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The old and the new: the evolution of polymer and biomedical clusters in Ohio and Sweden*

Pontus Braunerhjelm[1], Bo Carlsson[2], Dilek Cetindamar[3], and Dan Johansson[4]

[1] Center for Business and Policy Studies (SNS), 100 44 Stockholm, Sweden (e-mail: pontusb@sns.se)
[2] Case Western Reserve University, Cleveland, OH 44106-7206, USA (e-mail: bxc4@po.cwru.edu)
[3] Sabanci University, Istanbul, Turkey (e-mail: dilek@sabanciuniv.edu.tr)
[4] Royal Institute of Technology, Industrial Organization and Management, 100 44 Stockholm, Sweden (e-mail: Dan_Johansson@lector.kth.se)

Abstract. This paper examines the rapid growth of the polymer-based and biomedical clusters in Ohio and Sweden – two regions of similar size and with similar traditions undergoing similar industrial restructuring.

Two issues are addressed: First, why has growth been so strong in these particular clusters, i.e., can we identify the sources of the growth and dynamics in these sectors? Second, why do these two clusters differ in Ohio and Sweden in terms of size, level and type of activity, number and composition of actors, size structure of firms and growth patterns over the last couple of decades? In particular, what is the role of public policies as well as cultural, historical, and geographic factors?

Our main conclusions are (1) that there is strong path dependence in both clusters in both countries, and (2) that the key to rapid development is a high absorptive capacity combined with rapid diffusion to new potential users. Our policy discussion addresses these issues.

Key words: Clusters – Evolution – Path dependence – Systems – Polymers – Biomedicine

JEL-classification: L23, O30

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Correspondence to: B. Carlsson

Introduction

Industrial restructuring has been a common theme in the economic growth of the advanced countries in the last two decades. Resources have been shifted from obsolescent facilities and activities into new ones. The new activities are often clustered in areas that are adjacent both technologically and geographically to the "old" activities. This paper examines the rapid growth of the biomedical and polymer-based clusters in Ohio, one of the largest industrial states in the United States and located in its industrial heartland, in comparison with the same clusters in Sweden – a country with similar traditions undergoing similar industrial restructuring[1].

In the late 1970s and early 1980s, the Ohio economy suffered a major downturn. Between 1979 and 1983, gross state product declined 10 percent, and employment in manufacturing dropped nearly 25 percent. Particularly hard hit were the heavy industries (the steel, machinery, and automobile industries) which constituted the core of Ohio's industrial economy. In the recovery and restructuring which followed, service industries have played a major role – but not just any service industries. The most rapid employment growth has occurred in business services, financial services, transportation services, and legal services – all closely related to the existing industrial base. In manufacturing (aside from one small sector, Lumber and wood products), the fastest growth has occurred in the Rubber and miscellaneous plastics industry and in Instruments and related products. These two industries (in reverse order) were also the fastest-growing in terms of the number of establishments over the period 1975-1995.

Why did these particular industries grow so fast?

The basic thesis of this paper is that in order to answer that question, it is necessary to look at the context in which the growth occurred. That context is not only the macroeconomic environment but also the *technological system* in which each of these industries is imbedded. Neither of these industries is independent of others; indeed, they are each a part of a larger cluster which we refer to as a technological system. By that we mean the networks tying the firms in the cluster together with each other as well as with the supporting infrastructure (academic institutions, research institutes, public policy agencies, industry associations, and financial services - especially venture capital)[2]. Thus, there is a whole range of historical and institutional factors at work. In order to help us identify which of these features are important, we compare the development in both of these sectors in Ohio with that in the same sectors in Sweden, a country of similar size, industrial structure, and restructuring challenges but with different history and institutional arrangements.

