Growth Dynamics in the Biomedical/Biotechnology System

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ABSTRACT. This article aims to understand the dynamics of growth in the biomedical/biotechnology system that consists of a variety of actors ranging from universities, medical supplies firms, and drug research firms, to clinical service suppliers. Based on a comparative study made in Ohio and in Sweden, we have analyzed three main factors: technology competencies, technology transfer, and networking capabilities. Our findings show a set of differences that can be grouped into two categories, viz. management and agglomeration externalities. Differences in management appear at three points: the resources allocated to technological competence development, managerial skills in the technology transfer phase, and the use of technology councils. Ohio seems to offer a better environment for starting up new firms and enabling these firms to successfully commercialize their technological assets. The agglomeration externalities that make a difference between the two regions might be grouped into two categories: increasing returns arising from network externalities and the advantages of networking with a variety of supporting organizations in the system.

1. Introduction

This article aims to understand factors affecting the performance of firms whose operations are based on biotechnology. An empirical study conducted in Ohio and Sweden is utilized in order to identify significant factors behind observed growth differences in the two regions.

As biotechnology is a generic technology having a wide range of applications in numerous industries, we adopt the technology systems approach to determine the factors behind the growth of firms based on biotechnology. In addition, we incorporate the cluster analysis into our study. Literature on high technology industries indicates the significant role of clustering in growth of firms (Saxenian, 1994). Particularly, as shown in a study by Swann et al. (1998), the main advantages of clusters, namely agglomeration externalities can be applicable to firms based on biotechnology. By using a sample of firms from Ohio and Sweden, this study is a further attempt to identify the role of growth factors.

Ohio and Sweden are two regions with a number of important similarities, such as: similar sizes in terms of population (11 and 9 million inhabitants respectively); the same average gross domestic product per capita (around $27,000); similar industrial structure, historically based mainly on heavy industry, such as machinery and steel; and, the need for restructuring their economies by investing in high-technology industries (Carlsson and Braunerhjelm, 1998). In both regions, biotechnology is considered a crucial technology for the renewal of the economic structure. However, as shown by Carlsson and Braunerhjelm (1998), the growth in this sector has been higher in Ohio than in Sweden. Actually, the biotechnology-based industry in Ohio is about twice as large as that in Sweden in terms of employment and number of firms and more than three times as large in terms of sales.

The interviews focused mainly on the analysis of three features of firms: technology competencies, technology transfer capabilities, and networking activities. The study shows that a partial explanation of the growth differences lies not only in the managerial competencies of firms but also in agglomeration externalities.

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Managerial and technological competencies are unevenly distributed among firms, since these have different characteristics based on their resources, business line, market size, and capabilities (Carlsson, 1997). Moreover, each firm is under the influence of its location due to a complex interplay of external economies characteristic of industrial agglomeration and clusters (Saxenian, 1994; Keeble and Oakey, 1997). That is why the analysis of firms will help us to understand how a technological system can emerge in old industrial regions by supplementing and renewing old competencies with the competencies gained in biotechnology.

The article is organized as follows. Section 2 identifies the components of the biomedical/biotechnology system. It is followed by Section 3 that introduces both the methodology of the study and the general characteristics of interviewed firms. Section 4 is an analysis of features of firms in Sweden and Ohio. The discussion here focuses on three main dynamics behind growth in the biomedical/biotechnology system, namely technology competencies, technology transfer, and networking. The final section presents the results of our comparative analysis identifying which managerial and regional determinants that affect the development and success of the system.

2. The biomedical/biotechnology system

A cluster consists of a group of firms located in the same geographical area and having related activities (e.g., same technologies or customers). Clusters are not characterized primarily by scale economies but rather by their ability to innovate and bring forward new products and services (see, e.g., Tson Söderström, 2001). This definition means that firms making up the biotechnology cluster do not come from the same industry. Instead, the common feature of these firms is the technology itself. Therefore, it has been natural for us to use the technology systems approach as the main theoretical point of departure. Technological systems can be defined as knowledge and competence networks supporting the development, diffusion and utilization of technology in established or emerging fields of economic activity (Carlsson and Stankiewicz, 1991).

Technological systems consist of four elements: firms, organizations, networks, and institutions (Carlsson and Jacobsson, 1997). Firms add economic value by creating, commercializing, and utilizing technologies. Organizations, such as venture capital firms and universities, provide different services including financial support and skilled labor. While networks reflect the interaction patterns among firms and organizations, institutions shape the infrastructure where firms and organizations operate. The term institution covers not only written rules, such as patents, but also tacit rules and routines characterizing a region, e.g., culture and trust. The well functioning of a technological system depends not only on the existence of successful actors (firms and organizations), but also on high connectivity among actors (i.e., the strength of the network) and the enabling function of institutions.

The technological systems approach offers many advantages when trying to understand the dynamics of specific technologies:

- It highlights the interdependence of the elements making up the technological system.
- It highlights the importance of understanding not only the creation of technology but also its diffusion and utilization.
- It explains different characteristics of individual technologies and their particularities arising from localities.
- It becomes possible to observe the evolution of a system at different stages where the influence of different environmental factors might vary.
- It allows analysis of a wide variety of technology applications. In comparison, any sector-based approach would limit the understanding of the potential diffusion of technology.
- Like the cluster theory, it sheds light on the importance of non-market-mediated interaction, which is a form of external economies and an important element of technology development (Carlsson, 1997).
- Like the management literature (see, e.g., Porter, 1990), it is concerned with the managerial competencies needed for the development, diffusion, and utilization of technologies.

Although the technological systems approach is a good tool for analyzing firms based on biotechnology, cluster analysis needs to be integrated in our study for a number of reasons. First of all, biotechnology will affect many industries including environment, energy, food, husbandry, agriculture, pharmaceuticals, chemicals, mining, and veterinary and human health care. The industrial structure and the infrastructure of countries and/or regions will determine its impact on these industries. In that regard, the cluster approach can help to link the technological systems with local mechanisms. By introducing a spatial delimitation, we begin to analyze somewhat a regional technological system.

