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Does co-location matter for formal knowledge collaboration in the Swedish biotechnology–pharmaceutical sector?

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Abstract

This article addresses the validity of assumptions about the importance of co-locality for innovation, by analyzing whether or not co-location matters for formal knowledge collaboration in the Swedish biotechnology–pharmaceutical sector, or biotech–pharma sector. The population of Swedish biotech–pharma firms has been defined, based on the three criteria of geographical location, their engagement in active knowledge development, and their specialized knowledge/product focus. The firms' patterns of regional, national and international collaboration with other firms and with universities is analyzed, as well as the differing collaborative patterns of small versus large firm. In addressing the theoretical questions about the relative importance of co-location for innovation, the article also provides an empirical overview of the Swedish biotech–pharma sector, especially trends over time. This paper thus contributes to the literature by expanding our empirical knowledge about one European biotech–pharma sectoral system, e.g. Sweden, as well as addressing the theoretical question about the relative importance of co-location for formal knowledge collaboration.

Keywords: Biotechnology; Pharmaceuticals; Innovation systems; Sweden; Collaboration

1. Introduction

This article addresses the validity of theoretical assumptions about the importance of co-locality for innovation. It does so by analyzing whether or not co-location matters for formal knowledge collaboration in the Swedish biotechnology–pharmaceutical sector (biotech–pharma). The first aim is to enlarge our empirical knowledge of one European biotech–pharma sectoral system, by focusing on one, knowledge-intensive country (Sweden). The second aim is to address the theoretical question about the relative importance of geographic co-location for innovation in general, relative to different types of partners. In carrying out this analysis, this paper thereby also explores the boundaries of the national innovation system as opposed to a sectoral innovation system.

Within the systems of innovation literature, innovation is argued to result from a collective process of knowledge development.[1] Existing information

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infrastructures influence the creation and diffusion of knowledge throughout a population of actors (Smith, 1997; Foray, 1997; OECD, 1997). This population of actors may include private firms or public organizations like universities and government, and the population in a system of innovation may be defined at the regional, national, sectoral or technological levels. Studies of regional systems of innovation (Cooke, 1998), of national systems of innovation (Niosi et al., 2000) and of sectoral systems of innovation (Nelson and Mowery, 1999; Malerba, 2001) analyze trends in basic research and in firm level research and development (R&D) as well as the role of related institutions and government agencies.

The studies of innovation systems differ in arguing which level of interaction should be considered most important for explaining innovative outcome and by extension, economic development. Still, two assumptions underlie the majority of innovation systems analyses, namely: (1) that interactions occur among the chosen population of actors; and (2) that these interactions influence innovations, and thereby economic growth (Edquist and McKelvey (2000). These are often strong assumptions about the importance of co-locality within a system to create innovations.

This article focuses on the specific theoretical and empirical problem about co-location and knowledge development, and it does not attempt to give a complete overview of the Swedish biotechnology–pharmaceutical sector (see Vinnova, 2001). In addressing this theoretical question, the article provides an empirical overview of the population of Swedish biotech–pharma firms, including their patterns of regional, national and international collaboration with other firms and with universities.

It is important to already here point out some of the reasons for choosing this intersection of sector and country as a test case for collaboration for innovation. The biotech–pharma sector is already known to have what appears to be a high proportion of formal alliances, even as compared to other sectors (Arora and Gambardella, 1990; Gambardella, 1995). The sector thus assumedly has enough instances of formal knowledge collaboration so that the analysis can systematically include the behavior of a high proportion of the nationally based firms within the sector, even in a small country. Existing research also indicates that technological knowledge development in biotech–pharma sector includes biotech firms, pharmaceutical firms, and universities. Formal collaboration can thus be examined across several types of organizations argued to be influential in an innovation system.

The rationale underlying collaboration from the perspective of firms is that the large pharmaceutical companies have been able both to develop in-house competencies and to have alliances with specialized biotech firms, in order to reap benefits from modern biotechnology. Although different strategies are possible, the large pharmaceutical firms seem able to maintain their dominance through alliances with smaller firms (Orsenigo et al., 2001). Collaborations and alliances allow the large firms to develop a network of relationships, which can change identifiably over time. Even so, these authors argue that the large firms retain access and hence control over knowledge even at critical junctures when knowledge branches into alternative hypotheses. A different way of analyzing co-existence of actors within a sectoral system of innovation is the division of knowledge labor argument (McKelvey, 1997). University researchers and biotechnology firms can supply the pharmaceutical companies with radically new knowledge and techniques that are under development. In that sense, the biotech firms sell certain types of knowledge and techniques which can be found between basic science and the needs of an existing sector like pharmaceuticals or diagnostics. Selling such potential development projects and potential knowledge is not a traditional market but one of selling innovation capabilities (see also Arora et al., 2001).[2]

[2] These empirical trends could be interpreted in two opposing manners. On the one hand, the international biotechnology–pharmaceutical sector has a large number of alliances and collaboration, such that these seem to be defining features of the sector. It may evidence that knowledge collaboration is crucial for innovations, and hence in the economy in general. This accords well with the systems of innovation view and with broader theories about the economics of innovation. On the other hand, the biotech–pharma sector may be a special case and not representative of trends in the larger economy. In this case, the special, defining characteristics of the sector need to be made specific, in order to define the limits and opportunities of collaboration also for other sectors. Rather than choosing between these two opposing interpretations here, the position taken here is that differences in knowledge bases, institutions, frequency of interaction and so forth should be identified and studied, not abstracted from in comparisons of different systems of innovations.

The country chosen to define the population of firms in the sector is Sweden, partly because the country can be taken as an example of small countries with a high domestic knowledge base (OECD, 1999). Note, however that domestic, multinational firms finance the majority of the total Swedish R&D investment, as opposed to government financing of basic science. Still, Sweden as funded through Swedish research policy has traditionally been a strong player within medical science research (Archibugi and Pianta, 1992). These facts taken together imply that some national knowledge infrastructure exists in medical research, making it potentially possible for nationally based firms to collaborate with national research scientists.

Based on the innovation systems approach, this article will analyze Swedish biotech–pharma through the defined population of firms (over time) and through the linkages between these firms to other firms as well as to basic scientists at universities and research institutes. In doing so, one of the objectives of this article is to get beyond the prevailing assumptions that collaboration ought to exist and ought to matter for innovations. These assumptions need to be tested empirically. How, and why, do such interactions occur between close geographically (regional or national) located partners or are they instead international partners within the global biotech–pharma sector?[3]

Section 2 defines the Swedish biotechnology–pharmaceutical sector. The section first addresses the definition of a sectoral system of innovation, leading into a discussion about whether theoretical reasoning would lead us to predict a high level of co-location for innovation among partners. It then defines the population of Swedish biotech–pharma firms, based on the three criteria of geographical location, their engagement in active knowledge development, and their specialized knowledge/product focus. Section 3 presents an empirical overview of data and historical trends for the Swedish biotechnology–pharmaceutical sector in general. Section 4 focuses specifically on the issue of collaboration, based on the total population of Swedish biotech–pharma firms and based on a unified database for the years 1985–2000. The analysis of collaborative patterns includes a comparison of firm-firm partners and of university–firm partners as well as a comparison of the larger MNCs relative to the small and medium sized firms. Section 5 draws out the conclusions in order to explore the limits, challenges and possibilities of the empirical results and of the theoretical framework.

2. Defining the Swedish biotechnology–pharmaceutical innovation system and relating it to geographic co-location

The Swedish biotechnology–pharmaceutical (biotech–pharma) sector is here defined based on the population of firms. The criteria for inclusion of firms are: (1) that these firms are located in Sweden; (2) that these firms invest in R&D nationally; and (3) that these firms are involved in the broad area of medical biotechnology and/or in the overlap between biotechnologies/biosciences and pharmaceuticals/health-care.