[1] See further Braunerhjelm and Carlsson (1999)
[2] For further discussion and elaboration of technological systems, see Carlsson (1995, 1997)

Background

The Rubber and plastics products industry is part of a large cluster of industries based on polymers[3]. The major applications of polymers are in a vast variety of consumer goods, industrial products, electronic components, rubber products, building materials, fibers and textiles, packaging materials and coatings. Thus, in addition to the plastic and rubber industries, many other industries such as motor vehicle parts, industrial machinery, chemical products, and adhesives and sealants are major producers and users of plastic products. As a result, only about 30 percent of the total production of polymers is carried out in the rubber and plastics products industries.

Northeast Ohio has the world's largest concentration of polymer industry. About half of the U.S. market for plastics products is located within a 500 mile radius of northeast Ohio, and several of the largest markets are even more concentrated regionally: for example, about 75 percent of both the automotive and household appliance manufacturers in the United States are located within the same area.

The present-day polymer cluster has strong roots in the rubber industry which grew up in Akron (about 40 miles southeast of Cleveland) in the late 19th century. At one time, all the major tire companies in the United States were based in Akron. For a variety of reasons (especially high labor costs and poor management) the tire companies either withdrew from the tire industry, moved their tire manufacturing operations elsewhere, or merged with other companies (some of which are foreign-owned). As a result, tires are no longer manufactured in Akron, but the polymer-related know-how which constitutes much of the technology base of the rubber industry still remains. Much of the research capability has its origin in the efforts, funded by the U.S. government during World War II, to make synthetic rubber in response to the curtailment of the supply of natural rubber.

By contrast, the rubber and plastics industry in Sweden has never been very large. One of the primary reasons is the absence of a strong chemical industry and resulting lack of industrial competence in chemistry and chemical engineering. Most of the major chemical companies in Sweden are now subsidiaries of multinational companies whose major R&D activities are located elsewhere. Thus, there is neither the competence nor industrial tradition that Ohio has in this area.

Similarly to rubber and plastics, the Instruments and related products industry is part of a larger cluster. Nearly half of the industry in Ohio manufactures medical instruments and supplies, the other half measuring and controlling devices. The former industry and large segments of the latter are part of what we refer to as the *biomedical cluster*. This is defined as consisting of firms producing drugs (including those based on biotechnology), medical supplies, measurement instru-

[3] Polymers are defined as “naturally occurring or synthetic substances consisting of giant molecules formed from smaller molecules of the same substance and often having a definite arrangement of the components of the giant molecules” (Webster's New World Dictionary)

ments, medical apparatus, diagnostic devices and services, software, laboratory services, manufacturing services and engineering services.

To the extent that this cluster is based on biotechnology, it is relatively new. But as will be shown below, biotechnology is not a large part of the Ohio cluster. In large measure, that is a result of the lack of major companies in the pharmaceutical industry. Instead, the strength lies in the sectors which are closely related to the old industrial base, namely instruments (both medical and others) and supplies. The main products of this cluster in Ohio are devices and services, not drugs.

By contrast, the pharmaceutical industry represents nearly two-thirds of the sales of the biomedical cluster in Sweden, the remaining third being mainly medical equipment. It was only after some major breakthroughs in R&D in the 1970s and 1980s that the Swedish pharmaceutical companies became major players. Among the main reasons for their success are large expenditures (both private and public) on biomedical research and the absence of a chemical industry mindset in the pharmaceutical companies which instead had their roots in pharmacology. This made it easier for the Swedish companies to absorb new findings in biotechnology than for their chemically based competitors elsewhere in Europe (Stankiewicz, 1997). Thus, the absence of a large chemical industry has been an obstacle to success in polymers but somewhat of a blessing in biomedicine.

What we have, then, are two clusters of industries. One (polymers) is “old” in the sense that it is rooted in long-established industries and builds on extending industrial competence into new applications (often involving substitution of polymers for other materials) in existing industries. The other (biomedicine) is “new” in the sense that it is less rooted in traditional sectors and involves either entirely new products (biotechnology) or new devices in new applications.

