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The changing pattern of industrial scientific research collaboration in Sweden

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Abstract

Fostering closer ties between industry and universities in order to achieve better technology diffusion has become one of the major political issues in Sweden. However, little is known to what extent industries participate in scientific research, what their contribution is to knowledge production. Against the background of the contemporary global changes that are taking place in knowledge production, an attempt is made to capture the changing pattern of industrial scientific research activities in Sweden. Like many other countries Sweden is changing its pattern of conducting research. Private firms are being increasingly integrated into national and international academic networks and collaborate with a variety of players. Cooperation and networking are proving to be ideal forms of scientific production for firms. We show that knowledge production is to a decreasing extent a self-contained activity in Sweden, and that through scientific co-authorships firms, primarily foreign firms, are becoming important players in Swedish industrial scientific research.

Keywords: Sweden; Industrial scientific research; Internationalization; Collaboration

1. Introduction

The creation of programs that will foster closer ties between industry and universities and achieve better technology diffusion has become one of the major political issues in Sweden (Organization for Economic Cooperation and Development, 1996b). Discussions on how to improve the interaction between the business community and higher education have been intensified (The Royal Swedish Academy of Engineering Sciences, 1994; Swedish Ministry of Education and Science, 1996). The recent Swedish R&D policy of 1997–1999 emphasizes the need for university researchers to be more socially oriented and encourages them to seek collaboration with other organizations in their environment. Support for technology diffusion in Sweden mainly takes the form of programs aimed at encouraging closer ties between industry and universities. The latter receive about two-thirds of government R&D funding. However, industry accounts for 74% of the total R&D funding in Sweden. Several mechanisms for providing structural and economic prerequisites have been introduced. For example university-owned holding companies for patenting and commercialization of research results are one of the latest creations. With

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the major objective of promoting knowledge-intensive production in Sweden and increasing cooperation and mobility of researchers between academia and industry, NUTEK has created 30 industry-related research centers, so-called competence centers, affiliated to universities. They are intended to operate for 5 to 10 years and are funded by the participating firms (1/3), the participating universities (1/3), and NUTEK (1/3).

Some facts about how Swedish industry is creating ties with the universities are easily available. Budget statistics reveal that research funding from the private sector to the universities is currently increasing. This means that scientific collaboration is intensifying between the industrial and academic research communities (Research and Development in the Higher Education Sector 1993/95 Statistics Sweden, 1996). Mobility data also describe some aspects of increasing interactions between industry and academia (The Swedish National Board for Industrial and Technical Development, 1995). However, how industries participate in Swedish scientific research—what their contribution is to the knowledge production in Sweden, how they interact with national and international universities—is as yet little known. These aspects may have been analyzed, but they have not been quantified or measured.

In this article, we aim to describe industrial scientific research activities in Sweden. We will attempt to identify firms—Swedish and foreign—participating in Swedish scientific publications and describe their contribution to knowledge production. Against the background of the changing environments in which knowledge production is taking place in the industrialized countries, we aim to examine how industrial scientific research stands in relation to the total scientific activity of Sweden. We will first give an overview of the global changing situation of scientific research focusing on the growing trend towards internationalization and collaborative activities. Second, we will quantify the industrial scientific research activities of Sweden by use of bibliometrics, present the major participants, and examine tendencies. Third, we will investigate the internationalization of firms and describe how networks are expanding within the Swedish boundaries and beyond. Fourth, the trend of firms shifting from in-house research to cooperative ventures will be examined. Fifth, we will analyze the advantages of cooperative research in comparison with the in-house research conducted by firms.

We aim to provide an overview of the participation of firms in Swedish scientific activities and to establish a state-of-the-art description of Swedish scientific research measured on the basis of scientific publications. Some studies using bibliometrics have already been presented in Sweden (Okubo et al., 1992; Swedish Natural Science Research Council, 1995; Melin, 1996; Melin and Persson, 1996; Persson et al., 1997). But bibliometric analysis of industrial research is rare (Callon and Laredo, 1995; Tijssen et al., 1996; Hicks and Katz, 1997a,b; National Science Foundation, 1998). Katz et al. (1995) have carried out a comprehensive analysis entitled *The Changing Shape of British Science*. Our study uses a similar bibliometrical approach. However, while Katz focused on a descriptive overview of various sectorial scientific trends in the UK, we will examine the scientific activity of the industrial sector of Sweden with special emphasis on the international publication patterns.

2. The changing pattern of R&D activities

Contemporary global changes in science and technology were perceived by Gibbons et al. (1994) as the emergence of a new mode of knowledge production, described as 'Mode 2'. They argued that fundamental changes are taking place in the ways in which scientific, social and cultural knowledge is produced, and that ''a distinct set of cognitive and social practices'' are emerging alongside the traditional mode. Knowledge production is carried out in non-hierarchical and heterogeneous organizational forms and includes a wider, more temporary and heterogeneous set of players, collaborating on a problem defined in a specific context. Mode 2 is characterized by the close interaction of many players and cooperative efforts constitute one of the crucial factors of knowledge creation, which is thus becoming more socially 'accountable'.

Research is now pursued not only at universities, public and private research institutions, and industrial research laboratories, but also in think tanks and consulting firms. Basic research, was earlier considered expensive, risky, and uncertain and was not of

an immediate interest to firms. Now, however, there are numerous reasons for firms to perform basic scientific research and to publish their results in scientific articles. Rosenberg (1990) argued that firms performing basic research may expect to acquire first-mover advantages and such research may also provide an admission ticket to a network for exchange of information. This network may be a way of attaining access to first-class research laboratories, participation in international conferences or publication in scientific journals. Since these contacts have to be kept at a scientific level, firms need to employ and train sufficient number of scientists. Second, firms often need to engage in basic research in order to better understand how and where to conduct research of a more applied nature. Third, the existence of a large market such as government military procurement contracts influences the R&D decisions of private firms that want to improve their visibility and eligibility. It is also argued that successful basic research projects give prestige to a company both in the business sector and the academic sector (Hirano and Nishigata, 1990). The improved reputation will not only enhance the company's credibility, but may help to establish the social appreciation that is necessary for the company to smoothly develop business activities.

