroversial as a performance measure when given in economic indicators such as sales, but for the number of employees, there are some specific characteristics, in particular in relation to the biomaterials field. Indeed, a firm with a small number of employees may still be considered successful for that stage of development. The division of labor is extensive in the biomedical and biotech sectors with many companies outsourcing activities and where manufacturers of medical devices often purchase R&D or components. Therefore, in the extreme case, new innovative firms, especially, can function as virtual organizations, with few employees but with an extensive network organization, and the magnitude of activity can be much greater than employment figures imply. In consequence, the number of employees alone does not reflect the magnitude of activity in the firms, but it is useful in combination with other measurements. For this set of firms it was found that while there were instances of no growth in the number of employees, the largest – and most successful firm in this respect this respect – had grown by 189 employees per year.[9]

## 6. The relation between connectivity and success

As will be presented in this section, the regression analyses gave support for several of the hypotheses posed, while other results were unexpected and require further research. Our first performance indicator, inventiveness, was found to be positively impacted by two dimensions of connectivity, both of which concern the firm's technological connectivity. The regression for this model resulted in an acceptable model fit with an $R^2$ of 0.566 (see Table II), and the resulting

TABLE II
The regression model for inventiveness

| Model | Unstand. Coeff. B | Std. Error | Stand. Coeff. Beta | T | Sig. |
|---|---|---|---|---|---|
| Constant | 0.601 | 0.380 | | 1.579 | 0.121 |
| NRTECHHigh | 0.913 | 0.368 | 0.287 | 2.480 | 0.017 |
| DIV | 0.300 | 0.084 | 0.421 | 3.553 | 0.001 |
| VC | −0.599 | 0.291 | −0.222 | −2.062 | 0.045 |
| REGM | 1.173 | 0.303 | 0.438 | 3.873 | 0.000 |
| APP I | −0.895 | 0.417 | −0.337 | −2.149 | 0.037 |
| APP II | −1.470 | 0.405 | −0.507 | −3.632 | 0.001 |

model is: Inventiveness = *f* (NRTECH high, DIV, -VC, REG Massachusetts, Application III).

This means, first, that a high *density of technology connectivity* (NRTECH) has an impact on the inventiveness of the biomaterials firms. Second, a *high diversity* of types of technological sources (DIV) comes out as influential. However, a surprising result is that firms with financing from a venture capital company have lower inventiveness. It is not clear in this case what is cause and what is effect, but the results can be interpreted in at least three different ways as suggested by interviews. Either venture capital financing affects inventiveness negatively, possibly implying that venture capitalists stress other strategic options than a focus on science and technology development. Other interpretations are that the result may indicate that VCCs invest in less inventive companies, or that firms with venture capital financing have a higher tendency to source inventions externally. Clearly this issue needs further analysis in future studies.

With regard to the control variables, both the location and the choice of application were related to inventiveness. First, being located in Massachusetts (REGM) is associated with high inventiveness, which was an expected result. Second, the firms working with applications included in group III have a higher tendency to be inventive (as measured by patents) than the firms working with other applications (APPI and APPII). In global terms, fields I and II are more patent intensive than field III. Therefore, some explanation is required for the result that biomaterials firms with the highest performance in inventiveness are focused in application group III. Our interpretation is that the technologies underlying applications I and II are science based as well as immature, and therefore to a large extent developed in research organizations rather than within company settings. Therefore, the finding may indicate that the firms that focus on applications I and II source a larger share of their technology externally. As a result, the firms have a lower amount of patents in house, and a lower score with respect to inventiveness.

Our next performance indicator is that of innovativeness and the regression for this model resulted in a model fit with an $R^2$ of 0.437 (see Table III) and the model can now be written as: *Innovativeness = f (DIV, LTBF)* meaning that innovativeness is positively related to two dimensions of connectivity. First, a high diversity of types of technological sources (DIV) is related to high performance. Thus, the number of types of partners – the diversity – influences not only

TABLE III
The regression model for innovativeness

| Model | Unstand. Coeff. B | Std. Error | Stand. Coeff. Beta | T | Sig. |
|---|---|---|---|---|---|
| Constant | −0.039 | 0.087 | | −0.453 | 0.653 |
| LTBF | 0.248 | 0.088 | 0.325 | 2.820 | 0.007 |
| DIV | 0.084 | 0.021 | 0.468 | 4.052 | 0.000 |

invention or technological development (see above) but also the process of turning this development into products (innovation). Apparently, the young firm needs to get technology-related insight from a range of different types of actors in order to develop a product that reaches the market. Second, in line with our hypothesis, firms that have connections with well-established companies for acquiring market-based resources (LTBF) perform better. This finding simply reflects the fact that connections to related companies increase the possibility of setting up formal distribution agreements. It is interesting to note that no relationship was found between success and the background of the firm with regard to the type of parent organization or the degree of initial technology transfer, and nor did the composition of the founding team matter. Perhaps most noteworthy, being financed by venture capital had no positive impact on innovativeness.