The paper is organized as follows. In the next section we present the methodology and data used in the rest of the paper. This is followed by a section describing the polymer clusters in Ohio and Sweden and their supporting technological systems and a similar section on the biomedical clusters. We then compare and contrast the results across both countries and clusters. We conclude with a discussion of the implications for public policy.

Methodology and data

Neither the biomedical cluster nor the polymer cluster corresponds well to any particular Standard Industrial Classification codes. They represent *technologies and competencies* in a broad sense rather than *industries* and are found in many different types of businesses. The supporting technological systems 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[4].

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. Having tried several approaches in previous studies (see Carlsson and Braunerhjelm, 1999, for details), we ended up using membership directories. These data were supplemented with information from the Harris Directory and the Central Register of Firms (Centrala Företagsregistret), respectively[5].

The measurement problems are even more difficult if we want to examine how the systems 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. But that does not seem to be a reasonable assumption, given the observation that biotechnology products and polymers have generally replaced alternative products over the last decades. 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. To the extent possible we also examined data on gross entry and exit and turnover of firms to get some idea of the dynamics involved.

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, 1999) we had also identified the other actors in each technological system and interviewed a sample of them as well[6].

The question that arises, then, is: What are the features of the technological systems supporting economic activity in biomedicine and polymers which have led to the observed differences in patterns and rates of growth?

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[4] It is useful to define the relationships among three key concepts used in the present study. *Industry* is used in the conventional way as referring to groups of firms producing similar products. *Clusters* refer to groups of firms whose activities are closely related (and geographically close) even if they are not in the same industry, comprising service as well as manufacturing production. Clusters are sometimes narrower, sometimes broader than industries in their makeup; they may consist of subsets of firms in several industries. *Technological systems* constitute the broader framework within which clusters function. As stated earlier, they are made up of networks of actors (not just business firms) interacting with each other both via markets and outside the market. They include the infrastructure

[5] The following sources were used for Ohio: the Edison BioTechnology Center (EBTC) and the Edison Polymer Innovation Corporation (EPIC) membership directories. The Swedish data were obtained from Grönberg (1996, 1997), Ekonomisk litteratur AB, (1996), and the database Svenska Aktiebolag

[6] 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’)

The polymer technology system

The industrial/commercial cluster

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.

As noted earlier, 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. This is due in large measure to the presence of high quality universities and infrastructure. 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.

Sweden

The industrial/commercial polymer industry in Sweden consists of about 1,400 firms with about 75,000 employees and sales of about $18 billion in 1996. Thus, 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. However, this town has a long tradition of manufacturing of rubber products. 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. It is clear that Sweden does not have the same tradition of production in domestically owned chemical firms as does Ohio.

New firm formation

Because of the fact that the polymer cluster is made up of segments of many different industries, it is difficult to track over time. What we can do on the basis of the data available to us is to study the firms established after 1990 and compare them to the rest of the cluster. The results are shown in Table 1. Of the 2,832 firms in Ohio in 1996, only 94 (3.3 percent) were established in 1990 or later. But while the total number of firms in Sweden in 1996 was less than half of that in Ohio (1,387), as many as 242 (17.4 percent) were established in the 1990s. Thus, the relative rate of firm formation appears to be much higher in Sweden than in Ohio. On the other hand, the picture is quite different when we examine the growth of the newly established firms. The 94 new firms in Ohio created as many jobs (6,166) as the 242 in Sweden (6,268), and their combined sales were nearly 50 percent larger. This means that each new polymer firm in Ohio was 2.5 times larger than its Swedish counterpart in terms of employment and 3.5 times as large in terms of sales. The lower density of polymer firms in Sweden seems to have opened many opportunities for new firms, while the more mature polymer industry in Ohio invited less entry while at the same time providing a more supportive environment for the firms that did enter.