The same arguments apply to scientific publication by industries (Nelson, 1990; Hicks, 1995). Industries which earlier rarely published research results, now participate more actively in the science and technology circulation and diffusion system (Godin, 1996). Publication of articles enables firms to demonstrate their competencies. Kobayashi (1997) showed that firms participated in more than 40% of the publications in the field of electricity and machinery in Japan. In the case of Sweden, 17% of the total scientific publications in the field of engineering and technology were generated with industrial participation in 1994. Industry is thus becoming one of the important participants in the knowledge production of a nation. As markets become segmented and demand more technologically sophisticated solutions, firms must become more directly involved in knowledge production (Gibbons et al., 1994).

Another trend among researchers is that they tend to collaborate more frequently in the publishing of articles. Cooperation between scientists is also developing beyond the institutional and national boundaries into the international arena (Crawford et al., 1992; Okubo et al., 1992). Moreover, multi-lateral collaboration is rapidly expanding. In Sweden, for example, the publications produced by authors from more than three countries increased from 17% of the total Swedish international publications in 1986 to 25% in 1994. Similarly, collaboration between more than five countries increased from 3.7% to 5.5%. This phenomenon is probably largely due to the Swedish participation in EU research programs.

Price (1986) once argued that collaboration arises more from economic than from intellectual dependence and that its effect is ''often that of squeezing full papers out of people who only have fractional papers in them at that particular time''. Firms, where flexibility and response time are the crucial factors, are by no means exceptions to this trend (Okubo, 1995; Hicks et al., 1996). It is argued that when a firm needs to build its capability, it often seeks competencies in universities (Hicks and Katz, 1997a). Rosenberg and Mowery (1989) list three advantages of industrial cooperative research. First, it diminishes the problem of limited appropriability of research results, as R&D cooperation among firms lowers the costs for each individual firm at the same time as more results become available. Second, cooperative research programs allow participants to monitor developments in specific technologies to a greater extent than to in-house research can do. Third, cooperative research lowers the risk of wasteful duplication of research activities by competing firms. It also has the effect that firms can continue to specialize in particular areas and use the competence of other organizations when needed.

Collaborative ventures represent a considerable shift away from in-house R&D (Rosenberg and Mowery, 1989). Such R&D is expensive and the capability of maintaining it is limited. Corporate R&D laboratories have in recent years emphasized the creation of links with external sources of knowledge since this facilitates successful innovation (Freeman, 1991). Ability to commercialize knowledge nowadays means that firms often have to play a part in its production, which in turn implies participation in a broader collaborative effort (Gibbons et al., 1994). Successful practice of science depends not only on creative ability but also on active participa-

tion in collaborative projects. As Callon (1994) argues, the most important result of scientific activity is to produce heterogeneous networks. Firms are assimilating this pattern, they engage in networking and in creating linkages, not as a substitute for internal R&D, but as a complement. In this regard, R&D is an absorptive capability, a means of learning from others.

Against the background of this changing R&D environment in industrialized countries, we shall try to capture the changing pattern of Swedish scientific research, with a special focus on industrial scientific collaboration.

3. Industrial publications

In this article a bibliometric approach is used, i.e., the scientific performance of countries and institutions is measured by their production of scientific publications. The underlying assumption of this approach is that the result of scientific activity is knowledge and that this knowledge is expressed in the form of 'literature' (Okubo, 1997). The volume of publications therefore indicates the level of scientific activity of a nation or a research institution. It does not, however, measure all research efforts. The following definitions will be used.

Swedish publication signifies any publication that includes at least one author from a research institution located in Sweden.

Industrial publication signifies any Swedish publication connected with a Swedish or foreign firm. An industrial publication may be produced by one firm alone, by several firms or by one or more firms in collaboration with public research institutions and universities. In order to highlight international activity, we have classified the industrial publications of Sweden into the two following categories.

(1) *Domestic industrial publications* (DIP)—publications with only Swedish connections and with at least one author from a *firm located in Sweden*. This includes Swedish firms and foreign subsidiaries of firms located in Sweden. A firm located in Sweden may produce DIP on its own or through collaborative efforts with Swedish research institutions.

(2) *International industrial publications* (IIP) are the sum of the following two groups of publications: (a) IIPa—co-authored publications which have at least one author from a *firm located in Sweden* who collaborates with industrial or academic *authors abroad*; (b) IIPb—co-authored publications which have at least one author from a *firm located outside of Sweden* who collaborates with *authors from Swedish academic institutions*. The word 'firm' here denotes a subsidiary of a Swedish firm located abroad or a foreign firm located outside Sweden.

Thus, the total industrial publication of Sweden comprises: DIP + IIPa + IIPb. This classification makes it possible to study the activities both of Swedish firms and of foreign firms operating in collaboration with Swedish academic institutions. Industrial publications enable us to measure the entire *national and international industrial influences* on Swedish scientific research activities. However, the classification does not consider the research activities of subsidiaries of Swedish firms *located abroad*, unless they collaborate with Swedish institutions.

The main data used in this study is extracted from the CD-ROM (1986 and 1994) of the Science Citation Index (SCI) database produced by the Institute for Information Science in Philadelphia, USA. This database has several advantages compared to other databases. First, the SCI is the only existing scientific database established according to strict citation index criteria. It covers the scientific journals that are most widely read, recognized, and influential in the world, as measured by their citation indices. Second, the SCI database covers a large area of science and is general in scope. Third, the SCI records the affiliation (research laboratory address) of the author or authors of each publication. This unique characteristic of the SCI enables us to identify collaborating research institutions and to describe scientific networks.

Research collaboration is, in this study, identified as *co-authorship of scientific publications* covered by the SCI database. Among the various types of publications registered in the SCI, we include only articles, notes, reviews and letters. We consider these publications appropriate for measurement of scientific merits (Schubert et al., 1990).

We started our study by identifying the firms or similar organizations in the Swedish publications

extracted from the SCI CD-ROM database. Unfortunately, the denominators that indicate firms (Ltd., BV, Inc., SA, etc.) are very often eliminated in the database and abbreviations instead of full names are used for organizations. There are also numerous typographical errors. We used the Swedish UC-select database [1] to check Swedish firms and a close examination of these firms was conducted by NUTEK in Sweden. For foreign firms, various embassies (in France) were of great help in classifying the organizations of their countries. Nevertheless, it should be noted that the set of firms examined is not exhaustive. About 40 organizations which could not be identified were excluded from this study. The data thus consists of a smaller number of firms than would have been the case if every single organization could have been identified. Firms are grouped and named according to their situation in January 1997. Kabi, Pharmacia and UpJohn were, for example, grouped as Pharmacia & UpJohn.

