SWEDEN'S GLOBAL CONNECTIVITY IN RESEARCH

An analysis of international co-authorship

Preface

This report has been produced as a contribution to the project "Agenda for Research" coordinated by the Royal Swedish Academy of Engineering Sciences (IVA). For more information on this project, see http://iva.se/en/Projects/Agenda-for-Research/, where additional reports and analysis of issues and challenges facing contemporary Swedish science policy can be found.

One of the lines of investigation of the project has been the impact on national research policy of the growing globalization of businesses and of research communities in most fields. Increasingly, research and innovation, as well as the interaction between the two, are taking place in global networks of firms and research organizations. If government research and innovation policy is to be effective, this fact has to be considered. Our knowledge of the structure and dynamics of these networks of interacting, innovating firms and research organizations therefore needs to be constantly improved and updated.

This report maps the global connectivity of the Swedish research community and proposes policy conclusions that can be drawn from observing the current patterns of collaborative networks of Swedish scientists. The analysis focuses in particular on the balance between intra-European and intra-continental collaboration. Thanks to the EU Framework Programmes for R&D, European research co-operation has been greatly strengthened over the past 20 years. Swedish researchers are today participating very actively in this co-operation. While the strengthening of the European Research Area (ERA) in and of itself is a very positive development, it raises the issue of whether this co-operation has diverted attention away from developing much needed research co-operation with other parts of the world.

The analysis has been performed by Lennart Stenberg, senior adviser at VINNOVA, who has also written the report. Staffan Karlsson at the Swedish Research Council (VR) has provided customized data for the project from Thomson Reuters' Web of Science (WoS) database at the Swedish Research Council.

Author's preface

In the spring of 2011, I was asked by the leadership of the Agenda for Research project to identify issues related to the internationalization of research policy in Sweden and the types of analysis that would be of particular relevance for improving the evidence base for such policies.

One of the themes I suggested was what I believed to be a rather straightforward mapping of the pattern of Sweden's international co-authorship of scientific articles in comparison to the same patterns for other relevant countries. Over the past decade I have attempted minor studies of this issue on many occasions based on online searches of bibliometric databases. In doing so I identified several shortcomings in the analysis which could only be solved through large-scale and technically much more advanced analysis of bibliometric data.

When the Agenda for Research project expressed interest in the study I had proposed, I contacted Staffan Karlsson at the Swedish Research Council to discuss the technical feasibility of the project I had in mind. Through continuing discussion and several iterations of data extraction by Staffan Karlsson and my own data analysis, the project got underway in the late autumn of 2011. Ideas for the categorization of data continued to develop and, as a result, so did the iterations between Staffan Karlsson and myself as well. As both Staffan Karlsson and I had many other tasks to attend to, progress was often delayed causing concern for the leadership of the Agenda for Research project. It has been a true pleasure to co-operate with Staffan Karlsson who has shared very generously both his deep expertise and his precious time, including on weekends and during vacations. I am afraid that I have on too many occasions abused his generosity.

Presentations of the project were made on three occasions. On 21 February 2012 early results from the project were presented to analysts with expertise in bibliometrics and related areas at a seminar arranged by the Agenda for Research project. On 29 May a presentation was made to the Steering Committee for the Agenda for Research project and on 29 August an open and well-attended seminar was arranged at the Royal Swedish Academy of Engineering in order to present the main results of the project to a wider audience. I am very thankful to the Agenda for Research project for providing these opportunities and to the seminar participants for providing very valuable comments. Special thanks are extended to Professor Agneta Richter-Dahlfors and Professor Lennart Bergström for the comments they prepared and gave at the August seminar.

I would also like to thank several persons who have read and offered very useful comments on drafts of the report: Joakim Appelquist, Liselott Bergman, Anders Broström, Gunnel Dreborg, Staffan Karlsson, Hans Pohl, Anna Sandström and Sylvia Schwaag Serger. I am, however, solely responsible for the contents of the report.

A large part of the actual writing has been done at the University of Tokyo, where Professor Takehiko Kitamori at the School of Engineering kindly arranged a quiet work space for me. I am very grateful for this as well as for many stimulating discussions about the realities of international research co-operation.

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Lennart Stenberg, VINNOVA

Contents

Summary

The main purpose of this report is twofold. First, to provide a consistent set of basic facts concerning Sweden's links to the international scientific community as reflected in the co-authorship of scientific articles between researchers in Sweden and researchers in other countries. Second, to reflect on the wider context and policy implications of the pattern of Sweden's global research connectivity that emerges from the analysis. The major conclusions are:

- Rapid expansion of research in countries outside Europe and North America, led by China, is causing a major rebalancing of the global research system in a process that has only just started and is certain to continue.

- In Chemistry, Materials Science, Engineering and ICT ("Engineering-related fields") the combined scientific power of China, Japan, India, South Korea, Taiwan and Singapore is already comparable to that of Europe or North America. In Life Sciences the USA remains the dominant player, followed by Europe with Asia still lagging behind although growing rapidly.

- Closely related to the changing global research map, new patterns of international research collaboration and movement of students and researchers are emerging. Simultaneously and connected to this, there is intensified global competition for talented students and researchers as well as for partnerships in research and innovation.

- While spontaneous adjustments occur through the actions of individual students and researchers, the need for research institutions and governments to act proactively and strategically in developing international research exchange has increased.

- For Sweden, like other European countries, internationalization of research is occurring partly through the progressive integration of the European Research Area and partly through the development of global research exchange. Sweden needs to actively participate in both processes, but there are indications that Sweden is not pursuing research exchange vigorously enough outside Europe. Large and growing funding for European research co-operation combined with very limited special funding for research co-operation outside Europe may have contributed to less effort being made in Sweden to build up new strong research partnerships than would be desirable, e.g. in Asia. However, regardless of external funding opportunities, Swedish universities need to put the development of global research connectivity higher up on their agenda.

- While the EU Framework Programme (FP) has an important role in strengthening the integration of the European Research Area, it is crucial that the design and implementation of the FP is such that it proactively facilitates the global connectivity of European research. The fact that research links with leading Asian countries appear to play a relatively larger role in North America than in the EU is a warning sign.

- Considering its size, Sweden has developed a strong presence in China in Engineering-related fields, but this presence is largely due to partnerships developed by the Royal Institute of Technology (KTH).

- Sweden's presence in Japan and India is less prominent than in China, but not markedly smaller than the presence of comparable coun-

tries. Sweden's relative presence in Japan has, however, declined over the past decade.

- The strong research in South Korea, Taiwan and Singapore in Engineering-related fields is not yet sufficiently reflected in Sweden's research exchange with these countries.

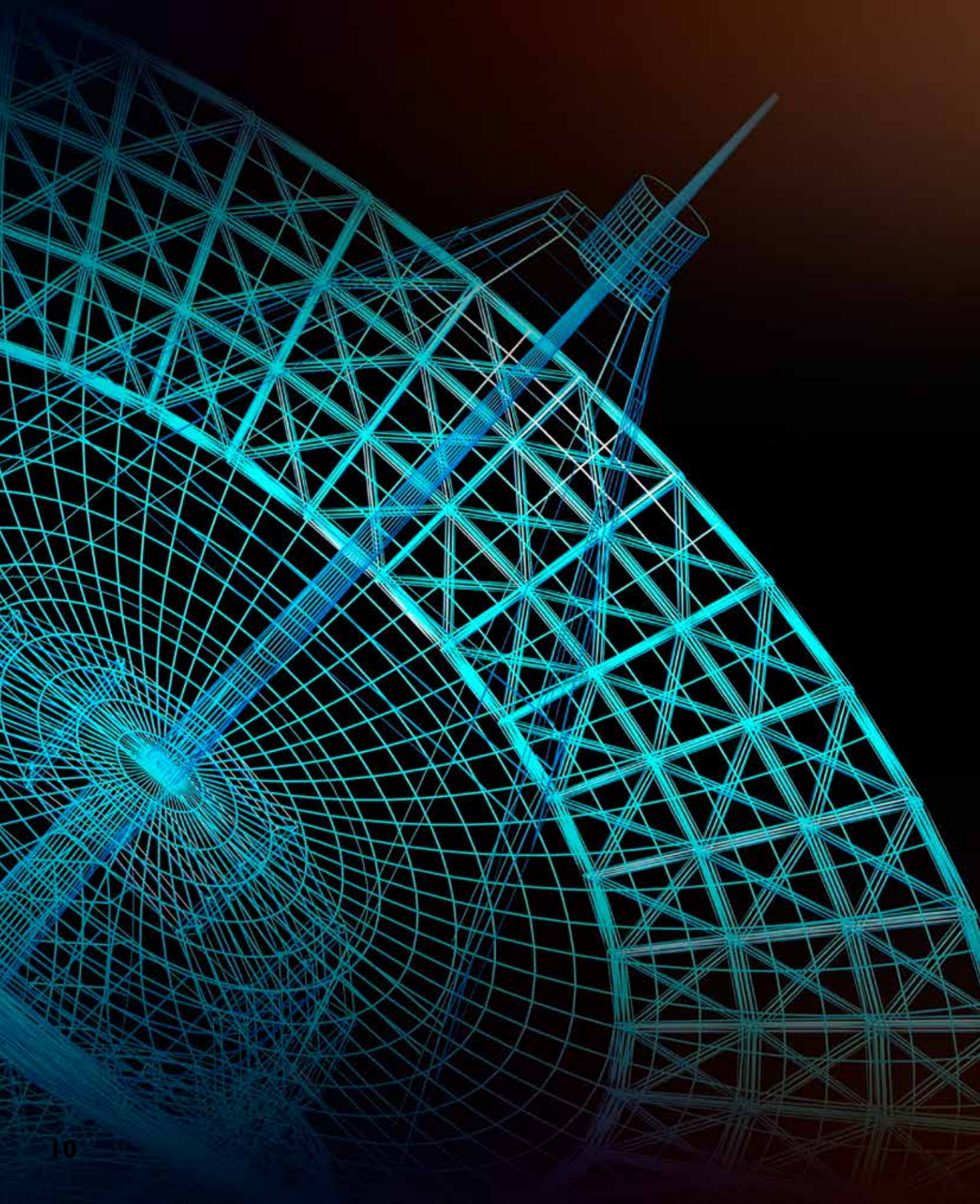
- The very uneven development of Sweden's research connections in Asia among Swedish universities and among Asian partner countries suggests that more needs to be done to develop these connections. In Engineering-related fields, Swedish institutions, being usually the minor partners, need to take the initiative.

- One cause for concern is that Sweden's position as a producer of highly cited scientific articles has declined over the past decade in Engineering-related fields compared to most scientifically advanced nations. Decline in relative citation rates and weak volume growth have both played a role. The weakening of Sweden's position is most apparent in the fields of Mathematics and ICT.

- By combining resources from several universities, research institutes, innovative companies and other actors, Swedish institutions can increase their attractiveness as partners and will be better able to develop and sustain strategic research partnerships with globally leading research environments. Government R&D funding organizations could play an important role by providing incentives for Swedish actors to co-operate in developing strategic international partnerships.

- The mobility of students and researchers is important for the development of research connections. Special measures are needed to increase the mobility of students and researchers between Sweden and the leading scientific nations in Asia in both directions.

- The benefits of strengthening the "knowledge triangle" – the connections and synergies between education, research and innovation – apply not only domestically but are at least as important in efforts to strengthen Sweden's global research connectivity.



1. Importance of the global connectivity of Swedish research

Scientific research has long been considered an inherently international activity in the sense that concepts, theories and experimental findings are basically shared, debated and evaluated on an international level. Nonetheless, the internationalization of research – as well as higher education – has become an important issue for policy development at the national level as well as at individual universities and other research institutions. The major reason for this can be summarized as a perceived need for various actors to create more deliberate and strategic policies and actions for positioning and connecting their country or institution on the global research stage. This in turn can be related to growing global competition for talented students and researchers, for strategic partnerships in research and development (R&D) and for investments in new business development. Being attractive from these perspectives at the global level is becoming increasingly paramount for countries, regions and cities, as well as for individual universities and research institutes.

Through the accelerated globalization of its industry over the past couple of decades, Sweden is today very exposed to the discretion by global industrial groups as to where they will make their investments in R&D and create new business. The outcome of these decisions for Sweden is influenced by the quality of the knowledge environment in terms of factors like the availability of high quality engineers and researchers and nearby access to suitable partners for collaboration in R&D at universities, research institutes and various types of companies. For universities and research institutes to play their part in this context, they themselves have to be attractive and competitive on a global scale, both for the recruitment of students and researchers and as research partners for other research institutions and innovative companies worldwide.

CONNECTIVITY FOR RESEARCH ITSELF

It is desirable for the Swedish research community to be well connected with leading researchers elsewhere in the world. As this is a key assumption in the present study, it may be worth dissecting this assertion in a bit more detail.

In order for a researcher to work effectively, he or she will usually need to interact directly with other researchers. While research results can, to a certain extent, be obtained through the study of scientific publications that are generally available, really effective access to new developments in scientific research usually requires a much more direct interaction with other researchers, and especially with those who are leading the way in the new developments. This interaction may take a number of forms, including communication at conferences or person-to-person communication at a distance. In research, as in many other activities, much of the important knowledge and skills is tacit in nature and may only be accessible through

the experience of working together directly and solving specific problems together. Working side-by-side on a project may be necessary, but modern communication technologies offer more scope for intense exchange from a distance than was the case in the past.

Solving difficult scientific problems increasingly requires the integration of diverse knowledge, competencies, research tools and other resources. The extent to which these can all be found locally or must be sought in different locations will, of course, vary greatly for a number of reasons. Judging from the actual conduct of leading researchers and research groups, it does appear that there is a growing need to combine resources at an international and even a global level. The increasing occurrence of international co-publications also supports this assertion, although, as will be discussed later, co-publications may to some extent simply be an indication of the increased mobility of researchers and thus not necessarily the result of greater international collaboration.

When we say that researchers are well connected, we mean that they communicate well with each other. For this to happen, each of them needs to be willing to take the time and make the effort needed for extensive communication. As researchers who have proven high capability receive many requests from other researchers and consequently need to be selective in which requests they respond favorably to, there is considerable competition among researchers for the attention of other researchers.

While factors other than the scientific capability of the researcher making the request, such as personality, an introduction from other researchers, proximity etc. may play a role in each individual case, a high regard for the other researcher's professional knowledge and expertise will generally be a decisive factor. Another important factor is, of course, that the request comes from a researcher who works in an area perceived as relevant by the researcher receiving the request.

ATTRACTIVENESS, MOBILITY AND CONNECTIVITY

There is a strong interdependence between the attractiveness of research in Sweden, how well it is connected with leading research environments around the world and the extent and quality of students and researchers moving in and out of Sweden. This report focuses on connectivity in research, but ideally all three aspects should be viewed together.

Measures aimed at strengthening the global connectivity of the Swedish research system cannot be disassociated from the basic characteristics and development of higher education, research and innovation in Sweden and related policies. National policies that influence Sweden's attractiveness as a place to study and work and as a partner for co-operation include those which determine: the total resources made available for research; their allocation between different fields; the criteria and mechanisms for allocation of resources to specific institutions, research environments and individuals; incentives and platforms for co-operation among actors in Sweden including exchange between universities and industry.

Attractiveness is in turn a precondition for promoting exchange with high quality partners, for the recruitment of talented students and researchers and for ensuring the outward mobility of students and researchers to leading research environments.

When analyzing the relationship between connectivity, mobility and attractiveness, it becomes clear that the benefits flow in both directions when pairing any of the aspects. If a research environment is known to have good connections with leading research groups around the world, this will in and of it itself enhance its reputation and attractiveness. A research environment that is attractive enough to successfully recruit particularly talented students and researchers will, through such recruitment, be able to increase the quality of its education and research and thereby become even more attractive in a virtuous circle. Its ability to recruit talented people will also typically greatly increase its reputation. Furthermore, the mobility of students and researchers is usually

an effective way of intensifying, and occasionally establishing new, connections. Established trusting relationships between research leaders are often very useful as channels for the mobility of students and young researchers.

Discussions concerning the so-called knowledge triangle at universities emphasize the importance of better exploiting the potential synergies between activities within higher education, research and innovation. The goal of strengthening the knowledge triangle is also likely to be highly relevant when considering university policies and actions internationally. A university's attractiveness for students and its roles as a partner in research and as a contributor in innovation processes are all strongly interdependent. The international reputation of a university among prospective students is, for example, largely determined by its research achievements. In analyzing the international connectivity of research in Sweden, it would therefore be desirable to study these activities in an integrated fashion. This study takes a narrower view and focuses on exchange in research. There is, however, a need for studies that take a more comprehensive view.

COMPETITION FOR GLOBAL ATTRACTIVENESS AND CONNECTIVITY IS BECOMING CRUCIAL FOR SWEDEN'S ECONOMIC FUTURE AS WELL

Several developments during the past couple of decades have made attractiveness and connectivity at the global level a matter of significance that goes far beyond research itself and is arguably a key factor in the long-term growth of the Swedish economy. These developments can be summarized as follows:

- Integration of industries in Sweden into global corporate structures in which companies in Sweden are constantly evaluated on their performance and subject to the effects of frequent restructuring[1]
- Growing attractiveness of emerging economies not only as markets but increasingly as sites for manufacturing, and more recently for R&D and other high-paying value-creation activities as well
- Researchers and research-based knowledge have generally become more important in knowledge-based economies such as the Swedish one
- The movement towards "open innovation" (triggered by faster and more complex innovation processes) is making exchange between industry and universities or research institutes more important
- Growing global competition for talent in the form of students as well as young and senior researchers and engineers
- Declining interest among young people in industrialized countries in studying engineering and natural science

The changes listed are strongly interconnected in a complex way. While the changes are felt in most countries, it can be argued that the globalization of industry represents a bigger challenge – which includes threats as well as opportunities – for Sweden than for most other countries. In relation to its size, Sweden was until recently the home base for an unusually large number of highly international and successful companies. Many of the same businesses still remain in Sweden but they are now integrated into larger global corporate structures, a rapidly increasing proportion of which are controlled from headquarters outside Sweden. Even in the global corporations that are still controlled from Sweden, the Swedish company units in many cases hold a much less privileged position than they used to.

Global industrial groups, whether they are headquartered abroad or in Sweden, make their R&D investment and new business development decisions based on a global perspective. For companies located in Sweden that belong to global industrial groups, the quality of the local environment in terms of sufficient availability of high quality engineers and researchers and nearby access to suitable partners for collaboration in R&D at universities, research institutes and different types of companies will, in the long run, influence the extent to which their parent companies are willing to invest in Sweden. Decisions by global corporate groups on where to locate various activities, including where to make investments in the creation of

new businesses, are very complex and involve a number of factors. The research and innovation environment in a particular location is only one such factor. There is no doubt, however, that a company unit that has numerous productive links in its vicinity – be it locally, regionally or nationally – with research groups and other companies that are perceived as innovative, has a much stronger raison d'être and is more difficult to move than a unit that lacks such links.[2]

Keeping existing industries in Sweden is not sufficient to secure the long-term health of the Swedish economy. Attracting foreign firms to invest in Sweden is now more important than in the past. In the form of acquisitions of Swedish firms, this has already happened on a large scale.[3] It is more difficult to find good examples of inward "greenfield" investments in Sweden in the development of new ventures. Whether it is realistic or not to expect such investments in Sweden is open to argument. Does the small size of the Swedish market and, maybe more importantly, Sweden's location at the periphery of Europe logistically far away from the large markets on the European continent, put Sweden at an insurmountable disadvantage for investments in the creation of new businesses by global companies? A large number of global industrial groups already own companies in Sweden. Investment by those groups in new business within the companies they already own in Sweden may be the most feasible mechanism for inward investment in new business creation.

Whatever the precise nature of the investments by global industrial groups in Sweden, they are likely to be dependent on Sweden's attractiveness as an environment for R&D and innovation. In this context, the attractiveness and competitiveness of universities and research institutes in Sweden as partners in R&D are crucial factors.

As interest among young people in Sweden in studying science and technology has been on the decline, there is great concern that an inadequate supply of high quality engineers and researchers will become a serious bottleneck for development in Sweden's business sector and, as a result, future economic growth will be constrained. Against this background, it will be increasingly important for universities to be able to secure a net flow of talented students and researchers into Sweden. In recruiting students and researchers, universities are increasingly competing on a global scale.

INTERNATIONAL AND GLOBAL CONNECTIVITY

In Sweden policies for internationalization of research have been dominated by issues related to European research co-operation. Integration of the European Research Area (ERA), the overarching objective of successive Framework Programmes (FPs), is important for the development of globally competitive research institutions in Europe. It is crucial for Swedish research organizations to achieve a leading position within the ERA in their chosen focus areas.

It is significant, however, that the strong focus on "regional" integration, which characterizes policies for international research co-operation in Europe, has no real equivalent in the rest of the world. Outside of Europe, internationalization leans much more towards the development of global links, while regional integration plays a much smaller role. The most obvious explanation for this difference is the uniqueness of the European Union as an international institution and the lack, or relative weakness, of similar institutions for regional co-operation elsewhere. Other factors do, however, also play a part. One is the uneven development of scientific research across the globe, which has made it more attractive for researchers in Asia, Africa and Latin America to seek co-operation with researchers in North America and Europe rather than with regional partners. As the level of scientific excellence has been raised in several countries in Asia, there are some signs that regional research co-operation is increasing in relative importance, although exchange at the global level is still the dominant mode. For countries like the USA and Australia it is more or less a geographical necessity for international co-operation to primarily mean co-operation at the global level.

While intra-regional co-operation is an important phenomenon in Europe, it should be

emphasized that Europe is also experiencing the globalization of its research. As Chapter 5 will show, for Europe as a whole, internationally co-authored articles that include authors from outside Europe are twice as common as articles co-authored by European authors alone.[4]

A major challenge in the work presented in this report has been to compare the levels and patterns of internationalization between countries in Europe and countries outside Europe. One conclusion is that it is necessary and important to distinguish between processes of "regional integration," such as the integration of the European Research Area on the one hand and the development of research connections at the global level on the other.

CONTENTS OF THE REPORT

The main purpose of this report is twofold. First, to provide a consistent set of basic facts concerning Sweden's links to the international scientific community as reflected in the co-authorship of scientific articles between researchers in Sweden and researchers in other countries. Second, to reflect on the wider context and policy implications of the pattern of Sweden's global research connectivity that emerges from the analysis.

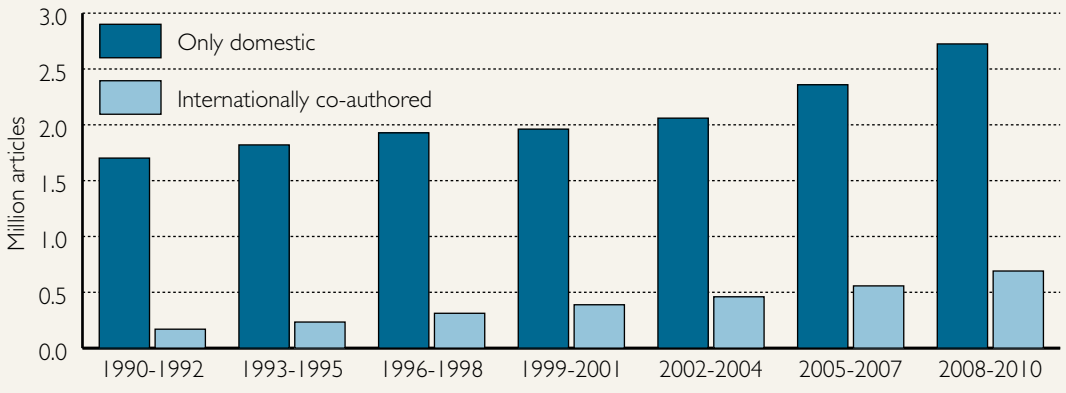
The focus is on comparing the geographical pattern of Sweden's research connections with the same pattern for other countries. Data for individual Swedish universities and 19 selected foreign universities complements and gives more depth to the analysis at the national level. The changes over time in co-authorship patterns and differences between 12 major fields are quite significant and therefore given much attention. In order to shed some light on the differences in the quality of the published research, data for the world's 10 percent most cited articles in the world is compared with data for all articles.