Table 1. 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
Firms established 1990-96									
94	242	6.166	6.268	1,6	1,1	65,6	25,9	16,5	4,7
3,3%	17,4%	2,3%	8,2%	2,6%	6,3%	67,9%	47,1%	79,5%	36,0%
All firms									
2.832	1.387	273.413	76.271	58,7	18,1	96,5	55,0	20,7	13,1

Key differences between Ohio and Sweden in the polymer technological systems

The key differences between Ohio and Sweden in the technological system for polymers are summarized in Table 2. Several of these differences can be traced to two underlying factors. One is historical: as mentioned earlier, the concentration of large companies and research resources to northeast Ohio is a result of the location at an earlier time of the United States rubber industry to that area. The other factor has to do with the nature of knowledge pertaining to polymers.

The main research in polymers is currently in the area of thermoplastics and is concentrated primarily on catalysts which are used to manipulate the polymer 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.

As shown in Table 2, there are important differences between Ohio and Sweden in several dimensions of the technological system for polymers: in infrastructure, competence, connectivity, technology transfer, and new business start-ups. In each category, Ohio firms have the benefit of a more fully developed system.

The biomedical system

Whereas the polymer system is defined by a particular type of technology, namely that involved in the generation, diffusion, and application of polymer materials, the biomedical system is not a ‘pure’ technological system in that it is not defined entirely by a particular generic technology (such as biotechnology). Instead, it consists of a whole cluster of technologies, and the boundaries of the system are defined instead by the users: health care providers and consumers[7].

The composition and origin of the industrial/commercial cluster

Ohio

The biomedical system in Ohio consists of a large number of actors in research, goods and service production, finance, and technology policy. The firms in the commercial cluster may be divided into three main groups: one based on drug manufacture and related services, one consisting primarily of medical supplies (intermediary products used by health care providers and drug companies, as well as products used directly by patients/consumers) and one focused on medical hardware (apparatus and instruments). The first group represents nearly half of the firms, employment, and estimated sales in the cluster. The other half is divided roughly equally between medical supply and hardware companies. The drug

[7] Thus, all applications of biotechnology other than to health care are excluded from this study. The health care sector itself is also excluded

Table 2. Key differences between Ohio and Sweden in the technological system for polymers

	Ohio	Sweden
Infrastructure	2 major academic research institutions (University of Akron and Case Western Reserve University).	No major academic research institutes in polymers. Research is divided among numerous units.
	$20 Million per year in academic polymer research.	$12 million per year in academic polymer research.
	Edison Polymer Innovation Corporation (EPIC) supports polymer research and technology at Ohio universities in collaboration with local industry; provides technical support to existing industry.	No major bridging institution facilitating scientific and technical exchange between academia and industry.
	Major international companies (incl. Goodyear, BF Goodrich, BP Chemicals) spend $400-600 million on polymer-related R&D each year. Smaller companies spend a similar amount jointly.	Major companies are subsidiaries of multinational companies headquartered elsewhere; R&D is concentrated in parent companies. Approx. $350 million spent annually on polymer-related R&D.
Competence	High absorptive capacity in major companies which spend a lot on R&D.	Limited absorptive capacity in large companies.
	Some personnel have university degrees.	Few employees and managers have university degrees.
Connectivity	Large number of firms and geographic concentration facilitate informal networking.	Fewer firms and more geographic dispersion impede networking.
	Many firms have links to local universities and community colleges.	Few firms have links to universities and research institutes.
Technology Transfer	Large company funding of R&D orients research to needs of large firms, often firm-specific.	Low level of interaction between academia and industry.
	High absorptive capacity in large firms facilitates technology diffusion and adoption.	Limited absorptive capacity in industry impedes technology diffusion and adoption.
	Most common method of technology transfer is hiring of Ph.D. scientists and engineers.	Few Ph.D.s hired.
New business start-ups	Ohio firms older (34 years on average) and larger than Swedish ones (27 years). Expansion via internal growth.	Weaker polymer technology base, esp. in large firms, and less mature system imply more growth via new start-ups.

companies tend to be older and larger than other firms in the cluster, while service providers (companies producing software, laboratory services and manufacturing and engineering services) tend to be the youngest and smallest (see Table 3). However, Ohio does not have a strong tradition in the pharmaceutical industry which has tended instead to locate along the eastern seaboard of the U.S. and in California.