'Unit' signifies *a research group* of a firm, university or any other research institution. It is identified by the address that an author gives in a publication. If seven authors belonging to three different departments of a single institution collaborate, the resulting publication will be a joint work of three research units. One firm, university or public institution may therefore hold several units. In the study, 517 units were identified in 413 firms. Astra, for example, had 16 units located all over Sweden and abroad.

4. Results

4.1. Industrial publications in relation to Swedish Scientific Production

Of all OECD countries, Sweden (mostly firms) spends the highest proportion of its GDP on Research and Development (Organization for Economic Cooperation and Development, 1996a). Sweden is one of the largest science producers in the world, ranking as the 12th or 13th largest producer in the 1980s and 1990s and accounting for approximately 1.89% of the world's [2] total production of scientific publications.

Table 1
Swedish publications in the SCI (1986 and 1994)

	1986	1994
Total Swedish publications (1)	8670	11,002
Industrial publications (2)	672	915
2/1 (%)	7.8%	8.3%
Domestic Swedish publications (DSP)	6743	6956
Domestic industrial publications (DIP)	447	414
DSP/DIP (%)	6.6%	6.0%
International Swedish publications (ISP)	1927	4046
International industrial publications (IIP)		
IIPa	122	163
IIPb	103	338
IIP/ISP (%)	11.7%	12.4%

Source: SCI CD-ROM 1994 and 1986.

In this context, it is worth mentioning that industrial scientific research, in contrast to development, accounted for 7.8% of Swedish scientific research in 1986 and 8.3% in 1994 (Table 1). This indicates a rather stable share of firm participation.

There was an increase of 27% in the absolute number of Swedish publications, but the proportions of DIP in relation to the total Swedish *domestic* publications in 1986 and in 1994 were almost identical (6.6% and 6.0%). Likewise, the proportions of IIP in relation to the total Swedish *international* publications were similar in 1986 and 1994 (11.7% and 12.4%). These observations indicate that not only the contribution of firms, private or public, to the Swedish scientific knowledge base was fairly stable over time, but also the industrial participation in Swedish collaborative scientific activities. Firms accounted for approximately 6% of the total Swedish domestic publication activities, and 12% of the international collaborative activities. Firms were particularly visible in the transnational scientific work.

The industrial contribution to Swedish R&D varies by field. We will discuss this in Section 4.3.

The stability of industrial scientific research in relation to the total Swedish scientific activities may be partially explained by the fact that the number of industries, which have a substantial research capac-

[1] The UC-select database is a commercial database produced by the firm Upplysningscentralen in Sweden.

[2] 'World' in this study indicates the countries, which appear in the SCI database.

ity, is fairly stable. The publication activity is dominated by large companies such as Astra, Pharmacia & UpJohn and Ericsson. There is a high concentration of scientific activities in a limited number of firms. Out of 250 industrial research units located in Sweden, only 43 units participated in both national and international publication activities, the others in only one of these types. If we examine the productivity of publications per research unit, 43 units produced on average 7.1 publications each, whereas the other units produced 1.5–1.6 publications each (Table 2). The concentration of the productivity in the 43 units was therefore exceptionally high, three to four times higher than the average. Astra, Pharmacia & UpJohn and Ericsson contributed 34% of the industrial scientific production.

The stability of the proportion of industrial scientific research in Sweden can also be explained by the stability of the research potential in the business sector in relation to the total Swedish scientific research. Although, Swedish industries have recently employed more and more PhDs to reinforce their R&D competencies, there being a net growth of 7% in the employment of PhDs in the business sector between 1990–1993, the research competencies in the academic sector were reinforced at a rate of double that in the business sector (Stenberg et al., 1996). As a consequence, the industrial scientific research will seemingly remain stable in relative terms in the overall publication activity of Sweden, at least in the case of the Swedish domestic publication activity. Astra, for example increased its scientific publication by 19% between 1986 and 1994, but its position in the total Swedish scientific research remained stable, accounting for 1.8% in 1986 and 1.7% in 1994.

4.2. The increase in industrial research units participating in Swedish research and the development of internationalization

In 1986, approximately 230 industrial research units, national or international, were identified in the scientific activity of Sweden. In 1994, the number of units more than doubled, reaching 517.

Our first finding was that pharmaceutical firms were the greatest participants in the industrial publication activity of Sweden (44%), followed by biomedical firms (other than pharmaceutical ones—14%), engineering firms (11%), food and chemicals-oriented firms (8%) and resource-related firms (forest, steel, power, and mining-related firms—4%).

Our second finding was that, small enterprises (measured by the number of employees) are also engaged in the scientific activities of Sweden. Twenty-nine percent of the firms that participated in the DIP activity had less than 50 employees (56 units). They were mainly engineering firms and firms specializing in biomedicals, food, and chemicals, primarily biotechnology-oriented firms, frequently the spin-offs of a university research team or of a large pharmaceutical company. This visibility of small enterprises in Swedish R&D corroborates the observation made by Rosenberg (1990), who showed

Table 2
The average number of publications per industrial research unit (1994)

	Number of units	Number of publications	Average number of publications per unit
Industrial units in Sweden participating in domestic and international publications (DIP and IIPa)	43	305 (33.3%)	7.1
Industrial units in Sweden participating in domestic publications only (DIP)	151	242 (26.5%)	1.6
Industrial units in Sweden participating in international publications only (IIPa)	56	82 (9.0%)	1.5
Industrial units in foreign countries collaborating with Sweden (IIPb)	267	338 (36.9%)	1.3
Total	517	915 (105.7%)[a]	1.8

[a] The total does not become 100% owing to the co-publications between different category of units.
Source: SCI CD-ROM 1994.

Table 3
Trends of Internationalization of firm activities compared with that of Sweden as a whole (1986 and 1994)

	Type of publication	1986	1994
Firms	International industrial publication/industrial publication	33.5%	54.8%
Sweden	International Swedish publication/Swedish publication	22.2%	36.8%

Source: SCI CD-ROM 1994 and 1986.

that a similar phenomenon existed in the USA and pointed to first-mover advantages as the principal motivation for small firms to participate in a risky research venture.

Our third finding was that internationalization developed remarkably well in the firm-related research activity, better than in the case of the total production of science. In 1986, international collaboration represented 33.5% of all publications with firm participation, whereas in 1994, 54.8% of all industrial publications were produced through international collaborative projects (Table 3). During the same period, the internationalization rate [3] of Sweden increased from 22.2% to 36.8%. Internationalization thus developed more rapidly when firms took part in academic research.