This definition allows us to identify a population of firms, and thereafter, to examine the occurrence, frequency and direction of their formal knowledge collaboration both with other firms and with universities/research institutes. There is no assumption that a sectoral or national system exists; our purpose is instead to question the extent to which such a system is created through collaboration, which may in turn, be observed to run regionally, nationally, and/or internationally. These questions are obviously and clearly related to a variety of literature on the benefits, or disadvantages, of having knowledge partners to develop new types of knowledge and/or innovate (see Alm and McKelvey, 2000).

This article analyzes formal knowledge collaboration which involves at least one Swedish biotechnology–pharmaceutical firm. Formal knowledge collaboration is here defined as activities such as co-development, co-authorship and collaborative R&D, where both parties are expected to actively contribute to knowledge development and where those activities are ‘visible’ in terms of joint agreement and/or joint results like patents or scientific papers. Our demand is that collaboration be visible through agreements or through results, and thereby allows

[3] In a long-term perspective, the insights are clearly related to discussions about whether and when close geographic knowledge collaboration makes a difference to firms, in terms of their relative success or failure to innovate and in terms of the characteristics of the resulting innovations.

us to compare the relative frequency, and direction, of a large sample across Swedish biotech–pharma firms.[4] Thus, rather than just listing the expected knowledge and innovative capacities of this sector in this nation, this article identifies and contrasts the relative existence of regional and national interactions as opposed to international, sectoral interactions across the population of firms. It is a way to question, rather than confirm, assumptions about innovation systems.

As also stated, our purpose is thereby to start from a sectoral definition and thereafter examine the relative importance of international sectoral collaboration as opposed to national and regional collaboration. Therefore, a definition of sectoral systems of innovation is in order. Malerba (2001) defines a sectoral system of innovation and of production, where he emphasizes the myriad actors involved as well as the various patterns of interactions. The systemic elements come particularly through elements of formal and informal interaction and learning among the set of actors. Change is a part of the system. The relevant knowledge bases, institutions, inputs and demand interact and influence each other over time, thereby implying that the elements are linked and mutually affect one another.

A sectoral system of innovation and production is a set of new and established products for specific uses and the set of agents carrying out market and non-market interactions for the creation, production and sale of those products. A sectoral system has a knowledge base, technologies, inputs and an (existing and potential) demand. The agents composing the sectoral system are organizations and individuals (e.g. consumers, entrepreneurs, scientists). Organizations may be firms (e.g. users, producers and input suppliers) and non-firm organizations (e.g. universities, financial institutions, government agencies, trade unions, or technical associations), including sub-units of larger organizations (e.g. R&D or production departments) and groups of organizations (e.g. industry associations). Agents are characterized by specific learning processes, competences, beliefs, objectives, organizational structures and behaviors. They interact through processes of communication, exchange, cooperation, competition and command, and their interactions are shaped by institutions (rules and regulations). Over time a sectoral system undergoes processes of change and transformation through the co-evolution of its various elements (Malerba, 2001).

In Malerba's definition of a sectoral system of innovation, our specific issue of collaboration among firms as well as collaboration between firms and other non-firm organizations would clearly be important because such collaborations should result in interactive process of learning. Interactive learning, in turn, is argued to result in new knowledge. This new knowledge about technical and market opportunities is vital for innovation and for new forms of competition based on new knowledge.

Within a sectoral system of innovation definition, the debate framing the current article is whether the pattern of collaboration among partners should be expected to be reflected in actors' co-location in a geographic area (regional or national) or whether the pattern should be expected to be international across the sector.

Co-location or not is an important question, because much of the existing empirical literature on systems of innovation simply assumes that linkages and interactions are (or ought to be) close geographically, sometimes without critically questioning the relative impact of close linkages as compared to international ones. Depending on the type of system studied, the linkages and interactions within the system may relate to geographic locality (at the regional and/or national level) and/or else due to the sectoral or technological system level (see Edquist and McKelvey, 2000).

Much evidence has been put forth about the importance of geographic locality for innovative capabilities, often due to theoretical influences from streams within economic geography as well as streams within economics, especially institutional economics. Much of this work emphasizes the importance of informal interaction and/or regional advantages. Concepts such as 'social capital' and 'associative governance' are used to explain why regional development occurs in certain geographic areas but not others (Cooke, 1998; Porter,

[4] Our indicators should be contrasted with 'informal' collaboration or social interaction that is not reported, such as when a larger community of practitioners meets informally. Informal collaboration for knowledge development requires a different method to identify how systematically, and frequently, it occurs across the population.

1998, 1990).[5] People know each other and they move around, and both these informal interactions are argued to facilitate trust among the group and thereby also the diffusion of knowledge (Saxenian, 1994). This perspective emphasizes the importance of informal linkages among a population of actors. Such interaction is in turn assumed to depend on co-location in a geographic area.

Within evolutionary economics, a similar emphasis on the importance of co-locality for interaction can be found, but which is said to more explicitly depend on the relative importance of tacit and informal knowledge. National (or regional) institutions, information infrastructures, and government policy are other elements which are often formed relative to specific geographic locality (Nelson, 1993; Lundvall, 1992). Thus, economic development is said to result from an interactive process of learning, which implies that knowledge and innovations in a locality result from this close collaborative and collective process.

Other research puts more emphasize on the sectoral, especially international, dynamics of knowledge development, and thereby focuses on when and why firms may gain access to new and/or relevant knowledge, which is crucial in economic competition. Nelson (1989, 1996) and Mowery and Rosenberg (1998) emphasize the importance interactions between basic science and economic growth for explaining differential patterns in national and sectoral growth. In this process, there are important productivity effects, which come from the translation of scientific knowledge into products, routines, and processes, which are of economic value. The economic benefits to new knowledge run not only to the innovating firm but also more widely across the economy.

Cantwell and Santangelo (2000), Pavitt (1991), and Dosi (2000) put more emphasis on the importance of specific firms and sectors in organizing and consolidating scientific and technical knowledge within specific firms and sectors. A diversity of firms in terms of technical and market knowledge bases should be visible, although the population of competing firms in a sector may also share some common knowledge bases. Nelson and Mowery (1999) and Malerba (2001) provide evidence of the similarities and differences of different sectoral systems of innovation. These theoretical arguments lead to a view that while individual firms will differ, special characteristics and features of knowledge development may run by sectors, rather than being nationally dominated.

Our definition of Swedish biotech–pharma sector starts from the population of firms sharing the three characteristics: (1) geographical location; (2) their engagement in active knowledge development; and (3) their specialized knowledge/product focus. This definition allows us to define, categorize, and examine the relevant populations of firms, with assumptions of differences as well as similarities. Within evolutionary economics, for example, Metcalfe (1998), following the micro-foundations of macro-economic trends must clearly seen to be differential and competing firms. However, economics traditionally defines sectors (industries) as competing firms, often ones within well-defined product groups.

Our perspective defines a sectoral innovation system around the broad scientific and technical knowledge area of biotechnology–pharmaceuticals. Thus, we cannot define these firms solely based on traditional definitions of sectors or even of firms competing in a market. The definitions of biotechnology—especially, for our purposes here, medical biotechnology—vary but are clearly based on shared knowledge bases related to transformations of biological materials. The international definitions clearly have such a focus (see de la Mothe and Niosi, 2000; Van Beuzekom, 2001). The three characteristics were chosen to define the firm population along the relevant sectoral/knowledge/national boundaries. The population thereby includes a set of firms which are partly competing, partly complementary, partly different firms.

Therefore, it is useful to move on to a discussion of the actual population of firms in Swedish biotech–pharma sector, and in doing so, continue to explain the rationale for the choices made. This section therefore now identifies the basic population of Swedish biotech–pharma firms, the firm characteristics in terms of size and location, as well as the definitions and indicators of formal knowledge collaboration. This section also provides an outline of the methodology and definitions chosen.