There is a very specific methodological issue concerning articles with a large number of authors from many countries. In bibliometric analysis this is often dealt with by using so-called fractionalization where only part of an article is assigned to each country. This method is, however, difficult to apply in a meaningful way in analysis of co-authorship. In cases where multi-country articles play a large role, articles with authors from five or more countries have been excluded from the analysis as they are not considered helpful in providing useful information about connections between individual countries.

Chapter 2 explains the nature of the data being used and highlights some of the changes in the global geography of the production of scientific articles over the past 20 years. In Chapter 3, data and methodological issues related to analysis of international co-authorship are introduced. In Chapter 4, the pattern of Sweden's international co-authorship is compared with that of other European countries, including an extra detailed comparison with Switzerland. Chapter 5 focuses on co-authorship with six countries in Asia, and the comparison of Sweden's publication patterns is expanded to include countries outside Europe as well. In Chapter 6 the analysis goes into more detail for a select group of individual universities. Finally in Chapter 7, findings from the analysis of co-authorship data are summarized and possible measures for strengthening Sweden's global connectivity in research are discussed.

2. Global shifts

Figure 1: Number of articles in Web of Science database by year of publication



INTRODUCING THE DATA USED IN THIS REPORT

The data in this report has, unless otherwise indicated, been extracted from the Thomson Reuters Web of Science (WoS) database at the Swedish Research Council (VR).[5] Currently around 1.2 million articles are added to the database each year (Figure 1). In the late 1990s the corresponding figure was around 800,000 articles per year.[6] During the 1990s the growth was considerably slower. As will later be discussed, internationally co-authored articles have grown faster than the total volume of articles.

The WoS is a very comprehensive database of scientific publications. Still, it must be emphasized that it does not include all scientific publications. Decisions about which journals to include in the database will to some extent be subjective. It can be assumed that more or less all well-established and scientifically important journals will be included. Decisions about if and when to include less reputable journals and journals that have not yet had time to establish their reputation will necessarily be somewhat subjective. Over the past 15 years one notable change in the WoS is that the number of articles in journals from US publishers has grown at a significantly slower pace than the total number of articles in the database.[7] The difference in growth rate has been 2–3 percent per year over the past 15 years. This change in the geography of publishers may simply be a reflection of changes in the geography of scientific activity, but it might also reflect changes in the journal selection policies of Thomson Reuters.

Even if the geographical distribution of pub-

Figure 2: Internationally co-authored publications as a share of all publications

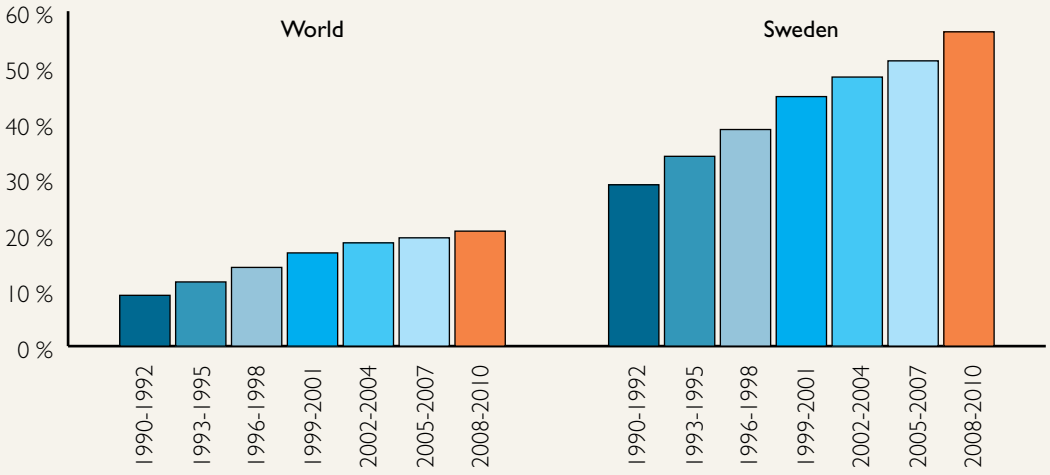
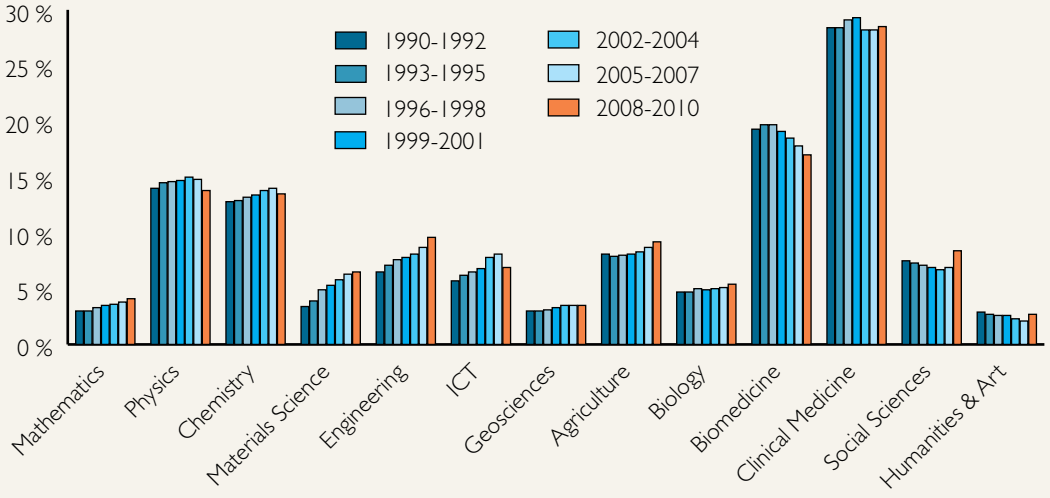


Figure 3: Articles in different fields in relation to all articles in the WoS database 1993–2010 (percentage of all articles)



lishers has changed, there have not been any significant changes in the languages used in the journals. The share of articles in English has remained constant at around 95 percent over the past decade, after increasing from around 90 percent in the early1990s. Other languages, which made up more than 0.5 percent of all articles 2008-2010, were French, German, Portuguese and Spanish. During the same period, articles in Japanese, Korean and Chinese made up only 0.12, 0.08 and 0.04 percent respectively.

Around 20 percent of all articles in WoS published from 2008 to 2010 were written by

authors from more than one country, an increase from around 12 percent from 1993 to 1995. As will be discussed in detail later, there are major differences between countries in terms the share of internationally co-published articles. Sweden's share has grown from around 40 percent in the mid-1990s to around 65 percent in recent years. Considering the frequent references to the rapid internationalization of research, international co-publications as a percentage of all publications globally has grown more slowly than might be expected in recent years. A major reason for this is that, while international co-publications in China have grown very fast, the publication of purely domestic articles has actually grown even faster. Thus, on the whole, publications in China have become less international.

In the WoS database, the journals in which the indexed articles were published are classified by scientific field. In a classification developed at the Science Policy Research Unit (SPRU) at Sussex University, the fields have been aggregated into 13 broad fields as shown in Figure 3.[8]

In some cases a journal may be classified as belonging to two or even more fields.[9] There is thus some overlap between the different fields, e.g. between Chemistry and Materials Science and between Biomedicine and Clinical Medicine. This explains why the sum of the percentages of all 13 fields is 129 percent and not 100 percent as would have been expected if there was no overlap.

As Figure 3 shows, the size of the different fields varies considerably and the fields have also grown at different rates. Clinical Medicine and Biomedicine dominate, but Physics and Chemistry are also fields with a large number of articles.[10] Other fields, such as Engineering and Materials Science, have, however, grown more rapidly and increased as a percentage of the total number of articles. As will be shown shortly, the relative weight of different fields varies significantly from country to country. The growing weight of Engineering and Materials Science partly reflects the greater weight of these fields in China and other countries with rapidly growing research communities compared to slower growing North America and Europe, where life sciences play a larger relative role.

HIGHLY CITED ARTICLES AS A MEASURE OF QUALITY

There are significant differences between articles in terms of how much they contribute to progress in their respective fields and the attention they receive from the scientific community. The scientific impact of a scientific article is often measured in terms of the number of citations it receives during a certain period. Citation rates are also usually seen as a measure of the quality of the research presented in an article.

In this report we will define "highly cited articles" as all articles cited higher than the 90th percentile in the respective journal subject field. This technical definition translates in practice to about 8–9 percent of all articles in the respective field. The exact percentage varies between fields and years. For simplicity we will use the terms "highly cited articles", "top-cited articles" and "the world's 10 percent most cited articles" as all having the meaning just described.[11]

Two technical aspects of arriving at this measurement should be mentioned, although they need not concern the reader too much. First, the average citation frequency varies greatly between fields. In order to deal with this, different citation rates are normalized in relation to the standards for each field. Field in this context refers to a rather fine division of all articles into around 250 subfields.

Second, the number of citations depends on the length of the period after publication during which citations are counted. In this report the chosen "citation window" is three years. This means, for example, that for articles published in 2007, citations included in publications from 2007 to 2009 are counted. The last year for which citations are counted is 2011. This means that the citation window for articles published in 2010 will be only two years. The citation rates of the 90th percentile are, however, counted separately for each year of articles.

INTERNATIONALLY CO-AUTHORED ARTICLES COUNTED AS WHOLE ARTICLES FOR EACH CONTRIBUTING COUNTRY

One particular issue is how to treat articles with authors from several countries. In this report we have used so called "whole counts," which means that articles with authors from several countries are also counted as one article for each of the contributing countries.

An alternative approach that is common in bibliometric analysis is to divide such articles among the contributing countries. With this methodology – so called fractionalization – an article with authors from three countries will be counted as a third of an article for each of the three countries. One advantage with this approach is that the sum of all countries' articles will add up to the total number of articles in the world.

We have chosen the whole count approach because the focus is on co-authorship in this report. Fractionalizing data for co-authored articles makes the analysis very difficult to explain in non-technical terms.

In order to avoid too big of an influence from articles with authors from a large number of countries, when using the whole count approach, this report sometimes treats articles with authors from five or more countries separately. This will be discussed further in the next chapter.

It is worth mentioning that the choice of methodology between whole and fractionalized counts in some cases may yield different results. One effect of the difference in methodology is the weight given to internationally co-authored articles. When the whole count method is used, a country's purely domestic articles and its internationally co-authored articles are given the same weight, while with the fractionalized count method, the internationally co-authored articles are given less weight in proportion to the number of countries involved in the respective article. To the extent that there are significant differences in citation rates between domestic and international articles, the choice of methodology will result in different average citation rates. For many countries, Sweden included, there is a tendency for internationally co-authored articles to have higher citation rates than purely domestic ones. This is especially true of articles with a large number of authors from many countries, which is one reason why articles with five or more countries are sometimes treated separately in this report.

As will be demonstrated, there is a much bigger difference in citation rates between domestic and internationally co-authored articles in Sweden than in e.g. Denmark and Switzerland. In Sweden the citation rates for purely domestic articles are on average significantly lower than those for internationally co-authored articles, while this is not the case in Denmark and Switzerland.[12]

This difference in relative citation rates of domestic and international articles is so large that its causes need to be clarified. The difference suggests that there might be major differences in the basic features of the research system in Sweden compared to the research systems in Denmark and Switzerland. Depending on the underlying reason for the difference, the appropriate policy response should be expected to differ.[13]

DOMINANCE OF NORTH AMERICA AND EUROPE CHALLENGED, ESPECIALLY IN ENGINEERING-RELATED FIELDS

The research map of the world is changing dramatically.[14] While the underlying processes of change have been in place for at least a couple of decades, research in countries outside North America, Europe and Japan have only recently reached a scale such that the earlier dominance of the former is being challenged. There is reason to believe that this rebalancing of the research landscape will continue and that as a consequence research will increasingly become a truly global activity.

The most striking change in the research map of the world has been the rise of China as a major power in scientific research. The size of China means that its developments are par-

Figure 4: Countries with 1 % or larger share of the world's 10 % most cited articles in Engineering

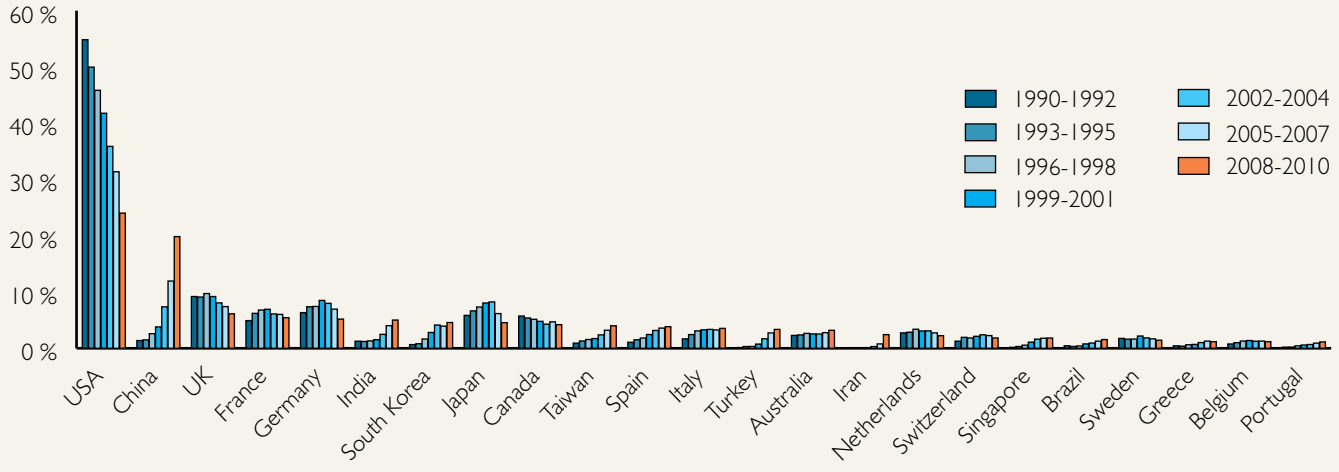
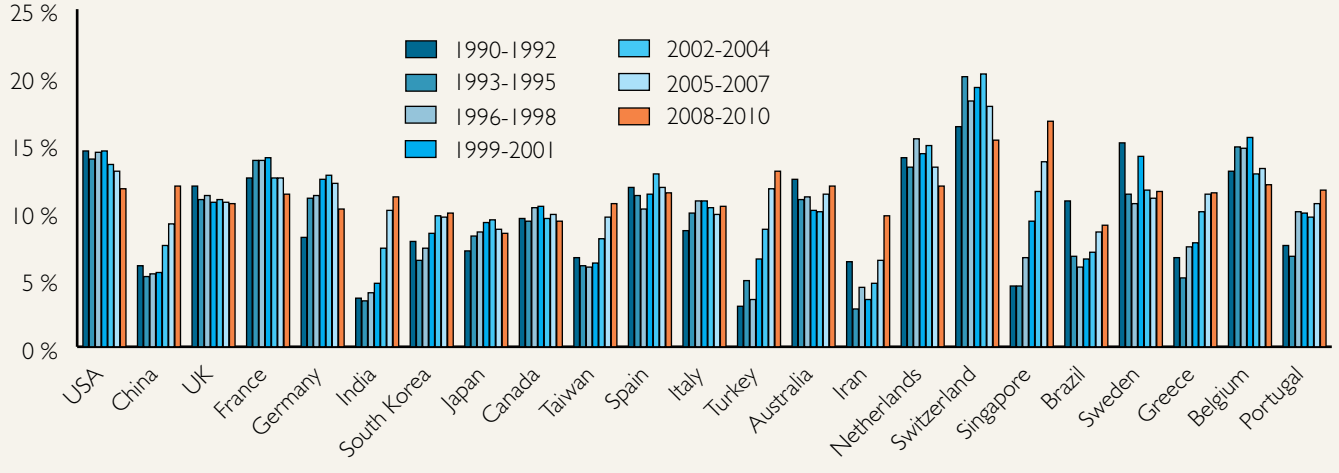


Figure 5: Quality of country's articles measured as share of the world's 10 % most cited articles among country's total articles: Engineering



ticularly widely felt, but as will be shown, the changes are occurring on a much broader scale than China.

The situation varies from field to field. Global averages tend to hide much of the most interesting dynamics. We will use two fields to illustrate the shifts under way: one is Engineering and the other Clinical Medicine. It needs to be said that large parts of ICT-related engineering (e.g. electronics and computer science) are not included in what will be referred to as Engineering. They are classified under the separate category of ICT. Still, there is some overlap between ICT and Engineering.

It is frequently claimed that scientific articles from China and other emerging scientific powers are still inferior in quality to those from scientifically more established countries and that the rapid growth from the former is therefore not as significant. It is indeed true that, if citation frequency is used as a measure of quality, on average the quality of articles from e.g. China has tended to be lower than the quality of articles from leading scientific nations. This situation is, however, rapidly changing, at least in certain fields and for some countries, including China.

Figure 4 shows the reshaping of the global research map in the field of engineering over the past two decades. In the early 1990s USA was by far the dominant player, with researchers from the USA appearing in more than half of all of the 10 percent most cited articles. Twenty years later this had fallen to just over 20 percent.[15]

China experienced the reverse development, with its share growing from 1.3 to 19 percent during the same period. This brought China to more or less the same level as the USA and almost four times the level of the United Kingdom, which ranked third during the period 2008–2010.

It may seem surprising, but the rebalancing is actually somewhat less drastic if all articles are considered rather than only the 10 percent most cited ones. In this case the USA's share decreased from 37 to 19 percent while that of China grew from 2.3 to 16 percent. The reason is that the quality of articles from China has grown very significantly over the past decade and was even higher than those from the USA during the most recent period (Figure 5). Meanwhile the percentage of all articles from the USA belonging to the 10 percent most cited ones decreased somewhat although not dramatically.

Turning to the field of Clinical Medicine, the picture is altogether different. The USA has maintained its dominant position and China is still only ranked in tenth place after Australia, followed closely by Switzerland. During the period 2008–2010 the USA's share was around 50 percent of all articles, which was around 14 times that of China. The relative size of the two countries in Clinical Medicine is totally different from in the field of Engineering. The overall trend, however, shows some similarity with very rapid growth for China, albeit from a low starting point, and the USA's share declining albeit at the more modest rate of 10 percent over the two decades studied in the case of Clinical Medicine. The relative quality level of Chinese articles on Clinical Medicine is still rather low and has only modestly improved in recent years in strong contrast to the rapid improvement to a high quality level in Engineering. Comparisons of China and the USA in Engineering and Clinical Medicine can be generalized to other engineering-related fields (Chemistry, Materials Science and ICT) on the one hand, and other Life Sciences (Biology, Biomedicine) on the other.

If we look at other countries among the 23 top ranked countries in each of the two fields in terms of the percentage of articles among the 10 percent most cited articles in the world, we also find very significant differences.[16] In engineering, India, South Korea, Japan and Taiwan are all at a level comparable to that of the leading European countries (United Kingdom, France and Germany) and Canada, and the trend indicates that India, South Korea and Taiwan are increasing their share, while the European leaders, Japan and Canada are in relative decline. Other countries that have expanded rapidly into significant players are Spain, Turkey and Iran. All of the aforementioned rapidly expanding countries today have reached a quality level comparable to the leading European countries and a level that is more or less the same as that of Sweden. India, Taiwan and Turkey in particular have raised the quality of their articles from a rather low level. Notable is also that Singapore, with less than half of Sweden's population, ranks higher than Switzerland, Brazil and Sweden in the number of top cited engineering articles. After a remarkable improvement in quality from a very low level in the early 1990s, Singapore is now leading in terms of the top cited articles as a percentage of all of its engineering articles. Brazil continues to show mediocre quality.

Similar to China, the other countries that have rapidly strengthened their position in Engineering are showing a significantly weaker position in Clinical Medicine. Their share of top cited

Figure 6: Countries with 0.95 % or larger share of the world's 10 % most cited articles in Clinical Medicine

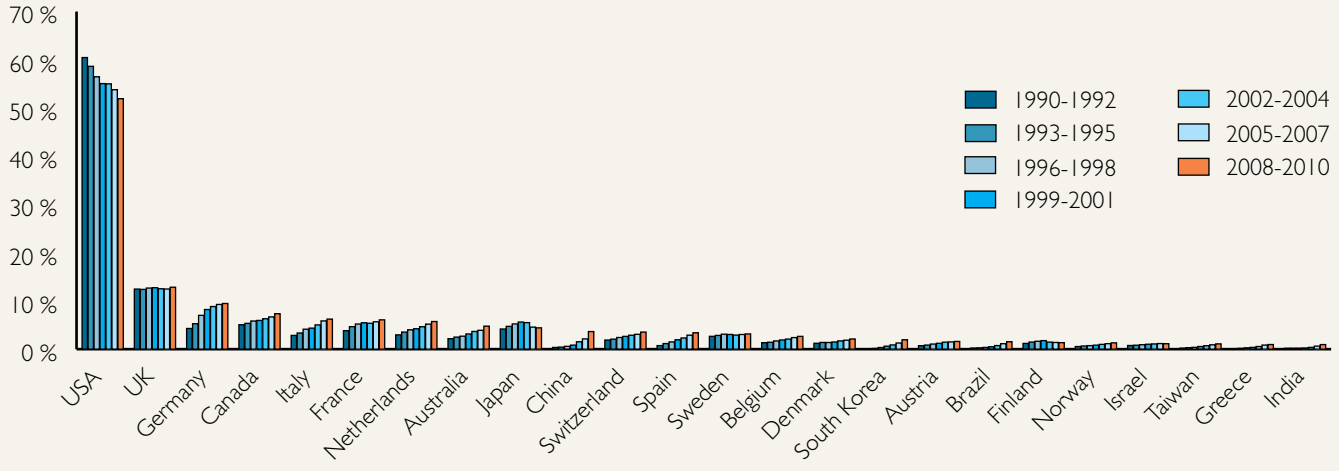
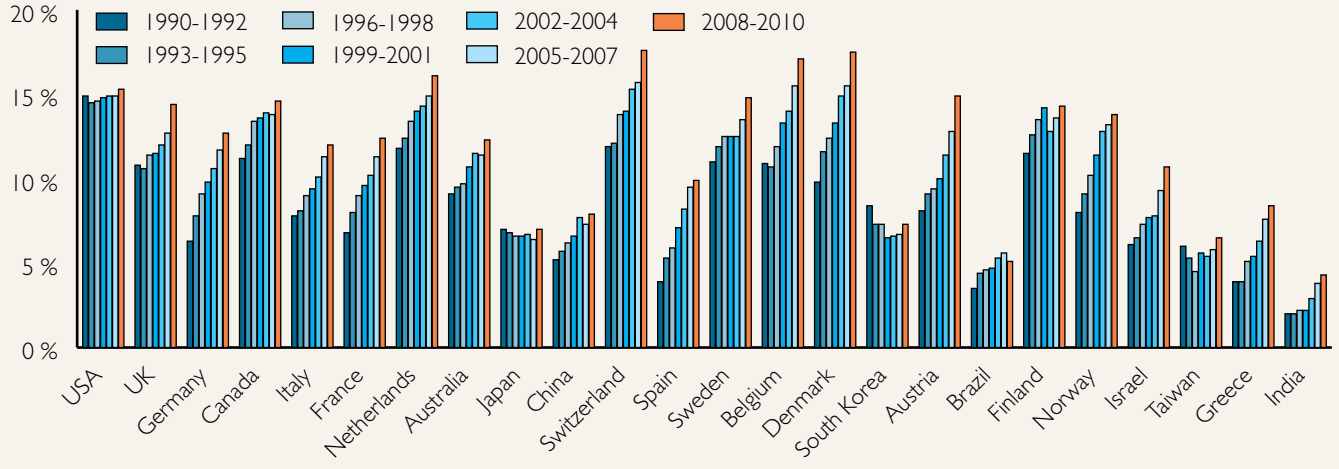


Figure 7: Quality of each country's articles measured as their share of the world's 10 % most cited articles among each country's total articles: Clinical Medicine



articles in the latter field is typically 3–5 times lower than in Engineering and there is not the same quality improvement in Clinical Medicine as in Engineering, with Singapore as an exception. The ranking of small European countries such as Switzerland and Sweden is significantly higher in Clinical Medicine, and three other Nordic countries are among the top 23 in Clinical Medicine, while none of them reaches that level in Engineering.