The final model concerned the growth of the firms as measured by number of employees, and the resulting model had an $R^2$ of 0.458, and included six variables, where the fitted model is: *Growth = f (DIV, PARENT, TEAM, EXP, REG Massachusetts, APPL III)*. It is important to note that to conduct this analysis the best performing firm had to be excluded from the analysis, as its size gave an outlier value. However, even when including this company, the analysis resulted in a model with three of the same variables (DIV, TEAM, REG Massachusetts), and an $R^2$ of 0.437 (see Table IV).

Precisely as in the previous models, it was found that a high diversity of technological sources (DIV) had a positive impact. Interestingly, this model says that performance is enhanced by a high degree of technology transfer from the parent organization (PARENT), and the composition of the founding team matters where both the size of the founding team (TEAM) and the experience of the founding team (EXP) are positively related to success. Finally, two of the control variables were found to be significant. In accordance with our expectations from the interviews, the firms have grown larger if they are located in Massachusetts (REG Massachusetts), but it is not self explanatory what is cause versus effect: do the firms grow because of a supportive environment in Massachusetts, or do firms with other characteristics conducive to growth locate in Massachusetts? Also, firms that explored applications in group III had higher growth, which was also true with regard to inventiveness. As application III in general can be said to be more mature than the other applications, it may be more likely that the firms have reached the stage of production and marketing. This would positively influence firm growth in terms of employees.

## 7. Conclusions

In this paper we set out to analyze whether there are dimensions of connectivity that influence firm performance. It was found that seven of the nine dimensions of connectivity analyzed were associated with higher firm success, albeit with different dimensions of performance. In particular, technology-related connectivity proved important. The one dimension of connectivity that was significant to all three performance measures was to have high *diversity* in the types of sources for

TABLE IV
The regression model for a firm's relative size

| Model | Unstand. Coeff. B | Std. Error | Stand. Coeff. Beta | T | Sig. |
|---|---|---|---|---|---|
| Constant | 0.315 | 0.556 | | 0.567 | 0.573 |
| DIV | 0.327 | 0.111 | 0.343 | 2.932 | 0.005 |
| PARENT | 0.846 | 0.457 | 0.217 | 1.850 | 0.071 |
| TEAM | 0.161 | 0.069 | 0.278 | 2.324 | 0.025 |
| EXP | 0.884 | 0.421 | 0.261 | 2.102 | 0.041 |
| REG Mass | 0.914 | 0.415 | 0.284 | 2.200 | 0.033 |
| APP I | −1.085 | 0.568 | −0.340 | −1.912 | 0.062 |
| APP II | −1.424 | 0.570 | −0.406 | −2.500 | 0.016 |

technology-related input. Moreover, a *high density* of technology connectivity, that is, a high number of technological relations, was positively associated with inventiveness. This is interpreted as that in order for successful technology development to come about, the firm needs to be networking with many partners. These findings confirm that the multi-technological, dynamic nature of the innovation process in biomaterials requires firms to acquire technology externally from a multitude of informants. Thus, it is strategically important both to have a wide span of search and to be connected to many partners that are potentially able to transfer technological resources, where the risk of lock-in is accentuated in a narrow firm network, which may limit the number of technological sources.

A high degree of *technology transfer* from the parent organization was positively related to growth of number of employees. This confirms earlier studies and indicates that connections giving initial technological resources are important to have. Following our interviews, it could also imply that a strong connection with a parent organization ensures that the vision of how to pursue the technological opportunities is kept alive within the young company. However, as no relation was detected for the other two performance indicators further studies are required.

We hypothesized that firms that have connections to well-established companies for acquiring market-based resources perform better, and this was found to be true with respect to innovativeness. It appears that such agreements spur product development, perhaps leading to a development more directly focused on commercialization. Interestingly, venture capital financing negatively impacted inventiveness. Either VCCs invest in firms that are less inventive or source more inventions externally, or the VCC money focuses efforts on commercialization rather than invention. This finding requires further analysis.

