Institutions, Entrepreneurship, and Growth: Biomedicine and Polymers in Sweden and Ohio

Bo Carlsson

ABSTRACT. This paper examines the role of institutions in explaining the differences in performance with respect to entrepreneurship and growth in two industry clusters in two countries: the biomedical/biotechnology and polymer-based industry clusters in Sweden and Ohio. Both clusters are about twice as large in Ohio as in Sweden, even though the industrial history and the composition of industrial output in general are quite similar in the two regions, and even though the Ohio economy is only about 25% larger than that of Sweden.

Four types of institutional factors are examined: The science base and mechanisms of technology transfer; the density of networks and the role of business support services and companies in related industries; the entrepreneurial climate, especially the availability of finance; and the policy environment and other infrastructure.

Major findings are that the science base plays a different role in the two clusters and that the regions differ in the absorption of new technology, partly due to the differences in the size and structure of firms, that bridging institutions have contributed significantly to connectivity of networks in Ohio, and that the greater availability of venture capital and entrepreneurial management skills makes the Ohio environment for entrepreneurship more supportive than that in Sweden.

1. Introduction

What are the linkages between institutions, entrepreneurship, and growth? The purpose of the present paper is to examine the role of institutions in explaining the differences in performance with respect to entrepreneurship and growth in two industry clusters in two countries.

In a series of papers, my colleagues and I have studied the biomedical and polymer clusters in Ohio and Sweden.[1] The reasons for studying these particular clusters and regions are provided in our previous work.[2] In the present paper, the aim is to examine the institutional differences that have contributed to the differences in economic performance. Even though the industrial history and the composition of industrial output in general are quite similar in the two regions, and even though the Ohio economy is only about 25% larger than that of Sweden, both of these clusters are about twice as large in Ohio as in Sweden. Why have these particular clusters grown faster and become larger in Ohio?

The paper is organized as follows. We begin with a discussion of the rationale for looking at clusters and why certain economic activities tend to cluster. This is followed by an overview of the biomedical/biotechnology and polymer clusters in Ohio and Sweden and their development in the 1990s. Next, we examine the institutional factors which we have identified in our previous work as important in understanding the differences in industry structure and performance. The concluding section formulates the policy issues to which the analysis gives rise.

2. Clustering of economic activity

In recent years there have been numerous studies of clustering of economic activity, particularly in "high technology" sectors such as biotechnology and electronics. Clusters may refer to concentrations of activity either geographically or in related sectors and industries, and sometimes both.[3] One of the main advantages of studying clusters of economic activity is that it emphasizes the context, both institutional and otherwise, in which the activity takes place.

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Case Western Reserve University
Weatherhead School of Management
Department of Economics
Cleveland, OH 44106-7206, U.S.A.
E-mail: bxc4@po.cwru.edu

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Biotechnology is a field in which economic activity tends to be heavily concentrated geographically. Most of the activity in this rapidly evolving field is located in two main areas in the United States – California and the northeastern seaboard from Massachusetts to North Carolina –, in two areas in Britain – Oxford and Cambridge –, and a scatter of smaller clusters elsewhere in Europe (UK Department of Trade and Industry, 1999). The main reason for this geographic concentration is the strong dependence of economic activity in this domain on academic research which happens to be located in these particular regions (Prevezer, 1997; Darby and Zucker, 1996). Studies have shown that the spillover effects of academic research tend to be highly local in nature (e.g., Jaffe et al., 1993); this is certainly true in biotechnology (Audretsch and Stephan, 1996).

If the field of study is broadened to include not only biotechnology (narrowly defined as genetic engineering) but also medical technology more broadly – pharmaceuticals, medical devices, medical instruments and equipment, etc., referred to here as biomedicine and defined more in detail below – the geographic concentration is no longer as strong. The science base is not as concentrated and clearly defined, and the links to other industries (particularly engineering) exert a stronger influence than in biotechnology (Zucker et al., 1994). Thus, the previously existing industrial activities play more of a role (path dependence). But due to the fact that this broader field is not well defined and cuts across several conventional statistical categories, not much is known about the magnitude, growth, and location of economic activity.

Thus, the biomedical cluster consists of a wide variety of activities in various industries. The defining feature of the cluster is that the goods and services produced all have the same end use: they are inputs in the provision of health care, either directly by patients or indirectly via hospitals, clinics, physicians, etc.

Similarly to biomedicine, the polymer cluster consists of activities in many different industries. The major applications of polymers are in building materials, fibers and textiles, packaging materials and coatings, transparent and optical materials, biological and medical materials. All of these materials are classified in different manufacturing industries. The common feature which makes it useful to look at these products as belonging to the same cluster is that the same material (polymers) is used.

Thus, neither the biomedical nor the polymer cluster corresponds well to any particular Standard Industrial Classification codes. They represent goods and services as well as technologies and competencies which are produced in many different types of businesses. The supporting infrastructures go beyond the "industry" in that they encompass entities outside the market process, in addition to firms within the industry and those in upstream and downstream activities.

The fact that both of the clusters are made up of firms in a variety of industries – manufacturing and services – and that these firms represent only a fraction of the total activity in those industries means that it is difficult to identify the population and therefore also to measure the size of each cluster. We ended up using the membership directories of the Edison BioTechnology Center (EBTC) and the Edison Polymer Innovation Corporation (EPIC) in Ohio, while surveys of the Scandinavian plastics industry, the Nordic biomedical industry and the Nordic biotechnology industry were used to gather the data for the Swedish clusters.[4] These data were supplemented with information from the Harris Directory and the Central Register of Firms (Centrala Företagsregistret), respectively. See Carlsson and Braunerhjelm (1999, 2002) for details.

The measurement problems are even more difficult if we want to examine how the clusters have developed over time. It is easy to measure growth in sales, the number of firms, and the number of employees in the industries which fall entirely within the cluster. But it is not easy to determine how much of the growth in industries whose coverage falls only partially within the cluster should be attributed to firms belonging to the cluster, unless one assumes that the coverage remains the same over time. What we did instead was to examine how much of the total activity (measured in terms of sales, employment, and number of firms) in each cluster in 1996 was attributable to firms established in 1990 or later.