As mentioned earlier, the global research map differs considerably from field to field. Figures 8 and 9 compare the situation in 13 fields for China and the USA. The situation for Materials Science, Chemistry, Mathematics and ICT is very similar to the one discussed above for Engineer-

Figure 8: Development of China's share of the world's 10 % most cited articles in different fields

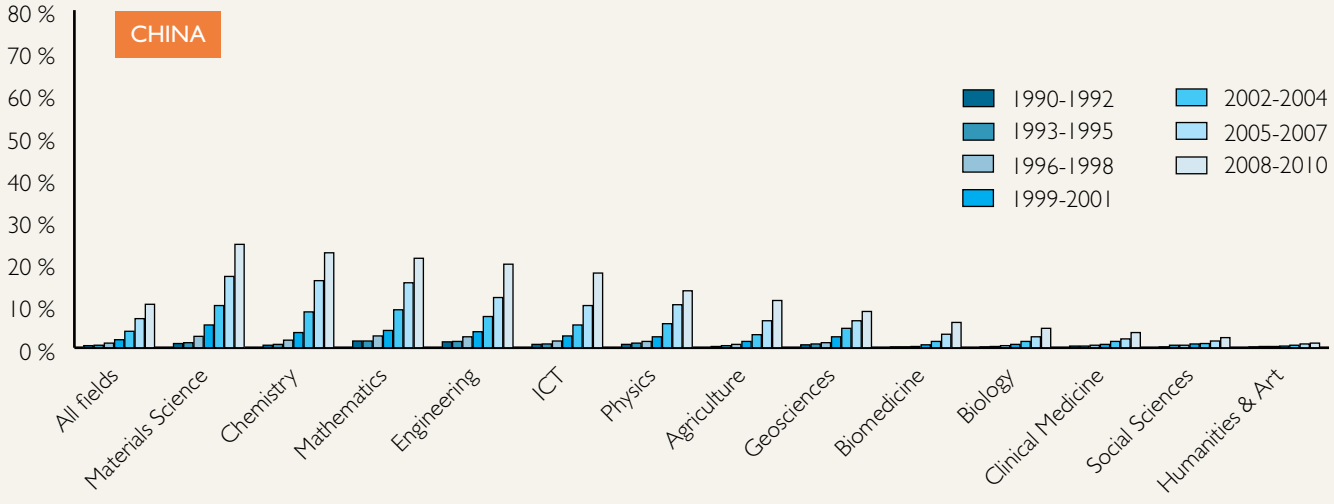
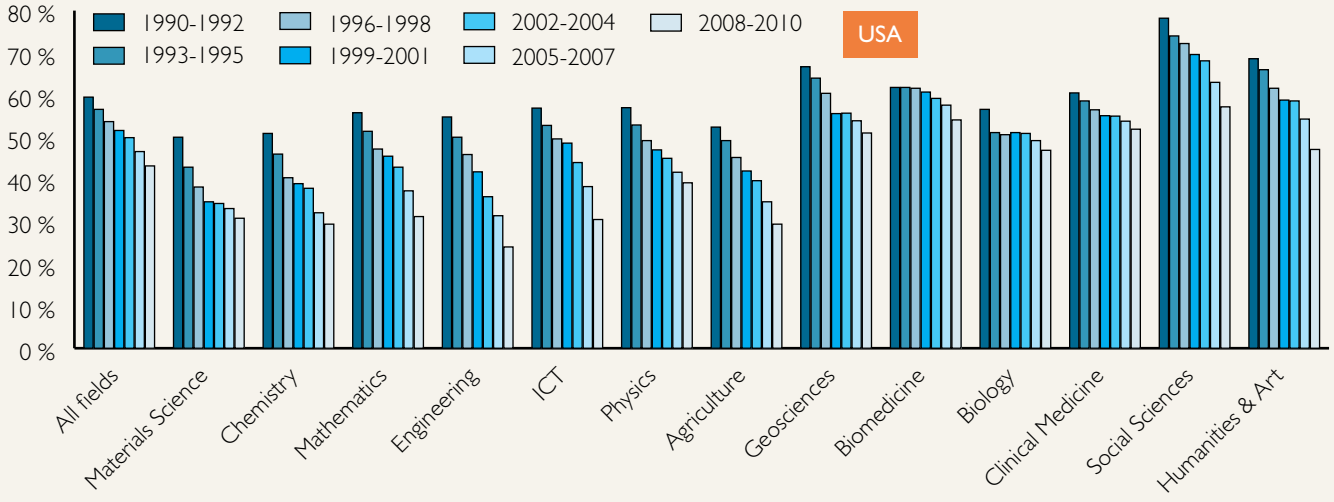


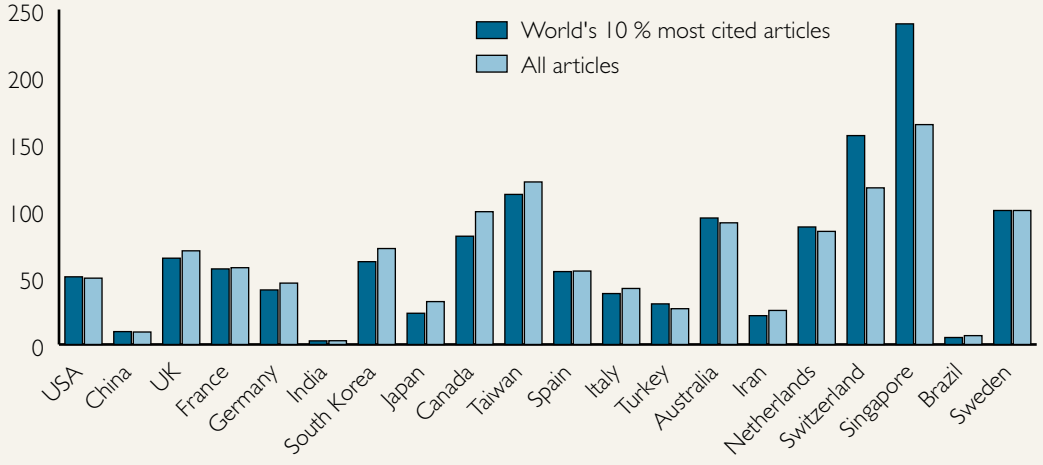
Figure 9: Development of the US share of the world's 10 % most cited articles in different fields



ing. China's share in these fields today varies between 17 and 23 percent and that of the USA between 21 and 30 percent. USA's share has drastically fallen in all of these fields from around 50 percent two decades ago, while China's share has multiplied manyfold during the same period.

The situation in Biomedicine and Biology is quite similar to that of Clinical Medicine, one difference being that China's share in Biomedicine is about twice that of Clinical Medicine. In both fields the USA's share remains high at around 50 percent and in Biology it is only marginally lower. Social Sciences and Humanities & Arts are China's weakest fields, while the former field

Figure 10: Articles in the field of Engineering per capita for Top 20 countries (Articles per capita 2008-2010 Rebased: Sweden=100).
Countries ordered by their share 2008-2010 of world's 10 % most cited articles in the field of Engineering



is heavily dominated by the USA, although somewhat less than the extreme situation two decades ago. USA also maintains a very strong position in Geosciences, while China is a stronger player in this field than in the Life Sciences. Physics and Agriculture resemble the Engineering-related fields, except that the USA has been more successful in maintaining its position in Physics, while China is somewhat weaker in Agriculture than in the Engineering-related fields.

If all fields are considered together, China's share is around 10 percent and USA's share around 40 percent. As mentioned before, in most individual fields the relative size of China and the USA differs from these average numbers.

WHICH COUNTRIES SHOULD SWEDEN BE COMPARED WITH?

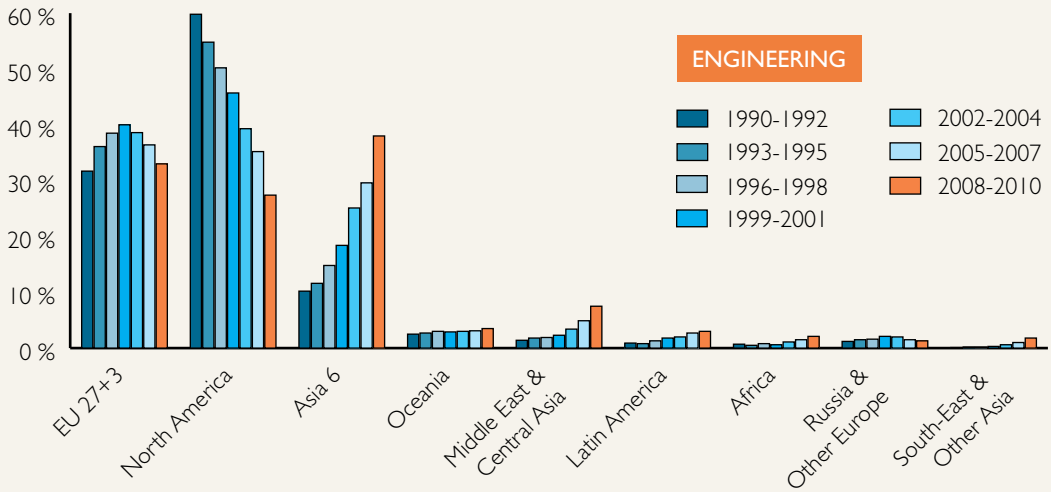
The data presented so far has been in absolute terms without taking into account the difference in size of the various countries. That difference is indeed huge. Singapore, ranked in 17th place for authorship of the world's 10 % most cited articles, has a population of only 5 million people, which is less than 0.4 percent of the population of China. On a per capita basis Singapore authors 23 times as many top cited articles as China and 2.5 times as many as Sweden (Figure 10).

In relation to its population, China's production of highly cited articles is thus still quite low, although somewhat higher than that of other so-called BRIC countries (Brazil, Russia and India[17]). In other words there is nothing really remarkable about the size of China's scientific production. If anything, it should be expected to continue to increase considerably in the years to come. What is remarkable is the speed with which it has increased.

In most international rankings of countries in terms of their research, innovation and competitiveness, Sweden usually scores very high. This is because Sweden performs very well on a per capita basis in most of the relevant variables. This is also true for the authoring of scientific articles. Among the top 40 countries for a high rate of cited articles in Engineering – not one of Sweden's strongest fields – only Taiwan, Australia, Singapore, Switzerland and Denmark score higher.[18] It should be mentioned that among the much smaller countries, Iceland, Cyprus and Lichtenstein show higher per capita authorship than Sweden, which might serve as

Figure 11: Share of World's total number of highly cited articles in the field of Engineering by "country group"

Share of world's 10 % most cited articles



a warning against taking Sweden's high ranking on many per-capita scoreboards too much at face value.

Large countries with a strong tradition in research such as USA, United Kingdom and Germany, show significantly lower per capita authorship in most fields than leading small countries such as Switzerland, Netherlands and the Nordic countries. One factor contributing to this is that large countries are much more likely than the leading small countries to include diverse regions, with the effect that the less advanced regions bring down the average performance for the large countries.

It would therefore be desirable to disaggregate the large countries in order to make more meaningful comparisons, but unfortunately many technical difficulties would arise if this were to be done systematically. Figure A1.2 in Appendix 1 gives some indication of the importance of more disaggregated comparisons using examples from the USA. At the country level, Sweden today excels over the USA by almost a factor two in terms of published articles in all fields per capita.[19] If Sweden is instead compared with one of the most research-intensive states in the USA, Massachusetts, the level of the latter is well beyond twice that of Sweden. Two other more "average" states, Minnesota and Illinois, are more or less at the same level as Sweden. Similarly, there are big regional differences in, for example, Germany.

In Europe there are many countries with a population size comparable to that of Sweden and several of these, notably Switzerland, the Netherlands and the other Nordic countries, are advanced enough to make meaningful comparisons with Sweden possible. This, of course, does not mean that it would not be even more meaningful to compare Sweden with individual regions in larger European countries.

Going outside of Europe, it is much more difficult to find countries with a size and level of research that make them suitable for comparisons with Sweden. The main candidates for comparison are limited to Canada, Australia, Singapore and New Zealand.[20] The first two are considerably larger than Sweden, at 33 and 22 million inhabitants respectively, while the latter two have roughly half the population of Sweden. In terms of industrial structure, they are all very different from Sweden. In any case they represent a very small part of the world outside of Europe.

Research groups and universities in Sweden are not just competing with those in other small countries. They are increasingly competing with institutions in large countries outside Europe. Benchmarking must therefore also include large countries, but given the big differences between regions and individual institutions in large countries, comparisons with Sweden have to be performed at a disaggregated level even if this is often technically difficult to accomplish. As a small step in this direction, in Chapter 6 we will introduce some data on the level of individual universities.

DEFINING COUNTRY GROUPS FOR OVERVIEW

In the following analysis of patterns of international co-publications it will frequently be desirable to consider groups of countries in order to limit the amount of detailed information and provide an adequate overview. The country groups chosen are shown in Figure 11 and a list of major countries in each group is presented in Table 1 in Appendix 1.

The three main groups are EU, North America and six leading Asian countries. Switzerland, Norway and Iceland have been added to the 27 EU countries, explaining the label EU 27+3. North America consists of the USA and Canada, with the former dominating the group with 86 percent of all top cited articles. Asia 6 includes China, Japan, South Korea, India, Taiwan and Singapore. Japan's development has, especially for the last 10-15 years, been very different from other countries in the group and more closely resembles that of the USA and mature economies in Europe. The uneven development of countries is, however, not unique to the Asia 6 group and is also very much the case in, for example, the EU 27+3 group. While EU 27+3 and North America can naturally be referred to as regions, this is less true for Asia 6. There is much less real economic integration among the Asia 6 countries. Geography is one factor, but perhaps not the most important one.

The other six groups are relatively much smaller in terms of scientific articles published, although not necessarily in population size. Oceania consists for all practical purposes of only Australia and New Zealand. European countries other than EU27+3 have been combined with Russia, which dominates the group. Asia, other than the Asia 6 group, has been divided into South-East Asia on the one hand and the Middle East and Central Asia on the other.[21] As it turns out, the South-East Asia group is dominated by Thailand and Malaysia while the large population countries Indonesia, Philippines and Vietnam still play a surprisingly small role in the scientific research of the group. In the Middle East and Central Asia, Israel, Turkey and Iran dominate, with Israel losing ground relative to the other two which have grown rapidly. The leading countries in Africa are South Africa and Egypt, while in Latin America they are Brazil, Mexico, Argentina and Chile. Please refer to Tables 1 and 2 in Appendix 1 for more details on the main countries in each of the groups (with the exception of the EU).

3. Co-publications as a measure of connectivity

WHAT IS MEASURED WHEN INTERNATIONALLY CO-AUTHORED ARTICLES ARE COUNTED?

After sketching the changing geography of scientific research as it is reflected in the publication of scientific articles, we now turn to the main subject of this report – international co-publications.

In the WoS database used in this report, for each article published, all of the addresses of the participating authors are listed. In some cases, the same author may report more than one address, indicating that he or she is affiliated with more than one organization. The different addresses may be at one and the same institution, e.g. a department and a research center at the same university. In other cases an author may hold positions at more than one institution in the same country or even in different countries. When an author reports two or more different affiliations, the precise nature of these affiliations may vary considerably. In some cases the different affiliations may not actually be simultaneous. The researcher may have moved during the period under which the research work reported in the article took place. Or, one of the affiliations may be temporary and the author then finds it appropriate to include both the temporary and the more long-term affiliation.

Internationally co-authored articles are articles that have author addresses from more than one country. Articles co-authored between Country A and Country B will include at least one address from each of the countries. Usually this will mean that there is at least one author from each of the two countries. As explained above, even an article with one single author could appear as an internationally co-authored article if that author reported addresses in more than one country.

Co-publications between countries are frequently used as an indication of research co-operation between them. Apart from the multiple addresses of single authors, there is another circumstance that should invite caution in making the connection between co-publications and research co-operation. Research practices as well as the associated publishing practices vary between fields. In some fields, e.g. high energy physics, astronomy, geosciences, genomics and clinical research, research is often carried out by very large numbers of researchers who work and publish together. Sometimes the research is performed in a common large facility housing e.g. accelerators or telescopes. In other cases the actual work is planned jointly but most of it is carried out in a decentralized fashion. This is true, for example, in large medical studies with patients from many countries. The large number of researchers participating in this kind of project is reflected in scientific articles with a very large number of authors from many different countries.

On a global scale only 1.6 percent of all internationally co-authored and top-cited articles involve authors from five or more countries (Figure 12).[22] The share is particularly high for Clinical Medicine and Geosciences at 2.9 percent, while for Mathematics, Chemistry, Materials Science, Engineering and Humanities it is 0.2

Figure 12: The relative importance of articles with many countries among internationally co-authored publications by field and for selected countries.
2008-2010 World's 10 % most cited articles.
Share of internationally co-authored articles involving five or more countries (percent)

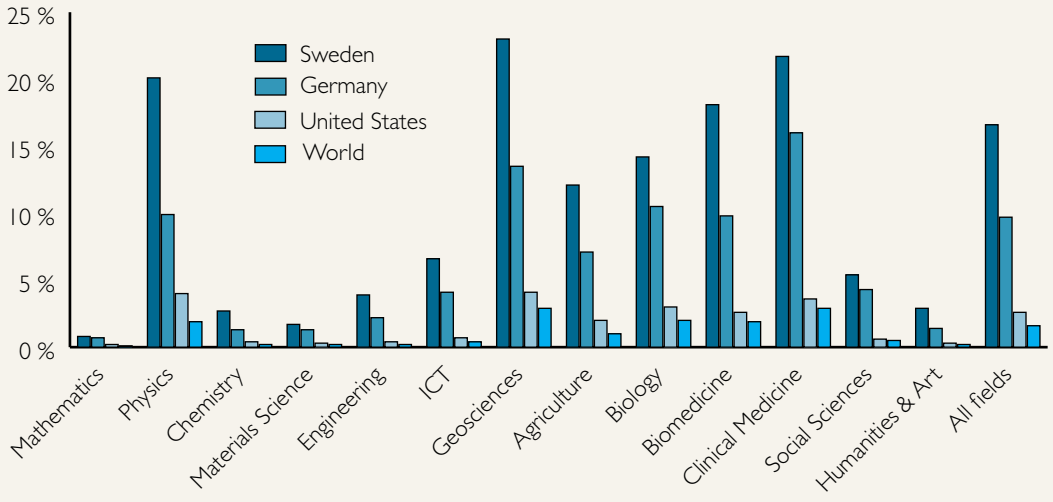
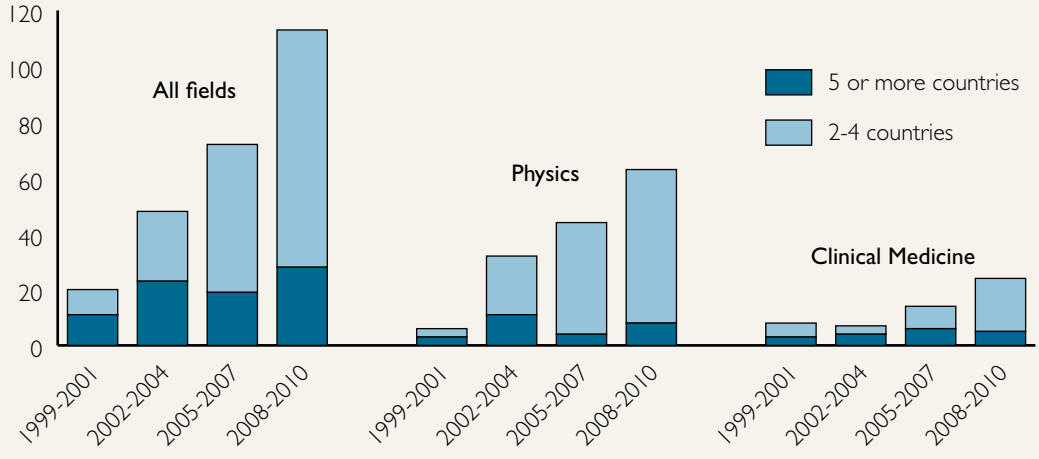


Figure 13: Articles co-authored between Sweden and South Korea. World's 10 % most cited articles.
Number of articles



percent or less and for ICT and Social Sciences it is only slightly higher.[23] Physics, Geosciences, Biology and Biomedicine are all close to the average level, while the share for Agriculture is somewhat lower at 1 percent.

For smaller countries like Sweden, co-publications involving many countries play a relatively much bigger role than the numbers just mentioned. For Sweden as much as one sixth of all internationally co-published articles include authors from five or more countries, which is ten times the average level globally. The differences between fields are similar to the situation globally.

One effect of the high preponderance of multi-country co-publications in small countries deserves special attention in the context of analyzing international co-publications. It is best explained by looking at a specific case. Figure 13 shows the development of co-authored articles between Sweden and South Korea. The selection of articles has been limited to those belonging to the world's 10 % most cited in the respective field.

When considering the total number of co-authored top cited articles between the two countries, it looks like the exchange between the countries has developed very rapidly from a low level of 6–7 articles per year ten years ago to around 35 articles per year in 2008–2010. As it turns out, the growth has been almost totally due to co-publications involving five or more countries, mainly in the field of Physics and to a lesser extent in Clinical Medicine. Articles that include authors from many countries are, of course, perfectly legitimate. They do not, however, indicate any particularly close exchange between any of the individual countries involved, although such exchange cannot à priori be excluded.