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 closely related to the industrial machinery cluster which has long dominated the industrial landscape in Ohio. The manufacturing know-how in these companies is part of the old manufacturing base in Ohio which is oriented mainly to producer and consumer capital goods markets, while their marketing is oriented specifically to the medical sector. The older companies in the cluster have continued to grow rapidly as a result of broadening of the product base and market expansion both domestically and overseas. The new elements which distinguish these companies from other industrial machinery firms are 1) their pursuit of non-industrial customer markets and 2) their greater emphasis on marketing.

The biomedical cluster also includes a number of younger and smaller companies in entirely new fields. 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. Other companies are software companies, consulting firms, and specialized manufacturing, engineering, and other service companies.

The geographic distribution of biomedical companies and their employment is similar to that in polymers. The large cities with their research universities clearly dominate, with the Cleveland area alone representing nearly 45 percent of the total employment.

Sweden

The Swedish biomedical cluster can be divided into four regional clusters, all located near leading universities. The Stockholm-Uppsala-Södertälje region with several major universities and research hospitals has the largest cluster. Pharmaceutical companies constitute the core of the Swedish biomedical cluster. They represent nearly two-thirds of total sales and about 55 percent of employment. Medical equipment firms, the second largest sector, accounts for another 30 percent of sales in the cluster. Thus, the drug companies make up a much higher share than in Ohio (Table 3).

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 drug companies was reduced from seven major companies in the late 1970s to only two large multinational firms (Stankiewicz, 1997, p. 95). In 1995, one of these, Pharmacia, merged with Upjohn, a U.S. firm, and in 1999 Astra merged with Zeneca, a British firm. Neither of the newly formed entities is headquartered in Sweden.

One of the prominent features of the Swedish pharmaceutical industry is that, unlike many of its foreign competitors, it is based more in pharmacology than in the chemical industry. The rapid sales growth has been generated by extremely successful innovation in the form of new drugs, including the first beta blocker

Table 1. Biomedical firms in Ohio and Sweden, 1996

	Number of firms		Number of employees		Sales, $ million		Employees/firm		Sales/firm, $ million		Establishment Year	
	Ohio	Sweden	Ohio	Sweden	Ohio	Sweden	Ohio	Sweden	Ohio	Sweden	Ohio	Sweden
Diagnostics	77	18	7.257	314	3.886	38	94, 2	17,4	50,5	2,1	1979	1986
Medical equipment	138	71	14.476	8.771	4.043	1.83 3	104,9	123,5	29,3	25,8	1971	1981
Medical supplies	101	111	13.880	2.812	795	403	13 7,4	25,3	7,9	3,6	1966	1982
Software	30	13	2.054	195	257	15	68,5	15,0	8,6	1,2	1987	1989
Pharmaceuticals	51	17	11.025	13.676	4.138	3.839	216,2	804,5	81,1	225,8	1960	1973
Mfg & eng. services	25		3.483		1.879		139,3		75,2		1981	
Total	422	230	52.175	25.768	14.998	6.128	123,6	112,0	35,5	26,6	1972	1981
Firms established 1990–96												
	108	73	1.791	982	1.663	133	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%		

to be approved by the Food and Drug Administration in the United States, and Losec, the peptic ulcer drug which is currently (1998) the world’s best-selling drug.

The medical equipment industry in Sweden is dominated by Gambro and Siemens (the German firm). Similarly to the Ohio medical equipment companies, both of these companies are closely related to the industrial machinery industry base.

The size and composition of the biomedical cluster of firms in Ohio and Sweden are summarized in Table 3. The biomedical system in Ohio is about twice as large as that in Sweden in terms of employment (52,000 vs. 26,000) and number of firms (422 vs. 230) and two and a half times as large in terms of sales ($15 billion vs. $6 billion), based on data for 1996. The Ohio firms are about 9 years older, on average, than the Swedish firms.