The number of industrial research units taking part in the international activity of Sweden tripled between 1986 and 1994, whereas in the domestic scientific activity of Sweden the number of units multiplied by 1.6. Today, more than half of the industrial scientific research in Sweden is conducted in the international arena.

Internationalization could be accelerated by the need of Swedish institutions to connect to global networks. Stenberg (1997) argued that because of its peripheral location in relation to major markets and knowledge centers, Sweden is exposed to the pressures created by globalization and regional integration earlier and more thoroughly than most other countries. The risk of becoming increasingly marginalized has urged Sweden to devise responses to these pressures in the area of R&D policy similar to those in other policy areas. The country is, for example, heavily dependent on highly internationalized firms, which can, with increasing ease, reallocate resources from Sweden to other countries. In a corresponding way Swedish companies have for decades undertaken significant R&D efforts abroad. The domestic lack of key competence and a need for better access to the international science and technology community are thus the major motivations for developing the internationalization of Swedish industrial scientific research (Granstrand and Sjölander, 1990).

However, this development is not only prompted by the demand of Swedish firms for external competencies; it is a *two-way phenomenon*. The rise in internationalization was in fact largely due to the contribution of firms located outside of Sweden, predominantly firms of foreign origin (Table 4). Foreign industrial units contributed 68% of the total IIP in 1994, whereas in 1986 their contributions only amounted to 46%.

This two-way phenomenon is most evident in the field of pharmaceuticals. The visibility of pharmaceuticals in Swedish scientific research is pronounced in 1994, owing to the existence of the two world-class R&D-intensive companies—Astra and Pharmacia & UpJohn (classified as having a foreign ownership since 1995). [4] They constitute one of the active driving forces in developing international research networks. In 1994 the participation of Swedish pharmaceutical firms located outside the country accounted for 2% of the IIP of Sweden. Simultaneously, foreign multi-national pharmaceutical companies collaborated with Swedish research institutions. For example, out of 20 large world-class pharmaceutical companies measured by market share—Novar-

[3] This rate can be obtained by dividing the number of Swedish (or firms') international publications by the total number of Swedish (or firms') publications.

[4] Since the data used in this study is of 1994, we treat Astra and Pharmacia & UpJohn as Swedish firms.

Table 4
Trends with regards to the number of industrial research units and their contribution to the Swedish international industrial publication, by unit located in Sweden and unit located abroad (1986 and 1994)

Types of units	Number of units (1986)	Number of units (1994)	Participation in scientific publication (1986)	Participation in scientific publication (1994)
Located in Sweden	43 (35.2%)	99 (27.1%)	54%	32%
Located outside Sweden	79 (64.8%)	267 (72.9%)	46%	68%
Total	122 (100%)	366 (100%)	100%	100%

Source: SCI CD-ROM 1994 and 1986.

tis, Merck, Glaxo, Hoechst, Rhone-Poulenc, etc.—15 conducted research together with Swedish research institutions and co-published with them in 1994. These strong contacts with international enterprises demonstrate the eminence of Sweden's research in the area of pharmaceutical and clinical science.

Twenty multi-national companies with a research institution in Sweden participated in the domestic publication activity of Sweden in 1994. This means that 13% of the 'domestic' industrial publications were in fact generated by firms of foreign origin. Internationalization is developing inside Sweden as well as abroad. ABB, one of the Swiss engineering firms that resulted from a merger between the Swedish Asea and the Swiss Brown Bovery in 1987, accounted for 40% of the activity, followed by Siemens (Germany) and IBM (USA).

In sum, 4.9% of the total 11,002 Swedish scientific publications were produced by research units of *Swedish firms*, alone, through national collaboration, or through international cooperation. Of the total Swedish publications, 3.4% were produced through international cooperation conducted by research units of *foreign firms*. The contribution of research units of foreign firms to Swedish scientific production has nearly tripled, from 1.2% in 1986 to 3.4% in 1994. Foreign firms have thus become important participants in the industrial scientific research of Sweden.

Our last finding was that the foreign industrial units participating in Swedish research have diversified considerably. In 1986, foreign industrial units were located in 10 different countries, whereas in 1994, they were from 25 countries. Collaborations with 'new-comers' in 1994 were still too small in quantity to display any distinguishable trends, but the Swedish scientific network is spreading to different continents, establishing contacts with more foreign industrial research units from various countries.

These observations all highlight the international character of Swedish industrial scientific activity.

Table 5
Distribution of firm publications by field: percent of firm publications in relation to total Swedish publications (1986 and 1994)

Fields	Industrial publications/Swedish publications		1994–1986
	1986	1994	
Engineering and technology	21.5%	16.8%	−4.7
Chemistry	11.8%	9.9%	−1.9
Biomedicine	8.5%	9.4%	+0.9
Clinical medicine	5.8%	7.6%	+1.8
Earth and space sciences	6.0%	6.3%	+0.3
Physics	4.2%	5.9%	+1.7
Biology	3.2%	4.2%	+1.0
Mathematics	2.2%	0.9%	−1.3
All fields combined	7.8%	8.3%	+0.5

Source: SCI CD-ROM 1994 and 1986.

Table 6
Profile comparison: Swedish industrial profile, Swedish profile and Godin's profile (1994)

Fields	Swedish profile	Swedish industrial profile	Godin's profile
Biomedicine	32.0%	36.0%	9.3%
Clinical medicine	25.5%	23.3%	17%
Engineering and technology	6.9%	14.1%	19%
Chemistry	8.6%	10.4%	15%
Physics	11.3%	8.0%	31%
Biology	11.0%	5.5%	2.4%
Earth and space sciences	3.7%	2.6%	2.8%
Mathematics	1.0%	0.1%	0.8%
Total	100% (11,002 publications)	100% (915 publications)	97.3% (9923)[a]

[a] Data compiled by Godin from SCI, 1989. The total number of papers was recalculated by the author of this article in order to be coherent with the Godin's article.
Source: SCI CD-ROM 1994.

They demonstrate the strong contributions of foreign firms to Swedish science, a trend that has been reinforced in recent years. This trend is one of the major factors behind the high internationalization of Swedish industrial scientific research. The firms participating in Swedish R&D are diversifying, and the Swedish scientific network is expanding worldwide, encompassing diverse players of various origins.

4.3. Field distributions

In the present study the publications were classified into the following eight large scientific fields in accordance with the classification of the National Science Foundation, USA: (1) mathematics, (2) physics, (3) chemistry, (4) engineering and technology, (5) earth and space sciences, (6) biology, (7) biomedicine, (8) clinical medicine. All the publications identified in the SCI CD-ROM 1994 and 1986 were attributed to these fields according to the journals in which they appeared.