Second, to a large extent biotechnology is made up of tacit knowledge. That is why all factors of agglomeration externalities, including the availability of labor, enhanced learning among firms, increased and improved communication, existence of public intermediate inputs, and increased specialization can strongly hold for biotechnology (Swann, Prevezer and Stout, 1998; U.K. Department of Trade and Industry, 1999; Jaffe, Trajtenberg and Henderson, 1993).

Third, the local factors are not only influential in the sense of developing a technology at a certain place. Local factors can also shape the firms' relationships with national and global networks. For example, biotechnology firms may receive venture capital financing from other regions and even from other countries. Furthermore, when firms are founded they often try to establish contacts with leading specialists in the specific technological fields they are working in no matter where these people are located. This, in turn, leads to close connections being established with researchers outside the region. Similarly, strategic alliances formed between small-dedicated biotechnology firms and large national or foreign pharmaceutical corporations prove that biotechnology is highly dependent on national and global networks. The nature of the local clusters can affect all these interactions.

As a conclusion, the technological system of biotechnology can only be understood by taking regional interactions into account. That is why we combine the technology systems approach with a cluster analysis in examining the observed growth differences.

In this article, the technological system of biotechnology is called the biomedical/biotechnology system, since both in Ohio and Sweden, firms based on biotechnology are mainly producing products for the health care sector (Carlsson and Braunerhjelm, 1998). The actors of this technological system are made up of two types of components: firms in the production chain and supporting organizations (Granberg, 1997). The firms in the production chain, namely producer-supplier-user firms, may show different characteristics depending on the level of vertical integration and the industrial structure of the region (Porter, 1990). Supplier firms in the biomedical/biotechnology system deliver inputs such as steel, polymers, chemicals, and machines to the core producer firms. Users consist of a wide range of firms, organizations and individuals in the health care, pharmaceutical, environment, agriculture, and energy industries. The supporting organizations consist of research organizations (e.g., universities), intermediary organizations (e.g., industry associations), and financial organizations (e.g., venture capital firms). The relationships among this wide variety of firms and supporting organizations are classified either as strong or weak links based on the discussion in the literature (Senker, 1996) as well as on our own qualitative data collected through interviews. Strong links indicate high level of interdependence and significance of two-way exchanges.

This study focuses on three types of firms:

1. "medical devices firms" producing medical apparatus, measurement instruments, diagnostic devices, and medical supplies;
2. "biotechnology firms" including specialized drug research companies, bioinformatics firms, and manufacturers of "biotech supplies" (i.e., equipment and chemicals for biotechnology research and/or production);[1]
3. "service firms" which are either clinical service suppliers or production and research oriented design firms.

In principle, these categories are not mutually exclusive. In reality, it is common that firms belong to several of these categories. Even though we consider medical devices, biotechnology, and service firms as parts of a single technological system, there are distinct differences between these three categories of firms. If we start with the first two groups, some of the differences might be listed as follows. The market for new biotechnology (BT) products is highly uncertain; firm sizes are in general small; the trend in the market is towards the disintegration of product development into small firms; and regulations are strict. Drug-oriented BT firms need approval from appropriate authorities (such as the Food and Drug Administration, FDA, in the United States), which requires a long process of patenting, clinical testing in several phases, etc. Therefore, it often takes many years before the first product is sold, and the risk of failure is high. In the medical devices (MD) field, by contrast, the market tends to be less uncertain compared to BT; firm sizes range between medium to large; and regulations are less strict for MD firms than BT firms, which, in turn, makes the innovation period shorter and less risky. Production and sales can often start within a short period of time, and the return on investment tends to come earlier than for BT firms. Firms may grow rapidly and become large.

In the case of service firms, there is no question that they are technologically capable, but unlike the BT and MD companies they do not, in general, have any production of goods and in most cases they do not bring about new technologies in biomedicine. They help producers to develop their technologies and products, e.g., by contributing engineering or design services to manufacturers of medical devices. Thus together with the manufacturing firms, they add value to the final product in the biomedical/biotechnology system.

Throughout the article, the analysis of the biotechnology, medical devices, and service firms will be done separately whenever they differ. By conducting interviews, we aimed to explore the reasons behind the performance differences between the biomedical/biotechnology systems in Ohio and Sweden. Therefore, in our search for explanatory factors we will consider similarities and differences in competencies of core firms (intra-firm characteristics), but also briefly discuss the characteristics of other supporting system components (environmental factors).

3. Methodology and data

We have a wide range of data at the macro level. However, the inquiry into the renewal and growth mechanisms of firms requires a different set of data on individual firms in Ohio and Sweden, such as start-up characteristics and commercialization activities. This led us to conduct a comparable set of interviews with core firms in the two regions that are shown in Table I.

The total sample consists of 22 firms in Ohio and 15 in Sweden.[2] In order to get a representative sample, the firms to be interviewed were selected on the basis of three criteria: location, product category, and size. In the case of Ohio, we made a list of companies by examining the Edison Biotechnology Center (EBTC) directory (EBTC, 1998). After we had generated the list, we contacted EBTC specialists in their Cleveland, Columbus, and Cincinnati offices in order to get some feedback information on whether candidate interviewees were representative of the biomedical/biotechnology system in Ohio on the basis of sub-sectors included in our study. Depending on their comments, we dropped some candidates and added new names to our list. We started with a list of around 25 firms to be interviewed but could interview only 22 firms, constituting 5% of all firms in Ohio (Carlsson and Braunerhjelm, 1998; Carlsson, 2001). Data from the EBTC Directory related to the selected firms were supplemented with information from the Harris Directory that supplies information on employment and sales.

In the case of Sweden, the selection of companies was based on the main characteristics of the already selected Ohio firms in order to have a comparable database. That was considered important, since we wanted to make inter-regional comparisons between different categories of biomedical firms. To start with, a number of similar firms were selected from the directories "Nordiska företag i bioteknik" (Nordic companies in biotechnology) and "Nordiska företag i medicinsk teknik" (Nordic companies in biomedicine) (Grönberg, 1996). After having added a few other firms, in order to make the sample more similar to the Ohio one, the final set consisted of 15 firms, i.e., about 7% of the total population (approximately 230 firms) (Carlsson and Braunerhjelm, 1998).