[5] One avenue of addressing these proposed explanatory factors would be, of course, to explore the informal nature of relationships among groups of firms as well as the mobility of individuals across different organizations. Do they exist and how does it matter to the firms and innovations involved?

The Swedish population of biotech–pharma firms includes any firm which has (modern) biotechnology related research in this health-care area within Sweden.[6] Examples of firms under this definition include: contract research organizations and diagnostic firms; genomic firms; firms developing biological material in this area; small biotechnology firms involved in pharmaceutical development and pharmaceutical firms. The definition is wide, partly in order to capture the differing actors and knowledge bases necessary to compete in the overlap of biotechnology and pharmaceuticals. Note further that this definition includes both small and large firms. Thus, rather than only including small dedicated biotech firms, all firms engaged in R&D in the appropriate knowledge areas and in the geographical locality are included.

Enough debates exist over whether large firms should be included in definitions of biotechnology exist in order to justify some discussion here (see also de la Mothe and Niosi, 2000). Two defining characteristic of firms included here are that they have to engage in some specialized R&D (or innovation search activities) and that this R&D must be in the wide intersection between biotechnology and pharmaceuticals/medical/health. For example, a pharmaceutical firm which actively uses or develops some type of biotech is included in our population of 'biotech–pharma' firms. Including large and small firms is particularly important because some American definitions strongly emphasize the small, specialized firms. Here, the argument behind including both large and small firms is that large firms are a key element, both for their own extensive in-house R&D and for providing a market for development activities done in dedicated biotechnology firms (McKelvey, 2000). Thus, focusing only on small, specialized firms misses much of the knowledge and economic dynamics of the sector as a whole. Biotech firms are often a link between universities and large, existing pharmaceutical firms, where each type of organization has respective specialized techniques and knowledge. Especially in a small country context, a single large firm can have disproportionately large effects on the orientation and existence of a national system of innovation (Verspagen, 1999). For such reasons, large firms doing research are also included in our population of firms.

Moreover, as defined here, the national context for the firm population requires both locality and search activities at the firm level. For our purposes, this implies that the firm is based on Sweden, and that on that locality, the firm is involved in some active research and/or development work in the overlap of biotechnology and pharmaceuticals. This implies that even a subsidiary and/or a research center for MNCs and for foreign-owned biotech firms are included in the population, if they meet our three criteria.[7] Conversely, the firms are not necessarily Swedish owned firms nor organically started here.

Two arguments support our choices. If close interactions matters, then the attribute of geographically situated should be more important characteristic of the firm than ownership. Moreover, the structure of the Swedish economy is dominated by large MNCs and overall trends towards globalization. Given these characteristics of the Swedish economy, categorizing firms by ownership leads to serious problems for classification, such as in the case of Volvo cars and Saab now being American owned.

Because our definition of the Swedish biotech–pharma sector begins with the population of firms, this implies that we are making no assumptions or claims about the supremacy of internal Swedish contacts within the innovation system. In fact, that is one of the claims we wish to challenge. The formal knowledge collaborations analyzed here must involve at least one of these Swedish biotech–pharma firms, but only one of the partners needs to be located in Sweden.

The rationale is that this choice allows us to identify whether such collaboration is in fact occurring within one defined regional or national context and/or whether these interactions are crossing internationally boundaries. One reason this is important is that much knowledge development in biotech–pharma is said to involve best practice science (anywhere in the world), hence leading to a situation where the local development of knowledge is also fundamentally compared and criticized in relation to international developments.

[6] Firms involved in medical devices are excluded if they do not develop biological materials.

[7] Note, MNCs which only have marketing or sales, etc. divisions are excluded as our population only includes firms with active R&D or active innovative search activities.

Methodologically, these definitions of collaboration allows us to compare and contrast the results from the new databases BioSweden and PHID with international databases, where the latter have often been used in studies of the international biotech–pharma sector.[8]

In summary, the population of firms identified are united by active search activities within an overlapping knowledge area (modern biotechnology–pharmaceuticals) in one geographical location, e.g. national context (Sweden). The definition of formal knowledge collaboration requires that both partners are involved in active search activities for new knowledge and/or innovations.

3. An overview of trends in the Swedish biotech–pharma sector

The Swedish biotech–pharma sector can be characterized as reflecting knowledge-intensive innovations in a small country context. Globalization and internationalization have long been dominant phenomena for the MNC part of the Swedish economy, as well as for the leading edges of national scientific research. In international literature, the three key organizations for biotechnology trends are widely agreed to be universities/research institutes, large pharmaceutical companies, and dedicated biotechnology firms. In terms of these three organizations for biotech–pharma, Sweden has a somewhat different history than much of Europe (see also McKelvey and Orsenigo, 2001), one which lies closer to the American phenomena. Sweden has traditionally had strong medical research, has spawned parts of two international pharmaceutical companies (AstraZeneca and Pharmacia Corp.), and has had relatively large number of small, dedicated biotechnology firms, especially in recent years (see Archibugi and Pianta, 1992; Vinnova, 2001; Ernst and Young, 2000).

The main metropolitan areas—Stockhom/Uppsala, Lund/Malmö, Gothenburg, Norrköping/Linköping, followed by areas such as Umeå—are characterized by being the main areas for economic, cultural and scientific activities. In a country with 8.5 million inhabitants whom are spread over a large geographical area, the major metropolitan areas cluster many types of activities, as would be expected. In terms of medical research, the Karolinska Institute in Stockholm clearly dominates in publications and citations, whereas other universities (Salgrenska, Lund/Malmö, etc.) also have leading medical research in some areas. The engineering universities (KTH, Chalmers, Lund, Linköping) have traditionally been strong in Sweden and also provide research and a base for start-up firms in engineering related biotechnologies such as biosensors, biological materials and diagnostics equipment.

In terms of trends in economic development and in scientific research relevant for biotech–pharma, Sweden has been changing rapidly in the past two decades. These changes must, of course, be seen as changes from a particular Swedish situation in terms of power-sharing between Social Democratic party, trade unions, and large firms in traditional industries (see Henrekson and Jakobsson, 2001). Relevant changes in recent years include: (1) the merging of the formerly Swedish pharmaceutical firms of Astra and Pharmacia into MNCs of AstraZeneca and Pharmacia Corp.; (2) the large numbers of start-up companies in geographical areas like Uppsala which were previously dominated by P&U; (3) government policy to encourage university entrepreneurship and university–industry linkages; and (4) fundamental changes within the Swedish research system, which has increased funding in the new knowledge areas like biosciences.

Coming from this national context of changes driven nationally and globally, this section will now present data about Sweden. Firstly, an overview of the actual firms included within the Swedish biotech–pharma sector is given, based on BioSweden. Secondly, an overview is provided of the changing trends of interactions between universities and firms within Sweden, but presented from the perspective of the universities. These trends are based on an analysis of co-authorship of scientific articles, broadly defined as being related to biotechnology/biosciences. Of course, scientific publications are only indicative of the development of a particular type of knowledge.

The first overview is of trends in the population of firms within the Swedish biotech–pharma sector. This data is taken from BioSweden, a Swedish language database developed by the authors. BioSweden

[8] Of course, this type of data does not allow us to examine different explanations for our observed differences in results. Explanations could be that P&U uses alternative and less formal arrangements, that their collaboration is less reported in the international media and/or that company indeed engages in a much lower total number of agreements.