Having identified the population of firms in each cluster in both countries, we then supplemented our data through interviews with a sample of firms. Through previous studies (esp. Carlsson and Braunerhjelm, 1999a) we had also identified the other actors in supporting activities and interviewed a sample of them as well. In total, 43 interviews were conducted in Ohio (21 in biomedicine, 10 in polymers, 5 with venture capitalists, 4 with academic institutions and 3 with other organizations) and 32 in Sweden (8 in biomedicine, 10 in polymers, 3 with venture capitalists, 10 with academic units, and 1 with a "bridging institution").

3. Overview of the biomedical/biotechnology and polymer clusters in Ohio and Sweden

As summarized in Table I, both the biomedical/ biotechnology and the polymer clusters are roughly twice as large in Ohio as in Sweden in terms of number of firms. The differences are even larger in terms of employment and revenues. The biomedical/biotech cluster has 422 firms and more than 52,000 employees in Ohio, compared with 230 firms and nearly 26,000 employees in Sweden. The polymer cluster consists of more than 2,800 firms and 273,000 employees in Ohio vs. about 1,400 firms and 76,000 employees in Sweden. The total revenues are more than twice as large in Ohio as in Sweden in biomedicine ($15 billion vs. $6 billion) and more than three times as large in polymers ($59 billion vs. $18 billion). The Ohio firms are larger than their Swedish counterparts in both clusters, due in part to the fact that they tend to be older: the average Ohio biomedical firm was established in 1972 vs. 1981 in Sweden. The average polymer firm was established in 1962 in Ohio and in 1969 in Sweden.

Table I also provides summary data about new firm formation. 108 of the Ohio biomedical firms surviving in 1996 were established during the period 1990–1996 vs. 73 in Sweden. This means that a larger fraction of surviving firms in Sweden were established during the 1990s than in Ohio. The same is true for the polymer cluster: 242 (17.4%) of the surviving firms in Sweden were established during 1990–1996 vs. only 94 (3.3%) in Ohio. Thus, this comparison points to a potential problem in Ohio with the rate of new firm formation, less so in Sweden.

However, the picture changes dramatically if we look at the growth of the newly established firms. The 108 new biomedical firms in Ohio created nearly 1,800 new jobs, compared with less than 1,000 jobs in the 73 new Swedish firms. In terms of revenues, the Ohio firms were more than 8 times as large. In polymers, the story is similar: the 94 new Ohio firms created almost as many new jobs as the 242 Swedish firms, and the average revenues per firm were nearly four times larger than in the Swedish firms.

This suggests that there are factors at work which encourage new firm creation (entrepreneurship), particularly in Sweden, and also factors which inhibit growth in Sweden relative to Ohio.

TABLE I
Biomedical/biotech and polymer firms in Ohio and Sweden, 1996

	Number of firms		No. of employees		Revenues, $ billion		Employees/ firm		Revenues/firm, $ million	
	Ohio	Sweden	Ohio	Sweden	Ohio	Sweden	Ohio	Sweden	Ohio	Sweden
All firms										
Biomedicine/Biotech	422	230	52,175	25,768	15.0	6.1	123.6	112.0	35.5	26.6
Polymers	2,832	1,387	273,413	76,271	58.7	18.1	96.5	55.0	20.7	13.1
Firms established 1990–1996										
Biomedicine/Biotech	108	73	1,791	982	1.7	0.1	16.6	13.5	15.4	1.8
Percentage of total	25.6%	31.7%	3.4%	3.8%	11.1%	2.2%	13.4%	12.0%	43.3%	6.8%
Polymers	94	242	6,166	6,268	1.6	1.1	65.6	25.9	16.5	4.7
Percentage of total	3.3%	17.4%	2.3%	8.2%	2.6%	6.3%	67.9%	47.1%	79.5%	36.0%

The findings also suggest that there are important differences not only between the countries but also between the clusters.

Before proceeding to the analysis of these differences and the role various institutions play, it is necessary to outline the product composition (specialization) of output, size distribution of firms, and geographic concentration of each cluster.

3.1. *The biomedical cluster in Ohio*

In terms of sales, the cluster in Ohio may be divided into four roughly equal groups: Pharmaceuticals, medical equipment, diagnostics, and "other" (consisting of services, medical supplies, and software). The distribution of employment and number of firms across these groups are quite different, however, with medical equipment and medical supplies together representing more than half of the totals. This reflects large differences in employment and sales per firm. The largest firms in terms of both sales and employment are pharmaceutical and service firms.

About half of the sales in the biomedical cluster in Ohio are made up of medical and diagnostic equipment. Three of the largest companies, each with annual sales exceeding $700 million, are Picker International (manufacturer of CAT scanners and other imaging equipment), Invacare (the world's largest manufacturer of wheelchairs), and Steris (manufacturer of sterilization equipment). Picker International was established in 1915 and Invacare in 1971; the manufacturing activities of both these companies are closely related to the industrial machinery cluster which has long dominated the industrial landscape in Ohio. Steris was founded much more recently (1987), with both capital input and other support from Invacare. The manufacturing know-how in these companies is part of the old manufacturing base in Ohio, while the marketing is oriented to the medical sector rather than other manufacturing industries. The older companies (particularly Picker International and Invacare) have continued to grow rapidly as a result of acquisitions of other companies (often overseas) in related products.

The biomedical cluster includes a number of young and small companies in entirely new areas. Some of these are biotech companies which are much more research-intensive than their older counterparts. In fact, many of them have no products at all to sell; all their revenues consist of research funding in the form of research grants as well as seed or venture capital. Several of these companies are university spin-offs or have other important ties to academic research, particularly at Case Western Reserve University (CWRU). Once the companies are established, their local ties become less important as they network with and recruit from universities everywhere. Other companies are software companies, consulting firms, and specialized manufacturing, engineering, and other service companies.

Geographically, the biomedical/biotechnology firms are heavily concentrated in the major metropolitan areas where the major universities are also located. About three-quarters of the firms and employment and almost 90% of the sales are associated with firms in Cleveland, Cincinnati, and Columbus, the three largest metropolitan areas. Each of these cities is home to at least one major research university: Case Western Reserve University, the University of Cincinnati, and The Ohio State University, respectively. These three regions also have a disproportionate share of the newest firms. The chemically based drug industry is heavily concentrated to Cincinnati (strongly associated with Procter & Gamble), while the biotechnology-based sector is tied primarily to Cleveland.