The fields in which Swedish firms publish is as follows in order of frequency: engineering and technology, chemistry, biomedicine, clinical medicine, earth and space sciences, physics, biology and mathematics (Table 5). In comparison with the overall Swedish publication in a given field, the high proportion of *engineering and technology* is remarkable. Firms publish in this field twice as much as in all the other fields combined.

An analysis of industrial publications by field has been undertaken by Godin, focusing on the most patenting firms in the world (Godin, 1996). A comparison of our results with that of Godin, who used the same data source, enabled us to shed light on the field preferences of industrial scientific research in Sweden compared to other worldwide multi-national industrial activities (Table 6). It turned out that Swedish publications were particularly oriented to the life sciences (biomedicine, biology, and clinical medicine). In our study 65% of the industrial publications in Sweden was devoted to one of these three fields, while in Godin's study, 29% of the articles dealt with the life sciences. Our study thus highlights the exceptional concentration on life science fields that characterizes the scientific research publications of Swedish firms, compared to other active producers of patents.

Katz et al. (1995) also analyzed the distribution of fields publications belong to. According to their study, industries in the UK devoted approximately 42–50% of their scientific efforts to the life sciences. [5] This is considerably less than our percentages for Swedish firms (62%–68%). [6]

[5] In their study, publications were classified into 17 scientific fields. The proportion varies between 42–50% depending on the fields which we include here as life sciences. 42% includes 'Life Sciences' and interfield (IFL), whereas 50% includes also some 'multi-disciplinary' fields related to life sciences. It is extremely difficult to compare the studies, because the objectives of the two studies are not the same. Nevertheless, one can observe an approximative trend in the two countries.

[6] The percentages here indicate the proportion of publications in the life sciences in the Domestic (62%) and International (68%) industrial publications of Sweden.

Table 7
Types of domestic Industrial Publications (1986 and 1994)

Types of industrial publications	Publications (1986)	Publications (1994)
A single unit signature publication	43.8%	30.9%
Cooperative research publication with academic sector and/or with firms	56.2%	69.1%
Total domestic industrial publications	447 (100%)	414 (100%)

Source: SCI CD-ROM 1994 and 1986.

In fact, Swedish science is renowned for its propensity towards the life sciences (Miquel and Okubo, 1994). The high proportion of clinical research in Sweden was one of the most conspicuous features in the 98 countries compared, not only in domestic research, but also in international activities. Investment in state health care in Sweden, parallels the priorities given to the life sciences. Their dominance reflects the Swedish competencies in these fields, especially those of public research institutions.

The concentration of industrial scientific research in certain fields was somewhat reduced in 1994; nevertheless, industrial research in medical fields (biomedicine and clinical medicine) became particularly prominent in the international cooperation of firms.

4.4. A shift from 'in-house' research to cooperative ventures

Firms are increasingly engaged in cooperation with other research units, especially foreign ones.

In 1986, 43.8% of all Swedish DIP were produced by one research unit (in-house research of a firm) (Table 7). Eight years later this percentage had dropped to 30.9%. The research behavior of firms has tended to shift from a 'one-player game' to a 'multi-player game', thereby increasing the degree of 'cooperativity'.

The decrease in the proportion of in-house research (measured by publications) is particularly noticeable in large pharmaceutical companies such as Astra. In relation to Astra's total scientific publications, publications based on in-house research dropped from 36% in 1986 to 19% in 1994. The shift from in-house to cooperative ventures in Astra is striking when compared to other large multi-national pharmaceutical firms such as Hoechst, Glaxo Group Research, or Takeda Chemical. The names of the companies are those of 1994, as they appear in the Science Citation Index CD-ROM. Okubo (1995) discussed the proportions of in-house research in these companies. Each of them was characterized by growing internationalization, but the variation stabilized in 1992, when approximately 40% of each company's research was the result of internal efforts and the remaining 60% was brought about through association with domestic and international research organizations. This proportion was observed in each company as if it was an optimal balance of 'in-house' and 'collaborative' research in the large pharmaceutical industry in that particular year. Ciba-Geigy, a company located in a country with a scientific size similar to that of Sweden, showed a similar trend. There, internal R&D remained nearly 40% of the scientific production. The shift to cooperative ventures has thus occurred much more rapidly in Astra than in these enterprises.

4.5. Increase in cooperativity

Not surprisingly, when firms collaborate, the most prevailing pattern of collaboration is between firms and the academic sector.[7] This type of pattern accounted for 97% of the total Swedish firm publications produced through cooperation in 1994. Collaboration between firms accounted for only 3%. Universities were the major collaborative partners, followed by hospitals (Table 8). In this type of collaboration public research institutions, especially universities, function as nodes in open knowledge networks.

[7] The academic sector signifies 'universities', 'hospitals', and 'public research institutions'.

Table 8
Number of references to Swedish and foreign public research institutions in industrial publications of Sweden, by country (1994)

	Universities and academies	Hospitals and health	Institutions	Other	Total
Sweden	407	377	203	25	1012
USA	199	95	40	17	351
Germany	65	19	11	3	98
England	27	50	8	10	95
Canada	29	33	4	3	69
Netherlands	26	25	6	6	63
France	7	35	10	6	58
Denmark	16	23	11	6	56
Italy	20	11	12	12	55
Finland	25	16	2	2	45
Foreign	21.8%	16.1%	5.5%	3.4%	46.8%
Swedish	21.4%	19.8%	10.7%	1.3%	53.2%
Total	43.2%	35.9%	16.2%	4.7%	100%

Source: SCI CD-ROM 1994.

The principal collaborative partners of firms located in Sweden were Uppsala University (and Hospital) and Lund University (and Hospital). Firms located abroad collaborated predominantly with Karolinska Institute (Laboratory and Hospital). The major partners of firms therefore shifted from Uppsala and Lund to Karolinska as the scientific activity moved from a domestic to an international setting. These three institutions are Sweden's central information resource for industrial scientific research activities. Collaboration between Swedish firms and foreign public institutions is also a key factor in the advancement of Swedish industrial scientific research. In 1994, 47% of international firm publications involved participation by foreign institutions.