Table 1
Founding date for the 105 Swedish biotech–pharma firms existing in the year 1998 and 2000 (BioSweden)

1998	4	1988	6
1997	5	1987	8
1996	8	1986	3
1995	6	1985	3
1994	4	1984	8
1993	2	1983	4
1992	3	1982	3
1991	7	1981	1
1990	5	1980	0
1989	6	Before 1980	19
All years			105

Table 2
The size distribution of the 105 Swedish biotech–pharma firms (BioSweden)

Size of firm (employee)	Number of firm
0	19
1–9	38
10–49	25
50–499	15
>500	5

Unfortunately it was impossible, so far, to get information about number employees for 15 of these firms concerning the year 1998. For 12 of these firms we used data about number of employees the years 1995–1997. For three of the firms we have not been able to get any information of number of employees 1995–1998.

identifies 105 firms based on the three criteria and based on having existing in 1998 as well as 2000.[9]

The *first trend* is a steady influx of new firms. This population thus includes all firms that 'survived', from their date of incorporation (e.g. any year up to and including 1998) as well as a firm in 2000.[10] This provides us an overview of entry of new firms, where the founding dates of these 105 firms can be found in Table 1.[11] Information is given on the number of entrants per year, for all these firms.

Interestingly, as Table 1 shows, the entrance rates for the total population of Swedish biotech–pharma firms which survived is fairly steady. After 1980, the rate of entry fluctuates some but is fairly steady at a low level during these years (also note that observers claim a large increase in new firms incorporated in 1999/2000 and hence not in this dataset).

The *second trend* is the lasting skewed distribution by size. The size distribution of these 105 firms is quite interesting, especially the size distribution within the total population. In terms of total numbers, the fact that Sweden has 105 such firms seems very impressive, relative to European trends with, perhaps, the exception of the UK (Ernst and Young, 2000). In fact, however, many are extremely small. Thus, despite the apparent large numbers of firms involved in some types of biotech–pharma R&D in Sweden, very few firms are large or even medium sized firms while many are very small firms. While this skewed distribution is true in absolute numbers, the size distribution seems rather normal within many sectors for Sweden (and hence should not be taken as a unique characteristic of this sector).

Table 2 shows that only seven firms have more than 100 employees. Moreover, 57 firms have less than 10 employees, and of these very small firms, 19 have zero (full-time) employees. Still, these firms must be considered potentially active in the development of knowledge relevant for innovations. In the Swedish context, these 19 firms are most likely consulting companies developed by individuals (assumedly university researchers) with other full- or part-time jobs.[12] Thus, despite having zero full-time

[9] This is a new database, built up through the ESSY project and through parallel research. This database has been built up to include datapoints about the firms at the years 1975, 1981 and 1995–1998. The material used relies on intensive and systematic search of existing sources of literature, including the previous Nordic Biotech Directory, Nutek reports, questionnaires sent to all Swedish firms suspected of being involved in biotech in any way, and searching the Swedish language business and technical press. Nutek (2000) and Vinnova (2001) also identified firms which were active in the biotech area in Sweden 1998. They found 116 so-called biotech firms using somewhat different boundaries of the bio-pharma sector. Nutek (2000) study excludes some of the largest firms in the bio-pharma sector and take into account firms whom produce but not develop biotech-related technologies.

[10] Other work by the authors examines the dynamics of firm entry and exit in 1998 as compared to 1975 and 1981.

[11] Note that only the founding date of the firm as a whole is used as criteria to be in the database. Although we know that all firms engaged in biotechnology–pharmaceutical research in 1998, there is no information about when these firms began engaging in in-house biotech–pharma research.

[12] University researchers have the rights to both own their own patents individually and to consult on up to 20% of their total work time. Both of these rights are conferred to the individual researcher, and neither provides IPR or financial returns to the

employees, the firms can play a role in selling specialized biotech–pharma knowledge, but their economic activities undoubtedly vary greatly from firm to firm and within a firm in different years. They are therefore included.

The *third trend* is strong geographical concentration. The geographic distribution of firms is also important. In terms of the importance of co-locality for the existence of firms, then there is a clear concentration of firms in the four major regions of scientific medical research.[13] To demonstrate this importance, only four firms of the 105 firms are not located in the dominant four major regions. The other 101 firms are located in four of the major Swedish metropolitan areas, in order of dominance: (1) Stockholm–Uppsala; (2) Skåne, which is the southern region including Lund and Malmö; (3) Gothenburg; and (4) Umeå. In terms of number of firms, Stockholm–Uppsala dominates with 48 firms, followed closely by Skåne with 31 firms. After these two regions, Gothenburg has 13 firms and Umeå with 9. Interestingly, the metropolitan area of Norrköping/Linköping is not an important area to locate firms, leading to the observation that not all Swedish metropolitan areas with research also have a large number of firms. One explanation is that systems-intensive engineering firms such as Saab and Ericsson have traditionally dominated this region. However, Linköping University has a history of research strength in biosensors and is now moving into biotechnologies research, not least through 16 new professors.

The second overview of fundamental changes within Sweden is given from the university perspective to firms, because basic research is an extremely important input to changes internationally. This section reviews an analysis by Nilsson et al. (2000), Sandström et al. (2000), and Vinnova (2001), which examines the publication of papers, including co-authorship between Swedish universities, Swedish firms, and international partners (universities or firms). Note that co-authorship of scientific papers similarly requires active participation by both parties.[14] Publication is a result of interaction which can be counted, however, rather than an intention to collaborate. While Nilsson et al. (2000) mostly analyze the Swedish perspective (and Swedish collaboration) in their study, this section reexamines their results in a wider, internationally perspective. The following five trends are evident.

The *first trend* is that the subset of population defined as 'smaller firms which also write scientific papers' tend to collaborate with regional actors although this result requires some further testing. This implies that the subset of small firms which write papers also tend to do so with partners located close geographically. One explanation for this trend is very likely close personal and work relationships. Moreover, as with international trends, some of the small Swedish firms are linked in various ways to researchers working both at the university and at that firm and/or to researchers which recently left a university department to move to a firm.[15]

The *second trend* is that the two large pharmaceutical companies previously dominated co-authorship of papers with universities in Sweden. The current MNCs of Pharmacia Corp. and AstraZeneca emerged from the two Swedish pharmaceutical companies of Pharmacia and Astra (which each followed upon previous merges within Sweden). Particularly in the time period before 1986, both of the two large pharmaceutical companies had extensive co-authorship of scientific papers with Swedish universities. Over time, the two MNCs continue to dominate in total numbers of co-authorship, but their interactions within Sweden are decreasing.

university directly.

[13] Note again that the BioSweden database includes only biotechnology–pharmaceutical firms, and thus do not include specialized biotechnology firms in other areas like environmental engineering or agriculture. We are only analyzing medical and/or human health care biotechnologies.

[14] Nilsson et al. (2000) thus present a bibliometric analysis from 1986 to 1997 about the science base for the Swedish biotech–pharma sectoral system. The definition of the biotechnology innovation system is: 'the actors that develop, produce, analyse or use biological systems on a micro, cellular or molecular level and the public and private institutions that affect their behavior' (Nilsson et al., 2000, p. 8). This source differs from the other two in that: (1) it uses a different indicator for alliances; (2) it only gives a picture of Swedish to Swedish alliances; and (3) it covers a long-time period. Bibliometerics are based on the publication of scientific papers as an indicator of output (through quantity) and as an indicator of quality (through citations and impact analysis). Like collaborative R&D, co-authorship indicates an active relationship between the actors involving new knowledge.

[15] Remember that in the Swedish context, forty-four of the Swedish firms identified above contain less than four employees.

The *third trend* is that these two large pharmaceutical companies mainly co-author papers with researchers at those few Swedish universities which have major medical research and/or related biochemical or chemical engineering. The four largest and best known universities for relevant fields include Karolinska Institute (Huddinge/Stockholm), Uppsala University (just north of Stockholm), Gothenburg University/Sahlgrenska, and Lund University (near Malmö).[16] The two major pharmaceutical companies and these four major universities dominated the overall Swedish scientific output in medical biotechnology as well as the number of interactions between firms and universities. Even within this small group, however, Karolinska Institute is clearly the dominant actor in terms of scientific output, and Stockholm–Uppsala is clearly the dominate region. This shows that one very strong scientific center exists in the national context, but with others also being poles. Moreover, the two large companies tended to write articles with researchers at those strong scientific centers and not with the newer, geographically distributed colleges.