As is apparent from the above discussion, our two samples are not representative in a statistical sense. Instead, we chose to stratify the sampling, since we wanted to make sure that all categories of firms based on biotechnology were included. Nonetheless, it is our belief that the samples are sufficiently representative to enable us to identify

TABLE I
Main products, employment, and sales (1996)

Code	Main products	Employment	Sales (total) – 000$
O1	Implants	100	75,000
O2	Gene therapy	15	None
O3	Manufacturer	450	75,000
O4	Gene therapy	65	1,090
O5	Customer products	2,400	620,000
O6	Software	50	None
O7	Diagnostic equipment	1,300	1,050,000
O8	Neuro-prosthetic product	29	1,500
O9	Oxygen for wounds	1	None
O10	Neural electrodes	3	250
O11	Drug dispensing system	6	None
O12	Diagnostic kits	425	1,300,000
O13	Cell culture products	15	1,000
O14	Oral drug delivery products	68	60,000
O15	Surgical instruments	1,200	21,600,000
O16	Clinical services	300	2,555
O17	Diagnostic test kits	180	35,000
O18	Reagents	15	–
O19	Diagnostic kits	14	None
O20	Medical device design services	30	17,000
O21	Biochemicals	100	682,000
O22	Gene and cell therapy	20	None
S1	Biotech supplies	1,225	224,000
S2	Diagnostic equipment	40	5,800
S3	Renal dialysis equipment	886	1,400,000
S4	Medical and surgical equipment, implants	450	75,600
S5	Orthopedic implants	71	5,600
S6	Pacemakers	400	150,000
S7	Therapeutic equipment	75	7,500
S8	Implants	2	100
S9	Measurement instruments	3	375
S10	Implants	55	750
S11	Clinical services	1	40
S12	Drug licenses	20	2,600
S13	Drug licenses, drugs	22	11,000
S14	Therapeutic equipment	8	2,500
S15	Biotech supplies[a]	0	None

[a] Since this firm was not established until in 1997, it did not have any employees in 1996. At the start there were only two employees. By the end of 1998 the number had increased to eight.
O = Ohio; S = Sweden.

important firm-level differences between the two clusters.

For each firm, the interviews were generally conducted with one manager and one researcher during the period of 1997–98. The interview questions were kept broad in order to capture different characteristics of firms in the biomedical/biotechnology system. As already pointed out, our focus is not only on intra-firm characteristics but also on relevant environmental and relational factors.

Furthermore, in addition to the interview data, our analysis is based on a number of complementary sources. For example, for a review of the main trends in the biomedical industry we benefited from several studies (Berry, 1996; EBTC, 1994; McGrath, 1994; Baunach, Furgalus and Shesser, 1993). We also used information gathered first hand from various associations, such as EBTC in Ohio. The results of our interviews were discussed with experts at EBTC in order to get a feedback on the general trends in Ohio and on our specific findings. These discussions were quite helpful in shaping our conclusions. With regard to Sweden, we benefited from a previous study on the biomedical industry carried out by one of us (Laage-Hellman, 1998; Nilsson, 1998).

Our sample consists of a relatively small number of firms that limits the possibilities to make generalizations. That is why we have put special emphasis on the analysis of our data. First, we attempted to raise questions rather than general statements. Second, we used our data in sketching general trends and ideas that to some extent have been observed in other studies.

4. Comparison of the biomedical/ biotechnology systems in Ohio and Sweden

In this section, we seek to identify and illustrate determinants behind the observed growth difference by comparing firms in the biomedical/ biotechnology system in Ohio and Sweden. As Sweden seems to have had no problem in forming new firms, but rather has experienced growth problem (Carlsson and Braunerhjelm, 1998), our attention is focused on competencies of firms as well as on cluster effects that bring dynamic externalities (Swann, Prevezer and Stout, 1998). To capture these dynamics, our analysis is based on the characteristics of the biomedical/biotechnology system in three major areas: technology competencies, technology transfer, and networking activities. In the literature, these areas are consistently pointed out as sources of growth in new technologies (Carlsson and Eliasson, 1995; Senker and Vliet, 1998; Sharp, Thomas and Martin, 1993; Prahalad and Hamel, 1990; Goezt and Morgan, 1995).

The analysis of *technology competencies* helps us to see whether the firms in our systems have the basics required for growth (Carlsson, 1997; Prahalad and Hamel, 1990). As the biomedical/ biotechnology system is based on science, technology competencies in particular will determine the strength and weakness of medical devices and biotechnology firms (Acharya, 1998). *Technology transfer* is a process of utilizing and diffusing existing technological resources of a region for the creation of new products and/or new firms. In other words, it shows us the success of the system in introducing new firms, often representing new technologies and new competencies, into the system (Swann, Prevezer and Stout, 1998). It shows the capacity of utilizing technologies developed in research organizations as well as existing firms. The failure to transfer technology, particularly from universities, has been considered an explanation why many European countries have problems with their competitiveness (Saviotti, 1998). For the growth of the cluster, the creative destruction induced by new entry can lead to growth of the cluster. Finally, the *networking* highlights how economic competence and renewal capacity can be transformed into growth through local advantages and increasing returns (Carlsson and Eliassson, 1995; Biemans, 1992).

4.1. *Technology competencies*

Our data indicate that technological competence is a significant factor for growth in both regions. For the medical devices and biotechnology companies more than half of the respondents stated that research and technological expertise was their most critical competence. For service firms, it goes without saying that providing customer service is the key competence. Nonetheless, these firms also consider the technological capability to be a prerequisite for success. For example, clinical research organizations need high competence in order to provide clinical testing and ancillary services that enable their clients to receive regulation approvals for new pharmaceutical and medical devices products (e.g., from FDA).