3.2. *The biomedical cluster in Sweden*

The Swedish biomedical cluster is more strongly dominated by pharmaceutical companies than is that in Ohio. The Swedish drug companies represent nearly two-thirds of total sales in the biomedical cluster, with medical equipment firms making up another 30 percent. Thus, the drug companies make up a much higher share than in Ohio.

The pharmaceutical industry has a long history in Sweden and has enjoyed extraordinary sales growth in the 1980s and 1990s while at the same time undergoing rapid consolidation. The number of major drug companies was reduced from seven in the late 1970s to only two today (Stankiewicz, 1997, p. 95): Astra, the largest company, merged in early 1999 with Zeneca, a British company. Its rapid sales growth has been generated by extremely successful innovation in the form of new drugs, including the first beta blocker to be approved by the Food and Drug Administration in the United States, and Losec, the peptic ulcer drug which is currently (1999) the world's best-selling drug. The second largest company is Pharmacia-Upjohn, the result of a 1995 merger of Pharmacia with the U.S.-based Upjohn company.

The medical equipment industry in Sweden is dominated by Gambro (founded in 1964) and Siemens, a German firm which established production in Sweden already in 1927. Similarly to the Ohio medical equipment companies, these firms may be seen as closely related to the industrial machinery industry, with sales oriented to the medical sector rather than other manufacturing industries.

There is also a large number of small medical supply firms Sweden. This is the only field in the biomedical area in which there are more firms in Sweden than in Ohio. But these are generally quite small firms; they are similar in size to those in the software and diagnostics sectors. These latter companies are much more heavily represented and are also much larger in Ohio than in Sweden.

Similarly to Ohio, the geographic location of economic activity in this field is strongly tied to universities with high research capability. The Stockholm-Uppsala region dominates, with other clusters based in Göteborg and Lund and also in Linköping and Umeå. There is a certain amount of specialization among the regions. The Linköping region is relatively large in biomedical software; Göteborg is specialized in medical instruments and supplies, while Uppsala is biggest in diagnostics. However, the Stockholm region is largest in most fields.

3.3. *The polymer cluster in Ohio*

The polymer cluster in Ohio consists of more than 2,800 firms with a total employment of nearly 275,000 and sales of about \$59 billion in 1996. Nearly two-thirds (about 1,800) of these are small firms engaged in fairly simple processing of plastic products. Another major segment (nearly 400 firms, generally much larger than in the previous group) is made up of materials manufacturers. The remaining firms are machinery manufacturers, mold manufacturers, tool & die manufacturers, and providers of various services (e.g. distribution). Thus, the polymer cluster is made up of a combination of very large, multinational firms and numerous small firms.

It is noteworthy that the large (mostly tire and rubber) companies have elected to keep their headquarters and major research units in Ohio, even though they have shifted a large part of their manufacturing activities elsewhere. As will be shown below, this is due in large measure to the presence of high quality universities and infrastructure – or, more generally, an environment highly conducive to close interaction and strong linkages among people with the right skills, high-performance mold making companies, suppliers, metal-cutting industry, and compounders, as well as firms providing highly developed financial and legal services. In addition, proximity to major markets has been advantageous. The area between Akron and Cleveland is often referred to as "Polymer Valley" because of its high concentration of polymer firms. Ohio's polymer firms are heavily concentrated to the large cities. This distribution is identical to the location of heavy industrial activity in general.

3.4. *The polymer cluster in Sweden*

As mentioned before, in the Swedish polymer cluster there are only about half as many firms and one-third the employment and sales as compared to the corresponding cluster in Ohio. Swedish polymer firms are broadly scattered throughout the country, although a few distinct clusters can be identified close to the three largest cities. Noteworthy is a large polymer cluster around Gislaved, a small southwestern town without a university. This, along with the relatively even distribution of polymer firms, suggests that a substantial part of the technology used in polymer production is well-known and relatively easy to apply and that dependence on know-how from the universities is modest.

A characteristic feature of the Swedish polymer production is the dominance of companies which to a large extent are foreign-owned (e.g., BASF Svenska AB, Bayer Sverige AB, Borealis Industrier AB, Norsk Hydro Sverige AB, and

Akzo Nobel AB). Hence, Sweden does not have the same tradition of production in domestically owned chemical firms as does Ohio.

4. The role of institutions

The question that arises, then, is: What are the differences between Ohio and Sweden which have led to the observed differences in patterns and rates of growth in biomedicine/biotechnology and polymers?

One set of explanatory factors surely reflects differences in the economic environment. Between 1990 and 1996, the Swedish GDP grew hardly at all (only 3% over the period as a whole) as Sweden went through its worst slump in the entire postwar period. Similarly, most other countries in Europe also experienced slow growth. Meanwhile, the Ohio economy expanded by about 16%, and the U.S. economy by 13%. The fact that Ohio firms have easier access the large and rapidly growing U.S. market than do Swedish firms to the more slowly growing European market probably also plays a role. But it is difficult to determine how much of the differences in growth should be attributed to such economic factors and how much to other factors. In the following, we will focus on some institutional factors which have emerged in the studies referred to earlier.

In a previous study, "institutions" were defined as

> the normative structures which promote stable patterns of social interactions/transactions necessary for the performance of vital societal functions. . . . By the institutional infrastructure . . . [is meant] a set of institutional arrangements (both regimes and organizations) which, directly or indirectly, support, stimulate and regulate the process of innovation and diffusion of technology. The range of institutions involved is very wide. The political system, educational system (including universities), patent legislation, and institutions regulating labor relations are among many arrangements which can influence the generation, development, transfer, and utilization of technologies (Carlsson and Stankiewicz, 1995, p. 45).

In the present study, however, only a subset of these institutions are considered. Left out, for example, are the broader aspects of the political and educational systems and the regulations pertaining to the labor market. Remaining for consideration here are several institutional factors which we have found in our work on biomedicine and polymers as important in understanding both the differences between the two clusters and the differences between the regions. These may be summarized in the following four groups:

1. The science base and mechanisms of technology transfer
2. The density of networks and the role of business support services and companies in related industries
3. The entrepreneurial climate, especially the availability of finance
4. The policy environment and other infrastructure.

5. The science base and mechanisms of technology transfer

There are important differences between the two types of clusters with respect to the role of science, reflecting differences in the nature of knowledge and in the appropriate mechanisms of knowledge sharing or technology transfer. We begin, therefore, with a discussion of the nature of knowledge in each field.