For purposes of policy related to international exchange, it would appear that it is quite important to separate exchange between countries that is fairly direct, from exchange that takes place within complex international settings involving many countries. For this reason, in this report all articles have been divided into three categories:

- **Purely domestic articles** with all authors from one and the same country
- Internationally co-authored articles with authors from **2–4 countries**
- Internationally co-authored articles with authors from **5 or more countries**

The choice of four countries as the cut-off limit for articles deemed to exhibit direct exchange between the countries involved is open to question, but has been judged as reasonable. Changing the number of countries up or down by a number or two is not expected to change the main results of the analysis presented.

AVERAGES COVER UP A HETEROGENEOUS WORLD

The relative importance of international co-authorship varies greatly between fields and countries. Not surprisingly there is a tendency for the size of a country to influence the degree of internationalization. There are, however, other factors at play as well that, in some cases, reduce or even negate the effects of country size on the degree of internationalization. While the percentage of all articles that are internationally co-authored has increased at a global level, this has not necessarily been the case for all individual countries or for all fields.

Many countries that have increased their production of scientific articles have increased the number of purely domestic articles faster than internationally co-published ones. Even so, their share of the total global production of internationally co-authored articles has increased. Thus, although in relative terms these countries' research systems have become less internationally oriented, their relative weight on the international scene has actually grown.

The analysis of international co-authorship to follow will mainly be based on data for the world's 10 percent most cited articles in the respective field. One issue is how strong the influence of this selection on the results of the analysis will be.

To illustrate how a complex interplay of many factors influences the dynamics of internation-

Figure 14: Turkey's world share of all and the 10 % most cited articles in the field of Engineering by extent of international co-authorship.
Percent of world total

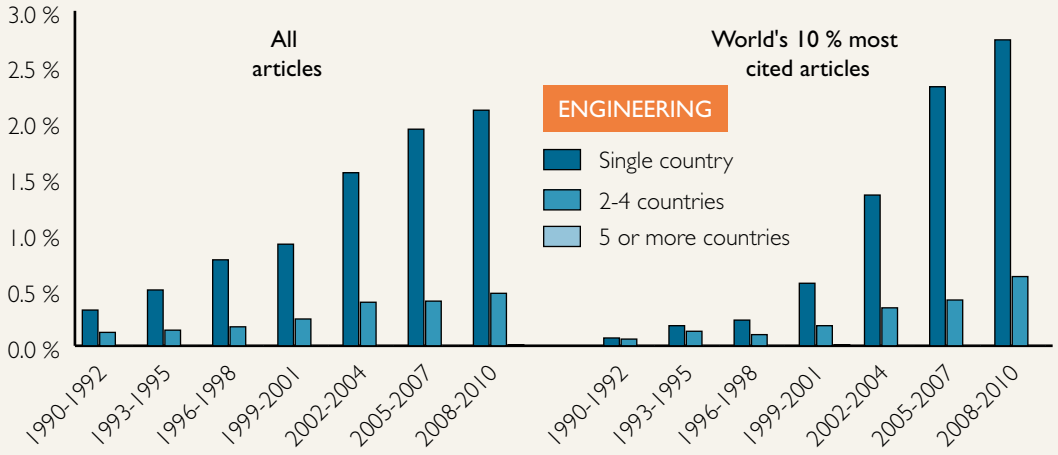


Figure 15: Turkey's world share of all and the 10 % most cited articles in the field of Biomedicine by extent of international co-authorship.
Percent of world total

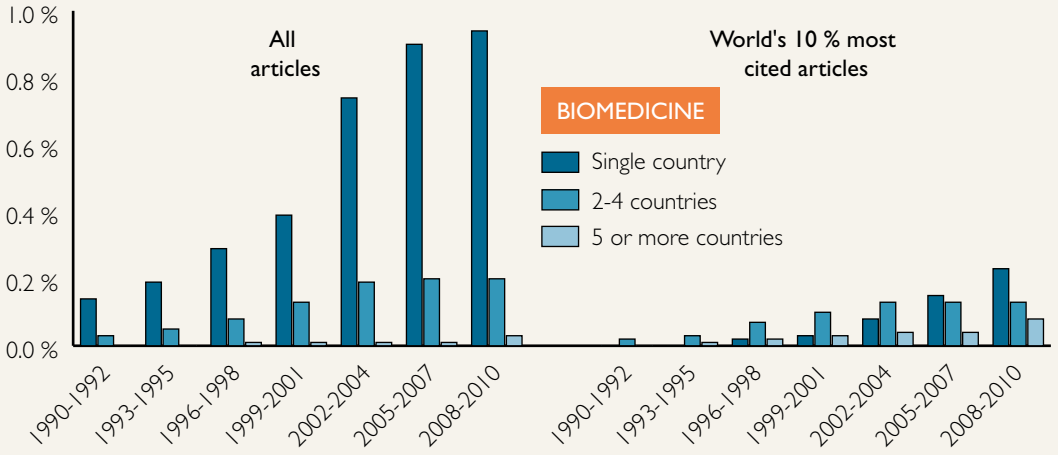
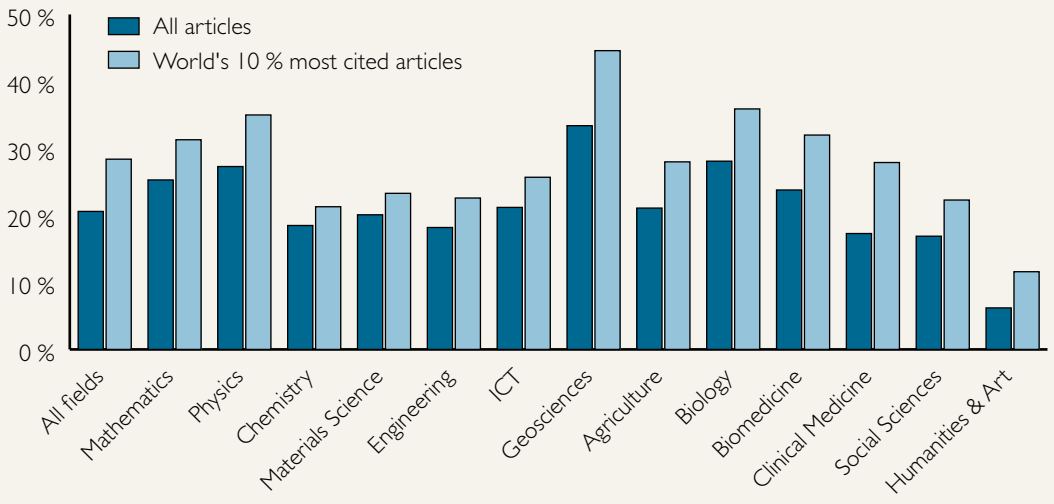


Figure 16: Internationally co-authored articles as a share of the world total for different fields for world's 10 % most cited articles and for all articles respectively. World total 2008-2010.
Share of articles that are internationally co-authored (percent)



alization in a single country, the development of two fields, Engineering and Biomedicine, in Turkey will be used as an example (Figures 14 and 15). Engineering has developed into a strong research field in Turkey, while Biomedicine remains much weaker. Counting all articles, in 2008–2010 Turkey's share of the world total was around 2.5 percent for Engineering and 1.2 percent for Biomedicine. The difference becomes more pronounced when only the world's 10 percent most cited articles are considered. In this case, Turkey' share of the world total is 3.3 percent for Engineering and only 0.4 percent for Biomedicine.

Looking at all articles, the percentage of internationally co-authored articles is nearly the same for Engineering and Biomedicine and has not changed very much over time. It has fluctuated in the interval of 16 –19 percent for Engineering and 16–22 percent for Biomedicine.

For highly cited articles, the degree of internationalization exhibits much bigger changes over time and differences between the two fields. In both fields, the share of top cited articles which are internationally co-authored has fallen sharply. For Engineering the share was around 40 percent in the first half of the 1990's and after gradually falling it stabilized around 15 percent during the period 2002-2010. In Biomedicine in the early 1990's Turkey contributed very few of the world's most cited articles and almost all of them were internationally co-authored. Over the past decade the share of purely domestic articles has increased and the share of internationally co-authored articles is today around 45 percent. The share of highly cited articles that are internationally co-authored is thus today three times higher in Biomedicine than in Engineering.

Based on these two examples some observations can be made. First, there is not necessary a correlation between a high share of international co-authorship and a strong research position. Similarly, a declining share of international co-authorship does not necessarily indicate a weakening of the relative quality of a country's research. There may indeed be big differences in the research performance of a country if its position is measured by top cited articles or by

all articles. The first measure seems preferable, but it needs to be understood that it is not only the level but also the dynamics of the two article sets that can vary in a number of ways that are often difficult to grasp intuitively.

For most countries in Europe and North America the share of internationally co-authored articles has consistently increased across all major fields. For many other countries the development is not as simple and the dominant trend has instead been a declining share. The reduced "dependence" on internationally co-authored articles seems to have been more pronounced among the top cited articles than for all articles. As Europe and North America together still dominate the global picture, the tendency towards increased internationalization in these two regions will be reflected in a similar tendency for the world total. As explained, this may not be representative of developments in other parts of the world.

With the caveat expressed in the above discussion, the global percentages of internationally co-authored articles for different fields are shown in Figure16, comparing the situation for highly cited articles and for all articles respectively.

4. Sweden's global connectivity in a European comparison

We will now proceed to look at international co-authorship in more specific ways and consider how individual countries are connected to each other. Our primary purpose is to understand how Sweden's position in the global knowledge economy is evolving. The main questions we will seek to answer are:

- To what extent has Sweden participated in the formation of an integrated European Research Area
- How have Sweden's links with other European countries developed in relation to links with other parts of the world?
- Is Sweden sufficiently connected to countries whose research capacity has been growing in recent years?
- What is a suitable reference for determining what is "sufficient"?
- Are Sweden's international connections beneficial? Do they produce results with a high impact?

We will begin by comparing Sweden's pattern of international co-authorship with that of other European countries. It will become obvious that there are many dimensions that need to be covered in such a comparison, which makes the analysis rather complex. We have therefore chosen to proceed with two steps. In the first step we will introduce the main elements of our model for comparative analysis by comparing Sweden with one other European country, namely Switzerland. In the second step we will expand the comparison to include data for 15 other European countries with different sizes and locations.

COMPARING SWEDEN'S AND SWITZERLAND'S GLOBAL CONNECTIVITY

Switzerland has a very strong reputation for scientific excellence in a broad range of fields and also ranks among the top countries in indicators of innovation and competitiveness. This is evident in high citation and per capita publication rates. Important in the present context is that a large share of Switzerland's articles are internationally co-authored. The fact that Switzerland's population at 7.6 million is close to Sweden's 9.3 million (2009) also makes it a suitable country to use as a benchmark for Sweden. Like Sweden, it has a successful export-oriented manufacturing industry. Among small economies it is the only one with a large machinery industry that matches the one in Sweden.

There are also differences between Sweden and Switzerland that are of importance when comparing international co-authorship. Languages and geography are among them. Located centrally in Europe and sharing languages with a host of large neighboring countries, Switzerland naturally has stronger connections in Europe than Sweden has with its peripheral location and a language that is only understood in the Nordic countries. The high connectivity with Europe would seem to hold in spite of the fact that Switzerland is not a member of the EU.

The structure of its research system shows both similarities with and differences from Sweden. Like in Sweden, universities play the main role in Switzerland. Only the two technical universities, ETH in Zurich and EPFL in

Figure 17: Development of Sweden's and Switzerland's share of the world's 10 % most cited articles and of all articles respectively 1990-2010
Share of world's total (percent)

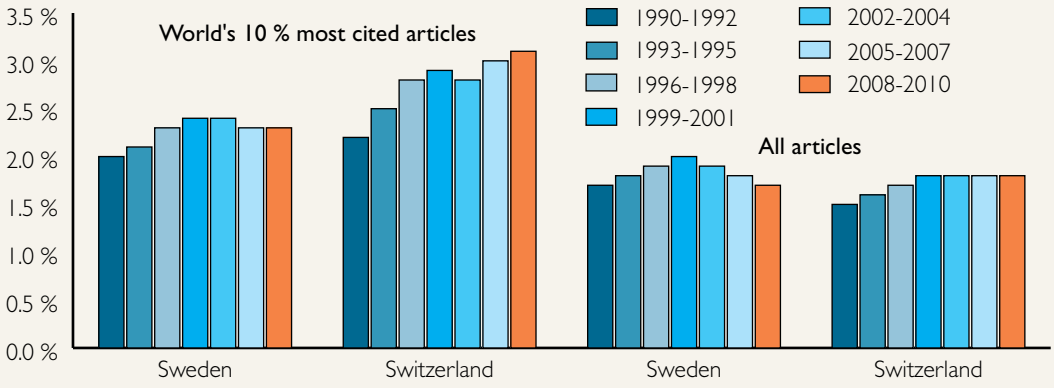
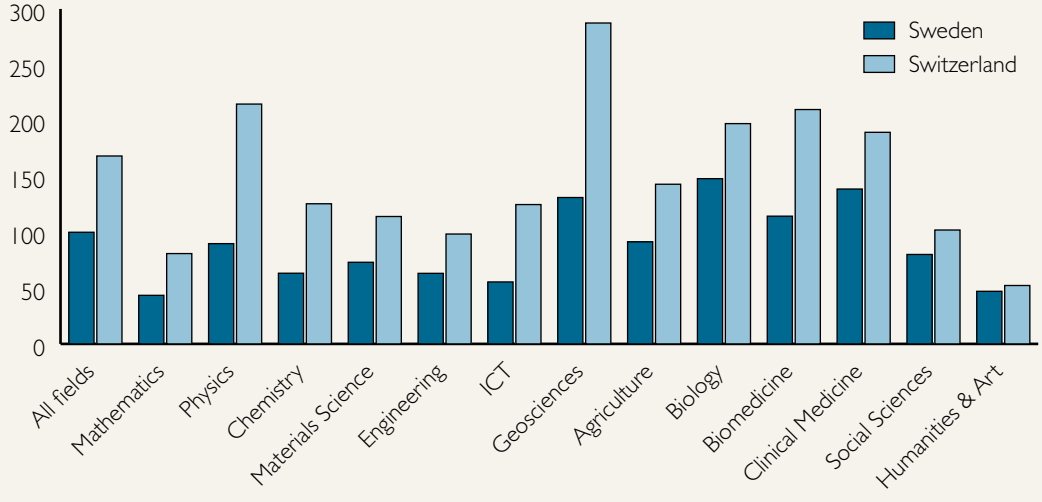
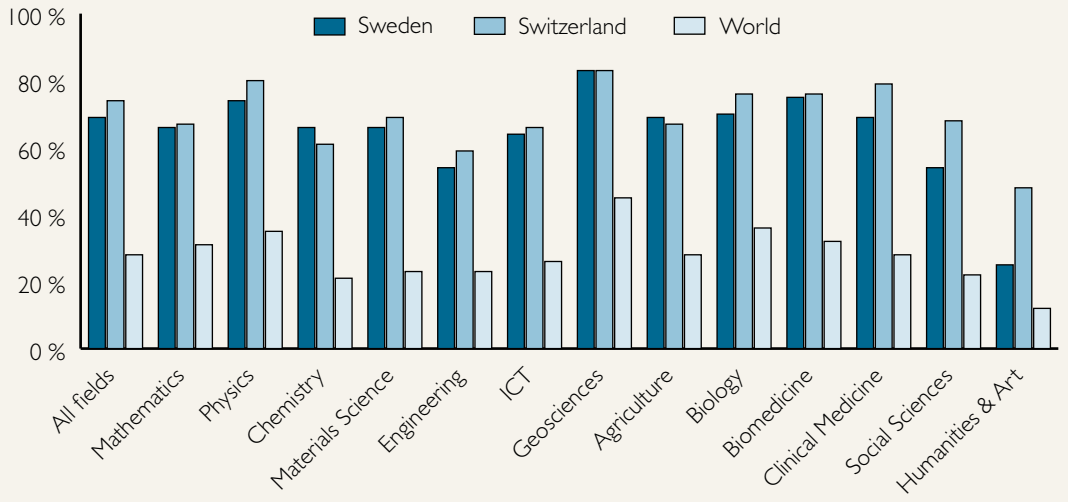


Figure 18: Comparison of Sweden's and Switzerland's share of the world's 10 % most cited articles by field adjusted for population size 2008-2010
Relative share of world 's 10 % most cited articles adjusted for population size. Rebased: Sweden, All fields = 100.



Lausanne, are federal institutions and both rank among the world's top universities. Other universities are governed by cantons. As a result, the university system may be more fragmented than would be expected of a country with an area as small as Switzerland. CERN gives Switzerland a unique position in Europe in high energy physics. In terms of industrial structure, the pharmaceutical and financial industries are more developed in Switzerland, while telecommunications equipment, transport equipment and raw materials-based indus-

Figure 19: Internationally co-authored articles as a share of Sweden's, Switzerland's and the world's total number of top cited articles in different fields 2008-2010.
World's 10 % most cited articles. Percent of country's articles internationally co-authored 2008-2010.



tries in Sweden hardly have any counterparts in Switzerland.

Of the world's 10 % most cited articles (normalized according to differences in citation levels between individual fields), authors from Switzerland appeared in 3.1 percent during the period 2008–2010 (Figure 17), significantly higher than Sweden's share at 2.3 percent. If the smaller population in Switzerland is taken into account Switzerland's share was almost 70 percent higher than Sweden's (Figure 18). Both countries' share of all articles is lower, indicating above average citation rates. The difference is larger for Switzerland, implying higher average citation rates than for Sweden. While Sweden has seen its share of the world's top cited articles decline over the past decade, Switzerland has experienced some growth.

The relatively stronger performance of Switzerland in relation to Sweden is not limited to a few fields but applies to more or less all fields, although to different degrees (Figure 18).[24] The difference is towards the lower end in Engineering and Clinical Medicine. For these two fields, the population-adjusted Swiss shares of top cited articles are 53 and 34 percent higher than those for Sweden.

On average for all fields, close to 70 percent of highly cited articles from Sweden are internationally co-authored (Figure 19). The share is around 5 percent higher for Switzerland. The share has steadily increased in both countries, in Sweden from around 40 percent in the early 1990s, when the share in Switzerland was around 50 percent. The difference in the degree of internationalization has thus decreased somewhat.

Figures 20 and 21 show the dynamics for two fields, Engineering and Clinical Medicine. Most notable is the rapid increase in co-authorship involving five or more countries in Clinical Medicine. Such articles now occupy 20 percent of all top cited articles in the field in both countries, while their share was negligible twenty years ago. In Switzerland this is very close to the same share as that for purely domestic articles.

The difference in the degree of internationalization between fields is very similar between the two countries. The largest deviation is found in the Social Sciences and in Humanities & Arts in which fields Switzerland exhibits a much larger

Figure 20: Changes in the relative importance of international co-publications for Sweden and Switzerland in the field of Engineering
World's 10 % most cited articles. Percent of country total.

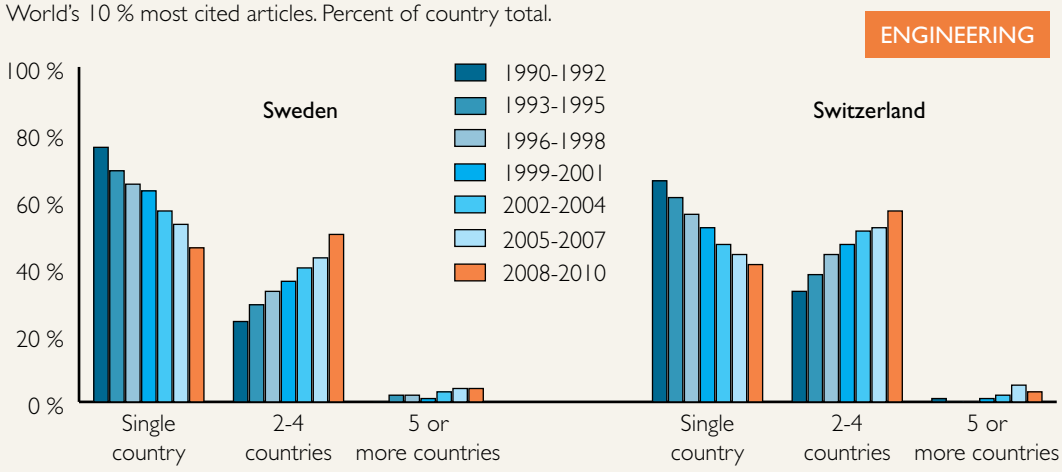
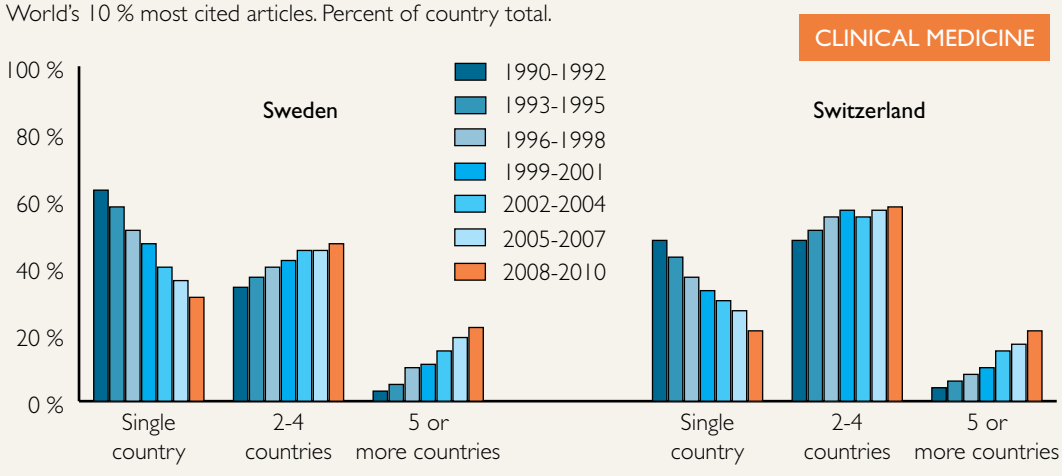


Figure 21: Changes in the relative importance of international co-publications for Sweden and Switzerland in the field of Clinical Medicine
World's 10 % most cited articles. Percent of country total.



international share. It is also notable that in Chemistry, contrary to other fields, Sweden has the largest international share of the two countries.

To investigate the geographical patterns of the two countries' international co-authorship, we will choose Materials Science as the example and then compare the situation in this field with that in other fields. For both Sweden and Switzerland, the overall pattern is one of a rapid increase in the relative importance of co-authorship inside Europe (Figures 22 and 23). In the period 2008–2010, co-authored articles with EU 27+3 made up almost 40 percent of all Sweden's highly cited articles in Materials Science. This was somewhat higher than the share for "purely domestic" articles. Ten years ago there were more than twice as many purely domestic

Figure 22: Distribution of purely domestic and internationally co-authored articles belonging to the world's 10 % most cited in Materials Science by country groups for Sweden
World's 10 % most cited articles. Percent of country total.