As in the polymer system, it turns out that the percentage of firms established in the 1990s is higher in Sweden (31.7 percent) than in Ohio (25.6 percent). But in this case, too, the Ohio firms grew faster. The 108 new firms in Ohio generated 1,791 jobs, compared with 982 in the 73 Swedish firms. The Ohio firms had combined revenues (sales and research funding) in 1996 of $1,663 million versus only $133 million in Sweden. As a result, the Ohio firms were 23 percent larger in terms of employment and 8.5 times larger in revenues per firm.

According to data from Statistics Sweden, biomedical research by academic units in Sweden in 1996 can be estimated at about $500 million. Based on data from the National Institutes of Health, the corresponding Ohio figure is about $300 million. Thus, Sweden appears to have a larger research base in the medical field as a whole, although Ohio appears to have more research in biomedical engineering. The research intensity is also higher in the Swedish biomedical firms: R&D expenditures as a percentage of sales represent about 15 percent in Sweden and 7 percent in Ohio, in part reflecting larger share of pharmaceutical firms in Sweden.

Key differences between Ohio and Sweden in the biomedical technological system

Table 4 summarizes the most important differences between Ohio and Sweden in the biomedical technology system. In viewing the table, it is important to keep in mind that Ohio's biomedical system is oriented primarily to biomedical engineering, while the Swedish one relies heavily on the pharmaceutical sector. Another important factor is the nature of knowledge underlying the system.

Even though we are treating biomedicine and biotechnology as parts of a single technological system, 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 U.S. biomedical cluster, 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. 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. The product 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.

Conclusions

The two major questions raised in this paper are 1) why have these particular clusters grown so fast in both Ohio and Sweden, and 2) what accounts for the differences within the clusters between Ohio and Sweden?

Our analysis suggests that the basic answer to the first question has to do with path dependence. It is quite clear that the industrial tradition in each region strongly influences the pattern and structure of growth. In polymers, Ohio was once the world's largest producer of rubber tires, implying that industrial tradition and knowledge stemming from former rubber production could be implemented in the polymer sector more broadly. Also, a large part of the U.S. industries which are heavy users of polymers are located within a radius of 500 miles from Ohio. Sweden does not have the same tradition and has not fared as well in the polymer sector as Ohio. The biomedical cluster in both regions arose from an existing base rooted in the machinery industry in both Ohio and Sweden and in the Swedish case also the pharmaceutical industry. Hence, one conclusion is that economic path dependence determines the trajectory of future technology developed and used in a region.

In spite of path dependence, new knowledge and technology has played a crucial role in the growth process in both sectors. In the polymer case, new knowledge seems to have sprung primarily from large private firms and secondarily from universities. In the biomedical case, the knowledge breakthroughs seem to be a result chiefly of close interaction between universities and private firms.

Table 4. Key differences between Ohio and Sweden in the biomedical technological system