The flexibility of enterprises with regards to collaboration with other research units, industrial or academic, is even more visible in recent years. Thus, in 1994, 86% of the industrial publications were produced through joint efforts of more than two units, compared to 71% in 1986. Collaborative work is a method of crucial importance for increasing access to competencies in competitive areas of research. Scientific research of relevance to industrial development is carried out in the corporate sector and in various research institutes. All these types of research activities are becoming increasingly interdependent. As we shall see below, in the case of Sweden, the propensity to cooperate with another research unit for knowledge production is greater for industries than for the Swedish scientific community as a whole.

4.5.1. Measure of cooperativity with other research unit—inter-unit collaboration

The propensity of firms to collaborate with other research units, industrial or academic, nationally or internationally, is analyzed here (*inter-unit collaboration*).

In 1986, the percentage of the publications produced by 'one research unit' was 29.2% for *industrial publications* and 45.4% for *non-industrial publications* in 1986 (Table 9). [8] This means that the propensity to collaborate with other research units was greater for firms than for non-industrial organizations. In addition, the 'one research unit' pattern has dropped sharply for industrial publications, both in absolute and relative term, between 1986 and 1994. The shift from one research unit to cooperative ventures has been greater for firms than for non-industrial organizations in Sweden.

[8] Swedish publications were split into industrial publications (publications including firms) and non-industrial publications (publications without firms). The number of non-industrial publications is obtained by subtracting the number of industrial publications from the total number of Swedish publications.

Table 9
Comparison between the industrial and non-industrial publication patterns: inter-unit collaboration (1986 and 1994)

Type of publications	Non-industrial publications	Industrial publications	Total
1986			
1 Research unit publications	3631 (45.4%)	196 (29.2%)	3827 (44.1%)
2 Research unit publications	2498 (31.2%)	260 (38.7%)	2758 (31.8%)
3 Research unit publications	1190 (14.9%)	122 (18.2%)	1312 (15.1%)
4 Research unit publications	390 (4.9%)	51 (7.6%)	441 (5.2%)
5 + Research unit publications	289 (3.6%)	43 (6.3%)	332 (3.8%)
Total	7998 (100%)	672 (100%)	8670 (100%)
1994			
1 Research unit publications	3786 (37.5%)	128 (14.0%)	3914 (35.6%)
2 Research unit publications	3144 (31.2%)	292 (31.9%)	3436 (31.2%)
3 Research unit publications	1806 (17.9%)	245 (26.8%)	2051 (18.7%)
4 Research unit publications	708 (7.0%)	100 (10.9%)	808 (7.3%)
5 + Research unit publications	643 (6.4%)	150 (16.4%)	793 (7.2%)
Total	10,087 (100%)	915 (100%)	11,002 (100%)

Source: SCI CD-ROM 1994 and 1986.

Research in order to produce one scientific publication is, with firm participation, most frequently a collaborative activity together with two or three research units, whereas *without* firm participation this research is conducted by a non-industrial organization alone or in cooperation with one other research unit.

The trend of firms to work with more than three research units increased by 22% for industrial publications, but only by 7.9% for non-industrial publications. Similarly, the propensity to produce publications by the joint efforts of more than five research units increased from 6.3% to 16.4% for industrial publications, while for non-industrial publications it changed from 3.6% to 6.4%. The shift to a multi-unit collaborative pattern was thus more strongly demonstrated for the *publications in which firms participate* than for those without their participation.

4.5.2. Measure of cooperativity with different countries—inter-country collaboration

The second analysis of the degree of cooperativity was performed on the inter-country collaborative pattern. The propensities *to conduct research in Sweden, to cooperate with 2 countries, 3 countries, 4 countries,* and *more than 5 countries* were measured for both industrial publications and non-industrial publications (Table 10).

Sixty-seven percent of the *industrial publications* and 79% of the *non-industrial publications* were produced within Sweden. The propensity towards international collaboration was found to be greater when firms participated in research than when non-industrial organizations performed their research alone in 1986. In 1994, only 45% of the *industrial publications* were produced within the country, whereas the large majority of *non-industrial publications* (65%) were still produced within Sweden.

The trends towards multi-country collaboration developed for both firms and non-firms between 1986 and 1994. However, here again the development was greater for firms than for non-firms. The high degree of cooperativity of firms was particularly pronounced in a project involving *more than five countries*. The propensity of firms to take part in such collaboration developed rapidly from 1.0% in 1986 to 5.1% in 1994, while it only changed from 0.8% to 1.7% for non-industrial research units.

Multi-lateral cooperation becomes more frequent and the propensity to join research units from different countries becomes greater when firms are involved in research than when research is carried out only by non-industrial institutions. Research projects are conducted in a wider network when firms are involved.

4.5.3. Measure of cooperativity in domestic collaboration and international collaboration

Lastly, an analysis of the cooperativity of firms was performed involving a comparison between DIP

Table 10
Comparison between the industrial and non-industrial publication patterns: inter-country collaboration (1986 and 1994)

Type of publications	Non-industrial publications	Industrial publications	Total
1986			
1 Country publications	6296 (78.7%)	447 (66.5%)	6743 (77.8%)
2 Country publications	1409 (17.6%)	186 (27.7%)	1595 (18.4%)
3 Country publications	190 (2.4%)	26 (3.9%)	216 (2.5%)
4 Country publications	38 (0.5%)	6 (0.9%)	44 (0.5%)
5 + Country publications	65 (0.8%)	7 (1.0%)	72 (0.8%)
Total	7998 (100%)	672 (100%)	8670 (100%)
1994			
1 Country publications	6542 (64.9%)	414 (45.2%)	6956 (63.2%)
2 Country publications	2667 (26.4%)	360 (39.3%)	3027 (27.5%)
3 Country publications	563 (5.6%)	70 (7.7%)	633 (5.8%)
4 Country publications	139 (1.4%)	25 (2.7%)	164 (1.5%)
5 + Country publications	176 (1.7%)	46 (5.1%)	222 (2.0%)
Total	10,087 (100%)	915 (100%)	11,002 (100%)

Source: SCI CD-ROM 1994 and 1986.

and IIP. The question was whether firms collaborate more with another research unit in a *domestic* scientific activity than in an *international* one (Table 11).

The dominant collaborative pattern identified in the *domestic activity* of firms in 1994 was a 'two-unit' collaboration (52%), whereas in the *international activity* of firms there was an equal distribution between 'two-unit' (29%), 'three-unit' (30%) and 'more than five-unit' collaboration (27%). Firms located in Sweden tend to work in groups of two, and though this behavior somewhat changed between 1986 and 1994, the majority of the DIP in 1994 were still produced by research groups consisting of *two units*. These firms rarely form multiple groups of more than five research units within Sweden.