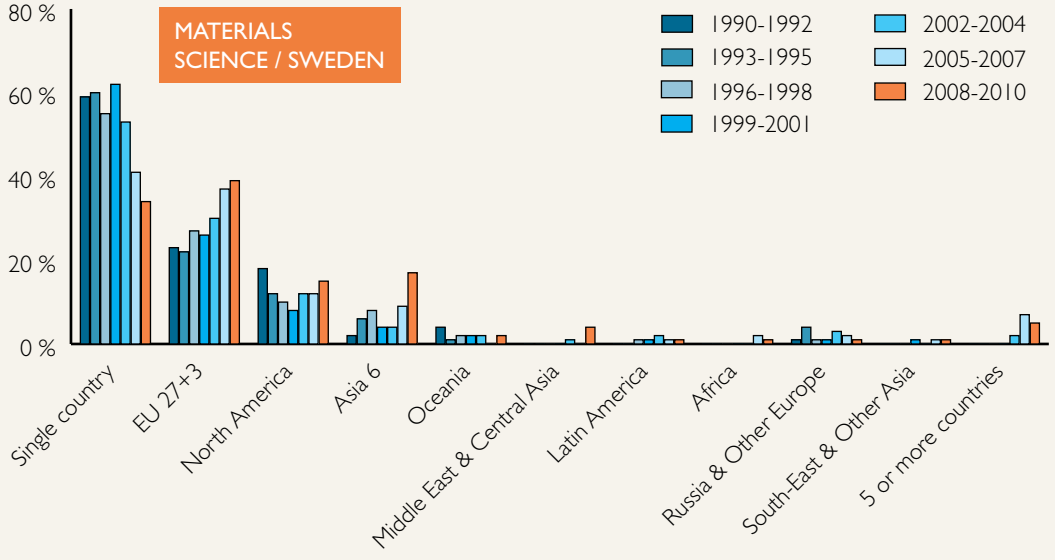


Figure 23: Distribution of purely domestic and internationally co-authored articles belonging to the world's 10 % most cited in Materials Science by country groups for Switzerland
World's 10 % most cited articles. Percent of country total.

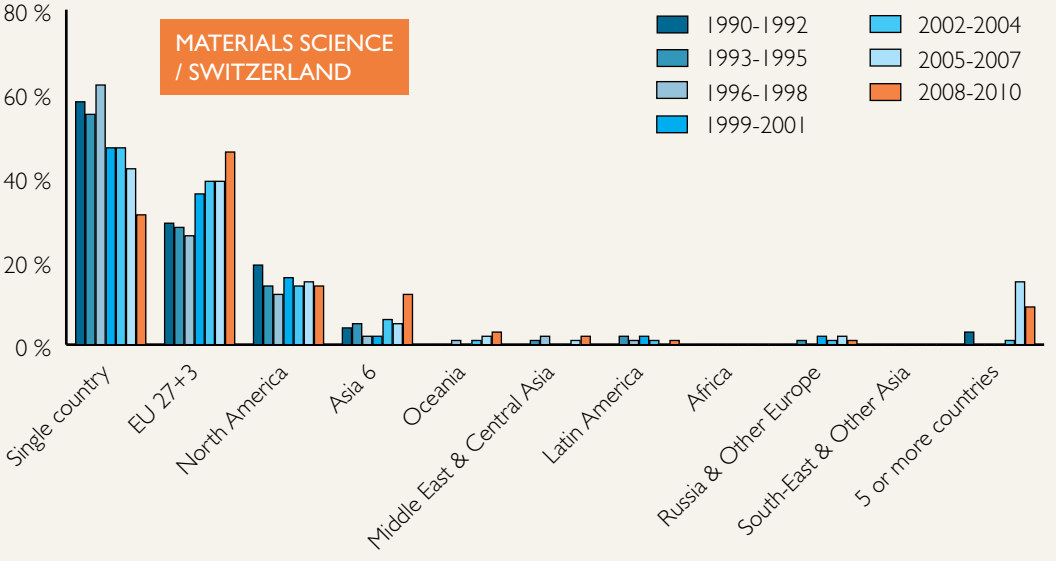


Figure 24: Articles with authors from Sweden and Switzerland in Materials Science belonging to the world's 10 % most cited: purely domestic and co-authored with three main country groups
World's 10 % most cited articles. Number of articles.

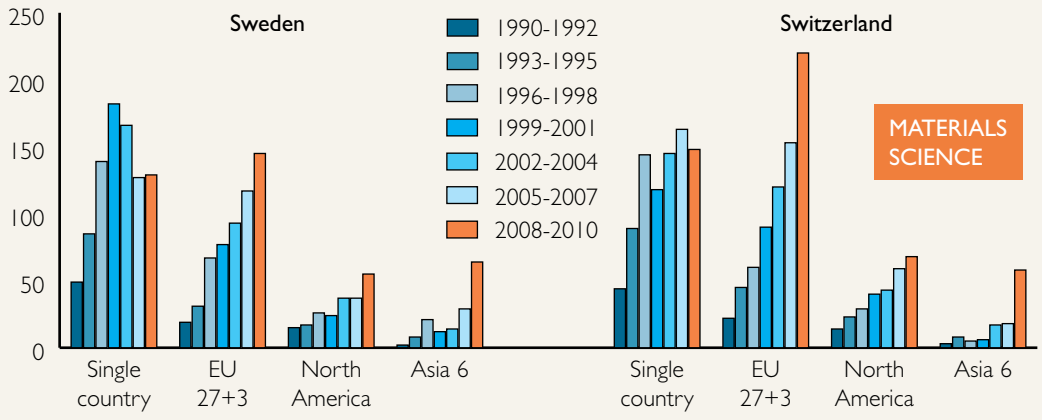
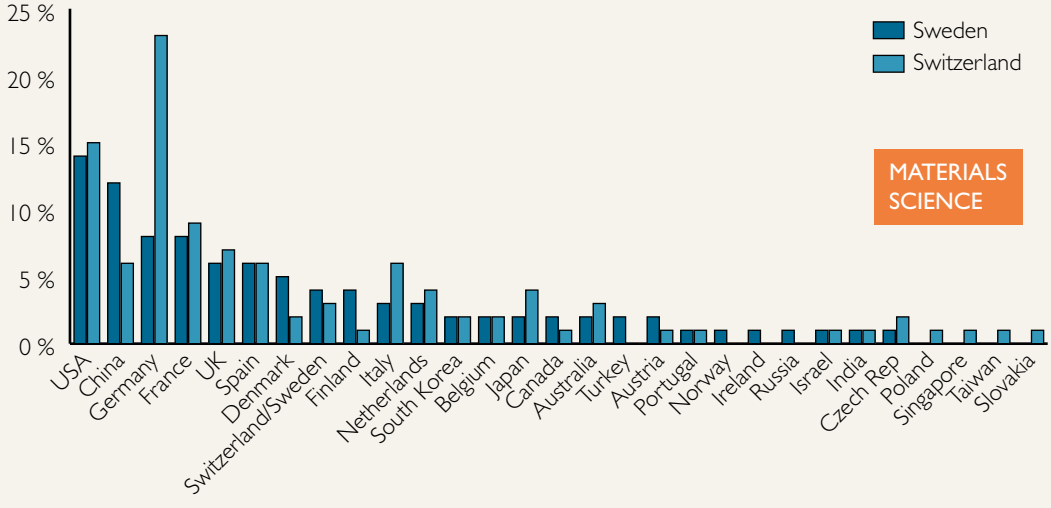


Figure 25: Co-authored articles in Materials Science 2008–2010 with Sweden and Switzerland by partner country for all countries with at least 4 top cited articles with either Sweden or Switzerland
World's 10 % most cited articles. Share of country total (percent).



articles than articles co-authored with EU 27+3. A similar development has occurred in Switzerland, but the EU 27+3 share today is 15 percent higher than that of purely domestic articles.

The combined share of purely domestic and EU 27+3 is, however, at a similar level for both countries; 73 percent for Sweden and 77 percent for Switzerland. In this sense the Swiss research system is thus more integrated into the European research system than Sweden's system. Considering the difference in their geographical position in Europe, this is probably to be expected.

Also, when looking outside Europe, the pattern is similar for both countries. The share of Asia 6 has rapidly grown in recent years and today it is comparable to that of North America. In Sweden the Asia 6 share is even somewhat higher. In Switzerland the share of North America has stayed fairly constant over the years at around 15 percent. In Sweden it declined sharply during the late 1990s but has since then recovered to reach the same level as in Switzerland. Figure 24 gives a sense of the development in absolute numbers.

If we consider Sweden's and Switzerland's co-authorship with individual countries, some important differences emerge (Figure 25).[25] Most striking is the much stronger connection with Germany that Switzerland has compared to Sweden. On the other hand, the relative strength of the connection with China is more than twice as high for Sweden as for Switzerland. As a result Switzerland's international co-authorship is dominated by Germany and the USA, but Sweden's by the USA and China.

Geography and language certainly must play a big role in the strong connection between Switzerland and Germany (as viewed from Switzerland) and probably also for Switzerland's connections with Italy. Sweden's even stronger links, in relative terms, with the other Nordic countries can at least partly be explained in the same way.

Obviously, language and geography do not tell the whole story. There is, for example, only a marginal difference between Sweden and Switzerland in the relative strength of their links with France, and Sweden has a stronger connection (although a weak one) with Austria.

Looking at the whole pattern of links with Asia 6 countries, Sweden has a much stronger focus on China than Switzerland has. South Korea's share and India's share are about the same for Sweden and Switzerland, while Japan's is more than 60 percent higher for Switzerland. Top cited co-authored articles with Taiwan and Singapore are few for both Sweden and Switzerland, but while there were five for each country in the case of Switzerland, there was only a single article with each country for Sweden!

As for connections with other non-European countries, the differences are rather minor except that Sweden was the only one that co-authored highly cited articles with Turkey.

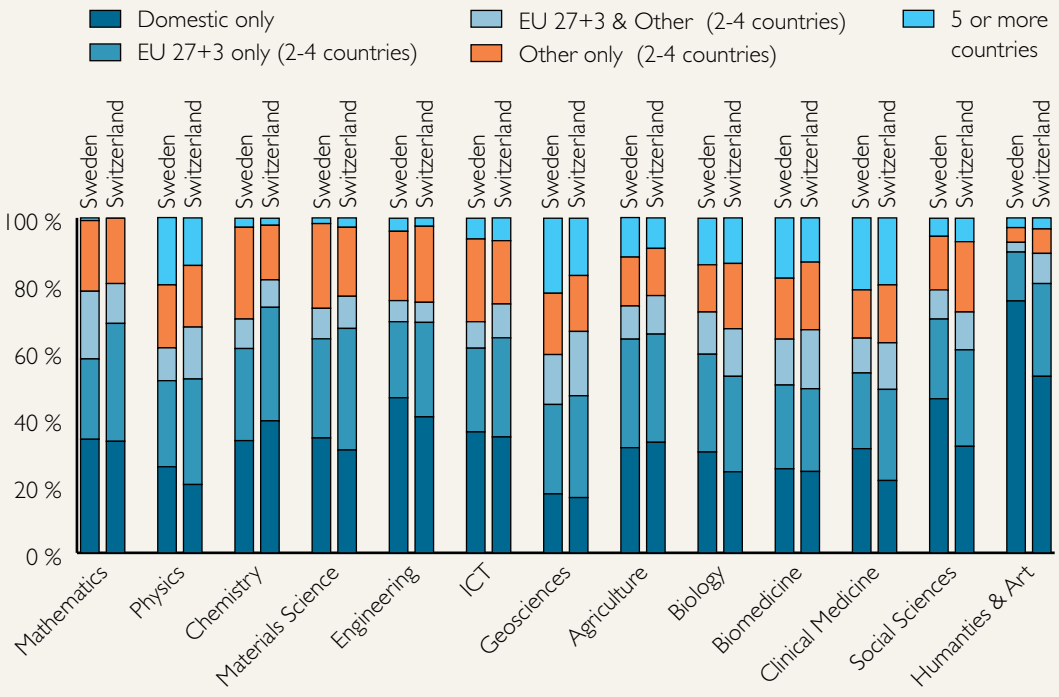
Before leaving the example of Materials Science, we would like to introduce one more aspect into the analysis of co-authorship. We have already considered the number of countries involved in co-authored articles and made a distinction between articles having authors from 2–4 countries and those with authors from 5 or more countries. Even within the first group there are indications of structural changes in most recent years.

In the case of Materials Science, co-authored articles with authors from both Asia 6 countries and North America have become much more common, especially for Sweden. In fact, in Sweden's case such articles accounted for almost all of the growth in co-authored articles with the USA between the years 2005–2007 and 2008–2010 (Figure A1.3 in Appendix 1). The change is much less pronounced for Switzerland. Although the increase in Sweden's "three continent co-authorship" is noteworthy, it is not clear whether it has a deeper significance that can be generalized.[26]

When summarizing our comparison for the field of Materials Science, we found that while the sum of purely domestic articles and articles co-authored with other European countries (more precisely EU 27+3) represented just below 70 percent in both countries, the ratio of domestic and European co-authored articles was rather different. It was around 50/50 for Sweden compared to close to 40/60 for Switzerland. In this sense Switzerland could be said to be more integrated into the European research system. At closer inspection we have seen that much of the difference in the degree of European integration is due to Switzerland's strong links with Germany.

Figure 26 provides data for the co-authorship patterns of Sweden and Switzerland for highly cited articles in different fields covering the period 2008–2010. For each field and for each of the two countries, all articles are first divided into three categories: purely domestic articles; articles with authors from 2–4 countries; and articles from five or more countries. The second category is subdi-

Figure 26: Comparing the degree of European integration and global connectivity of Sweden and Switzerland for highly cited articles in different fields 2008–2010
World's 10 % most cited articles. Share of country's articles (Percent).



vided into three categories: articles co-authored only with EU 27+3 countries; articles co-authored with at least one EU 27+3 country and at least one other country; and articles co-authored only with countries outside EU 27+3.

In all fields, a larger share of highly cited articles consists of ones that are co-authored with other European countries in Switzerland than in Sweden, although for Agriculture and Biology the difference is minor. In Engineering, Clinical Medicine and Humanities & Arts this largely corresponds to a higher share of purely domestic articles in Sweden and thus reflects a lower degree of European integration for Sweden. In the fields of Chemistry and ICT, the higher Swiss share of articles co-authored in Europe is instead explained by the more global orientation of Sweden. In Materials Science the two patterns are combined in that Sweden has a higher share of both purely domestic and of globally co-authored articles. In Physics, Geosciences and Biomedicine, articles with authors from five or more countries represent a significantly higher share of highly cited articles in Sweden than in Switzerland. In Physics this is combined with a higher Swedish share of purely domestic articles to produce a big difference in European co-authorship between the two countries.

For Sweden and excluding articles with authors from five or more countries, in all fields except Agriculture, Biology and Humanities &Arts, there are more highly cited Swedish articles with authors from outside Europe than articles co-authored only within Europe. Of all Sweden's highly cited articles co-authored with European countries, in most fields between one fourth and one third include authors from outside Europe. If we assume that most articles with authors from

five or more countries include co-authorship outside Europe, it is clear that global connectivity and European integration are already of comparable importance for Swedish research. This is particularly evident in Engineering-related fields.

As has already been made clear, Sweden's and Switzerland's co-authorship outside Europe is dominated by North America and Asia 6. In Materials Science we found that the two country groups today have about the same weight for both Sweden and Switzerland. For Sweden the situation in Chemistry is similar to that in Materials Science (Figure 27). Also in Engineering, the weight of North America and Asia 6 are similar for Sweden, while a much larger share of Switzerland's co-authorship is with North America. A similar difference between the two countries applies to Physics. In the field of ICT Sweden's co-authorship with Asia 6 is lower than that with North America but, significantly, the difference is much smaller than for Switzerland.

In all the other fields, both Sweden and Switzerland have a much larger share of co-authorship with North America than with Asia 6. The share of Asia 6 is typically in the range of 3–5 percent and even lower in some fields.

The comparison between Sweden and Switzerland has so far related to articles in the world's 10 percent most cited in the respective field. The share of such articles among all of the articles co-authored with a certain country group gives some indication of the quality (in citation terms) of the exchange with that country group, as long as the number of articles is reasonably large.

As shown earlier, internationally co-authored articles are more likely to be highly cited than purely domestic articles (Figure 16). This holds true for both Sweden's and Switzerland's co-authorship with any of the three major country groups in every field with the exception of Switzerland's co-authorship with EU 27+3 and with Asia 6 in ICT (Figure 28).

Articles co-authored with North America consistently have a higher share of top-cited articles than articles co-authored with EU 27+3, while the comparison of co-authorship with North America and Asia 6 depends on the field and shows some differences between Sweden and Switzerland. Co-authorship with Asia 6 shows a particularly strong citation performance in both Chemistry and Materials Science. While the share of top-cited articles is much lower for co-

Figure 27: Co-authored articles with North America and Asia 6 as a share of Sweden's and Switzerland's top cited articles in different fields 2008-2010

World's 10 % most cited articles. Share of country's highly cited articles in the respective field (Percent).

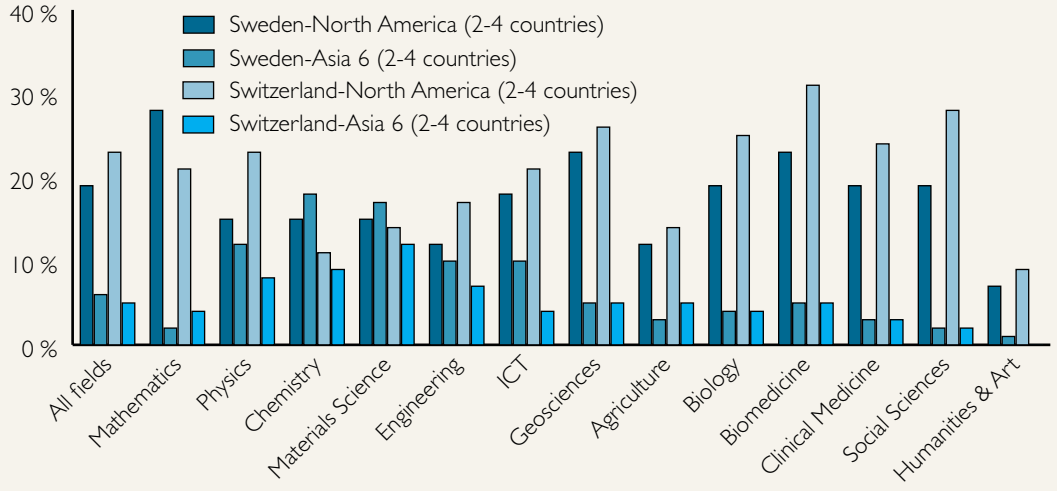
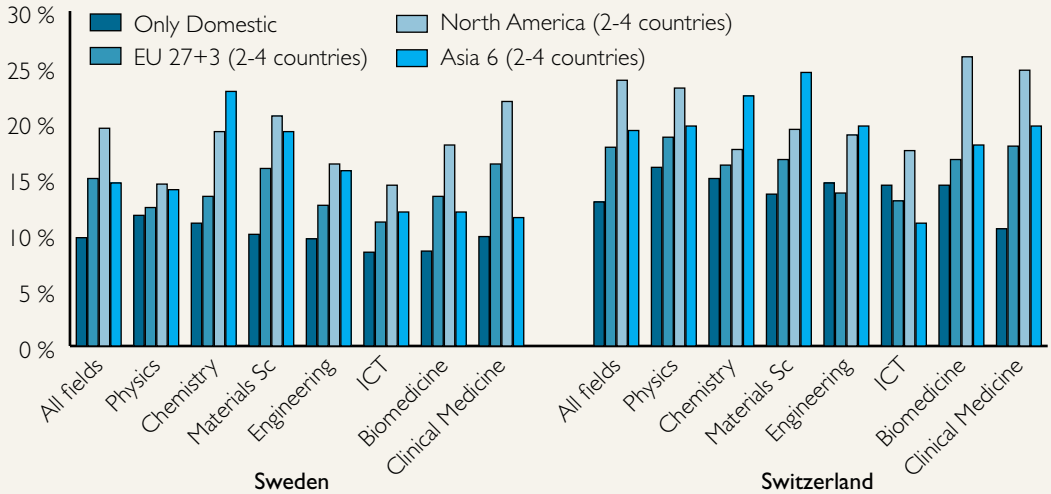


Figure 28: Top cited articles as a share of all articles co-authored by Sweden and Switzerland with major country groups 2008–2010

Share of co-authored articles with region in the world's 10 % most cited in the respective field (Percent).



authored articles in Engineering, there is no significant difference between North America and Asia 6 in this field. In all three fields, citation performance is higher for articles co-published with Asia 6 than those with EU 27+3.

In Biomedicine and Clinical Medicine, Switzerland's co-authorship with Asia 6 is on par with that with EU 27+3 in terms of citation performance, while for Sweden co-authorship with Asia 6, citation performance is not as strong.

Overall, Switzerland produces a larger share of top-cited articles than Sweden in almost all categories.[27] Articles co-authored with North America in the fields of Chemistry and Materials Science are the main exceptions, with Sweden showing a higher share of top-cited articles. For articles in Clinical Medicine produced domestically or co-authored with EU 27+3, the difference is small.

COMPARING WITH OTHER EUROPEAN COUNTRIES

The same type of comparison as the one presented above between Sweden and Switzerland has also been made with other European countries. Some of the main observations from this will be presented below.

When comparing Sweden and Switzerland we found that geographical location is probably an important factor contributing to the seemingly higher degree of integration into the European research system for Switzerland. The location factor seems to have the same effect on the relative weight of purely domestic articles and articles co-authored with EU 27+3 countries if we extend the comparison to some other countries of a similar size. Austria and Belgium, both located centrally in Europe, very closely follow the pattern of Switzerland, while the other Nordic countries, Ireland and Portugal resemble Sweden (Figure 29).

The size of a country also plays a role. In Figure 29 countries have been placed in order of the size of their population. The large countries to the right of the graph clearly tend to have a higher share of purely domestic articles. This should be expected at least to some extent because of their larger size.[28] The Netherlands falls somewhere in between the large and small countries, both in terms of population and in

Figure 29: The relative weight among top-cited articles of purely domestic articles, articles co-authored in Europe and multi-country-articles for selected European countries 2008-2010
All fields. World's 10 % most cited articles. Share of country total (Percent).