	Ohio	Sweden
Infrastructure	$25-30 million annually in biomedical engineering research. Major players are The Cleveland Clinic Foundation, Case Western Reserve University Biomedical Engineering Department and School of Medicine, several Cleveland hospitals and the University of Akron. Total academic research in medicine is about $300 million annually. The National Institutes of Health and the National Science Foundation are primary sources of funding.	Swedish universities and hospitals conduct leading research in medicine. The Karolinska Institute in Stockholm is the largest. Other major research hospitals are in Uppsala and Gothenburg. There are more than 100 research units in Sweden in medicine. Total academic research in medicine is about $500 million annually. The Cancer Foundation, the Swedish National Board for Industrial and Technical Development (NUTEK), and the technical, medical, and science research councils are the primary sources of funding.
	Industrial R&D in biomedicine/biotechnology >$1 billion per year.	Industrial R&D in biomedicine/biotechnology >$0.5 billion per year.
	Bridging institution: Edison BioTechnology Center (EBTC) provides links between academic research and industry and between new start-ups and potential financiers. EBTC's primary task is to encourage and support the creation of new firms based on biomedical engineering and biotechnology.	No major bridging institutions specifically oriented to biomedicine existed in 1996. Science parks and NUTEK were the main bridging institutions.
	EBTC operates 2 business incubators dedicated to biomedicine	There is no incubator or science park in Sweden dedicated to biomedicine.
Competence	No major pharmaceutical company is headquartered in Ohio.	2 major pharmaceutical companies based in Sweden, but both have recently merged with foreign companies and have moved their headquarters elsewhere.
	There are more companies in Ohio than in Sweden specialized in computer software, legal services, regulation-related services, and intellectual property rights.	Outsourcing of services is more difficult in Sweden.
Connectivity	Type and degree of connectivity similar to that in Sweden. Ohio firms are older and larger than the Swedish ones and have more extensive networks with other companies and universities.	Type and degree of connectivity similar to that in Ohio. Hospitals and pharmaceutical companies play a bigger role in Sweden than in Ohio because of the relative strength of the pharmaceutical industry and the weakness of bridging institutions.

Table 4 (continued)

	Ohio	Sweden
Technology Transfer	Intellectual property rights to academic research results belong to the universities. This provides incentives for universities to commercialize research results.	Intellectual property rights to academic research results belong to the researchers.
	Since the mid-1980s major universities have set up offices of technology transfer to facilitate commercialization of research results.	Previously negative attitudes towards technology transfer have changed recently. Karolinska Innovation AB was the first technology transfer unit set up in Sweden in 1997. Subsequently, several universities have set up similar units.
New business start-ups	The primary task of EBTC is to support new start-ups.	NUTEK supports new start-ups, but to a more limited extent than EBTC.
	Venture capital: 17 local VC firms with a total capital of nearly $10 billion of which $2 billion is committed to biomedicine. Also access to VC firms located elsewhere in the U.S.	Only a few VC firms in 1996; more firms have entered in subsequent years. Swedish VC firms are smaller and less specialized and have less management and marketing competence than their Ohio counterparts.
	Presence of “business angels” who provide ‘seed’ and ‘start-up’ capital.	Few “business angels” exist in Sweden. The entrepreneurial climate and supply of entrepreneurial capabilities are lacking relative to Ohio.
	Access to the entire U.S. venture capital market and entrepreneurial talent pool gives Ohio an advantage over Sweden.	Poor local supply and limited access to international supply of venture capital and entrepreneurial talents hamper new firm growth in Sweden.

For new technology to result in economic growth, complementary competencies and skills, comprising services as well as manufacturing production, must be available. This, in turn, implies that the education system must be designed to supply the required skills, ranging from internationally competitive research to skilled blue- and white collar workers[8]. An “experimental” environment allowing new ideas to be tested on the market is another crucial element in order to develop a heterogeneous and diversified market. This also simplifies the application and introduction of new knowledge/technology in non-traditional areas. Together, the above-mentioned factors provide an infrastructure supporting the development of new technologies.

There are also distinct differences between the two sectors as far as the role of technology is concerned. First, polymer technology is much more mature and already highly diffused within the respective region. Except for a few large firms,

[8] Other research (e.g., Chang, 1999) suggests that the most important role of the educational system is to supply skilled labor. It takes decades to build leading-edge research institutions, and the leading researchers have to be trained in the top universities world-wide in order to reach the frontier. If the domestic capabilities are built entirely on indigenous research, they are likely never to catch up with the frontier but may fall further behind instead

links to the universities are not as close as in the biomedical sector. That means that the structure of the supporting system will differ in terms of incubators, science parks, etc. This difference shows up in a divergent size distribution of firms in the two sectors, where the biomedical cluster contains more small firms and more dynamics in terms of entry and exit. Growth in the polymer sector takes place primarily through expansion of existing firms, whereas spin-offs and start-ups of new firms are much more pronounced in the biomedical sector. Economies of scale are also derived on different levels. In the biomedical cluster, these appear to a large extent on the network level, while in polymers economies of scale seem to be more important on the plant level.