Fields of competencies

The major key competencies in the biomedical/ biotechnology system are related to the life sciences. Both regions have strong research capabilities in this area (Battelle, 1993; Laage-Hellman, 1998). Additionally, there are also other disciplines, such as mechanical and electrical engineering and materials science that are indispensable for the development of medical devices and biotechnology products (Zucker, Darby and Brewer, 1994). Firms in both regions have competencies in these areas, too. One difference is that the majority of firms in Ohio emphasized the importance of computer science more than their Swedish counterparts and said that they expected an increasing growth in the bioinformatics subsector. Only one Swedish company mentioned such a trend. Without any doubt Swedish biomedical firms are highly dependent on information technology in general. However, Sweden has a weak position in bioinformatics (Lundkvist and Sjöberg, 1999) compared to Ohio. There are only a couple of small academic research groups, and the industry has had difficulties in recruiting competent people. That is the reason, for example, why Astra (now AstraZeneca) decided to concentrate its bioinformatics activities to the U.S.

R&D activities

The performance level of firms' technological competencies might be measured by their R&D activities. The amount of R&D carried out by a firm can be measured, for example, in terms of number of researchers and R&D expenditures. Our data show that the Ohio firms on average employ a higher percentage of researchers than the Swedish firms do. Almost one of three employees in Ohio works with R&D while the corresponding figure for the Swedish firms is 15%. In both regions, as expected, there is great variation among the firms. Some companies have very high ratios (e.g., because they are pure R&D firms or constitute primarily R&D units within larger firms). However, the considerably lower average R&D intensity in the Swedish biomedical/biotechnology system (according to our data) is a remarkable fact that might contribute to explain the relative weakness of the Swedish cluster.

Compared to the large and multinational firms, the start-ups employ few researchers in absolute terms but much higher in percentages. Although the start-up firms have a smaller number of researchers, their R&D spending per researcher is often high. The ratio of total R&D expenditures to the number of researchers shows this clearly. Large firms, both in Sweden and Ohio, typically invest between $50,000 and $200,000 per researcher. Several of the small ones invest considerably more. The most extreme case is firm O4, which has a budget of $27 million for 30 researchers. In other words, it spends $900,000 per researcher. The fact that many of the small firms on average spend more money per researcher than the larger (i.e., older) ones, probably has to do with the type of R&D activities. A larger share of the established firms' R&D activities consists of more routine-like product and process development (e.g., incremental improvements of existing products and trouble shooting in the production plants). Furthermore, some of the small firms (at least in Sweden) have contracted out certain research activities, for example, to academic institutions or suppliers. This kind of strategy might lead to high R&D budgets per researcher.

Maintaining, developing and enlarging competencies

To remain useful, competencies require maintenance and development. Thus, firms in general use acquisitions or in-house R&D activities for maintaining, developing and enlarging their competencies. Through restructuring, firms can improve their competitive advantages in the market, and thereby contribute to the renewal of the cluster.

For the biotech firms, we observed similar patterns in Ohio and Sweden – renewal took place mainly through in-house research and cooperation with universities. For the medical devices firms, by contrast, acquisitions constituted a major source of new technologies and products in Ohio, but not in Sweden. As a matter of fact, more than half of the Ohio firms used acquisitions as an important means of restructuring. This does not mean, however, that medical devices firms have no in-house research. In fact, they also benefit from their own R&D activities, but these tend to be more development-oriented compared to biotech firms. The majority of medical devices firms in both regions emphasize the importance of contacts with universities as a source of competence development and renewal.

4.2. *Technology transfer*

The renewal of a cluster through the introduction and commercial exploitation of new technologies brings dynamics into the cluster and increases the competitive advantage of the region (Martin and Thomas, 1998; Keeble and Oakey, 1997). If a cluster inherently manages to realize such change, its growth dynamics can be said to be high.

Since medical devices and biotechnology firms, like many other high-tech firms, source new technologies mainly from research organizations, technology transfer from these organizations into business firms in the form of spin-offs has been a primary focus (Martin and Thomas, 1998). In addition, technologies might be transferred from existing firms into new start-ups. Therefore, the analysis of the start-up firms in both regions can show to what degree firms can exploit technologies developed in companies or research organizations.

Before proceeding, let us explain that we have chosen to classify firms as start-ups if and only if they were established in the 1980s or 90s. There are two main reasons for this. First, the appearance of modern biotechnology did not begin to affect the biomedical/biotechnology systems in the two regions until in the 1980s. Second, we are interested in the current differences between the two regions' growth performance that are rooted in regional economic and technological experiences in that period. We believe that the economic and technological conditions for the creation of new firms in the biomedical/biotechnology system might have been different in the years before 1980. Therefore, we suspect that the characteristics of the start-up process might also have been different compared to the present one.

Sources of start-up firms

Start-up firms in Ohio and Sweden are mainly spin-offs from universities (i.e., they have been established with the purpose of commercializing research-based inventions). Ten out of fifteen new start-ups in Ohio and five out of nine in Sweden are spin-offs from universities (see Appendix Table A1). With a slight difference, Ohio firms seem to exploit university technologies more than Swedish firms do.

Among biotech companies in our study, the majority of firms in Ohio are university spin-offs, while university spin-offs in Sweden constitute only one third. The relative dominance of company spin-offs in the Swedish sample might be explained by the sampling procedure. But it might also be related to the general industrial structure in which large firms are often dominant. Many of these large companies have been quite active in stimulating new spin-offs and nurturing them (Lindholm-Dahlstrand, 1997).

In the case of both medical devices and biotech firms, both regions' firms spin off mainly from universities. One service firm in Ohio spun off from a company, while one service firm spun off from a university in Sweden.

In Ohio, start-up firms spun off particularly from Case Western Reserve University (CWRU). CWRU has cooperated with the state of Ohio to establish the intermediary organization EBTC. That is why CWRU has played a crucial role in our sample firms' start-up process. In Sweden, the start-up firms are not as geographically concentrated as in Ohio. They are found in all major university towns, that is, Stockholm, Gothenburg, Uppsala, Lund, Linköping and Umeå.

Financing of start-up firms

Financial support for medical devices and biotechnology start-ups comes from various sources. Our sample (see Appendix Table A2) shows that private/individual capital is the main source, followed by venture capital firms, government contributions (such as the National Institutes of Health in the U.S.), and local firms.

Our data indicate that biotech firms receive more government financing in Ohio than in Sweden. This was somewhat surprising, and maybe a result of our small samples. Another explanation could be the wide variety of resources supplied in Ohio both by the state and by national government agencies. For example, two firms in our sample have received SBIR (Small Business Innovation Research) grants in their initial phases.[3] Although the U.S. is known as a country of market-driven innovations, similar to many advanced countries, the U.S. supports pre-competitive research for small and medium sized enterprises through public funding. This intervention is in line with the Arrow's (1962) statement of market imperfections in science.