The *fourth trend* is that the two large pharmaceutical companies reduced their co-authorship of scientific papers with Swedish universities in the period 1986–1997, relative to the previous period. This is assumedly related to each of the large Swedish pharmaceutical companies being merged within much larger multinational companies, which in turn source science internationally. However, 'it was also found that the two pharmaceutical companies had not replaced the Swedish collaboration with international collaboration, which might have been expected' (Nilsson et al., 2000, p. 34). In other words, according to the Nutek–Vinnova data, the companies are not necessarily moving their biotech related scientific research abroad, it is more that the two large firms are doing less totally of co-authorship of scientific papers with universities.[17]

The *fifth trend* is that while these two large pharmaceutical firms reduce their direct co-authorship with Swedish universities, a larger number of smaller biotech–pharma firms have started to co-author, especially with geographically close universities (nevertheless, the total number of co-authored articles between Swedish universities and Swedish firms is decreasing over time). The quantity of direct collaboration between universities and firms within the national boundaries (as measured through published scientific papers) has decreased, and is mainly due to behavioral changes in a few key actors.[18] Still, a larger number of firms are interacting with the universities, at least to participate in scientific publication.

Even with these five trends, however, the importance of interaction between Swedish firms and Swedish universities should not be over-emphasized. In fact, the partner of a university paper is most likely to be another university.

Thus, a solid trend is that university researchers are much more likely to collaborate with international researchers than with firms. International co-authorship was a much more common occurrence than collaboration between a national firm and a national university. Only 7% of the total cohort involved co-authorship between a university and a firm. In contrast, almost 30% of the articles analyzed were co-authored with someone in another country. USA is by far the most common co-authorship partner, with a mean of 12.3%. The next highest is UK with 4.3%, then Germany with 4% (Nilsson et al., 2000, 17th table).

Thus, this section has identified a number of characteristics and trends signaling change within the population of firms defined as the Swedish biotech–pharma sector. Major changes are underway within Sweden, with the MNCs apparently moving more and more abroad, with strong pushes of government and research policy into biotechnologies/biosciences, and with new firms being started in recent years. Clearly, the vast majority of firms (101 of 105) are co-located with the major centers of bioscience related research in the country, but that type of co-location is expected in a scientific-based sector in such a small, sparely

[16] With the exception of Umeå, these universities are located in the same geographic regions as where the biotech–pharma firms are concentrated.

[17] The relative value of this indicator may be discussed, particularly if behavior is changing. The indicator may be picking up a trend whereby firms put less time/effort on scientific papers with universities because this has less value than previously. Or the firms' behavior may have changed such that they still work with universities but choose not to publish.

[18] This collaboration may be a sign of there being more spin-off companies, which could have been stimulated by growing amounts of domestic venture capital and/or from the reductions in the larger MNCs 'freeing up' competent personnel to start new companies.

populated country. The question of this article is not whether firms are located in the same region as university research—even if much should be done on the hypothesis underlying the assumption that they should be co-located in this sense. Instead, the question here is instead whether firms also formally collaborate with co-located partners and if not, with whom they engage in formal knowledge collaboration.

4. Patterns of regional, national and international collaboration

This section analyzes the existence, frequency and direction of formal knowledge collaborations involving at least one Swedish biotech–pharma actor, including both the major research centers and the firms. This section allows us to identify both the numbers of collaborations (deals) as well as with whom each Swedish actor collaborates. By performing such a systematic analysis of all Swedish actors, we can identify the extent to which firms tend to collaborate regionally (including within a science park), nationally, and/or internationally. This analysis is based on one of the comprehensive database called pharmaceutical industry database (PHID), which has been set-up at the University of Sienna. It was sent up to overcome some major limitations common to all available international sources of information about R&D collaborations within the European bio-pharmaceutical industry.

As single information fonts (e.g. single databases) appears to be *partial* and *bias* toward the US, we decided to *merge* several fonts into a unified database and to *integrate* it with news from both international and local press.[19] The international databases we merged are: Recap, Pharmaventures, Windhover and Bioscan. Moreover, we searched further information in Scrip (Pharmaprojects, Scrip League Tables, Scrip World Pharmaceutical News), IBI (Institute for Biotechnology Information Historical Actions), BioCommerce (The European Biotechnology Directory), Pharmalicensing and Reuters Health publications. Finally, we combined information from the newly developed database BioSweden and collected news about science parks[20] and press releases both from companies internet sites and from press agencies (PR Newswire, Business Wire among others).

As a result of merging all these data sources, we identified 215 R&D collaborations made by 67 Swedish firms[21] or Swedish research institutes and 137 foreign partners. Of these 215 R&D collaborations, we identified both agreements among two Swedish actors (52 agreements) as well as among a Swedish and a foreign partner. These rough figures indicate clearly that national interactions are not so vital for formal knowledge collaboration in the Swedish biotech–pharma sectoral system. This

[19] This article first compared and contrasted collaboration from different sources, before merging them. We analyzed data about formal knowledge collaboration in Swedish biotech–pharma firms from two international, commercially available databases (biotech and pharmaceuticals), from one Swedish language database, and from one European innovation database. The comparison shows deficiencies in various databases. As compared to BioSweden, the two international databases provide inconsistent data about individual firms, and they also under-represent both the total number of collaborations as well as the total number of Swedish firms engaged in collaboration. While we might such expect inconsistent data for smaller Swedish firms, more surprisingly, the two international databases were the least consistent for the large multinational firms of AstraZeneca and Pharmacia & Upjohn. This discrepancy is visible even though the data was cleaned the same way in order to include only the Swedish heritage of the MNCs and the Swedish part of the merged firms during the time period. This discrepancy implies that the activities of larger European (or European/American) biotech–pharma firms may not be very accurately represented in databases—and/or that different databases are specialized to such an extent that they do not always overlap. We decided to clean and merge the data to present an overall picture here. These findings about the findings from international versus national language databases for a small country has some implications for future research. Firstly, it emphasizes the need for each article to take up a discussion about the validity of data to study non-American phenomena. Quality of data affects our ability to address certain analytical/theoretical questions. Secondly, this paper indicates the need for caution when interpreting results for small countries from international databases, including careful thought of which knowledge areas and/or sectors are likely to be covered. Thirdly, the results also demonstrate the value of new databases, which are complied from home country sources and which provide systematic and large scale material. Fourthly, biotechnology, biotechnology–pharmaceuticals and pharmaceuticals are all areas where definitions need to be made very clear (see de la Mothe and Niosi, 2000). Thus, specific definitions of the sectors are necessary for comparisons, because definitions may vary along such diverse variables as size of firms, knowledge area covered, sectoral influence, etc.

[20] As for Sweden, see http://www.swedepark.se/.

[21] In the case of multinational firms, we consider only the R&D collaborations that could be unambiguously attributed to the Swedish R&D centers and/or from the Swedish part of the firm.

Table 3
Leading Swedish bio-pharmaceutical organizations in terms of number of R&D collaborations

Swedish company (institution)	Number of deal
Amersham Pharmacia Biotech*	44
Astra AB	27
Karo Bio	16
Active Biotech	15
Oxigene Europe	8
Pharmacia AB	8
Biacore	7
BioPhausia	7
Karolinska Institute	7
Perstrop	7
Pyrosequencing	6
Medivir	6

Amersham Pharmacia Biotech is a joint venture between Nycomed Amersham (45%) and Pharmacia Corp. (55%).

is an interesting result, which clearly indicates that Swedish knowledge production is integrated into an international socio-economic system.