5.1. *Nature of knowledge in biomedicine*

Even though we are treating biomedicine and biotechnology here as parts of a single cluster in each country, there are distinct differences between the two fields as far as the knowledge base is concerned. Biotechnology relies heavily on basic science, primarily biology and biochemistry, and is therefore closely tied to academic research. Even large pharmaceutical companies (especially those based on chemical traditions) tend to outsource basic research to academia or to small, specialized biotechnology companies. The biotechnology companies, in turn, are often spin-offs from universities. They tend to focus on research rather than production. There is a clear division of labor: universities or scientific institutions are the main creators of knowledge; small start-up firms are the intermediaries which carry the research out from the universities and make the technology ready for use by large firms; and large firms manufacture, market, and distribute the products. This specialization seems to be most pronounced within the United States, partly propelled by the higher propensity of large U.S. firms to engage in outsourcing of R&D. However, there is evidence that a similar structure is slowly evolving in Sweden as well.

The market for new biotechnology products is highly uncertain; approval from the appropriate authority is necessary (the Food and Drug Administration in the U.S.) and requires a long process of patenting, phase I and phase II trials, clinical testing, etc. Therefore, it takes many years before the first output is sold, and the risk of failure is high. Finance comes from pharmaceutical companies and/or venture capital firms. Generally, the patented product is sold to large companies, or patenting is done together with a large company as a joint venture. As a result, biotech companies rarely become large.

In biomedicine, by contrast, the basic technology comes from biomedical engineering, with secondary inputs from mechanical and electrical engineering and computer science, as well as from macromolecular science and materials science. Thus, in addition to the life sciences, engineering and computer sciences are indispensable disciplines for the development of technology in the biomedical cluster. The relations between business and academia are not as tight as in the biotechnology case, however. Biomedical firms are oriented more to applied research and production. These firms either spin off from existing businesses or from academia. Their main focus is on the application of an innovation in production. The FDA approval process or its equivalent is relatively short. Markets are more certain, and the risk is lower than in biotechnology. Production and sales start immediately, and return on investment starts in a relatively short period. Firms may grow rapidly and become large.

5.2. *Nature of knowledge in polymers*

This contrasts sharply with the nature of knowledge in polymers. There are four classes of polymers: (1) thermoplastics (when heated they flow: plastics); (2) thermosets (solids, e.g. rubber); (3) fibers; (4) films and coatings. The main research is currently in the area of thermoplastics and is concentrated primarily on catalysts which are used to manipulate the polymer structure. But polymer research does not have a strong disciplinary base in the academic structure. Even though chemistry departments in the universities might seem to be the natural place for polymer studies, this is not where polymer research is typically done. Chemistry departments are traditionally conservative. Polymer research does not fit well with their well-defined, well-structured approach to research. It is much more experimental. But at the same time, chemical engineering, although an applied discipline and very different in character, culture, and approach from chemistry, does not offer a natural habitat for polymer research either. Chemical engineering continues to be concerned chiefly with the design of heat flows, cooling towers, and reactions. It is only the demands of industry that have forced universities to put the experimental, non-traditional polymer researchers together in their own departments. But this has happened only in a few universities and only fairly recently.

The technological changes take place in molecular structure as well as in the interaction between material and machine. As a result, chemistry, polymer science, and chemical engineering are all becoming connected to mechanical engineering. Besides macromolecular science, mechanical engineering, material science, and computer science are indispensable disciplines for the development of technology in the polymer cluster. This broadening of the required competence base is increasingly problematic for many of the smaller firms in both countries. It also means that the bulk of the research, even basic research, takes place in large companies. The research is highly application-oriented and does not lend itself to the discipline-based academic structures. The main function of universities is to educate and train highly skilled researchers; the research results are of secondary importance.

As a result of these differences in the nature of knowledge as well as the locus of knowledge creation, the mechanisms of commercialization of new scientific breakthroughs are quite different in the two clusters.

5.3. *Technology transfer and commercialization*

5.3.1. *Biomedicine*

The transfer of technology from the research lab to production units and the commercialization of innovations are critical ingredients in the dynamics in the biomedical cluster. The technology transfer problem arises because of the fact that, as stated already, a large share of the research takes place in universities. Technology transfer from academia and research institutions often takes the form of formation of new firms, i.e., the technology is carried directly by the researcher into a new firm. Another possibility is licensing of a patent to an existing firm. Successful transfer requires well-functioning institutions either for new firm formation or for commercialization via licensing, or, both. Many universities have established an "Office of Technology Transfer" (OTT) to facilitate commercialization.[5] The system features which promote start-ups will be discussed further in a subsequent section.

The commercialization activities cover a wide range of activities: managing the legal and contractual framework within which research partnerships operate, along with the intellectual property that may emerge; providing mechanisms for distribution of income resulting from invention and discovery between the university, the researcher, and outside entities; helping start-up firms or researchers file government grant applications such as for Small Business Innovation Research; providing business incubator services to entrepreneurs; providing private industry opportunities to locate close to the campus; training researchers for commercialization activities; promoting the use of inventions and discoveries for public good; and developing effective communications with industry.[6]

The attitude towards commercialization of research results in the Swedish academic community was for a long time fairly negative. This has gradually changed, however. Today commercialization of research is promoted, and universities and institutes of technology have adopted plans for the commercialization of research results. In fact, Swedish universities have been assigned three specific tasks by the government. In addition to education and research, the third task of the universities is to strengthen the collaboration and interaction with the commercial sector, particularly manufacturing. The commercialization of research and development conducted at universities and institutes of technology are therefore seen as one way to improve the competitiveness of Swedish firms. It is also recognized that this may be important for start-ups and growth of new firms.

Neither Ohio nor Sweden is a leader in the area of technology transfer. In this regard, Ohio's universities lag behind many successful universities elsewhere in the United States, such as Stanford and MIT. Even though there are no OTTs in Sweden, recent new legislation has allowed the universities to start firms for the purpose of promoting the commercialization of research results. The Swedish intellectual property rights state that the research results are owned by the researcher, not the university. However, the researchers usually have no knowledge, and little experience, of the commercialization process. Thus, the Swedish university-owned firms have a similar task as the OTTs. They help the researchers with the expensive and time-consuming patenting process, provide contacts with venture capital firms and other firms (e.g., industrial firms) that might be interested in the new technology and assist them in contract negotiations. The university-owned firms charge the researchers for their services, for example by getting part of the license revenues.