In contrast, for the IIP, the *more than five unit* collaboration pattern nearly doubled, from 15% to 27% between 1986 and 1994. Firms thus conduct their research in a wider network in international collaborative projects than in domestic ones.

The general trend is that firms combine more and more competencies, national or international, in their

Table 11
Comparison between the domestic industrial and international industrial cooperation patterns in Sweden (1986 and 1994)

Type of publications	Domestic cooperation	International cooperation	Total
1986			
2 Research unit publications	164 (65.3%)	96 (42.7%)	260 (54.6%)
3 Research unit publications	59 (23.5%)	63 (28.0%)	122 (25.6%)
4 Research unit publications	19 (7.6%)	32 (14.2%)	51 (10.7%)
5 + Research unit publications	9 (3.6%)	34 (15.1%)	43 (9.1%)
Total	251 (100%)	225 (100%)	476 (100%)
1994			
2 Research unit publications	148 (51.7%)	144 (28.7%)	292 (37.1%)
3 Research unit publications	96 (33.6%)	149 (29.7%)	245 (31.1%)
4 Research unit publications	27 (9.4%)	73 (14.6%)	100 (12.7%)
5 + Research unit publications	15 (5.3%)	135 (27.0%)	150 (19.1%)
Total	286 (100%)	501 (100%)	787 (100%)

Source: SCI CD-ROM 1994 and 1986.

scientific knowledge development. The propensity of firms to collaborate, domestically or internationally, has proved to be greater than that of non-industrial organizations. The shift of Swedish research from 'one-player' to 'pluri-player' performance is developing faster among firms than for the country as a whole. The heterogeneity of players increases considerably when research leaves the domestic arena to become highly international. In their pursuit of knowledge, private firms increasingly interact with the academic community. As a result they serve as bridges between the academia and the economy (Stankiewicz, 1995).

4.6. Visibility of firms in the scientific community

The question raised in this section is: does collaboration influence the visibility of industrial publications in the international scientific community? We will try to answer this question by use of the Journal Impact Factor measurement [9] (Magri and Solari, 1996; Magri et al., 1997). The industrial publications produced by (1) in-house research, (2) domestic collaborative research and (3) international collaborative research were classified into four journal categories according to the degree of visibility, and consequently impact, of the journals in which they appear—*extreme*, *high*, *central*, *low* (Fig. 1a). The resulting visibility is compared for publications produced by non-industrial research institutions, i.e., publication performance is analyzed for works produced without the participation of firms (Fig. 1b).

As the research pattern moves from an *in-house*, via a *domestic* to an *international* setting, the resulting industrial publications tend to *appear more frequently in the higher level journals*, measured by the number of citations. While only 38% of the in-house research publications appeared in journals belonging to the two higher impact categories, *extreme* and *high*, 50% of the domestic cooperative publications, and as high a proportion as 60% of the international cooperative appeared in such journals. When research was conducted in collaboration with other national research institutions and universities, the proportion of the industrial publications appearing in journals with *extreme* impact doubled (from 5.6% to 12.7%). This does not necessarily mean that industrial collaborative papers are more frequently cited

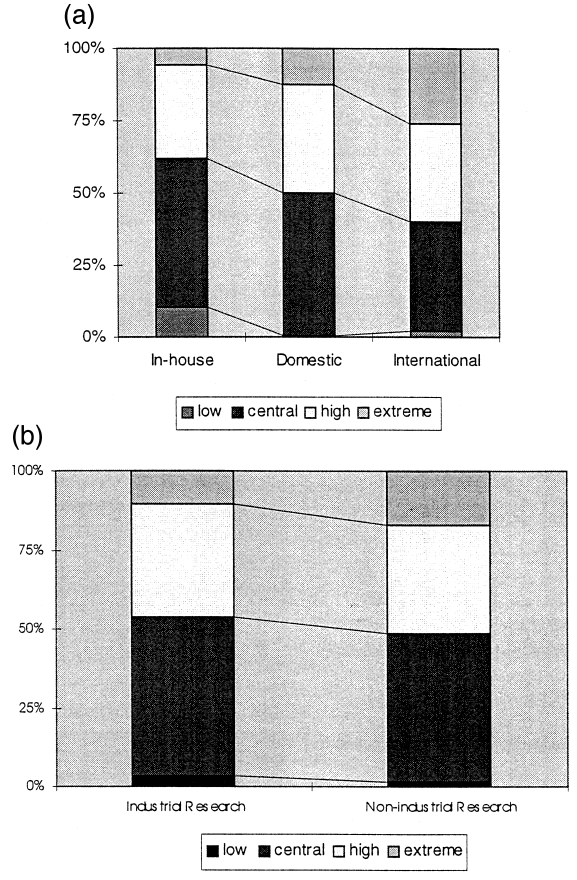

Fig. 1. (a) Scientific visibility of industrial research in Sweden: in-house, domestic, and international research. (b) Scientific visibility of domestic industrial research compared with domestic non-industrial research in Sweden.

[9] In relation to the number of citations a journal receives from the scientific community, each journal carries an impact factor. The impact factor of approximately 4,555 journals in the SCI collection, ranges between 57.000 and 000.9. These journals are aggregated into 4 groups designated 'low' (group of journals which receive a fairly low level of citations, below 0.294), 'central' (0.294–1.380), 'high' (1.380–3.008) and 'extreme' (3.008–57.778). The four categories were calculated by the box plot method by Magri and Solari (1996) and Magri et al. (1997), who have aggregated 4,445 journals which appeared in the SCI into these levels. This work serves as the basic 'reference' which any group of researchers can be projected into, in order to position themselves in the scientific community.

than in-house publications, but it indicates that publications tend to appear in higher impact journals when produced in collaboration. This means that collaboration with Swedish public institutions and universities provides firms not only with complementary scientific knowledge and competencies, but also with means to be more visible in the mainstream scientific community. In our study the scientific performance of national institutions and universities showed a higher level of visibility than that achieved by firms (Fig. 1b). Obviously, national non-industrial institutions are more competent than firms at presenting scientific results to a wider audience and to produce articles in highly reputed journals with international circulation. In fact, association with national non-industrial institutions has proved to be one of the key factors in linking firms to global research networks. It is particularly noticeable in our study that the proportion of publications in the *low category* journals diminished substantially (from 10.3% to 3.4%) when firms conducted research in collaboration with national public institutions instead of doing it on their own. Public institutions, primarily the universities, play an essential role in the processes of creation and knowledge diffusion.