With regard to receiver capability, firms that had a larger founding team had a higher employment growth, confirming earlier research. Having a founding team with previous experience from research as well as from industry was found to influence the growth of the firm's number of employees, implying that experience is important for the ability to grow and agreeing well with previous studies. It is also in line with the perception of the interviewed entrepreneurs, who pointed to lack of experience as a main factor for slow development and growth.

Interestingly, and surprisingly, no relations were detected with respect to the proposition that it would positively influence firm performance to be a corporate spin-off as opposed to a university spin-off firm. Neither was the hypothesis on geographical diversity of technology related connections found to be significant. These findings may mean either that there are no relations, or that the indicators were not sufficiently detailed for these dimensions of connectivity. Further studies are clearly required.

Importantly, with regard to the control variables, both *location* and *application* seem to matter for performance. Indeed, these control variables come out as significant in two of the three models, stressing that even though connectivity seems to matter for performance, these control variables are equally important, warranting further analysis. As anticipated, firms located in Massachusetts performed better on inventiveness and growth. Somewhat unexpectedly, it was firms with strategies to exploit the biomaterials technologies in applications in group III that performed best with respect to both inventiveness and growth. This may be explained this with the fact that applications I and II may require more patents to be sourced from research organizations, and that application group III is more mature, which may enhance growth. Also unpredictably, there was no relation between firm age and performance.

In summary, the findings lead us to conclude that the concept of connectivity seems viable to explore in order to better understand science-based firms' success. Indeed, given a certain application strategy and a certain location, performance was related to most of the connectivity dimensions analyzed. This is interesting, as there are few studies of this type, both with regard to the detailed level of connectivity measures, and with regard to actually analyzing the relation between connectivity and performance.

For management, this is good news. Firm performance in terms of inventiveness, innovativeness and growth of employees can be influenced through strategic firm behavior with regard to connectivity. However, the message is double-sided. On the one hand, management can strategically influence the behavior of the firm. On the other hand, a firm's connectivity is highly path-dependent, where the network patterns are often initiated at firm formation, shaping the patterns of connections over time. In addition, the networks have a spatial component, which leads to difficulties in breaking into unfamiliar spatial networks. Thus, while connectivity does matter to performance and is important to master, it is at the same time difficult to shape. Further research should not only develop the dimensions and operationalization of connectivity and performance indicators further but also in greater detail address this dichotomy.

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## Notes

[1] The start-up phase is operationalized as the first year of operations in the case of biomaterials firms.
[2] These methods involve somewhat varying procedures. The forward selection method enters the variables into the model one by one, starting with the one with the strongest correlation to the specific success indicator analyzed. In a stepwise manner, the variable with the strongest partial correlation is then added. At each step, the method tests the hypothesis that the coefficient of the entered variable is 0, and can be excluded from the model. The stepwise selection method is similar to the previous method, but instead at each step tests whether variables, which are already in the model, should be removed. Finally, the backward elimination method enters all the variables into the model, and eliminates the least important variable in each step.
[3] The paper does not give an account of all firms within biocompatible materials worldwide, but limits its scope to three spatially defined areas. As Sweden is a nation the two others are states within a nation (USA) this clearly strains the comparability of between these 'regions'. However, being geographically delimited areas with distinctive policy instruments and of somewhat comparable size of population they are well suited for this specific type of analysis. The three locations will in this paper be termed regions.
[4] Note that we are not only dealing with firms that are *small*, rather the *age* of the firm is the relevant selection criteria.
[5] For the companies that had ceased operations, the founder as well as the previous manager were interviewed.
[6] The US, European versus Swedish patent profile of our firms were compared and it was clear that independent of the location of the firm, most patents are registered in the US. For example, while the Swedish firms had a total of 51 patents issued at the EUPTO, they had a significantly larger patenting activity as measured by the USPTO (a total of 86 patents issued).
[7] The standard deviation was 1.3 patents per year.
[8] The market introduction of a product is sometimes carried out by the firm itself, but just as often the firm sets up agreements with other companies for co-development and for distribution by the partner firm. Often the partner is a larger incumbent company with a well-established product portfolio and widespread distribution channels.
[9] The mean value for the population was 10.4 employees per year.

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