Firms are very active in searching and analyzing the available technologies through technical publications, conferences, and patents. Because of the complex legal and technical issues involved, they all rely on outside firms to carry out their patenting. This service is outsourced to a larger extent in the United States than in Sweden.

5.3.2. *Polymers*

In the polymer field, technology transfer from academia to industry takes place through large firms, not small and medium sized firms. There are three reasons for this. First, large firms are the only ones capable of financing academic research and of absorbing the results. If large firms fund the research and are willing to buy the results, the researchers' incentive to go out to industry and set up firms to commercialize their own technologies is sharply reduced. Secondly, the funding affects the direction of research and orients it more towards the needs of large firms, which usually means product and process development, sometimes quite firm-specific in nature. However, an important portion of the research budget is also spent on basic science. But this type of research does not lead to new start-ups and is not sold to small firms. Again, large firms with well-structured research departments (with large R&D budgets and highly trained employees) are in a much better position to understand basic science and appropriate it for their own use. Thus, the market structure seems to be one explanation for the low diffusion of technology in the polymer cluster.

Thirdly, the competencies of firms are based mostly on production technology involving e.g. polymerization, low cost manufacturing, and use of computers. Firms maintain, renew and develop their competence through in-house research and university contacts. Large firms are not risk-takers in terms of pursuing new lines of research. The firms which conduct R&D are mostly large and well established, and they fund their research internally.

The leading universities in the polymer field have a wide spectrum of research capabilities. But while many academics think that specialized firms could work with high engineering polymers and thousands of new polymers in their labs, industry does not generally find many interesting prospects among these for the near future. Unlike firms in the biotechnology field, polymer firms commercialize their own technologies without the use of specialized intermediaries.

The nature and organization of research has changed over the last few decades. Twenty or thirty years ago, most large firms had central R&D labs at headquarters and conducted a fair amount of basic research. Occasionally they would also ask polymer departments in universities to do basic research. Today, their R&D function having been decentralized and much more closely oriented to individual divisions or product lines, industry's requests for academic research projects are much more targeted and operations-oriented. The scope for networking with academic researchers is much more limited now than it used to be. But a common method of technology transfer is still for companies to hire the Ph.D. students whose research they funded. This type of transfer involves large companies almost exclusively; only rarely does it involve the start-up of a new company. Our data show that the Ohio firms are not only larger but also somewhat older (34 years old vs. 27) than their Swedish counterparts. Thus, even though the Swedish firms spend more on R&D in relation to sales (approximately 2 percent versus about 1 percent in Ohio), the research base in absolute terms is considerably larger in Ohio, particularly on the industrial side, and Ohio firms are in a better position to exploit the results commercially.

Given the infrastructure, the nature of knowledge, and the technological change, etc., examined in this section, it is not surprising that most of the growth in this system in Ohio has come through expansion within large firms rather than through establishment and growth of new firms. In Sweden, where the polymer technology base is weaker, especially in large firms, and where the system is less mature, more of the growth has come from new start-ups.

5.4. *Biomedical R&D*

5.4.1. *Ohio*

The biomedical R&D infrastructure in Ohio consists of universities and hospitals, medical clinics, policy organizations and other institutions. In biomedical engineering research, the largest units in Ohio are The Cleveland Clinic Foundation (one of the largest and most highly ranked hospitals in the United States) and Case Western Reserve University (CWRU) whose Department of Biomedical Engineering is one of the leading institutions in its field in the United States. Other engineering departments as well as the School of Medicine at CWRU, other hospitals in the Cleveland area, and the University of Akron are other important research units. Together these institutions in northeast Ohio spend about $17 million on biomedical engineering research annually.[7] To this amount should be added the research which is conducted in other parts of Ohio. Based on our interviews and other materials available to us, we estimate that the total amount spent annually on academic biomedical engineering research in Ohio is about $25–30 million. Most of this research is funded by the National Institutes of Health, the National Science Foundation, and other federal sources.

5.4.2. *Sweden*

In Sweden, the Cancer Foundation, the Swedish National Board for Industrial and Technical Development (NUTEK), the Technology Research Council (TFR), the Medical Research Council (MFR), and the Science Research Council (NFR) are among the leading units that organize and financially support biomedical research. In the field of medicine as a whole, the Swedish academic research expenditures in 1995/1996 amounted to around $500 million. Among the private companies Astra is the most important actor with a total research budget of about $1 billion, half of which is spent in Sweden. We estimate that there are about 100 research units in Sweden in the medical field, including universities, research institutes, and private companies. The expenditures on biomedical research appear to have increased during the 1990s.

The Swedish universities are also important actors in the biomedical technological system. Several of them conduct world-leading research. For example, one of the youngest universities, Umeå University in the northern part of Sweden, has a good international reputation in biotechnology. The largest academic unit is Karolinska Institutet in Stockholm with more than 1,500 teachers and researchers (including 200 professors), and approximately 7,000 students (of which 1,700 are graduate students). About 200 Ph.D.s graduate at Karolinska Institutet each year. The research hospitals are a third group of important actors in the biomedical technological system. They carry out own research and have extensive contacts with the universities. The science parks and NUTEK are the main bridging organizations that try to facilitate the commercialization of research results.

5.5. *Polymer R&D*

5.5.1. *Ohio*

The concentration of the United States rubber industry to northeast Ohio is the main reason why two of the top three academic polymer research institutions in the United States are located in the area: the College of Polymer Science at the University of Akron and the Department of Macromolecular Science at Case Western Reserve University (CWRU) in Cleveland.[8] If we also include the University of Cincinnati, the Ohio State University, and other universities, the total academic polymer research in Ohio is estimated at about $20 million annually.[9]

The academic research is important (especially as a producer of Ph.D.s, less so as a producer of research results), even though it is literally dwarfed by the R&D carried out by major corporations. Goodyear alone spends about $300 million a year on R&D, but only a small portion of that is fundamental research. Other major companies with polymer-related R&D are BF Goodrich, BP Chemicals, Bridgestone/Firestone, Ferro, Gen Corp, and Loral. According to industry sources, a good guess is that somewhere around 2–3% of sales of materials manufacturers is spent on R&D. This would mean that corporate polymer-related R&D in Ohio is in the neighborhood of $400–$600 million a year, and perhaps as much as twice that amount if machinery, mold, and tool & die manufacturers are also included.