The need to communicate with, or be close to, universities is not decisive for competitiveness and supply of knowledge in the polymer sector, particularly not for smaller firms. Only the largest firms seem to have significant links to the universities. On the other hand, in the biomedical cluster, the smallest firms are the ones most dependent on universities. Moreover, firms in the biomedical sector also report dense in-house communication between their engineers and researchers, particularly in smaller firms. This is likely to be one important reason for more flexible and adaptive capabilities of small firms.

Another difference between the two clusters has to do with the role of venture capital. Because of the fact that growth occurs to a larger extent through new firms in the biomedical sector than in the polymer sector, venture capital plays a much more prominent role. Here the differences across regions also become important. In Sweden, venture capital firms are a relatively recent phenomenon and generally do not seem to have the same expertise as their U.S. counterparts. There is also a higher density of "business angels" in the United States than in Sweden. Because of their in-depth knowledge about the industry, accumulated through their own business experience, business angels represent competent capital. This gives Ohio an advantage over Sweden, since it can tap into the competence in other regions within the U.S., thus in effect having a much larger pool of talent to draw from. While we have not specifically investigated the role of labor market legislation in this paper, differences in the institutional set-up in the two regions also play a role. As Henrekson and Johansson (1999) have demonstrated, Sweden's tradition of high taxes, egalitarian policies, and other institutional arrangements have impeded growth.

We have also identified a few factors that mitigate against industrial dynamism and industrial transformation in the Swedish biomedical cluster. The Swedish bridging institutions and the Swedish venture capital market are not as mature and well developed as those in Ohio. That means that the potential of research, often world-class, in Swedish universities, is not fully utilized. In addition, our interviews indicate that there is a lack of entrepreneurial (as distinct from managerial) competence in Sweden that seriously hampers growth. As mentioned above, this is reflected in fewer working opportunities and less production created, despite the fact that Sweden invests more in R&D in relation to output than Ohio does.

The Swedish polymer technological system, on the other hand, is much less developed than the Ohio polymer technological system. There are not as many researchers, and the research funds are more scarce. Venture capital does not play much of a role in this field in either Ohio or Sweden. The role of bridging institutions is even more modest in Sweden than in Ohio.

From a public policy point of view, what lessons can be drawn from the analysis? One obvious lesson relates to the education system. For instance, Ohio universities educate highly qualified Ph.D.-level graduates in polymer science who are hired by large firms as research scientists. This helps the large firms stay on top technically. There is no similar supply of researchers in Sweden; the research spending on academic research is both too small and spread over too many units to reach critical mass. At the same time, the primary demand of many small and medium-sized firms is for training of skilled workers, not research scientists. The system responds relatively poorly to this need in both countries. As a consequence, the Swedish chemical industry association (Kemikontoret) has started its own research institute in close collaboration with the universities in order to ensure that small and medium-sized firms get access to highly qualified research employees.

Thus, the policy implications in polymers are the following: 1) Sweden needs to concentrate university research in a few areas and build a few world-class research units. 2) Both Ohio and Sweden need to devote more attention to the training of skilled workers and tie academic research more closely to industry needs. 3) Sweden needs to promote the building of stronger and denser networks as well as better bridging institutions. As mentioned above, the bridging institutions have been shown to play a decisive role in the growth process. It is important that there is a large variety of bridging agents, ranging from seed capital and venture capital firms to other more institutionalized actors such as EPIC.

In the biomedical sector, the primary needs in Sweden are to acquire more of the entrepreneurial and managerial skills that are the most important part of venture capital and to reduce the deeply rooted institutional impediments to growth. Much could also be done to improve the technology transfer from universities to industry. Even though Ohio does better in technology transfer, there is ample room for improvement there, too. In addition, improving the existing networks and bridging institutions, partly by increasing their visibility, could also contribute to a better climate for growth.

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