Therefore, this section identifies the overall patterns of interactions, based on network analysis. Our purposes are to identify the existence, frequency and direction of formal R&D collaboration, in order to ask whether co-located partners tend to interact more than others do. If they do not interact so much, then questions must be raised about the importance and type of close geographical interactions for innovation. The results presented in this section will also be used to check whether the findings in the subsequent sections hold.

Table 3 shows how many collaborations that each of the 12 main Swedish actor has, where leading is defined in terms of numbers of collaborations. Clearly, some firms have many more R&D collaborations than other firms do, as the range is from 44 to 6 agreements. Of these leading 12 organizations, however, eight leading organizations lie in the range of six to eight agreements. Note that the Pharmacia part of P&U is identified as having much lower total number of collaborations than the Astra part of AZ. Pharmacia also has less than a number of medium sized Swedish biotech–pharma firms such as Karo Bio, Active Biotech, and Oxigene Europe. Karolinska Institute is the only university or research institute which appears here as a leading Swedish actor, counted in terms of number of collaborations.

A network analysis was also performed of the linkages among national actors in the Swedish biotech–pharma system, cover collaborations in the years 1985–2000. These linkages are presented visual in Fig. 1, but the network characteristics clearly show that collaborations between national partners are not a defining feature of the Swedish system. The Swedish network appears to be quite sparse, with a density[22] of 0.010. The index of relinking[23] is well below one (0.13) attesting a general propensity to establish few collaborations with exclusive partners. Consequently, the degree of interconnection of the network is low. Despite the number of collaboration that each firm subscribe is highly disproportionate (see Table 3) no firms, or group of firms, play a central role in structuring the network (the Freeman network centralization index is about 25%).[24]

Fig. 1 presents a visual representation of the patterns of R&D collaboration by identifying the interactions involving at least one Swedish located firm and their partners, whether within Sweden or across national boundaries. Fig. 1 sorts the partners by geographical location (shape), and type of organization (color). These are sorted per partner and also coded by shape/color. Diamonds represent European partners, circles are other Swedish organizations, boxes are US partners, and triangles are all other partners. Moreover, established pharmaceutical companies (black nodes), dedicated biotechnology firms (white nodes) and public research organizations (gray nodes) have been set apart. Thus, Fig. 1 clearly shows the importance of alliances and collaboration with the USA as compared to within Sweden or within Europe. Thus, Swedish biotech–pharma firms are more part of an international or American-dominated system than a European one.

In terms of behavior of the individual actors, there are clear differences, whereby many of the Swedish

[22] For a network of N firms/institutions and M collaborations the density index is $M/(N^*(N-1))$.

[23] The index of relinking is computed as the mean number of collaborations minus one. In order to be included in our analysis, firms have to subscribe at least one R&D collaboration (free-standing firms/institutions are not considered). As a consequence, the index of relinking is a better measure of the relational intensity than the simple mean of the number of firms' collaboration.

[24] Freeman graph centralization measure expresses the degree of inequality or variance in our network connectivity as a percentage of that of a perfect star network of the same size.

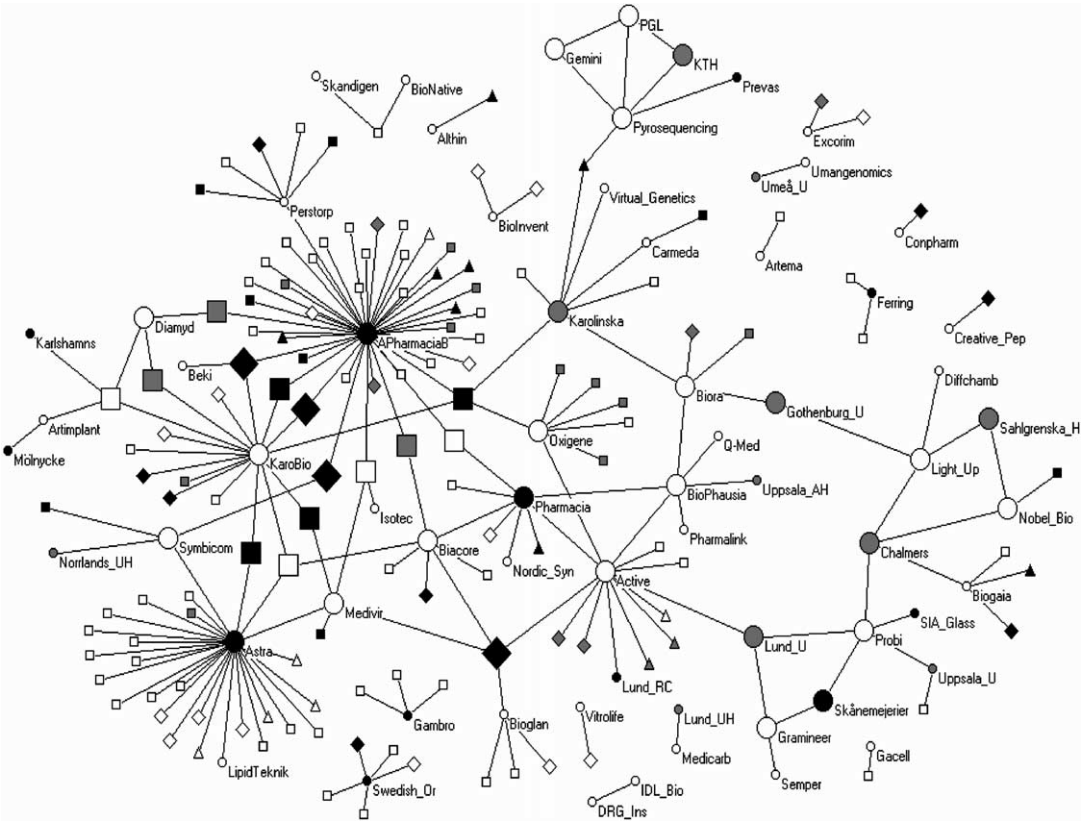

Fig. 1. The Swedish network of R&D collaborations in bio-pharmaceuticals. Shape: nationality—circles: Swedish organizations, boxes: US partners, diamonds: European partners, triangles: other partners. Color: organization type—white: new biotechnology firms, gray: public research organizations, black: large established companies. Size: critical points for network connectivity—large nodes: articulation points, small nodes: peripheral nodes.

main actors have clearly different and non-overlapping spheres of R&D collaboration. As visualized in Fig. 1 and also found in the network analysis of the data, the Swedish parts of Pharmacia, Astra and Amersham Pharmacia Biotech have very different spheres of R&D collaboration, both nationally and internationally. Thus, while the two major MNCs have little formal collaboration within the country, the two firms are also quite obviously interested in different types of partners. This undoubtedly reflects the firms' differing product profiles. Still, the lack of overlap is an interesting indication of the lack of competition between these pharmaceutical and medical devices companies.

Geographic co-location does appear to be important for one cohort, namely, smaller biotech–pharma firms located in regions of strong medical research. Geographic co-location, however, appears to be most strong within some types of scientific work and as related to some dependency relationship between a somewhat larger firm and co-located smaller firms. Thus, interestingly enough, we observe three Swedish triadic cliques: the first one (Active Biotech/BioPhausia/Pharmacia) is based on Pharmacia spin off activities in Lund and Uppsala, while the other two (Pyrosequencing/Professional Genetics Laboratory/Royal Institute of Technology and Gemini Genomics AB) include companies devoted to genomics and high throughput screening located in Uppsala. One could even say that some firms dominate formal collaboration between firms in some science parks and regions, as visible in Fig. 1. They are strong nodes for collaboration, seen in the network as a whole. Moreover, although not given in detail in Fig. 1, our data also indicates that the large international pharmaceutical

firms like Abbott, BMS, Aventis, Chiron, Novo Nordisk and Glaxo SmithKline tend to make R&D collaborations with more than one Swedish region or science park.