5.5.2. *Sweden*

About a decade ago, it was estimated that a total of about 60 million SEK (about $9 million) was spent annually on polymer-related research in Sweden at that time, with almost half being funded by the Swedish National Board for Industrial and Technical Development (then STU, subsequently NUTEK). Only 2 million SEK was spent annually on fundamental work in polymer chemistry and physics and was divided among numerous research units (STU, 1989). There seems to be an inadequate amount of polymer science in the training of college graduates. This means that, similarly to Ohio, there is limited access to research for the large majority of small and medium-sized firms, and very limited absorptive capacity. The large international companies in Sweden can get their research needs met both in Sweden and abroad, and they are well connected to both Swedish universities and research units elsewhere.

More recent figures estimate polymer-oriented research in Swedish universities to about $12 million annually (compared to $20 million in Ohio). The magnitude of industrial R&D is not known. But since much of the research is concentrated in the parent companies, and since many of the Swedish companies are subsidiaries of multinational companies headquartered outside Sweden, this reduces the R&D intensity in Sweden. Assuming that the average R&D intensity in the polymer firms is about 2 percent of sales, which is below the average in the Swedish manufacturing sector, total research expenditures – including universities, government support and the industry – are estimated at approximately $375 million.

Altogether, the academic and research infrastructure for polymers in Sweden seems to be somewhat inadequate. The need for bridging institutions in Sweden similar to EPIC in Ohio (whose role is explained below) in the polymer sector is also evident.

5.6. *Density of networks and the role of business support services and companies in related industries*

5.6.1. *Biomedicine*

In biomedicine, new companies are often based on original ideas and new products. The founders need good networks of relationships and knowledge of the market in order to be able to raise the venture capital needed for growth. Older firms have a large network of relationships with other companies and universities globally. In the initial stage, start-up firms are highly dependent on local actors, even though they also have relationships with more distant entities. The importance of local links drops radically when firms proceed to the later stages of their technology.

Both biotechnology and biomedical firms, and the institutions supporting them, show a strong tendency towards cooperation in research, usually of a long-term nature. Institutional contacts involve hospitals, universities, government organizations (such as NIH), intermediary organizations (such as EBTC and EPIC – see further below), and industrial associations. Firms have relationships not only with local universities but also with national universities as well as with foreign ones. These firms are highly specialized, and in case the local university is not satisfactory, they go and search for expertise wherever it may be found.

The type and degree of connectivity (linkages among various entities) are similar in Sweden to those in Ohio. The main differences can be attributed to the role of hospitals supporting the biomedical cluster. Biotechnology products are subject to strict clinical tests that cannot be performed without the existence of a strong hospital infrastructure. Due to the weaker bridging institutions similar to EBTC in Sweden, the hospitals, especially via their central purchasing agency in each county, play an even more important role in Sweden than in Ohio. Besides academia, the interviewed biotechnology firms also work closely with the pharmaceutical firms that buy their products.

5.6.2. *Polymers*

Polymer firms network with their customers, joint-venture firms, sister firms, parent firms, and other local firms. But the degree of collaboration among firms is not high. However, firms are quick in picking up new developments by hiring good engineers away from each other. The R&D staff in most large polymer firms have informal relationships with their counterparts in other firms. They read the same journals, attend the same meetings, and live in the same neighborhoods, at least in Ohio where the geographic clustering is stronger than in Sweden. The majority of the case study firms in Ohio have established relationships either with local universities or with local community colleges. Multinational firms also have contacts in foreign countries.

Given the competitive pressure on production costs, polymer firms try to rationalize their investments in research and concentrate more on product and process development. To the extent they engage in basic research at all, they employ outside experts such as university professors to perform the research for them.

There seem to be significant differences in connectivity between the Swedish and the Ohio polymer clusters. Generally the interviewed polymer firms in Sweden had little or no contact with universities and other research institutes. Employees and managers also had little formal education; university degrees are uncommon. The technology used is low-tech and developed in-house. The firms usually do not apply or search for new technology. Instead, they continuously improve the existing technology in a process of trial and error. Cost minimizing is extremely important and the major source of competitiveness for several of the interviewed firms.

The main sources of knowledge among Swedish polymer firms emanate from close linkages with customers and suppliers, who give impulses to improvements. Customers and suppliers are more or less regarded as strategic partners, and the polymer firms use them when developing new products and improving existing ones.

6. Entrepreneurial climate and the role of finance

Neither Ohio nor Sweden is particularly known for a favorable entrepreneurial climate. Both economies have traditionally been dominated by heavy manufacturing industry, and both have struggled in the last two decades to restructure and find new areas of growth. Due to resource limitations, our inquiries thus far have focused primarily on only one particular aspect of the entrepreneurial climate, namely the availability of finance.

In 1998 there were 17 venture capital firms in Ohio with a total capital of $9.6 billion, about $2 billion of which is estimated to be committed to biomedicine. All but four of these firms were founded after 1980. In addition to these local companies there are also venture capitalists whose main activities are outside Ohio. There are also "business angels" who are willing to provide "seed" and "start-up" capital.

It appears that although there are venture capital firms active in this field in Sweden, they are much fewer in number than in Ohio. We have been able to identify only a handful of firms active in 1996–1998, some of them foreign. But this does not mean that there is a shortage of capital. In recent years new actors have also become increasingly interested in the biomedical sector. For instance, Investor, the "holding company" of the dominant Swedish industrial group (the Wallenberg group), has recognized the biotechnology/biomedical industry as a potential high growth (profit) industry and acquired a company (Novare Kapital AB) for the purpose of investing in this area. However, as compared to the U.S., our interviews indicate that Sweden hosts few "business angels" and "competent" venture capital firms, connecting new ventures to management and marketing competence, i.e., the primary inputs provided by venture capitalists. The Swedish venture capital market is also less specialized and offers fewer alternatives than the more mature and differentiated venture capital market in the U.S.

Finance is usually the problem considered most important by the biomedical firms. It is related not only to the cost of research but also to the cost of clinical tests, patenting, and FDA approval. It is only during the later stages of technological development that venture capital (VC) firms become interested. If the founders do not have a good network of relationships and knowledge of the market, raising venture capital is difficult. This is where business incubators can play a crucial role (see further below).