What is even more noticeable is that, when firms conducted international collaborative research, the number of journals with *extreme* impact doubled as compared with when they conducted domestic collaborative research (from 12.7% to 26.2%). One of the motivations for firms to publish in scientific journals is to demonstrate and advertise their competencies, and maximize visibility in the scientific community. From this point of view, there is every reason to presume that cooperation is a desired form for a firm's scientific production. It is more efficient to collaborate with scientists outside the firm, and if possible with those from foreign institutions.

5. Conclusions

Industrial scientific research is one of the current Swedish policy issues. At the time of the present study the research performance of industries in Sweden as reflected by their written scientific output proved to be fairly stable, occupying approximately 8% of the space of the national publications. The major producers of scientific articles were Astra, Pharmacia & UpJohn and Ericsson, but along with these science-based industries, over 500 research units participated in this production. Small and medium-sized firms, especially those specialized in biotechnology or engineering, also took part in the scientific publication activities. These firms probably spun off from universities and large firms and were keeping good contacts with them. Different types of firms thus participated in research and the production of scientific publications, these producers grew increasingly numerous and varied.

Firms conducted research particularly in the fields of chemistry and engineering and technology. This phenomenon was noticeable in the international scientific activity of Sweden, where nearly one-fourth of international publications in engineering and technology were produced with firm participation. Swedish firms also showed a strong propensity towards research in the life sciences. In 1994, 65% of all publications with firm participation were devoted to one of the life science areas.

The internationalization of scientific research in Sweden was high compared to other industrialized countries, especially in the firms, which collaborated with international competencies in science more vigorously than the country as a whole. While Sweden's overall internationalization rate was 36% in 1994, the rate of firms' international scientific activities reached 55% in the same year. This means that more than half of the industrial scientific publications in Sweden were produced by the joint efforts of Swedish and international researchers. The internationalization developed more rapidly when firms participated in research than when research was conducted by universities and other public research institutions alone.

Sweden's research force remained relatively stable over some decades. In order to acquire other competencies necessary for the development of science, Sweden needs to call on foreign competencies, which accelerates the internationalization in this area. Sweden being an active country in science but geographically peripheral, has always been aware of the necessity to collaborate with the international community.

The need to collaborate with international competencies is also a global trend brought about by the

specialization of research observed in a wide range of fields of science today. Owing to the fact that scientific research is becoming more and more specialized and competitive and that more units operate near the frontlines of technology than before, researchers need to be in contact with competencies scattered all over the world. In the new competitive regime, commercial success requires the ability to generate knowledge using resources, which are not stored in-house but distributed throughout a vast and increasingly global network. It is therefore crucial for firms to develop new types of links with universities, government laboratories and other firms (Gibbons et al., 1994). Researchers seek competencies, evaluate their peers and select only the most suitable partners for the advancement of their research. The trend is that in order to advance research, researchers work in groups, linking heterogeneous research institutions from a variety of countries. In the case of our Swedish study, this merger of competencies was more evident among firms than among universities.

This entry into the international arena is a 'two-way phenomenon', i.e., Swedish firms show an increasing trend to collaborate with research groups outside their country, and at the same time foreign companies are collaborating more and more with Swedish public research institutions. In 1994, firms from 25 countries participated in the industrial R&D activities of Sweden, an increase from 10 countries in 1986. Out of the total transnational industrial research activities, 68% were produced with participation from foreign firms or from subsidiaries of Swedish firms located abroad. These trends are paralleled by the increase in foreign firm research funding to Swedish university research, which multiplied by 1.3 from 1993 to 1995 (Research and Development in the Higher Education Sector 1993/95 Statistics Sweden, 1996). Knowledge production thus takes place with greater interaction of heterogeneous international practitioners.

Karolinska Institute, Uppsala University and Lund University are the major 'knowledge suppliers' for firms in the publications identified by SCI. What is noticeable is that these institutions contribute to the industrial knowledge development of both Swedish and foreign firms. In case of Karolinska Institute, the scientific ties are twice as strong in relation to foreign firms as to Swedish firms. Does this mean that a substantial proportion of the results of national research funding is taken away to other countries? The answer is seemingly no, because as Pavitt (1992) argues, the linkage between science and technology cannot be totally internationalized, and national basic research continues to nourish technology, that is highly controlled by national enterprises. Cooperation is a mutually beneficial affair, and R&D is a means of learning from others. Internationalization provides an opportunity for Swedish national institutions to enrich their competencies and foster visibility. A policy implication here is that if research and education are considered to be increasingly important in the infrastructure of technological activities and productivity of a nation, it is important to attract foreign firms to collaborate or to localize their R&D in Sweden and to encourage national enterprises, via grants or other solutions that will support their research activities.

Firms publish in scientific journals to demonstrate and advertise their competencies. In order to achieve these objectives efficiently, cooperation, as shown by the present study, is an ideal form of scientific production for firms. Instead of conducting in-house research and publishing articles alone, the possibility of appearing in the higher impact journals increases when research is performed in collaboration with scientists from another national public institution. Such visibility in the scientific community is maximized when research is conducted in international collaboration.

Knowledge production in Sweden shows several aspects of the emergence of Mode 2, as described by Gibbons et al. Collaborative ventures are not irreversible phenomena, but will probably gain in strength in the future due to the increase in research costs, for example in clinical testing where costs are spiraling. Knowledge production is less and less a self-contained activity in Sweden. The capacity of knowledge creation in this country depends heavily on the capacity to engage in team-work with increasingly heterogeneous actors, at home and abroad. A recent attempt at establishing university-owned holding companies was one of the actions taken at the government level in Sweden to facilitate interactions between universities and industries. The rapid development of internationalization is changing the traditional manner of knowledge production. The national

industry–university policy must follow this trend and be adjusted to a broader perspective.

R&D strategists argue that the available technological resources and international knowledge networks of enterprises and researchers could be used more effectively to further innovation and economic growth in Sweden (Stenberg, 1997). A key issue concerns the role that the large international firms headquartered in Sweden or with a strong R&D-base in Sweden will play in the Swedish innovation systems. However, small and medium-sized firms also play an important role. In order to design and establish research and innovation policy, it is important to monitor how firms of various types are taking part in the overall Swedish innovation system. Our contribution here was to shed light on one of these aspects and observe how firms contribute to the written scientific output of Sweden.

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