We know from our previous research that there are at least 60–70 small drug/diagnostics-oriented companies in Sweden (Laage-Hellman, 1998). Three of them are included in our sample of start-up biotech firms. We know that governmental financing bodies, such as the Swedish National Board for Technical and Industrial Development (Nutek) and the Industrial Fund, were involved in the establishment of many of these companies. Typically, the amount of money was not large, but it came at a critical moment when it was difficult to get financing from other (private) sources. Let us take firm S12 as an example. The company was spun off from a larger pharmaceutical firm that had decided to leave a certain field of research. The company was founded by a group of six researchers, four of whom came from the pharmaceutical firm. The company tried to raise capital by contacting banks, pension funds, insurance companies and other possible investors, but they failed. Instead, they turned to the government. First, the Industrial Fund made a promise for a 25 million Swedish Crowns (MSEK) loan under the condition that the company get complementary financing from other sources, such as licensees. Second, Nutek's predecessor, STU, gave a 2 MSEK conditional loan, which could be used to finance continued research on a limited scale, as well as marketing activities. The latter resulted in cooperative agreements with foreign pharmaceutical firms, which brought new money. In reality, the company never had to use the loan promise from the Industrial Fund, but it played a crucial role as a guarantee. Especially the American pharmaceutical firms were impressed by the fact that the Swedish government supported the company and saw it as a proof that the company was serious. It can also be mentioned that a recent study of new technology-based firms in Sweden shows that one third of 368 investigated firms received financing from the government during the start-up phase and that this support was considered highly valuable for the growth of these firms (Karaömerlioglu and Lindholm-Dahlstrand, 1999).

Although venture capital firms are one of the financial sources in both regions, it is important to note that access to venture capital differs between the two regions. Start-up firms in Ohio have easier access to venture capital compared to their counterparts in Sweden. For example, when the research results obtained by a CWRU professor were published in a local newspaper, local venture capital firms immediately contacted him and offered him money. This led to the establishment of firm O4. Moreover, the abundance of venture capital in the U.S. makes a difference. For instance, when firms such as O2 and O6 could not convince venture capitalists in Ohio, they succeeded in raising money in California. Another exceptional example is firm O22, which received money from California and England as well as from Hong Kong.

In recent years, the possibility to raise venture capital in Sweden has improved (Karaömerlioglu and Jacobsson, 2000). New money has been brought to the market and new actors have entered the field. Some of the latter are focusing particularly on biotechnology and biomedicine. This development also means that the structure of the Swedish venture capital market is becoming more diversified and more similar to the U.S. one, though venture capital firms do not give comprehensive managerial support to the same extent as U.S. firms do. This is an important difference, since the role of venture capital firms cannot be restricted only to financing. As observed in Ohio, the real contribution of venture capital firms comes into play when these firms help their portfolio firms in solving various managerial issues, such as strategy formulation, finding the right managerial team, and networking with other companies.

In Ohio, there are additional sources of capital that do not exist to the same extent in Sweden, namely intermediary organizations for biotech firms and local companies for medical devices firms. This difference in financing possibilities might contribute to explain the difference in growth rate. For example, the parent company of firm O15 has not only financed it for a long time, but has also supplied network connections, marketing arrangements, and management support. In fact, this open support was one of the main reasons why firm O15 in only three years could outpace its competitor and become the market leader. Its size and export activities are also related to the parent company's worldwide network. So, when financing comes from external firms, either venture capital firms or parent companies or local firms, it brings with it complementary benefits that make a great difference for start-up firms.

Another difference is that banks seem to play a more important role in Sweden. It is not uncommon that new firms get some credit from a bank. The higher reliance of Swedish firms on loan financing compared to U.S. firms has been shown in another study (Eliasson, 1997). This characteristic is valid not only in Sweden but shared with many other European countries. This probably reflects the weak venture capital markets existing in Europe. In Ohio by contrast, bank loans are not at all important as a financing means for start-up companies.

Important factors for growth at start-up
As much as financing, our study shows that the development of start-up firms requires good management, existence of incubators, and strong networks (shown in Appendix Table A3). Firms in Ohio and Sweden value these success factors differently, particularly in the case of management and incubator availability. Even though respondents in both regions indicate the role of the former, medical devices firms in Ohio stress its importance more often than in Sweden. It seems that they have a somewhat different attitude towards management. While the Ohio interviewees consider that managers should be experienced, experts in their areas, and get involved in all sorts of managerial issues from the very early days, the Swedish interviewees did not express this need to the same extent. In Sweden it is more common, according to our judgement, that start-up firms are run by the founders regardless of their management skills. Given that the founders in many cases come from academia, it is not surprising if many of them concentrate their efforts on research and development matters with a disregard for other management tasks.

A second difference in terms of important factors in growth is the role of incubators. While Ohio for many years has had several well-functioning incubators specialized in biotechnology/biomedicine, there have not been until recently so many such specialized incubators in Sweden (Lindholm-Dahlstrand, 1998). Instead, the Swedish incubators have been rather diversified until recently.[4] In our sample, only one medical devices firm in Sweden benefited from an incubator. Many Ohio firms by contrast indicate that the existence of incubators in the region contributes a lot to them. Perhaps, this might be due to the bias of our sample, since nine of the start-up firms in our sample have been located in EBTC's incubators. Two actors, CWRU and EBTC, are active in helping spin-off firms by supplying space, equipment, and contacts through their incubators. Firms located in incubators use the nearby university's facilities, such as CWRU and Ohio State University labs, as well as receive financial and managerial support from EBTC. In the majority of these cases, the founders initially carried out all research in the university and later on officially established firms and shifted their physical location to EBTC's incubator. After some years, when the firms have reached a certain size, they move out of the incubator. Firms in our sample repeatedly indicated that the incubator had been a great advantage for them, since it had supplied space including laboratory infrastructures. The rental agreement for the EBTC incubator can last up to seven years, which gives enough time for firms to complete their initial laboratory work.