We found that five of six Ohio biotech start-ups but only one in three Swedish firms were university spin-offs. Among the non-biotech biomedical firms in Ohio, university spin-offs also dominated. In Sweden, company spin-offs turned out to be more common. This reflects both the general industrial structure in Sweden in which large firms tend to dominate and the prominent role of pharmaceutical firms in the whole biomedical cluster in Sweden.

We also found that few firms in our Swedish sample received support in the form of finance, laboratory equipment, networks, and people from their host (either the university or the company from which they were spun off). By contrast, the Ohio firms were found to have access to both finance and equipment. Even more importantly, they also benefit from network and managerial support during their initial years. This is because of the active involvement of venture capital firms, intermediary organizations, and parent companies.

The VC firms supply not only finance but also provide other services which are at least as important to their clients: finding a chief executive officer; assigning one or more of its employees as a member of the board of directors of the client; helping to establish the client's network with other producers and customers; supplying management know-how; improving the client's marketing capability; evaluating and improving business ideas; advising and, if necessary, intervening in strategic decisions of the client, such as mergers and investments; preparing the client's initial public offering;

communicating with suppliers; and forming a network with other venture firms that work in the same business. Hence, VC firms are important not only for the finance they provide but also because they are a major part of the mechanism that provides linkages to other actors in the cluster.

In Sweden, the venture capitalists have played a more limited role, largely limited to finance, than in Ohio where they also provide management competence and networking capability. This appears to be changing now in Sweden as venture capitalists there become more numerous and competent.

In biomedicine, most of the case study firms in Ohio have encountered financial problems also in the later (post start-up) stages of their technology development (clinical testing/phase III). These funding problems are often solved through licensing and joint ventures. The cost factor is in fact one of the main reasons behind the industrial structure in the biomedical cluster, since financial constraints mitigate against small firm growth.

In Sweden the bottlenecks to growth are different from those in Ohio. According to the interviewed firms, growth is hindered primarily by lack of managers with entrepreneurial experience. While Sweden has a large number of well-managed and successful multinational firms, the skills required to manage such firms are quite different from those required to manage new start-ups. There is a good supply of researchers, some of them world leading, with good technical skills and inventions with the potential to become profitable investments. However, commercialization is hampered by a shortage of people competent to manage new start-ups. In particular, the lack of business angels, or other agents fulfilling the same tasks, was pointed out as an important obstacle to growth. Since the Swedish tax system makes it difficult to accumulate private wealth through productive activities, there are very few business angels active in Sweden.

Our data indicate, somewhat surprisingly, that firms in the Ohio biomedical cluster receive more government finance than do those in Sweden. One possible explanation is the existence of a variety of resources by both state and federal government agencies in the U.S., particularly via SBIR (Small Business Innovation Research) grants.[10]

In the polymer cluster, venture capital plays a much less prominent role than in biomedicine in both Ohio and Sweden. On the one hand, polymer-based firms have had difficulty attracting venture capital in both locations; venture capitalists are looking for higher returns and faster pay-off in other types of ventures. On the other hand, many start-ups tend to be spin-offs from larger companies and thus obtain finance through the parent companies. The higher degree of geographic concentration in Ohio and the much higher density of firms have undoubtedly given Ohio firms an advantage over the Swedish ones.

7. Policy environment and other infrastructure

The substantially higher density of both venture capitalists and other service firms in Ohio than in Sweden explains a great deal of the observed differences in the growth of new firms once they are established. Another potentially contributing factor is public policy. Contrary to what might be expected, Ohio has taken a much more pro-active policy stance than Sweden in both the biomedical/biotechnology field and the polymer field. The Ohio Edison program is the main vehicle for technology policy in Ohio. It consists of funding for seven "centers of excellence" in various technology fields, two of which happen to be biomedicine/biotechnology and polymers.

In the biomedical field, The Edison BioTechnology Center (EBTC) plays an important dual role as a "bridging institution" between academic research (particularly at CWRU) and industry and between new start-ups and potential financiers. EBTC, founded in 1987, is an independent nonprofit organization affiliated with the Ohio Edison Program. It works closely with the leading universities and medical institutions, businesses, foundations, and civic and state organizations in Ohio. EBTC also collaborates with Enterprise Development, Inc. (EDI), a joint venture between the Weatherhead School of Management at CWRU and the Edison Program. EBTC's primary task is to encourage and support the creation of new firms based on biomedical engineering and biotechnology.[11] This is done in collaboration with EDI through technical and business assistance and advice (especially in writing business plans), training courses and seminars, and especially through two business incubators in which newly started companies have free access to office space, laboratory facilities and equipment, office services, and advice in exchange for a modest rent during a maximum of five years.[12] During the incubator phase, there is often no marketable product at all, just some ideas that need to be developed, along with a business plan. The funding is primarily in the form of research grants, often from government sources. Other sources of seed capital are personal savings and business angels. An important function of EDI is to arrange conferences a few times each year to bring together venture capitalists with people interested in presenting their business plans.

To a limited extent NUTEK, a governmental organization, serves the same purpose in Sweden. In addition, science parks and industrial parks represent another type of bridging institution. When the first parks were established in Sweden (in the 1980s), they had already been around for at least 30 years in the U.S.[13] The primary objective of science parks is to foster a closer cooperation between academia and industry. They also assist in raising venture capital and management support. Today 24 such parks exist in Sweden. The largest is located just north of Stockholm and hosts about 350 companies with 23,000 employees. The parks usually specialize in one or a few major spearhead technologies, usually information technology or biomedicine. Studies indicate that Swedish science parks have not performed well in an international comparison in terms of creating employment opportunities (Lindholm-Dahlstrand, 1997, 1998). The best record can be found in those Swedish science parks that have the closest ties to universities or multinational firms.

In addition to the services offered by venture capitalists, incubators, and science parks, many firms, particularly in biotechnology/biomedicine, may require a whole range of other services. Computer software (genomics, bioinformatics), legal services, regulation-related services, and intellectual property rights services are the main groups of services. Geographic proximity and density of networks play an important role here in enhancing the degree of specialization. This is an area in which Ohio firms have an advantage over Swedish ones.

In the polymer field, the Edison Polymer Innovation Corporation (EPIC) plays a similar role. Its function is to support polymer research and technology at Ohio universities in collaboration with local industry, and to provide technical services. The primary task is to support existing industry and to be a "change agent for cultural change" within the industry rather than to create new businesses.[14] Since EPIC's establishment in 1986, the research has been divided between generic research whose results are available to all members and research on specific topics specified by each sponsoring firms, the results of which are proprietary.