Thus, in terms of regional, national and international R&D collaboration, it is clear that Swedish firms tend to interact more internationally and towards the US than locally or even towards Europe. While many of the existing explanations in the literature suggest that the reason for this is to access American research and American biotechnology firms, this statement appears to be valid mostly for large European pharmaceutical firms. What our data shows is different. It shows that international partners do deals to access knowledge at small to medium sized Swedish firms and Swedish research organizations. This is a very interesting result, worthy of additional investigation.

Moreover, the network analysis shows that some small to medium sized Swedish biotech–pharma firms have a strong role in organizing interactions within their more local environment, whether defined as a science park or a region. This supports the argument that certain types of firms are likely to more bound and/or more dependent on geographically close knowledge resources. While not a surprising result in itself, the overall lack of co-location of partners for collaboration, even for locally bound firms, is an interesting and new result.

Our tentative hypotheses to explain these findings are that biotech–pharma is exceeding global in terms of both knowledge and markets for R&D collaboration—at the same time that local strengths in knowledge development are necessary to both create new scientific discoveries and to reap the economic rewards through innovations.

Of the total population of 105 firms, 31 Swedish biotech–pharma firms had at least one collaboration with other organizations (firms and non-firms) to develop and/or sell technology-related things. In total, BioSweden shows that these 31 firms engaged in 102 agreements. This result shows a much higher number of firms than an analysis done on the PharmaDeal database, which showed 10 firms engaging in collaboration. Moreover, BioSweden reports a higher total number of reported deals as well as higher number of firms engaging in such activities. Taken together, this indicates that the phenomena of collaboration for technological knowledge is more widespread among the Swedish biotech–pharma firm population and occurs more frequently than reported in international databases.

Of these 102 deals reported in BioSweden, 71 were between two firms, while 31 were between firm and university, as shown in Table 4.[25] Fifty-five of the 102 deals were between Swedish-based partners while 47 were between a Swedish-based firm and a foreign partner.

Table 4 shows that more Swedish firms collaborate and they collaborate more often than otherwise reported in international, commercial available databases. Nevertheless, this result indicates that even small and medium sized firms chose partners from the Swedish national context only about as evenly as from all other localities. After Sweden, partners are drawn firstly from USA, then the UK, then everybody else. These results show that collaboration is not randomly distributed. It is highly oriented towards a few geographical areas. Swedish partners are relatively only as attractive as all others are, which implies that there is some skew towards choosing close geographic partners, followed by Anglo-Saxon countries.

In terms of the size of Swedish biotech–pharma firms which engage in deals and in terms of whom they collaborate, BioSweden shows an interesting, and perhaps surprising, distribution by Swedish vs. international partners in firm to firm and firm to university deals.[26] Table 5 shows that the distribution of deals

[25] Here there is a methodological problem because university–firm interactions are not reported as frequent in the business press as firm–firm interactions. This has been found when interviewing biotech–pharma firms. These interviews have been done in parallel with working on the database. This has been done because of two reasons. First, it can be used to check the validity of the interactions reported in the media. The second reason is to get more in-depth information about each relation and to get greater understanding why these, and not other strategies, have been chosen.

[26] Note that the number of Swedish firm–firm interactions/relations have increased compared with Table 4. This is because every interaction/relation between two firms in this group of 31 firms have been counted twice (once for every firm). Thus, there are actually only 102 unique interactions. It is important to remember that the three largest firms are excluded (however, they exist in that sense that they interact with these other Swedish firms). With “no information about size” in Tables 2 and 5 means that we have no information about number of employees for 1998 (two firms were founded after 1998 and for two firms figures were not available for 1998).

Table 4
Total number of technology deals by Swedish firms, by partner (January 1993–May 2000, BioSweden)

Number of interaction	With other firm					With university				
	Sweden	US	GB	Other[a]	Total	Sweden	US	GB	Other	Total
31 Swedish firms	32	21	7	11	71	23	4	3	1	31

[a] For four of these 11 interactions the nationalities are unknown.

Table 5
Number of deals involving Swedish firms, divided by size (BioSweden)

Number of employee	Firm to firm		Firm to University		Number of firm
	Swedish	International	Swedish	International	
0	1	5	1	0	1
1–9	5	1	6	4	6
10–49	14	10	7	0	10
50–499	16	17	4	4	8
>500	4	4	3	0	2
No information about size	2	2	2	0	4
Total	42	39	23	8	31

involving the development and/or sales of technological knowledge, by size of firm and according to type of partner.

Three conclusions can be drawn. The first one is that firms are more likely to collaborate with geographically co-located universities as compared to international ones. This result is not so surprising, given the international results. Still, it leads us to question a claim often made by firms, namely that they actually choose to collaborate with the best scientists anywhere. Secondly, even very small firms (according to size of employees) can be active in technological development and therefore need to be included in analyses of sectoral systems of innovation. Thirdly, if we examine size, those firms with 50–99 employees play a much more active in deals than firms with 20–49 or 10–19 employees. Firms sized 50–99 employees also showed up in the international databases, while the smaller ones did not.

In relation to the specific subset of deals involving co-development of technology, BioSweden reports 48 deals. The distribution of chosen partners is even less oriented towards the Swedish national context than for the above analysis of all deals reported in BioSweden. Of the 48 deals involving co-development of technology, 19 are between a Swedish firm and a Swedish university; 14 are between two Swedish firms; 11 are between Swedish firm and international firm; and four are between Swedish firm and international university. This subset resembles the overall distribution of deals within the whole population. Most notably, however, the two multinationals of AstraZeneca and Pharmacia & Upjohn are involved in a grand total of one co-development deal with another Swedish firm. Thus, even BioSweden shows almost no direct and formal knowledge collaboration between the largest firms and all other firms in the Swedish biotech–pharma sectoral system.[27]

In summary, the evidence presented here clearly shows that co-location in the same region or the same country is not a major characteristic of Swedish knowledge collaboration in biotech–pharma. It exists and is more frequently reported than a random distribution, but it still not that common. Taken as evidence together, Swedish to Swedish deals are only about as likely as deals with anyone else, which should lead to some questioning about the relative importance of co-location. Even more strikingly, the existing co-location deals are most likely to be between a Swedish firm and a Swedish university, indicating the probable importance of having a strong national basic scientific community. Relative to firm–university

[27] That they are important to the national system of innovation for other reasons and in other ways is not under dispute. But our data shows they are not important in this way.

deals, deals involving formal knowledge collaboration are less likely to be between two Swedish firms. This indicates that firm to firm co-development and/or sales of technological knowledge are based on international marketplace more than on interactions with local partners. The deals that are the least likely to occur are those between the largest Swedish firms and the small and medium firms in the population. This indicates that the largest firms are truly international firms and do not seem to have much connections with the Swedish development of, and markets for, knowledge.[28] Some small and medium sized firms, however, play a role in linking other small and medium sized firms together in nodes.

5. Conclusions

Despite the discussion of myriad relations between universities, biotech firms and pharmaceutical and medical device firms in the international biotech–pharma sectoral system, much of the empirical material about biotechnology in general and biotech–pharma sectoral systems has been strongly based on the American experience, with a few notable exceptions.[29] Within this state of empirical and theoretical knowledge, this article has had two main aims. The first aim is to enlarge our empirical knowledge of one European biotech–pharma sectoral system, by focusing on the case of one, knowledge-intensive country, namely, Sweden. The second aim is to address the theoretical question about the relative importance of geographic co-location for formal knowledge collaboration relative to innovation in general. The rest of this section discusses the Swedish case, relative to this question, by analyzing co-location relative to different types of formal collaboration.

As to the existence of collaboration as a phenomena, the BioSweden database, combined with the international databases, shows that a larger number of Swedish biotech–pharma firms engage in formal knowledge collaboration to a great extent and with greater frequency than would be expected based on only international data. This result is important because it shows that Swedish biotech–pharma firms are clearly involved in active, technological collaboration and not just selling knowledge to leverage economic (and complementary) assets. They are knowledge partners, not just market actors.