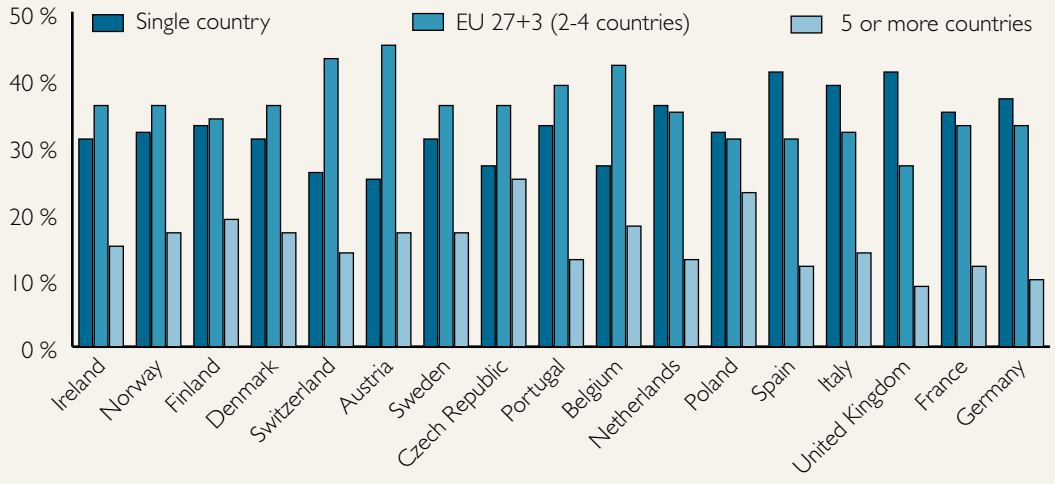
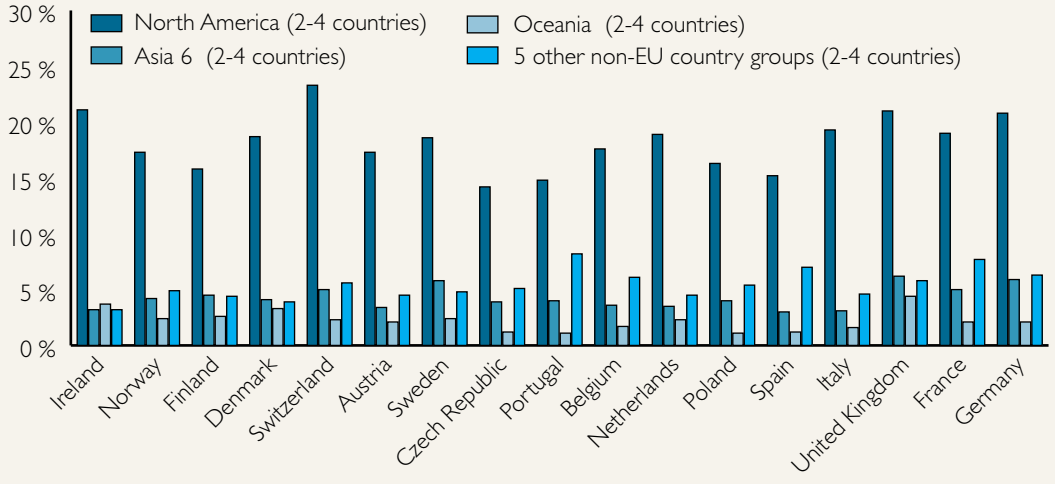


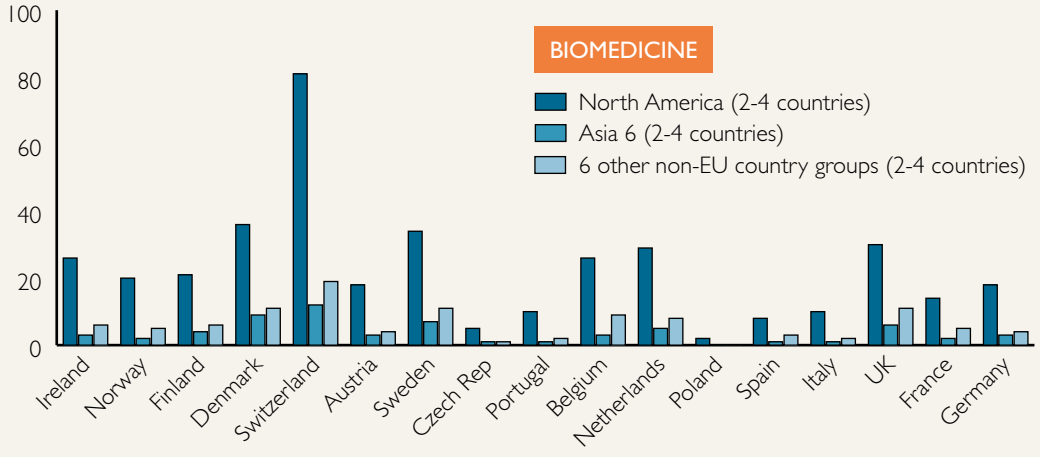
Figure 30: The relative weight of co-authorship with different country groups outside Europe in top-cited articles for selected European countries
All fields. World's 10 % most cited articles. Share of country total (Percent).



the relative weight of domestic and European co-authored articles. The Czech Republic and Poland still have relatively weak research systems with few top-cited articles. As a result, articles co-authored with five or more countries represent a much higher share of all articles in these two countries.

The United Kingdom distinguishes itself by

Figure 31: Number of highly cited articles per inhabitant co-authored with non-EU country groups in Biomedicine for selected European countries 2008–2010
World's 10 % most cited articles. Articles per million inhabitants.



having a lower share of European co-authored articles than any of the other countries and a higher share of co-authored articles outside Europe than any other country. Its share of domestic articles is somewhat larger than that of Germany and France.

For co-authorship outside Europe, location in Europe and population size should in principle play no role in the relative extent of such co-authorship. Factors like language and historical connections – which are often interdependent – do however matter.[29] Figure 30 distinguishes co-authorship outside Europe for four country groups: North America; Asia 6; Oceania; the sum of the remaining five other non-EU 27+3 country groups.[30] For all countries, North America is without question still the dominant partner for co-authored articles outside the EU. After Switzerland, Ireland and the UK have the largest share with North America closely followed by Germany. Sweden's relative emphasis on North America is around 2 percent lower than for the UK but about the same as for Denmark, the Netherlands, Italy and France.

The share of co-authorship with Latin America is around 3 percent higher for Portugal and Spain than for the other European countries, a difference which is surely strongly affected by language and cultural and historical connections. This is shown in the high share of co-authorship with the category "5 other non-EU country groups." France's high share of co-authorship with the same country group is mainly explained by stronger than average links with Africa.[31] The fact that Oceania (Australia and New Zealand) plays a relatively larger role for the UK and Ireland (when compared to other non-EU links) is not surprising.

Articles co-authored with Asia 6 make up between 3.1 and 6.2 percent of all highly cited articles, with the UK having the highest share and Italy the lowest. Germany at 5.9 percent, Sweden at 5.8 percent and Switzerland at 5.0 percent are, combined with the UK, the European countries that, relatively speaking, place the strongest emphasis on Asia 6.

In a European comparison and judging from the aggregate data presented above for all fields taken together, Sweden appears to be a fairly well-connected country globally. Switzerland is, however, definitely more internationalized. It is both more closely integrated into the European research system and is, relatively speaking, more strongly connected to North America than Swe-

den is. Outside Europe and North America the difference is small, with Sweden placing slightly more emphasis on Asia 6. Among the large countries, the United Kingdom and Germany appear to be the most globalized in terms of co-authored top-cited articles, although Spain and Portugal exhibit much stronger links with Latin America and France with Africa.

WEAK GLOBAL LINKS FOR SWEDEN IN MATHEMATICS AND ICT?

As mentioned previously on several occasions, the aggregate data hides important differences between fields. It also needs to be emphasized that most of the data presented so far has dealt with the relative share of co-authored articles among all the articles of a certain country. As a consequence, differences between countries in the strength of their research, whether in absolute terms or in relation to the size of their populations, have tended to be placed in the background. In extending our comparison of Sweden's global connectivity with that of other European countries to include the situation in individual fields, we will no longer restrict ourselves to relative numbers, but also consider direct comparisons in absolute terms as well as on a per capita basis.

When comparing the relative weight of co-authorship with North America and Asia 6, North America was stronger for both Sweden and Switzerland in Life Sciences (Figure 27). Among highly cited articles in Clinical Medicine, Sweden co-authored seven times more articles with North America than with Asia 6 and the ratio was even higher for Switzerland.[32] In Biomedicine, the ratio was 4.6 and 6.5 respectively (Figure 31). The situation is quite similar for other European countries (Figure 31 for Biomedicine). As Clinical Medicine and Biomedicine are the two largest fields, the data for these fields tends to strongly influence the overall picture for all the fields combined.

As discussed earlier, Materials Science and Chemistry offer the most conspicuous contrast to Life Sciences in terms of the balance between North America and Asia 6 (Figure 27). Measured on a per capita basis, Switzerland is outstanding in Europe in authoring top cited articles in both Chemistry and Materials Science.[33] In Chemistry, Sweden and Denmark follow at about half the level of Switzerland. In Materi-

Figure 32: Number of highly cited articles per inhabitant co-authored with non-EU country groups in Chemistry for selected European countries 2008–2010
World's 10 % most cited articles. Articles per million inhabitants.

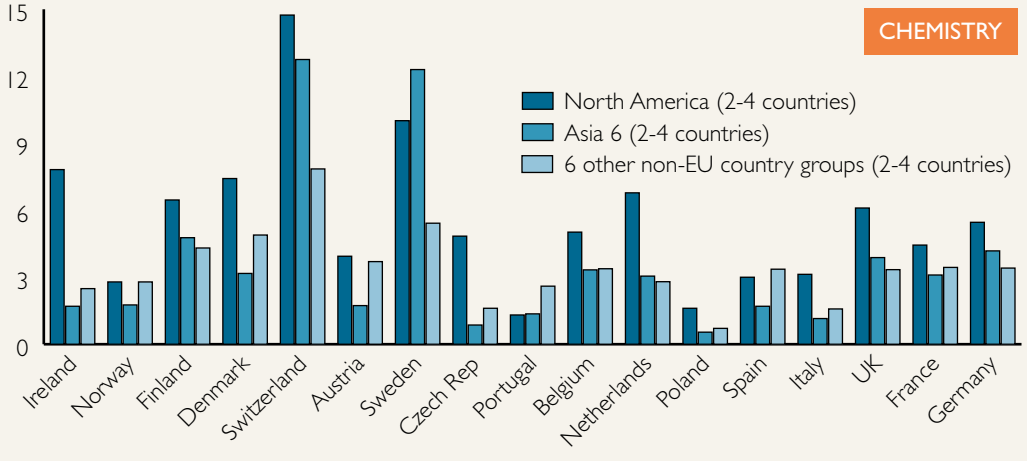


Figure 33: Number of highly cited articles co-authored with non-EU country groups in Chemistry for selected European countries 2008–2010
World's 10 % most cited articles. Number of articles.

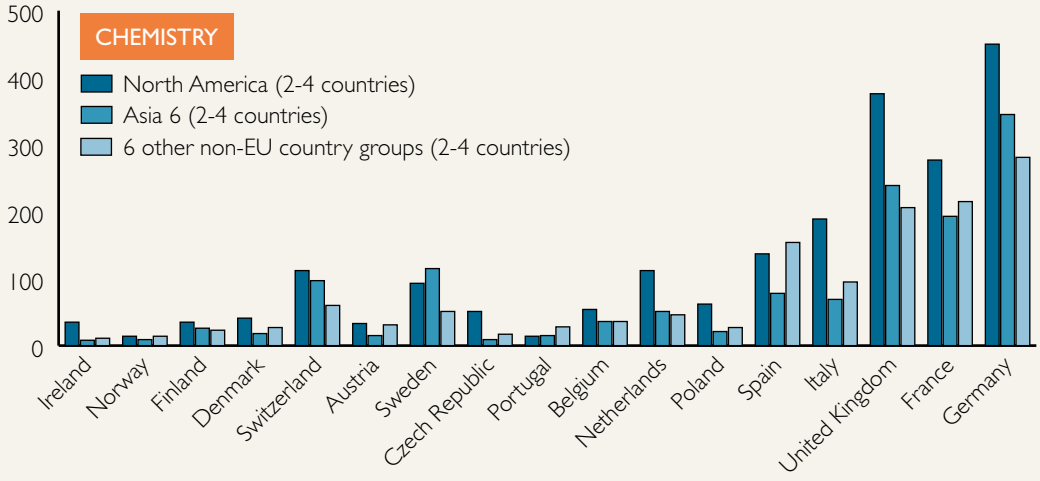
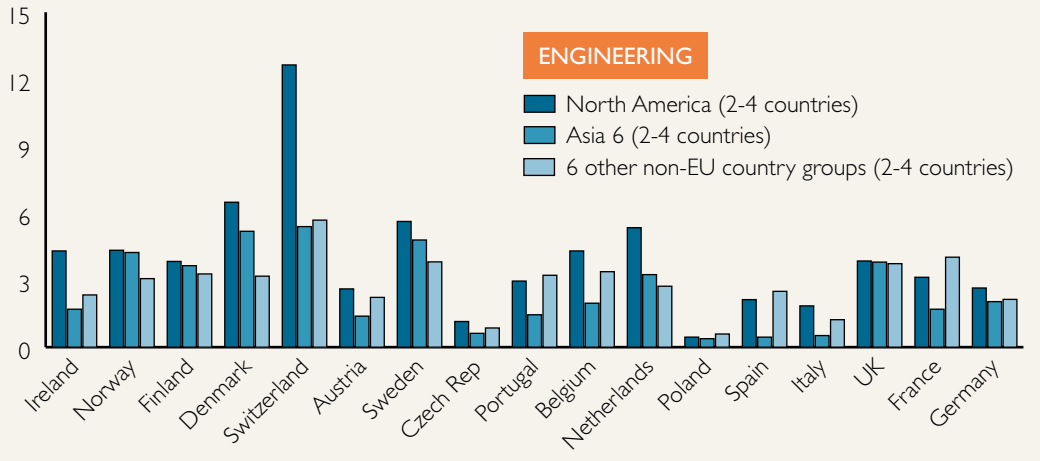


Figure 34: Number of highly cited articles co-authored with non-EU country groups in Engineering for selected European countries 2008–2010
World's 10 % most cited articles. Articles per million inhabitants.



als Science Sweden is ahead of other European countries at 60 percent of the level of Switzerland. If we look at presence through co-authorship outside Europe, the difference between Switzerland and Sweden is much smaller, especially in links with Asia 6 (Figure 32 for Chemistry; the situation is similar for Materials Science). Sweden's link with North America, in per capita terms, is also ahead of all other European countries except Switzerland.

One effect of the high per capita figures for Switzerland and Sweden is that these two coun-

Figure 35: Number of highly cited articles co-authored with non-EU country groups in ICT for selected European countries 2008–2010
World's 10 % most cited articles. Articles per million inhabitants.

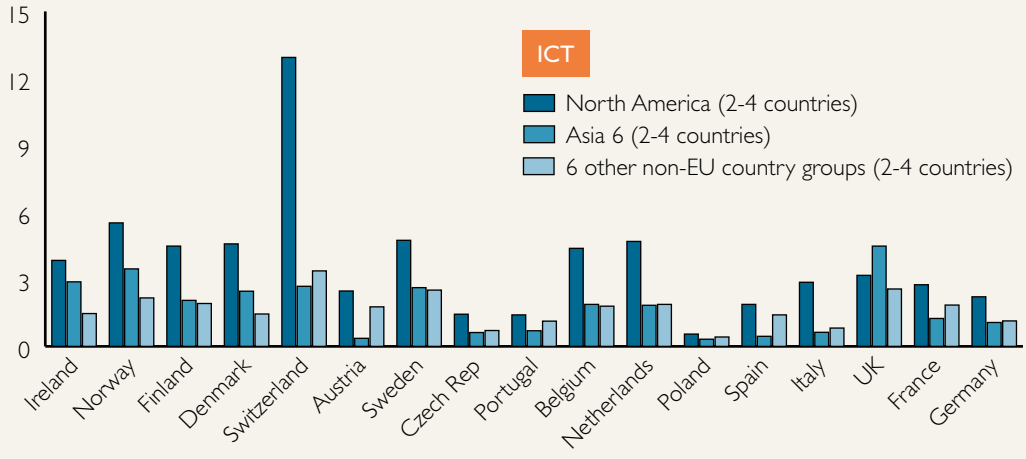
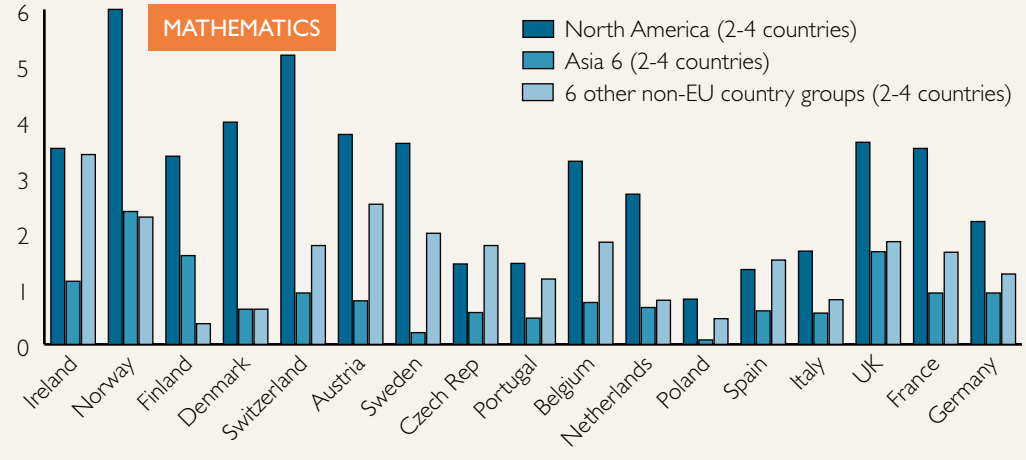


Figure 36: Number of highly cited articles co-authored with non-EU country groups in Engineering for selected European countries 2008–2010
World's 10 % most cited articles. Articles per million inhabitants.



tries have a noticeable presence on the world stage in the fields of Chemistry (Figure 33) and Materials Science which goes far beyond the size of their populations. This is most pronounced in the connections with Asia 6 countries where only Germany, UK and France have more co-authored top-cited articles in absolute terms in both fields. For France the number of articles is less than twice that for Sweden in both fields.

In the field of Engineering the relative emphasis on North America and Asia 6 in

co-authorship outside Europe varies greatly among European countries (Figure 34). Sweden, like the UK and the other Nordic countries, puts almost as much weight on Asia 6 as on North America, while for most of the other countries, co-authored articles with North America are usually at a level twice that of articles with Asia 6. Compared to Life Sciences the relative weight of Asia 6 is much larger for all countries. It is also noteworthy that countries outside the three main country groups play a more significant role as co-authorship partners for Europe in Engineering than in most other fields.

In the fields of ICT and Mathematics Sweden's global links appear relatively weak compared to Sweden's position in other fields (Figures 35 and 36). To some extent this reflects a lower per capita production of top-cited articles in international comparison than in other fields. It is especially noticeable that the links with Asia 6, particularly in Mathematics, are significantly weaker than for several other countries in Europe.

AT THE PERIPHERY OF EUROPE BUT FAIRLY GLOBALLY CONNECTED

Previously in this chapter we compared Sweden's international connectivity in research with that of other European countries. A detailed comparison was made with Switzerland, while the comparison with 15 other European countries is less comprehensive. In attempting to answer the questions posed at the beginning of the chapter, the findings of our analysis may be summarized as follows:

- Participation in the integration of the European Research Area has been a major component in the internationalization of Swedish production of scientific articles.

- As might be expected, countries similar in size to Sweden but more centrally located in Europe exhibit a higher degree of integration into the European Research Area than Sweden and other countries at the periphery of Europe.

- A large, and in several fields the dominant, share of Sweden's articles co-authored with European countries also include authors from outside Europe.

- Among European countries overall, only the United Kingdom, Germany, France and Switzerland show a somewhat higher global connectedness with respect to highly cited articles than Sweden.

- Asia, led by China, has developed into a partner for Swedish researchers similar in size to North America in the fields of Chemistry, Materials Science, Engineering and Physics, while in other fields North America remains by far the largest partner outside Europe.

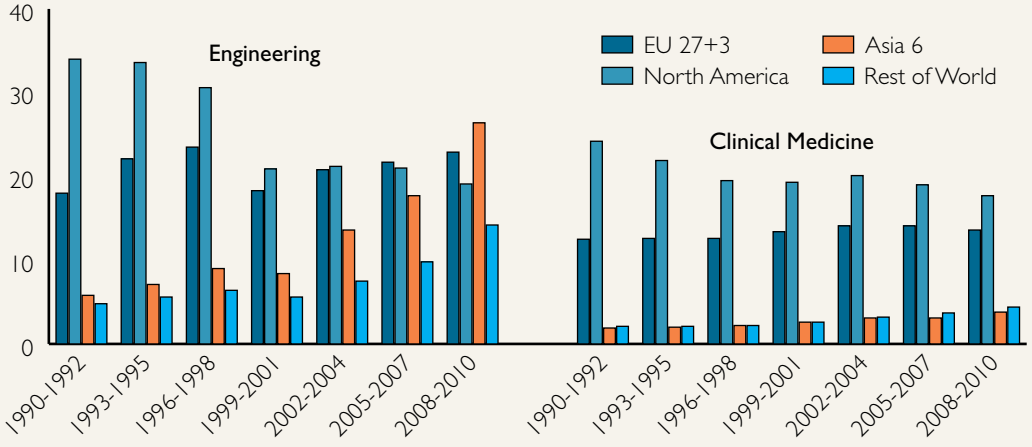
- Sweden's connections with Asia appear to be relatively undeveloped in ICT and Mathematics compared with many other European countries.

- In Physics, Geosciences, Biomedicine and Clinical Medicine 20 percent or more of all Sweden's highly cited articles include authors from five or more countries.

- Sweden's internationally co-authored articles tend to have significantly higher citation rates than purely domestic articles. In Chemistry, Materials Science and Engineering, Sweden's co-authorship with both North America and Asia yield articles with higher impact than those co-authored with countries in Europe.

5. Sweden's connections with China, India, Japan, South Korea, Taiwan and Singapore

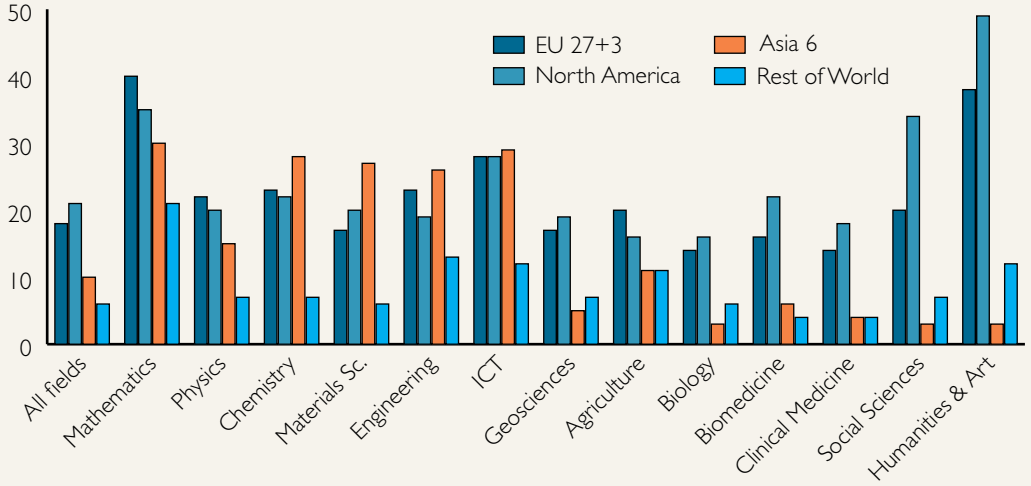
Figure 37: Production of highly cited articles in the fields of Engineering and Clinical Medicine in North America, EU 27+3, Asia 6 and Rest of the World relative to Sweden's production 1990–2010
World's 10 % most cited articles. Number of articles as multiples of Sweden (Sweden=1).