Networking is another factor that plays a role in technology transfer. In fact, the overall analysis of the start-up process repeatedly highlights the role of networking with external actors in the process of technology transfer. This is consistent with many studies of biomedical/biotechnology systems (Shaw, 1991; Senker, 1996; Thomas and Martin, 1998; Sharp, Thomas and Martin, 1993).

4.3. *Networking*

The growth of the biomedical/biotechnology system depends not only on the rate of new company formation, but also on the capability of firms to successfully bring new products to the market and grow in terms of sales and employment. In that regard, agglomeration externalities supplied by surrounding networks are important for growth, and hence also can contribute to explain the performance differences between the biomedical/biotechnology systems in Ohio and Sweden.

Increasing returns
The market size may have importance, especially when it comes to medical devices. As Sweden and Ohio have approximately the same population, it can be assumed that the demand for health care services and products is roughly the same, i.e., the size of the domestic market is similar for the two regions. But it can also be assumed that for many Ohio firms the relevant home market is not Ohio, but the whole U.S. or a substantial part of it. The barrier to start selling to other states is quite low. Swedish firms in a similar way have access to the large European market. However, expanding sales to Europe means exporting to several countries that differ in many respects, such as language, culture, governmental regulations, etc. Until recently, for example, medical devices firms had

to cope with different safety and quality requirements in the different European countries. All this made it more difficult and resource demanding for Swedish firms (relative to the Ohio ones) to sell their products outside of its immediate market close by. This might be one of the reasons why Swedish firms have not been able to grow as fast as Ohio firms.[5]

It is not only the size of the end-user market but also the size of the biomedical/biotechnology system as such that affects the growth potential for individual companies. The number of firms in Ohio is twice as large as in Sweden, and the Ohio firms are on average nine years older than their counterparts in Sweden (Carlsson and Braunerheljm, 1998). This size difference together with more accumulated experience could bring many advantages to firms in Ohio, including network externalities, a large pool of scientists and resources, and infrastructure support (Saxenian, 1994). Considering that the biomedical/biotechnology system is based on knowledge where spillovers and knowledge externalities bring increasing returns that are exploited locally, Ohio firms benefit from increasing returns thanks to their relative size advantage (Jaffe, Trajtenberg and Henderson, 1993). Even though Ohio is in a good position compared to Sweden, representatives of EBTC and many interviewed firms maintain that this is not enough. It is argued that Ohio needs to increase its critical mass of firms in order to become as successful as California and Massachusetts in terms of economic growth (EBTC, 1994; Peth-Pierce, 1995). In conclusion, the relatively small size of the biomedical/biotechnology system in Sweden compared to that in Ohio is one of the reasons why the former is not performing as well as the latter. The number of "large firms in related industries" is obviously related to the size of the cluster. Further, the larger market and the larger cluster that Ohio firms can benefit from, facilitate a rapid commercialization of new technologies, which in its turn can spur growth.

The role of network actors

Another reason for the difference in commercialization performance of the two regions could be the variety and the role of actors involved in networks. We start with a definition of commercialization offered by Senker and Vliet (1998, p. 7): "the outcome of a marriage between venture capital and university scientists in a culture that encouraged a close relationship between university science and industry and supported entrepreneurship". But we take one step further and broaden the set of actors involved in the commercialization process. Our interviews clearly show that the process of commercialization is much more complicated than being confined to the relationship between venture capital firms and universities.

The existence of a variety of firms and organizations in a system and their close integration can be a significant reason why firms grow faster in Ohio than in Sweden. These actors not only have important resources and competencies that can be made available to the new biotechnology and medical devices firms. In addition, these actors are market-oriented and have themselves a wide contact network that can be mediated to start-up firms. Further, the existence of networks stimulates organizational learning among firms (Senker, 1996; Biemans, 1992). Considering that technology diffusion and utilization is location specific, the existence and functionality of these networks can help us to explore the regional differences (Audretsch and Feldman, 1994; Shaw, 1991).

There are some important differences between the two regions. The biotechnology firms in Ohio benefit from several types of actors, which do not play such an important role for their Swedish counterparts: scientific advisory boards, intermediary organizations and venture capital firms (see Appendix Table A4).[6]

Scientific advisory boards consist of managers and researchers from various organizations – companies as well as universities. The members are not permanent employees, but rather "consultants" who meet with the companies several times a year to assist them in their strategic decision-making. Typically, they are experts of particular technology or product areas in which the firms are working. Not only academic researchers but also managers from other biotech or medical devices firms or supplier and customer companies may be invited to join these boards.

In Ohio, as many as six of the nine biotech firms and four of eleven medical devices firms benefited from the services of scientific advisory boards, while in Sweden only one of four biotech firms and two of ten medical devices firms used such networking mechanisms. In both Ohio and Sweden the majority of the members are locals. However, it is not uncommon that firms go outside of the region, or even the country, to find the right people. For example, firm O22 has only 20 employees but has a scientific advisory board consisting of two local managers, one professor from a European university, and three professors from prestigious universities in different states of the U.S.

The scientific advisory boards not only give feedback on research results obtained by the company, but they also give suggestions on how to carry out future research and marketing activities. This kind of networking mechanism helps to keep the firms oriented towards commercialization and to increase communication with other firms and organizations. With regard to the use of scientific advisory boards in biomedical firms, the difference between Ohio and Sweden does not seem to be as significant as in the biotechnology case.

Intermediary organizations, such as technology transfer centers set up at hospitals or universities, constitute another important type of actor, especially in the biotechnology field. These organizations support firms not only in the start-up phase, but also throughout the commercialization phase. They have experts in the biotechnology business to which researchers and company people can turn in order to get advice or help to establish contacts with potential partners. The best example of such an organization that we have found is EBTC. It supplies financial support, runs incubator facilities, and organizes seminars on important issues, such as regulations and patents. The lack of such organizations, and such support, in the Swedish biomedical/biotechnology system might be one contributing reason why it has been difficult for Swedish biotech firms to grow. However, it should be noted that in recent years several universities have established this kind of support units. This may indicate that an improvement of the commercialization strength of the Swedish cluster is under way. Also in the field of medical devices such intermediary organizations exist. Once again we find that the Ohio firms use this networking mechanism more extensively than their counterparts in Sweden.