Related to the importance of collaboration for innovation, Fig. 1 shows that American firms engage in collaboration and licensing for technological knowledge with Swedish biotech–pharma firms (as to a lesser extent, do European firms). Large American pharma also has Swedish biotech firms as knowledge partners. This result is interesting because in some literature, American biotech firms are portrayed as the actors, which sell this type of knowledge for European pharmaceutical firms. Our results show the contrary flow also exists. In other words, international firms are also coming to Sweden to find competent partners for technological development and/or sales—or to access their specialized knowledge bases of Swedish biotech–pharma firms of all sizes. This links to questions raised below about the relative quality of the Swedish scientific base as well as the relative value of the biotech–pharma knowledge and techniques within the Swedish firms.

The other theoretical issue relates geographical co-location to collaboration for active knowledge development. According to the analysis presented here, co-location of partners in the region and nation for formal knowledge collaboration is somewhat less common than might be predicted within the systems of innovation approach. Close collaboration occurs,

[28] Of course, it also indicates the need to empirically examine whether, and to what extent, that regional interaction and interactions in these knowledge fields may occur in different ways than through market transactions for R&D projects.

[29] Such as Senker, (1998). As to existing empirical bias towards Anglo-Saxon experiences, two alternative explanations could be put forth for this bias. One would be that the US, followed by the UK, so dominates the development and commercialization of these types of knowledge that the American phenomena is by and far the most important to understand. This first explanation rests on arguments about the overwhelming importance of both of American biotech firms and medical science. The USA has a very large number of dedicated biotechnology firms, such that Ernst and Young (2000) estimate that biotechnology companies directly generates 151,000 jobs and about US$ 11 billion in R&D spending. Moreover, the quantity and quality, of American medical-related research is considered quite high, even per capita. The other, alternative explanation is that existing data sources give us much more information about the American experience, thereby leading to studies of observable phenomena. In other words, it is a matter of looking for the key under the lamppost, rather than looking for the key where it would most likely be found. Thus, we know much about American biotechnology because many studies have been done, and not only because of its premier position.

but only about as commonly as all other types of deals, even according to the BioSweden database.[30]

Beyond these trends, one other result stands out and must affect our analysis of the 'Swedish-ness' of any overall Swedish biotechnology–pharmaceutical innovation system. There are two large MNCs in the pharmaceuticals sector, which have strong Swedish heritages. These two actors are not engaged in formal knowledge collaboration with the rest of the national firm population, and they are also reducing their involvement with Swedish universities over time. This raises questions about the extent to which these specific firms can be said to interact with the national knowledge infrastructure as well as, more abstractly, how to interpret the interactions of these types of firms within a national or sectoral system of innovation.[31] It also emphasizes the international nature of biotechnology–pharmaceutical sector, this time from the perspective of the large (and increasingly international) firms.

Interestingly for the rest of the small and medium sized Swedish biotech–pharma firms, the propensity to collaborate with geographically co-located partners differs depending on whether the collaboration is firm to firm, firm to university, or university to university. The overall finding is that geographical co-location is less important for firm to firm deals or for university to university co-authored papers than for firm to university deals. In other words, a large number of Swedish firms tend to collaborate with Swedish universities rather than international universities. Thus, the relative degree of co-located partners—as opposed to national or international partner—differs relative to the type of partner.

Small Swedish biotech–pharma firms are more likely to write scientific papers in collaboration with Swedish universities. Many firms do not engage in this type of scientific production, of course, but those who do demonstrate close geographical links. Although these are preliminary results, this trend at least be calls into question the firms' claims to always buy the best quality science, not the closest. Again, two possible explanations are possible, depending on the direction of causality and of other explanatory variables. One explanation is that Swedish biotech–pharma firms just collaborate with the nearest scientific partners after all due to reasons such as tacit knowledge, regional labor market, trust, etc. May be these factors—which have been advanced in evolutionary economics and/or economic geography—mean more than scientific quality for these purposes. The other explanation would be that these firms do purchase the highest quality international science. The firms are instead started here in order to take advantage of geographically close scientific specialization. These firms are usually started by scientists from those universities, and thereby continuing interaction is to be expected. This also implies a direct link between actors, where geographical proximity matters. Moreover from an economic perspective, this result implies that firms are started to create economic value from certain types of knowledge. Or, that the firms interact with local partners, due to their advantages in obtaining information about the economic value of geographically close scientific specialization. These explanations would help explain why small Swedish biotech–pharma firms would choose to collaborate with close university partners rather than distance ones.

If firm–university interaction reflects specialization in knowledge and advantages in spotting economic opportunities, then one would predict a very strong overlap in techniques and/or knowledge area between the firms and the scientific strengths of the close geographically located universities.[32] Analyzing and interpreting these two alternative claims requires further empirical studies and untangling the directions of causality.

For the other two categories of 'firm to firm collaboration' and 'university to university co-authored papers', close geographical co-location is not that important to find partners to jointly develop knowledge. The Swedish biotech–pharma firm's choice to have a Swedish partner for formal knowledge collaboration

[30] The two international databases and one European innovation database show it as hardly occurring.

[31] One proposal is to develop a perspective of a dynamic firm in a system of innovation, and then analyze how a large firm interacts with multiple national systems of innovation (McKelvey and Texier, 2000).

[32] The first hypothesis requires intimate knowledge of personal relations, and could be addressed through following the networks of a small cohort of particularly active researchers. The second hypothesis can be tested empirically through indicators combining and comparing scientific and technological strengths through patents, technological fields, bibliometrics and citations.

is more common than a random distribution would suggest, but it is still only about 50% of deals.

The small Swedish biotech–pharma firms demonstrate their international patterns of formal collaboration, as well as local and national ones. The explanation here is probably due to the global division of knowledge labor, where actors specialize and then collaborate. For university researchers in the fields, they usually prefer international partners for co-authorship.

At the regional and national levels, there are some Swedish cliques around specific and specialized knowledge areas, and these may include large companies and/or universities, as well as small firms. Some firms also act as nodes to interact with multiple partners in the same region, usually even within the same science park. As stated previously, the local strengths in knowledge development are necessary both to create new scientific discoveries and reap economic rewards—but at the same time as both science and these knowledge markets are exceedingly global. Even so, our results indicate that relative small firms in the size of 50–99 employees are active in the Swedish context—but also in the international knowledge markets. Generally, however, the Swedish network is fairly sparse, indicating a general propensity to establish a few collaborations with exclusive partners. In terms of the large MNCs, the Swedish parts of the three largest companies of Pharmacia, Astra, and Amersham Pharmacia Biotech tend to have very different spheres of collaboration. This result reflects their differing product profiles, thereby also emphasizing the specialized division of knowledge labor relative to final products.

After Swedish partners, the results show that the Swedish biotech–pharma firms and Swedish-based researchers in related fields have a skewed interaction with partners from Anglo-Saxien countries. Both Swedish biotech–pharma firms and scientific researchers appear to clearly prefer American, followed by British, partners than any other international partner. This result indicates the relative importance of actors in Anglo-Saxien R&D as partners, thereby assumedly also influencing the types and directions of R&D and exploitation of innovations. Many reasons could be speculated upon for this skewed distribution of collaboration, including the cultural and language orientation towards US English, the long-term research exchanges, industrial interactions in these sectors, etc. Note, however, that this American, then British, dominance in partners holds particularly between formal collaboration between the same types of organizations, e.g. firm–firm and university–university.

In summary, our analysis of Swedish co-location for formal knowledge collaboration in biotech–pharma exhibits simultaneously local, national and international patterns. Some variables which help explain the differentiated patterns are the types of Swedish actors involved, as well as the types of knowledge being developed and/or exploited. The network is not particularly Swedish, and the actors and their interactions are highly specialized into different knowledge and product areas.

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