Based on our analysis so far, Sweden seems to be doing fairly well in global connectedness compared to other European countries. Sweden's lower degree of internationalization than Switzerland and some other countries of a similar size to Sweden is mainly due to differences in the degree of integration into the European research system. The extent of connectedness outside Europe is at least at the same level as that for most other European countries. Switzerland, however, is ahead in most dimensions. The situation varies considerably between fields. In Chemistry and Materials Science Sweden is particularly well-connected, while the opposite appears to be true for Mathematics and ICT.[34]

European integration has been a key development for all European countries. One important question is whether this integration process has influenced the development of the European countries' connections with other parts of the world, and in this context specifically, what the effect has been on Sweden. Bibliometric analysis on its own will hardly be sufficient for obtaining any definitive answers to this question, but

Figure 38: Production of highly cited articles in different fields in North America, EU 27+3, Asia 6 and Rest of the World relative to Sweden's production 2008-2010
World's 10 % most cited articles. Number of articles as multiples of Sweden (Sweden=1).



hopefully it will help put the situation in Sweden in perspective.

It should be emphasized that we see no inherent conflict between an active participation in the European integration process and the development of strong global links. It may, in fact, be argued that, in order for a country or a research organization to achieve success in these two processes, the processes will be strongly interdependent and likely to mutually reinforce each other.

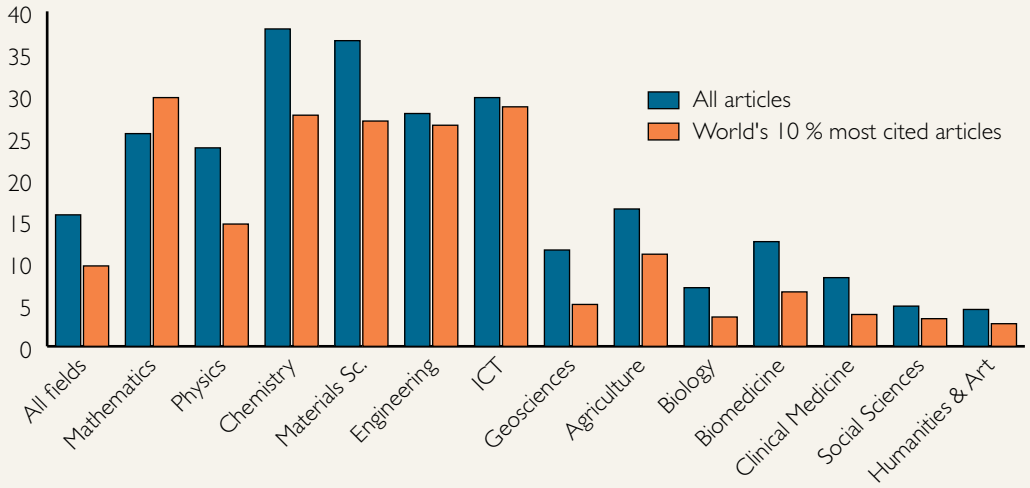
In this chapter we will look in particular at how Sweden's connections with leading Asian countries have developed. As will be discussed, there are a number of difficulties in assessing Sweden's performance. One of them relates to finding a suitable reference against which to benchmark Sweden. For that purpose we need to find a non-European country that is comparable to Sweden in terms of the development of its research system. It turns out that there are not that many countries to choose from. USA, Canada and Israel would be three candidates. Of these, Canada seems more suitable than the USA because of its smaller population size, although even Canada has a much larger population than Sweden – about 3.4 times larger. Among countries with well-developed research, Israel is one of the countries that have nurtured relationships with Asia the least. Australia or New Zealand might also be candidates for benchmarking. It could, however, be argued that in practice they are part of an emerging Asian Research Area and that increasing connections between these two countries and Asia 6 countries should be looked at in the same way as integration within the European Research Area.

THE CHANGING POSITION OF SIX ASIAN COUNTRIES IN THE WORLD AND IN RELATION TO SWEDEN

Over the past ten years several Asian countries have shown remarkable advancement in fields such as Engineering, ICT, Materials Science and Chemistry. Among the Asia 6 countries, all except Japan have shown very impressive growth with the result that for the four fields mentioned, Asia 6 today is a larger producer, or in the case of ICT a producer of equal size, of highly cited articles in comparison to both North America and Europe. Asia 6 has also already achieved a strong global position in Physics and Mathematics. There has

Figure 39: Production of articles 2008–2010 in different fields in Asia 6 relative to Sweden's production

Ratio between Asia 6's and Sweden's Production of articles.



been rapid growth for Asia 6 in most other fields as well, but the share of world production in life sciences, geosciences and social sciences, especially of highly cited articles, is still much lower than that of North America or Europe. Figures 37–39 provide some additional data on this development, including data which allows a direct comparison to be made with the size of Sweden's production.

Figure 37 shows the production of highly cited articles in Engineering and Clinical Medicine in EU 27+3, North America, Asia 6 and the Rest of the World 1990–2010 compared to that of Sweden. For each three-year period Sweden's production is set at 1.[35] In Engineering over the past decade, North America's production has grown at more or less the same rate as Sweden's, while growth in EU 27+3 has been noticeably higher after a period of slower growth around the turn of the century. The growth of scientific output in Engineering has, however, been much faster in Asia 6. In 1999–2001 production in Asia 6 of highly cited articles in Engineering was less than half that of EU 27+3. Ten years later it was instead around 15 percent higher. The rapid growth in the Rest of the World in the same field is also noteworthy.[36] In Clinical Medicine, North America and Europe are still dominating. Figure 38 provides similar data for 2008–2010 for other fields. Figure 39 focuses on the comparison between Sweden and Asia 6 and shows data for both highly cited and all articles, the former being the same as in Figure 38.

Sweden's field specialization is more or less the opposite of that of Asia 6, with a relatively strong position in Life Sciences and Geosciences and relatively weaker position in Engineering-related fields. This has some striking effects on the relative size of Sweden's production of scientific articles compared with production by Asia 6 for different fields. In Engineering-related fields, Asia 6 produces about 30 times as many highly cited articles as Sweden. On the other hand, in Clinical Medicine the corresponding factor is only around four, and for Biology closer to three (Figure 39). Not surprisingly, initiatives to seek research co-operation with Sweden from Asia 6 countries appear to be more common in the Life Sciences than in Engineering-related fields. One can argue that in Engineering-related fields the pressure on Swedish actors to take active initiatives will be much greater than in the Life Sciences if co-operation is to materialize.

China has played a dominant role in the recent

Figure 40: Production of highly cited articles 2008–2010 as a share of World Total in different fields for six Asian countries and Sweden
World's 10 % most cited articles. Share of World Total (Percent).

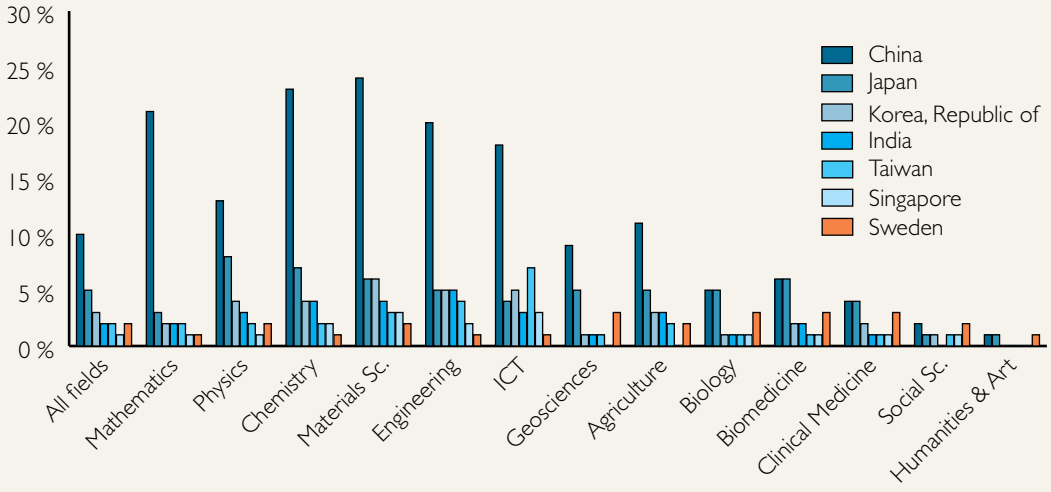
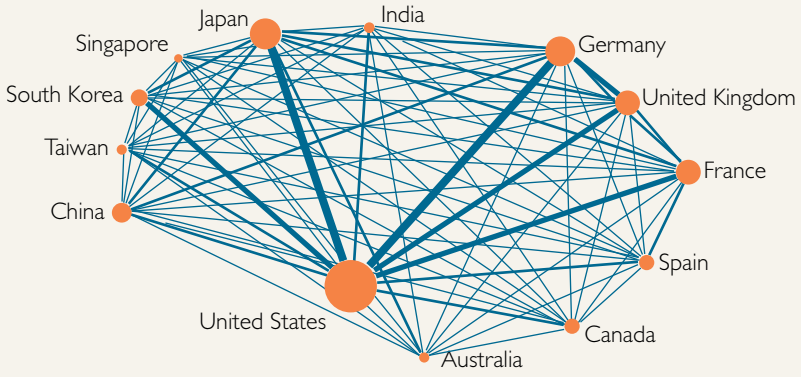


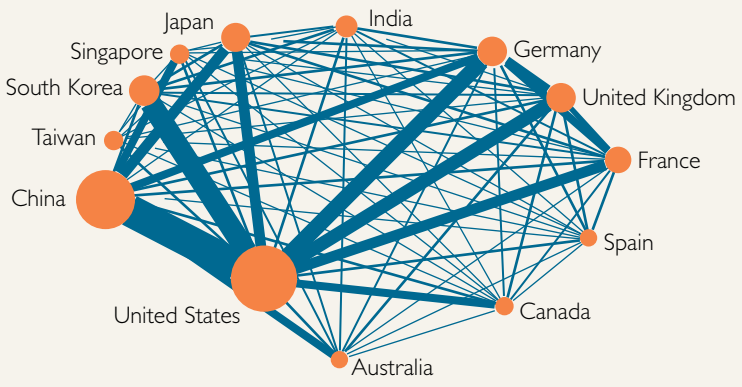
Figure 41: Total production and mutual co-authorship of highly cited articles in Materials Science 1990–2001 of the 13 largest producing countries in 2008–2010
Materials Science: 1999–2001. World's 10% most cited articles



Source: Graph by Anna Sandström based on data from Thomson Reuters' Web of Science (WoS) database at the Swedish Research Council.

build-up of Asian scientific prominence. With the exception of life Sciences, Physics and Geosciences, where Japan shows more or less equal strength, China is clearly the largest country in Asia in terms of production of scientific articles (Figure 40). This does not, however, necessarily mean that the leading universities or research groups in Asia in a particular field are to be found

Figure 42: Total production and mutual co-authorship of highly cited articles in Materials Science 2008–2010 of the 13 largest producing countries
Materials Science: 2008-2010. World's 10% most cited articles



Source: Graph by Anna Sandström based on data from Thomson Reuters' Web of Science (WoS) database at the Swedish Research Council.

in China. Considering the size of China's population, its position should be no surprise. What is surprising is that India with a population of almost the same size as China's does not have a larger production of scientific articles.

In 2008–2010, Asia 6 produced significantly more highly cited articles in Materials Science than either North America or EU 27+3. Asia 6 countries all were among the 13 largest producers of highly cited articles in the field. Figures 41 and 42 show the change in relative size of the 13 countries over the past decade as well as the change in the relative strength of their mutual exchanges through co-authorship. The emergence of China as a producer on par with the United States and as the latter's biggest co-authoring partner is clearly evident. The emergence of South Korea as the USA's second most important co-authoring partner is also eye-catching.

EUROPEAN INTEGRATION AND GLOBAL CONNECTIVITY

Before proceeding to analyze Sweden's connections with scientifically important countries in Asia, it would be useful to provide some background data on the relative weight of global connections in scientific articles for Europe compared to North America and the Asia 6 countries. Highly cited articles in the field of Engineering are used as an illustration (Figures 43 and 44). All articles are divided into those with only domestic authors ("single country") and those which are internationally co-authored. The latter category is further divided into articles with all authors from their own "region" and those that also include authors from other "regions." "Regions" here refers to EU 27+3, North America and Asia 6 respectively.

For all three regions, single country articles make up the largest share. For the period 2008–2010, EU 27+3 has a larger share of internationally co-authored articles than North America. Almost 30 percent of internationally co-authored articles by EU 27+3 countries do not include any authors from outside the region. As North America only consists of two countries of very different population size, articles co-authored by only these two countries form a very small part of total articles. If we look at articles co-authored with countries outside their own region as a share of all articles, North America most recently has a significantly higher

Figure 43: Number of highly cited articles in the field of Engineering divided according to extent of international co-authorship for EU 27+3, North America and Asia 6

World's 10 % most cited articles. Number of articles.

ENGINEERING

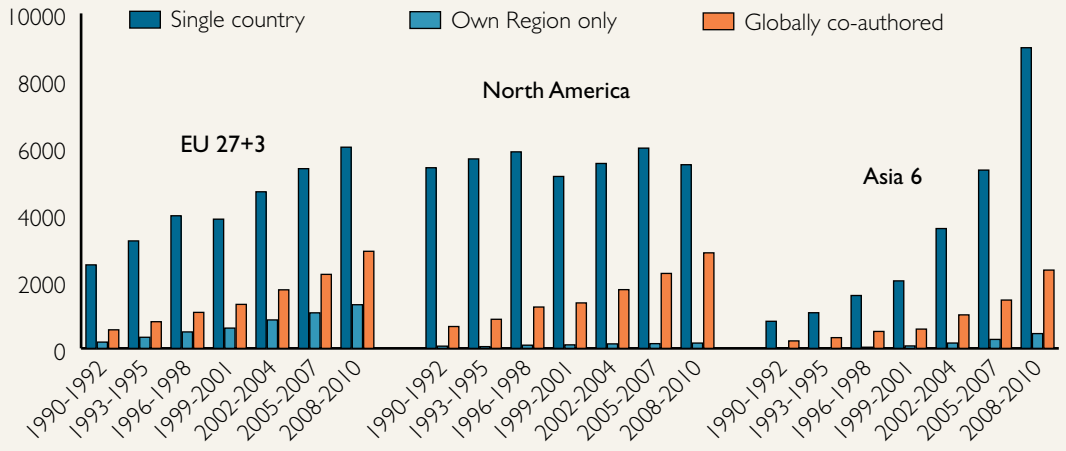
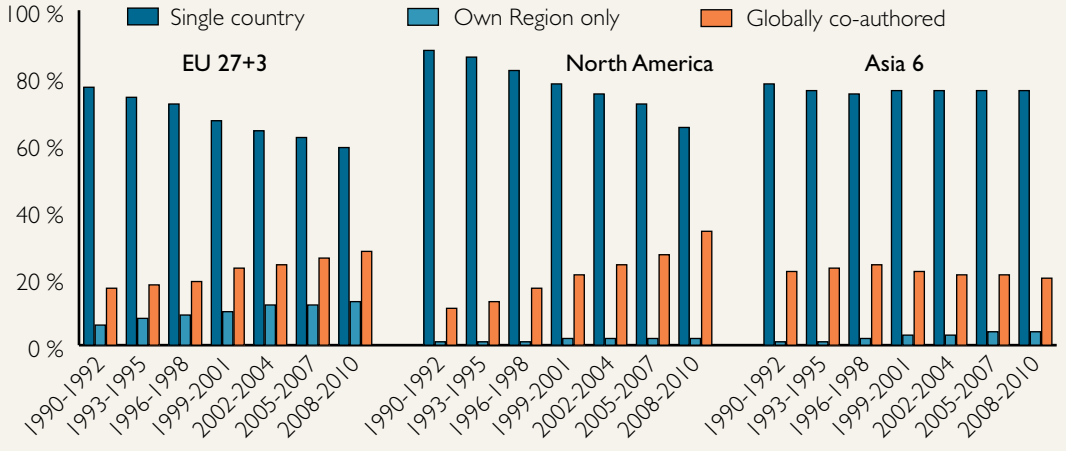


Figure 44: Highly cited articles in the field of Engineering divided according to extent of international co-authorship for EU 27+3, North America and Asia 6

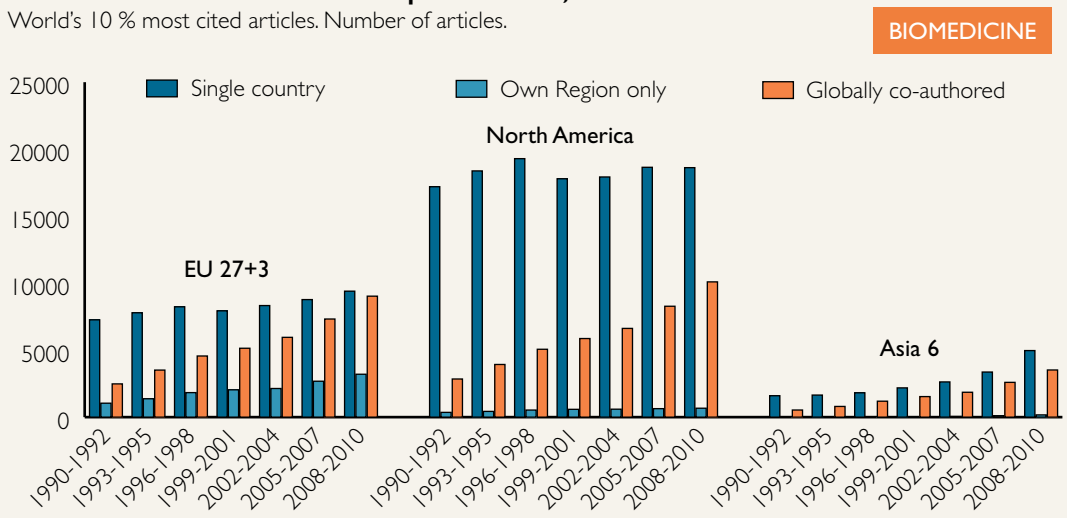
World's 10 % most cited articles. Share of country group's highly cited articles (percent).

ENGINEERING



share (34 percent) than EU 27+3 (28 percent). The same share for Asia 6 is only 20 percent. What is even more noteworthy is that the share of globally co-authored articles has increased more rapidly for North America than for EU 27+3. As a result, North America has very nearly kept pace with EU 27+3 in terms of globally co-authored articles, even though its total production has grown much more slowly. The number of globally co-authored articles by Asia 6 has grown extremely quickly and is rapidly approaching the level of North America and

Figure 45: Number of highly cited articles in the field of Biomedicine divided according to extent of international co-authorship for EU 27+3, North America and Asia 6
World's 10 % most cited articles. Number of articles.



Europe, from having been at below half their level a decade ago. Still, for Asia 6 the growth of domestically produced articles has been even faster than globally co-authored articles.

As previously noted the publication pattern differs from field to field. In fields other than Engineering and Physical Sciences, Asia still tends to play a limited role. In the Life Sciences North America is still dominating. As a result, in the field of Biomedicine, global co-authorship, which in this field primarily means co-authorship with North America, is much more important in the production of highly cited articles for both Europe and Asia than in the field of Engineering (Figure 45).

NORTH AMERICA PLACING MORE EMPHASIS ON EXCHANGE WITH ASIA THAN EUROPE IS

Broadly speaking North America, i.e. the USA and Canada, is placing greater emphasis on co-authorship with the leading research nations in Asia than Europe viewed as a whole is (Figure 46). This is especially true for exchange with South Korea and Taiwan, but there is also a clear difference in the case of China. In contrast, North America and Europe have about the same share of their articles co-authored with Japan, India and Singapore respectively. This pattern is more or less the same for Engineering-related fields and for Biomedicine (Figure 47). North America also has stronger connections with Singapore in the field of Engineering, while in Biomedicine there is little difference. The precise numbers differ somewhat if all or only highly cited articles are considered, but the overall pattern is basically the same.

The relative weight of exchange with the Asia 6 countries except Japan has increased very rapidly for both North America and Europe, especially over the past ten years. In Engineering-related fields, China is now the most important partner country for both North America and Europe, while in the field of Biomedicine Japan is still the leading partner.

With its rapid growth, China will soon move ahead of Japan as a co-authorship partner in Biomedicine as well, while Japan will continue to have a larger scientific output than the other Asian countries for a while at least. In Engineering-related fields, South Korea is already a more important partner for North America, while for Europe, Japan continues to be the favored partner after China.

Figure 46: Co-authored articles with six Asian countries as a share of all highly cited articles in USA and EU 27+3 in the fields of Engineering, ICT and Materials Science 1990-2010
World's 10 % most cited articles. Asian country's share of all articles from North America and EU 27+3 respectively (Percent).

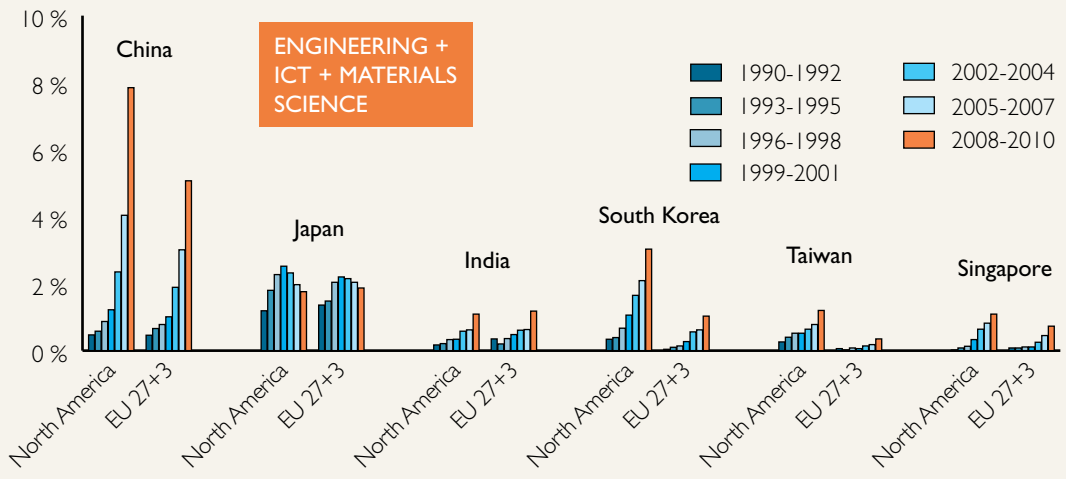
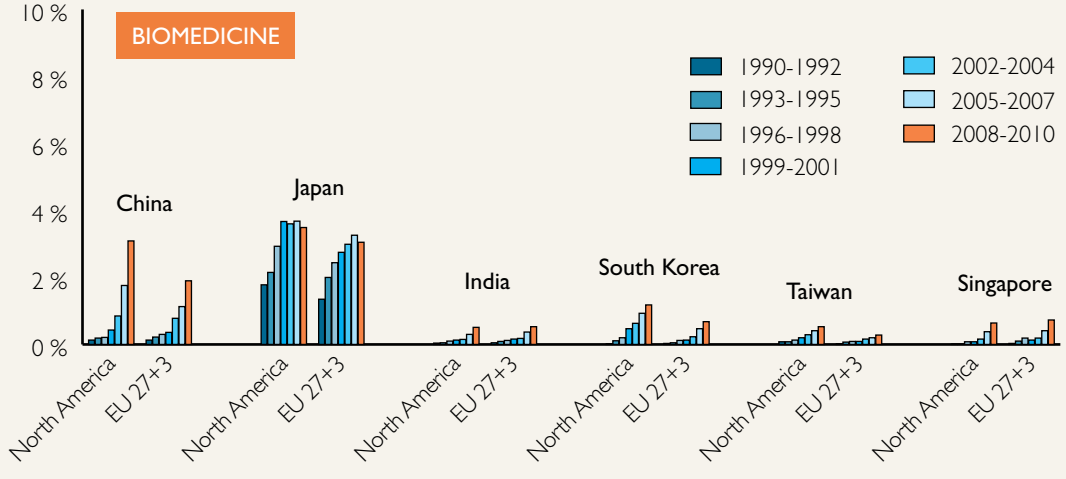


Figure 47: Co-authored articles with six Asian countries as a share of all highly cited articles in USA and EU 27+3 in the fields Biomedicine 1990-2010
World's 10 % most cited articles. Asian country's share of all articles from North America and EU 27+3 respectively (Percent).