Another set of actors that Ohio companies are in close relationship with is *venture capital firms*. Especially, in the case of biotechnology the venture capitalists play a more important role during the start-up phase in Ohio than in Sweden. Venture capitalists not only have a better capability to understand and assess biotechnology ventures than traditional financial institutions such as banks (Senker, 1996). Thanks to their deep knowledge of the business they can give useful advice to the managers of the new firms (e.g., how to organize the company, how to negotiate with various counterparts, etc.). They can also act as networking agents, for instance by helping start-up firms to get into contact with customers, financial institutions, and other types of actors in the biomedical/biotechnology system. Biotech firm O22, for example, not only raised money from a venture capital firm. It also gained a research partner, a large pharmaceutical firm, thanks to its deal with the venture capitalist. This helped the firm to gain necessary resources, such as capital and collaborating scientists, as well as fame (that in turn pooled more resources).

The Swedish venture capital market is lagging behind the American, as noted above. This explains why the venture capital firms had a negligible role in the technology transfer process among our sample firms most of which had been established prior to the rapid growth of the Swedish risk capital market in the second half of the 1990s (Karaömerlioglu and Jacobsson, 2000). Due to the ongoing development of this market, however, this may change in the future.

No specific regional differences have been observed with regard to the service firms (see Appendix Table A4). In addition, the sample is too small to draw any reliable conclusions.

5. Concluding remarks

The company data reported and analyzed in this article contribute to shedding some light on the observed difference in growth rate between the biomedical/biotechnology systems in Ohio and Sweden. We have searched for explanatory regional determinants that are related to firms' competence, technology transfer, and networking activities. Our findings show a set of differences that can be grouped into two categories, viz. management and agglomeration externalities.

5.1. *Differences in management*

Firm-related differences appear at three points: (1) the resources allocated to technological competence development, (2) managerial skills in the technology transfer phase, and (3) the use of scientific advisory boards. First, firms in Ohio tend to allocate more resources to R&D compared to the Swedish ones. Given the fact that product development in the focal industry is science-based, to a large extent, the importance of technological competence is a matter of course. Accordingly, the majority of firms both in Ohio and Sweden emphasize the importance of research and building of technological expertise. However, the Ohio firms in reality invest relatively more resources in R&D, which is reflected in the higher number of employees engaged in such activities. If we assume that the R&D productivity is the same in both regions, this difference would lead to the creation of higher technological competence in Ohio firms and, as a consequence, better prerequisites for development of new innovative products. If this technological superiority can be taken advantage of in the commercialization process, this will result in a higher growth rate. We have no clear evidence that Ohio firms in general have better technology than Swedish firms do. Nonetheless, the numbers of R&D employees might be taken as an indication that Swedish biotechnology and medical devices firms do not invest sufficient resources in development of new technological competencies.

Second, managerial skills of firms in the start-up phase seem to be higher in Ohio than in Sweden. Skilled management is an important success factor in all technology-based business. For the start-up firms it is therefore important to get access to qualified management competence as early as possible. Especially, spin-offs from universities run the risk of remaining too focused on technology. In order to commercialize effectively the research results to be exploited, there is a need for managers who understand the entire innovation process and know how to create a market-oriented and cost-efficient organization. In Ohio, the leaders of start-up firms often have thorough management skills and experience of building up new technology-based companies. Moreover, one of the main roles of venture capital firms in Ohio is to supply and/or recruit management capabilities. In Sweden, by contrast, it is more common that the founders themselves lead such firms. These people often have an engineering, medical or scientific background and therefore often lack the necessary management capability. Ever since the 1980s the supply of competent managers has been insufficient and hampered the growth of new biotechnology and medical devices companies in Sweden (Laage-Hellman, 1998). The fact that this industry started to develop earlier in Ohio is probably one of the reasons why the access to this critical resource is better there. In addition, it is easier for Ohio firms to recruit competent people from other parts of the U.S. than it is for Swedish firms to attract skilled managers from other European countries. Also contributing, we believe, is the stronger tradition in the U.S. when it comes to the formation and building of new businesses.

Third, Ohio firms have institutionalized scientific advisory boards more successfully than Swedish firms. Members of scientific advisory boards consist of managers and researchers from various organizations, including business firms and universities. Biotech and medical devices firms are kept oriented towards commercialization thanks to these boards. They also bring a wide variety of network contacts to firms. This, in turn, increases connectivity in the biomedical/biotechnology system.

We notice that the observed differences in resources allocated to technological competence development, managerial skills in the technology transfer phase, and the use of scientific advisory boards are to a large extent related to entrepreneurial climate and networks.

5.2. *Differences in agglomeration externalities*

Ohio seems to offer a better environment for starting up new firms and for these firms to successfully commercialize their technological assets, resulting in higher growth. These environmental factors arising from clustering and networking of firms can be grouped into two categories: (1)

increasing returns arising from network externalities and (2) the advantages of networking with a variety of supporting organizations.

First, compared to firms in Sweden Ohio firms benefit more from increasing returns arising from network externalities, even though Ohio is far behind more well-developed biomedical/biotechnology systems such as those in California and Massachusetts. These higher returns occur due to the larger number of firms (twice that in Sweden) and the higher age of the firms (on average nine years more than in Sweden). The existence of more actors with a longer business experience naturally leads to a higher level of competence in many dimensions including commercialization and networking capabilities. The existence of networks giving competitive leverage to the biomedical/biotechnology system in Ohio results in cumulative causation that might be one of the main explanations of the performance difference.

Second, Ohio firms interact with a wider set of external actors than their Swedish counterparts during both the start-up and the commercialization phases. The main explanation, we have found, is the availability of certain types of supporting actors that do not exist or are weakly represented in the Swedish biomedical/biotechnology system. First and foremost, availability of finance is much better in Ohio than in Sweden. Venture capital firms in Ohio do not only supply capital but also work actively with their portfolio firms at the managerial level. Another major difference is that Ohio hosts several types of intermediary organizations, which like the venture capitalists supply the start-up firms with various competencies and contacts that these firms need in order to develop products and bring them to the market. In other words, Ohio firms receive better support than Swedish firms. Furthermore, the existence of incubators, specifically designed for biomedical firms, is a highly valued element in Ohio's system. There is thus a variety of supporting actors in Ohio, which together make up an efficient infrastructure stimulating and facilitating the innovative activities in the region. Evidently, the lack of such an infrastructure has been a major weakness of the Swedish system.