Several difficulties have been encountered in pursuing this strategy. One has to do with the dual structure of the industry. The large firms have extremely high technical competence, often on a par with the universities from whom they hire their Ph.D. scientists. For these firms it is not always the case that the small amounts (compared to the total R&D budget) spent on EPIC projects (whether generic or specific) could not be better spent on internal projects. By contrast, the problem for the large bulk of small processor firms is that their absorptive capacity is too limited. In addition, many of these smaller firms are currently undergoing a generational shift. The older generation is often fiercely independent, reluctant to join any organization, and resistant to change. As the management and ownership shift to a new generation, numerous changes may occur, particularly involving consolidation of firms and upgrading of competence in all areas. Meanwhile, EPIC's strategy has recently shifted towards increased emphasis on research consortia through which member companies undertake joint research in specific areas on a much larger scale than previously.

There are many other factors which form the institutional infrastructure for business activity but which we have not been able to cover in this study. For example, in a recent paper, Henrekson and Johansson (1999) hypothesize that the failure of Swedish firms to grow to medium or large size is caused by a number of institutional impediments: the level of taxation and design of the tax system, credit market regulation, the Swedish wage negotiation system, the negative effects of the pension system on private savings, the labor security legislation with particularly detrimental effects on small firms, and the dominance of the public sector in services which could be produced in small firms.[15]

8. Conclusions

What are the policy issues arising from the preceding analysis? Let us address each of the four sets of institutional factors.

It was demonstrated that the science base appears strong in both regions in biomedicine/biotechnology and strong in Ohio also in polymers. Further, it was shown that the science base is much more important in biotechnology than in polymers and that the ability to absorb research results in polymers resides primarily in large firms. Thus, even though the science base in polymers in Sweden is weak, increased expenditures on research and development in polymers are not likely to yield positive results unless they are coupled with efforts to raise the absorptive capacity (receiver competence) in the industry (in both large and small firms.). The lack of major domestic polymer companies in Sweden is a problem in this regard. In biomedicine (particularly biotechnology), the main constraint with respect to the science base appears to be in converting scientific research into commercially exploitable technology (i.e., technology transfer). The transfer mechanisms currently existing in Ohio started to be developed a decade or so earlier than in Sweden, but clearly they need to be developed much more in both regions. Sweden's heavy reliance on (strongly science-based) pharmaceuticals makes it especially important to improve technology transfer to new start-ups, while in Ohio the lack of major pharmaceutical firms is a major barrier to effective technology transfer.

The density of the networks depends significantly on geographic proximity. For this reason, the larger population and smaller land area give Ohio an advantage. The existence of bridging institutions such as EBTC and EPIC also contributes to better networking opportunities. The creation of similar institutions in Sweden is an obvious public policy issue, as is the strengthening of their functions in Ohio.

The entrepreneurial climate appears to be the area where the preceding analysis indicates the most significant differences between Ohio and Sweden. Our research has identified the greater availability of finance (especially venture capital but also seed funding and business angels) as one of the main factors explaining the higher growth rates of new startups in Ohio than in Sweden. The easier access to both financial markets and product markets outside Ohio (i.e., in the United States as a whole) undoubtedly plays an important role. Improving the conditions for a thriving venture capital market should be a high priority for public policy in both Ohio and Sweden (reinforcing the developments in this direction in Sweden in the last few years). Other aspects of the entrepreneurial climate not dealt with in this paper (taxes, regulations, the functioning of the labor market, etc.) are also likely to be important, but much more systematic comparative research is needed before specific policy recommendations can be made.

Notes

[1] Braunerhjelm et al. (1998, 2000, 2002); Carlsson and Braunerhjelm (1999a); Carlsson and Braunerhjelm (1999b); and Cetindamar and Laage-Hellman (2002). The present paper draws upon material from these studies.

[2] The main reasons for the choice of regions are that Sweden and Ohio are similar in size, income level, and industrial history; and both suffered economic setbacks in the 1980s and 1990s; they differ in institutional infrastructure (one being a European country and the other a U.S. state). The location and affiliation of the researchers involved in the project made it possible to collect the detailed information required for the analysis. The main reason for selecting biomedicine and polymers is that these clusters include the fastest-growing industries in both regions over the past two decades.

[3] The theoretical literature suggests two main explanations for agglomeration of economic activities: (1) supply and demand (input-output) linkages and (2) technological spillovers which tend to be highly localized. For a review of the literature and a methodology for identification of clusters, see Braunerhjelm and Carlsson (1999).

[4] The following sources were used for the Swedish data: Grönberg (1996, 1997), Ekonomisk litteratur AB (1996), and the database Svenska Aktiebolag.

[5] The Bayh-Dole Act (1980) fundamentally transformed the legal environment for technology transfer in the United States by transferring the property rights to research results obtained in projects funded by federal agencies from the funding agencies to the universities.

[6] The most developed clusters, such as Silicon Valley, are characterized by access to highly specialized and differentiated services.

[7] Data obtained from Cindy Brogan, unpublished scientific paper, EBTC.

[8] The third and perhaps leading institution in the United States is the University of Massachusetts at Amherst.
[9] There appears to be no similar concentration of academic polymer research anywhere else in the world, the leading rivals being in Germany (Max Planck Institute and the University of Mainz) and Japan (the universities of Tokyo and Kyoto).
[10] The 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 in academic research. In 1996, SBIR investments amounted to $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).
[11] This is in contrast to EPIC's role which is primarily to support R&D in Ohio universities in collaboration with existing firms in the industry.
[12] It is important to note that these incubators are specialized in biotechnology/biomedicine. There are eight other Edison incubators in Ohio, plus a number of incubators not associated with the Edison program.
[13] The science park phenomenon stems from the U.S. (for a more detailed description and review of the literature, see Hauschildt and Steinküler (1994) and Keeble and Oakey (1997). Originally they were set up to enable entrepreneurial academics to link their findings to the market. The Stanford Research Park, later the base of Silicon Valley, is the classic example of a successful research park.
[14] To this end, EPIC has a research budget of about $1–1.5 million a year to support such efforts; none of the research is done in-house but is carried out at CWRU, the University of Akron, and more recently at the Ohio State University.
[15] For further analysis of these and similar issues, see Andersson et al., 1993 Jakobsson et al., 1998.

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