As we have tried to summarize here, this article attempts to understand why the biomedical/biotechnology system in Ohio has grown faster and become more fully developed than the corresponding system in Sweden. Our findings indicate that the performance difference between firms in the two regions can be explained in terms of two major factors: managerial skills and agglomeration externalities arising from networking.

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Notes

1 It is important to note that large, integrated pharmaceutical firms are kept outside the definition of biotechnology firms: The reason for not including "big pharma" in this study is that, unlike in Sweden, there are no such firms represented in the Ohio cluster. By excluding big pharma the comparative analysis of biomedical firms in Ohio and Sweden will be more relevant.

2 The Ohio interviews were conducted by Dilek Cetindamar while in Sweden the interviews were carried out by Dan Johansson, Annika Rickne and Jens Laage-Hellman. We are grateful for their input.

3 SBIR program receives funds from various federal agencies such as the National Science Foundation and the Department of Commerce and invests these funds in small high tech businesses as well as academic research. In 1996, SBIR investments reached $916 million. Another such award program, Small Business Technology Transfer (established in 1994), invested $64.5 million in high tech firms in 1996 (SBA, 1999).

4 In 1998, Sahlgrenska Biomedical Innovation Centre was inaugurated in Gothenburg. Berzelius Science Park in Linköping is another new incubator totally focusing on the biomedical field. It can be added that two older incubators, viz. Uminova in Umeå and Novum in Stockholm, have always had a strong biomedical profile.

5 The recent harmonization of safety regulations for medical devices in the European Union has now made it easier for Swedish firms to export their products to other European countries. This implies an improvement of the growth potential, especially for smaller firms.

6 Similar to the findings of a U.K. study (Department of Trade and Industry, 1999).

Appendix

The figures in parenthesis indicate the percentage representation of firms in the total sample. The columns do not necessarily add up to 100% as each firm might have more than one choice, e.g., more than one source of financing. The detailed information on tables could be found in a forthcoming study edited by Bo Carlsson (2001).

TABLE A1
Sources of start-up firms

	Ohio	Sweden
Biotech firms (6 firms in Ohio, 3 firms in Sweden)	University spin-off: 5 (83%) Independent: 1 (17%)	University spin-off: 1 (33%) Company spin-off: 2 (67%)
Medical devices firms (7 firms in Ohio 5 firms in Sweden)	University spin-off: 5 (71%) Company spin-off: 2 (29%)	University spin-off: 3 (60%) Independent: 1 (20%) Within large firm: 1 (20%)
Service firms (2 firms in Ohio, 1 firm in Sweden)	Company spin-off: 1 (50%) Independent: 1 (50%)	University spin-off: 1 (100%)

TABLE A2
Source of financing for start-up Firms

	Ohio	Sweden
Biotech firms (6 firms in Ohio 3 firms in Sweden)	Private: 3 (50%) VC: 5 (83%) Government: 4 (67%) Intermediary org: 2 (33%)	Private: 3 (100%) VC: 1 (33%) Government: 1 (33%)
Medical devices firms (7 firms in Ohio 5 firms in Sweden)	Parent: 1 (14%) Private: 5 (71%) VC: 1 (14%) Supplier: 1 (14%) Government: 3 (43%) Local firms: 3 (43%)	Parent: 1 (20%) Private: 2 (40%) VC: 2 (40%) Government: 1–2 (20–40%)
Service firms (2 firms in Ohio, 1 firm in Sweden)	Private: 1 (50%) Parent: 1 (50%)	Private: 1 (100%)

VC = Venture capital; Org. = Organization.

TABLE A3
Important factors in growth during start-up

	Ohio	Sweden
Biotech firms (6 firms in Ohio 3 firms in Sweden)	Finance: 4 (67%) Management: 3 (50%) Incubator: 4 (67%) Network: 4 (67%)	Finance: 3 (100%) Management: 3 (100%) Incubator: Network: 2–3 (70–100%)
Medical devices firms (7 firms in Ohio 5 firms in Sweden)	Finance: 6 (86%) Management: 7 (100%) Incubator: 3 (43%) Network: 4 (80%)	Finance: 3–5 (60–100%) Management: 2 (40%) Incubator: 1 (20%) Network: 2–4 (40–80%)
Service firms (2 firms in Ohio, 1 firm in Sweden)	Network: 1 (50%)	Network:

TABLE A4
Network partners

	Ohio	Sweden
Biotech firms (9 firms in Ohio 4 firms in Sweden)	Universities/researchers: 4 (44%) Suppliers: Customers: 6 (67%) Scientific advisory boards: 6 (67%) Acquired firms: 2 (22%) Intermediary org.: 4 (44%) Informal networks: 7 (72%) VC: 4 (44%)	Universities/researchers: 3 (75%) Suppliers: 2 (50%) Customers: 4 (100%) Scientific advisory boards: 1 (25%) Acquired firms: 21 (5%) Intermediary org.: Informal networks: 3 (75%) VC: 1 (25%)
Medical devices firms (11 firms in Ohio 10 firms in Sweden)	Universities/researchers: 2 (18%) Suppliers: 4 (36%) Customers: 3 (27%) Scientific advisory boards: 4 (36%) Acquired firms: 6 (55%) Intermediary org.: 3 (27%) Informal networks: 5 (45%) VC: 1 (9%)	Universities/researchers: 3–5 (3–50%) Suppliers: 2 (20%) Customers: 3–5 (30–50%) Scientific advisory boards: 2 or more (20% or more) Acquired firms: Intermediary org.: Informal networks: 5 (50%) VC: 1 (10%)
Service firms (2 firms in Ohio, 1 firm in Sweden)	Customers: 2 (100%) Hospitals: 1 (50%)	Customers: 1 (100%) Hospitals: 1 (100%)

VC = Venture capital.

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