SWEDEN'S RESEARCH CONNECTIONS WITH SIX ASIAN COUNTRIES

Sweden's scientific exchange with Asia has increased greatly over the past ten years but the growth has been unevenly distributed between countries. This is partly due to the difference in size of the research effort of the individual Asian countries, but as will be shown, this is only part of the explanation. To gain additional perspective on Sweden's research exchange with Asia, comparisons will be made with the corresponding patterns for Switzerland, Canada and Australia. As was the case earlier, the focus will be on the six countries that are the largest producers of scientific articles in Asia.

Around the turn of the century, Japan was still the largest research partner for Sweden among Asian countries in most fields. Over the past decade, exchange with China has grown sharply, while exchange with Japan has stagnated. In Engineering-related fields, during the period 2008–2010 Sweden had three times as many articles co-authored with China than with Japan (Figure 48).[37] Sweden's co-authorship with other Asian countries has also grown, but in most fields it is still considerably less than with Japan. Sweden's co-authorship with Japan is declining in Materials Science, while it is increasing with both India and South Korea.

As the Asia 6 countries vary greatly in size, China having a population almost 300 times that of Singapore, Sweden's co-publications need to be related to the size of the research effort in the respective country. For this purpose in Figure 49 each Asian country's co-authored articles with Sweden are compared with its total number of internationally co-authored articles. It turns out that for Engineering-related fields, Sweden's share of all internationally co-authored articles is highest for China at 1.75 percent, somewhat lower for Japan and India at 1.2–1.3 percent and at a much lower level of only 0.5–0.7 percent for South Korea, Taiwan and Singapore.

If we look at the trends, still in Engineering-related fields, Sweden has significantly increased its share of international co-publications with China, while the opposite has happened in Sweden's exchange with Japan. In relation to India, South Korea and Singapore, Sweden has more or less retained its relative share of these countries' international exchange.

Sweden's exchange with Taiwan used to be very limited but has most recently strengthened and has in relative terms reached about the same level as with South Korea and Singapore. It must be emphasized that, in absolute terms, Sweden's exchange with Taiwan and Singapore is still very limited at only around ten articles per year for each country in the fields of Engineering, ICT and Materials Science combined.

Due to the small number of articles co-authored by Sweden with several of the Asia 6 countries, the analysis in this section is based on all articles rather than highly cited articles, which would have been preferable. Figure A1.4 in Appendix 1 shows that in Engineering-related fields, the quality of Sweden's co-authorship with the Asia 6 countries, as measured by the share of highly cited articles, differs significantly among the countries. The high share for co-authorship with South Korea, where articles in the world's 10 percent most cited in 2008–2010 represented 22 percent, is particularly noteworthy. Co-authorship with Singapore scored highly as well.

If we look closer at each of the three fields mentioned separately, some differences emerge (Figure 50). The increase in relative importance of China over Japan as a partner for scientific exchange is much more pronounced in the field of Materials Science than in the other two fields. Sweden's shift of emphasis in its collaboration in Materials Science from Japan to China is indeed striking. We also see that the strengthening of the exchange with Taiwan is focused on the field of ICT. Considering Taiwan's special strength in this field, it is a development that should be welcomed. On the other hand, it is also clear that Sweden has not been part of South Korea's rapidly expanding international collaboration in ICT.

Figure 50 also shows data for Biomedicine and Figure 51 adds data for four more fields: Mathematics, Physics, Chemistry and Clinical Medicine. The collaboration pattern for Chemistry and Physics resembles the pattern for Materials Science. A major difference is that

Figure 48: Sweden's co-authorship with six Asian countries in the fields of Engineering, ICT and Materials Science combined 1999–2010
Number of articles co-authored with Sweden. Articles with authors from five or more countries excluded.

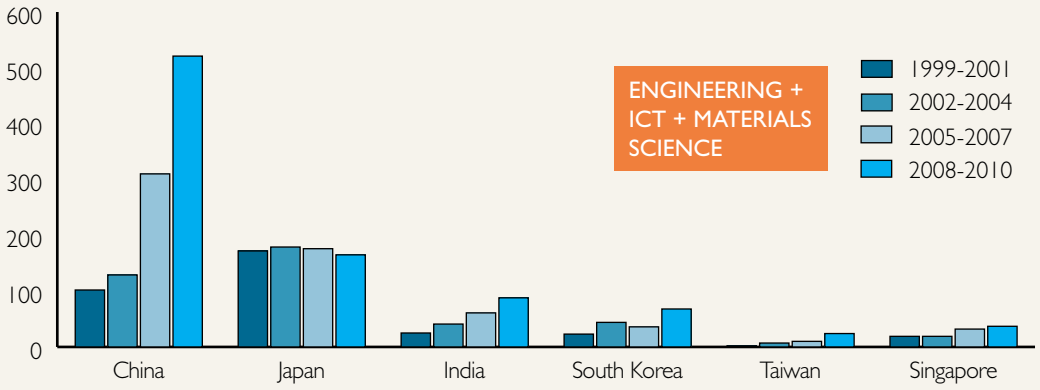
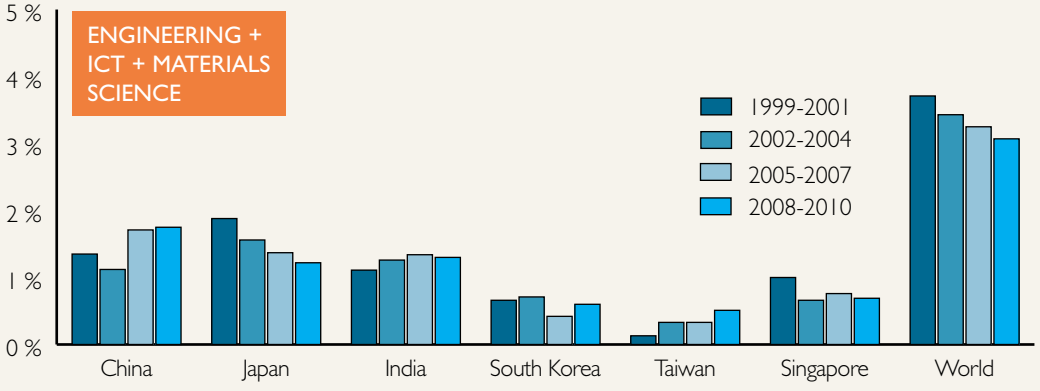


Figure 49: Sweden's co-authored articles with six Asian countries in the fields of Engineering, ICT and Materials Science combined 1999–2010 as a share of the respective country's total number of internationally co-authored articles
Sweden's share of Asian country's/world's Internationally co-authored articles (Percent).
Articles with authors from five or more countries excluded.



the connections with India in Chemistry, which in the past were much weaker than in Materials Science, have been strengthened to a level similar to that of other fields. With the exception of relations with Japan, Sweden's exchange with Asian countries in Mathematics can only be described as inadequate. The pattern of Sweden's co-authorship in Biomedicine and Clinical Medicine is fairly similar to the pattern in Physical and Engineering Sciences, with two main exceptions. One is the much stronger connections with Singapore in Life Sciences. A second difference is the decline in Sweden's relative position as a co-authorship partner in Life Sciences with all of the other five countries. There is no such clear predominance of declining

Figure 50: Asia 6 countries' co-authored articles with Sweden 1999–2010 in Materials Science, Engineering, ICT and Biomedicine as a share of all their internationally co-authored
Share of Asian country's/world's internationally co-authored articles (Percent). Articles with authors from five or more countries excluded.

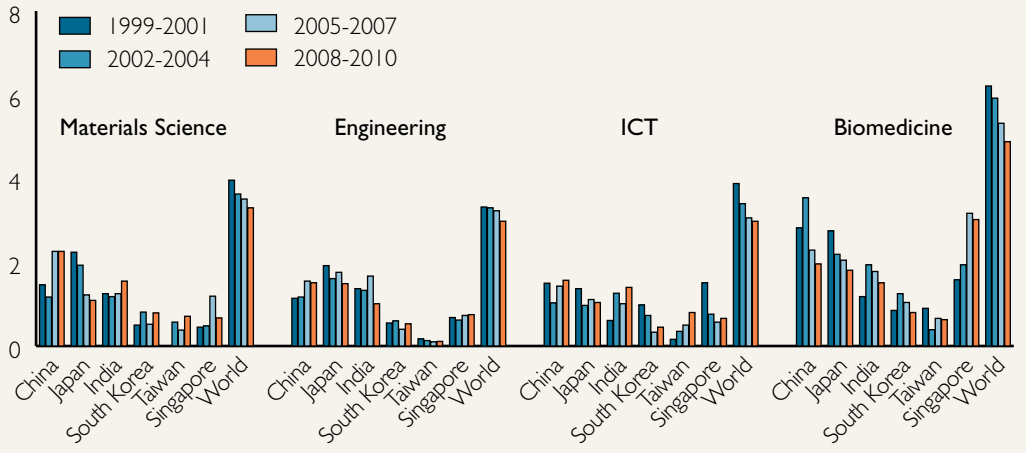
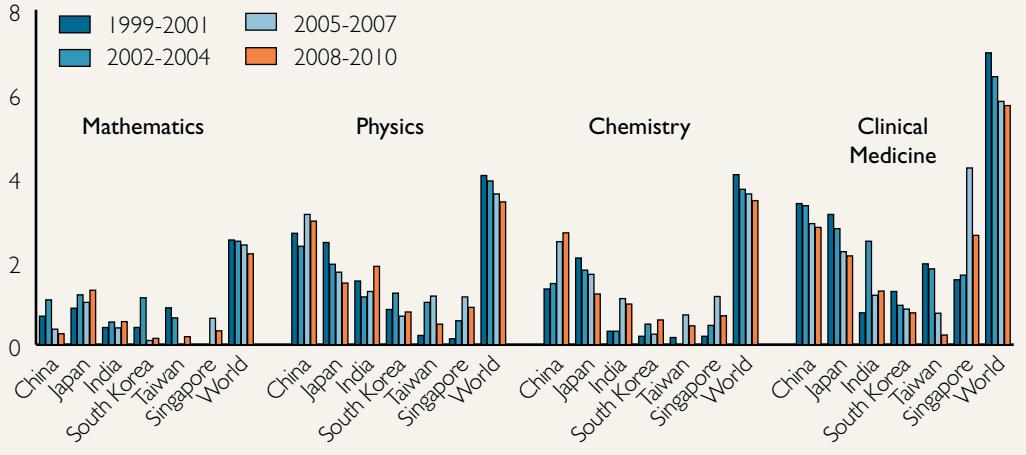


Figure 51: Asia 6 countries' co-authored articles with Sweden 1999–2010 in Mathematics, Physics, Chemistry and Clinical Medicine as a share of all of their internationally co-authored articles
Share of Asian country's/world's internationally co-authored articles (Percent). Articles with authors from five or more countries excluded.

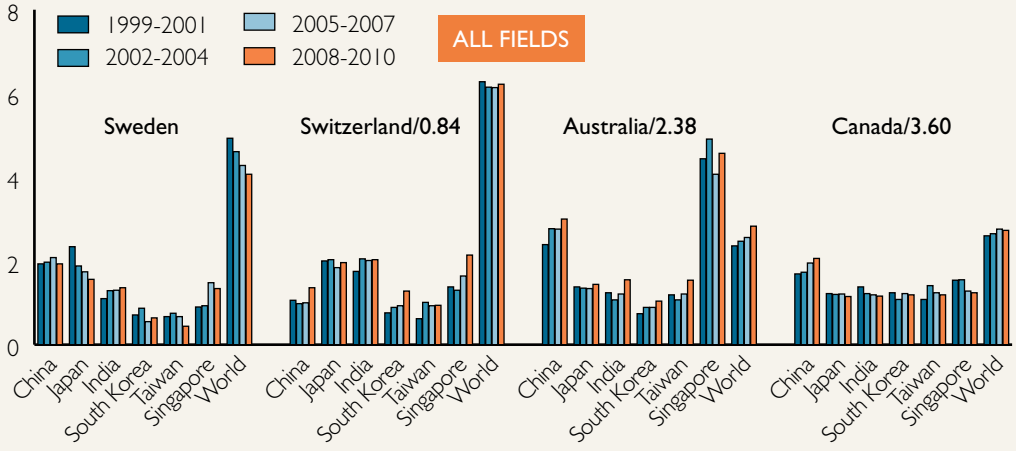


shares across countries in other fields as shown in Figures 50–51, Mathematics excluded.

In comparing Sweden's and other countries' research connections in Asia, we will limit ourselves to three countries: Switzerland, Canada and Australia, and provide details for four fields: Materials Science, Engineering, ICT and Biomedicine. The basis for comparison is the share

Figure 52: Asia 6 countries' co-authored articles with Sweden, Switzerland, Canada and Australia 1999–2010 in All fields as a share of all their internationally co-authored articles normalized by size of population relative to Sweden

Share of Asian country's/world's internationally co-authored articles (Percent). Articles with authors from five or more countries excluded.



of each Asian country's total international co-authorship. We will refer to this measurement as "relative presence" in the respective Asian country. To make the comparison of relative presence more meaningful, the data for Switzerland, Canada and Australia have been normalized by a factor corresponding to their population relative to that of Sweden.

As just discussed, the relative presence of Sweden differs greatly between the Asia 6 countries. This contrasts most sharply with the pattern for Canada (Figure 52). Like Sweden, Canada has the highest relative presence in China while, unlike Sweden, its relative presence in the other five countries is very nearly the same. Australia places even more emphasis on China, but the most striking feature is its very high relative presence in Singapore, which is three times that of Sweden even when adjusted for Sweden's larger population. Switzerland deviates from the other three countries in its much smaller relative presence in China. On the other hand, its population-adjusted relative presence in Japan, India and Singapore is greater than that of any of the other three countries except for Australia's presence in Singapore. Switzerland, Canada and Australia all have a population-adjusted relative presence in South Korea and Taiwan that is at least twice that of Sweden's presence.

Here, as in many other cases, the aggregate data for all fields masks important differences between fields (Figures 50, 53–55). Sweden's population-adjusted presence in Biomedicine is comparable to that of both Canada and Australia in all of the Asia 6 countries, except for a lower relative presence for Sweden than Canada in South Korea and Taiwan. In contrast, Sweden's relative presence in Engineering and even more in ICT is significantly weaker than that of Canada and Australia in all of the Asia 6 countries except Japan. Sweden is doing better in Materials Science. In this field its relative presence is comparable to that of Canada and Australia, except for Australia's stronger presence in China and Singapore. Generally speaking Sweden's relative strength in Biomedicine and Materials Science and relatively weaker position in Engineering and ICT shines through in comparison with Canada and Australia.

Switzerland's field profile is more similar to

Figure 53: Asia 6 countries' co-authored articles with Switzerland 1999–2010 in Materials Science, Engineering, ICT and Biomedicine as a share of all their internationally co-authored articles
Share of Asian country's/world's internationally co-authored articles (Percent). Articles with authors from five or more countries excluded.

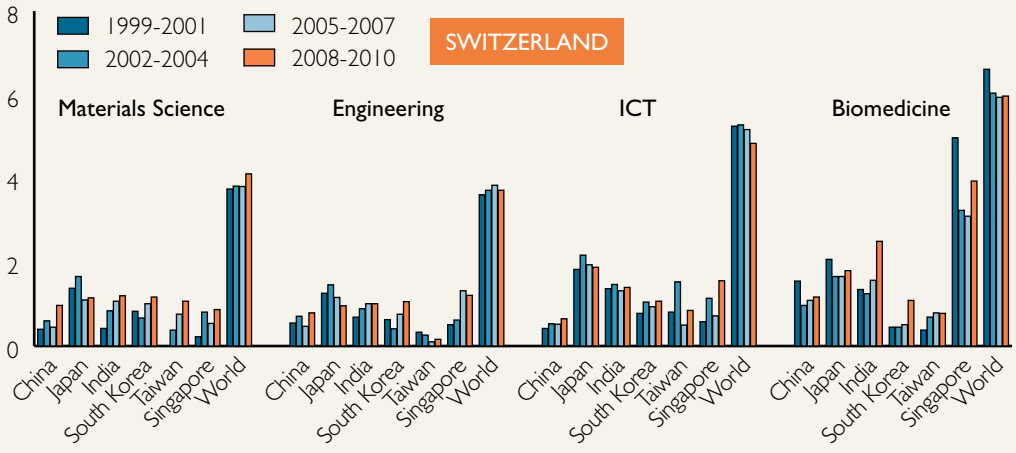
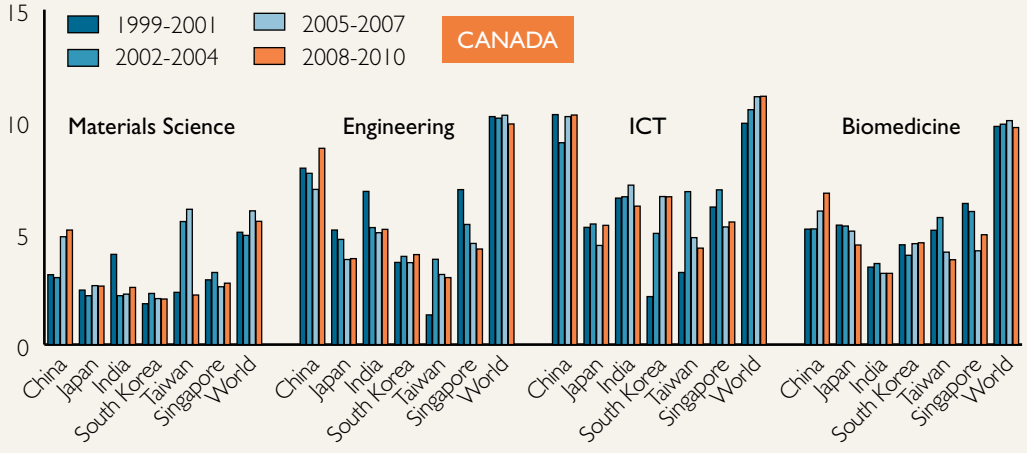
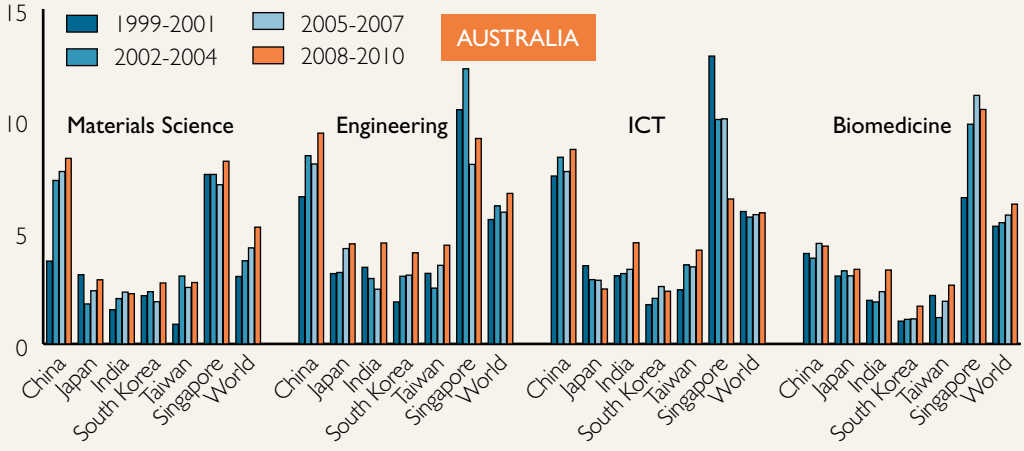


Figure 54: Asia 6 countries' co-authored articles with Canada 1999–2010 in Materials Science, Engineering, ICT and Biomedicine as a share of all their internationally co-authored articles
Share of Asian country's/world's internationally co-authored articles (Percent). Articles with authors from five or more countries excluded.



Sweden's profile to the extent that the country pattern of relative presence is more similar across fields. Sweden's relative weakness in ICT is, however, also apparent in the comparison with Switzerland. In this field, Switzerland's relative presence in South Korea and Singapore is three times – and in Japan twice – that of Sweden. It is also noteworthy that Switzerland's share of India's international co-publications in Biomedicine is twice that of Sweden's.

Figure 55: Asia 6 countries' co-authored articles with Australia 1999–2010 in Materials Science, Engineering, ICT and Biomedicine as a share of all their internationally co-authored articles
Share of Asian country's/world's internationally co-authored articles (Percent). Articles with authors from five or more countries excluded.



CO-OPERATING ON WHOSE INITIATIVE AND FOR WHOSE BENEFIT?

In summarizing the observations from the comparisons just made, it appears that Sweden's relative presence in China, Japan and India is at a level that compares fairly well with the levels for Switzerland, Canada and Australia when we consider differences in population size and Australia's relative proximity to Singapore. Sweden has strengthened its relative position in China in Chemistry and Materials Science, but its connections with China in Life Sciences have grown more slowly than China's total international exchange in that field. Sweden has not connected with the rapid advancement of Mathematics in China either. Sweden's relative position in Japan has weakened in most fields but especially in Physics, Chemistry and Materials Science.

Sweden's exchange with South Korea, Taiwan and Singapore is much less well developed, the major exception being connections with Singapore in Life Sciences. In Physical and Engineering Sciences, Sweden is clearly in a weaker relative position in these three countries when compared with Switzerland, Canada and Australia.

Sweden's exchange with Singapore highlights some of the challenges facing Sweden in developing its research links with Asian countries. Over the past decade Singapore has advanced enormously as a knowledge-based economy. From hardly being recognized for its scientific research 15 years ago, Singapore today performs world-class research in many fields. The active recruitment of researchers from abroad and the establishment of strategic alliances with leading research institutions world-wide have formed an important foundation for this development. With a population less than half of Sweden's, Singapore today produces more than 2.5–2.7 percent of the world's 10 percent most cited articles in Materials Science and ICT and around 1.5–1.9 percent of the articles in Physics, Chemistry and Engineering (Figure 56). The corresponding percentages for Sweden are in the range of 1.2–1.7 percent.[38] For other fields, including Life Sciences, Singapore's percentages are much lower than Sweden's. In all Life Sciences fields, as well as in Social Sciences, Singapore is, however, expanding rapidly, while growth in Engineering and ICT has begun to level off in recent years. This is a reflection of the

Figure 56: Singapore's share of the world's production of highly cited articles by field 1990–2010
Share of world total (Percent). Articles with authors from five or more countries excluded.

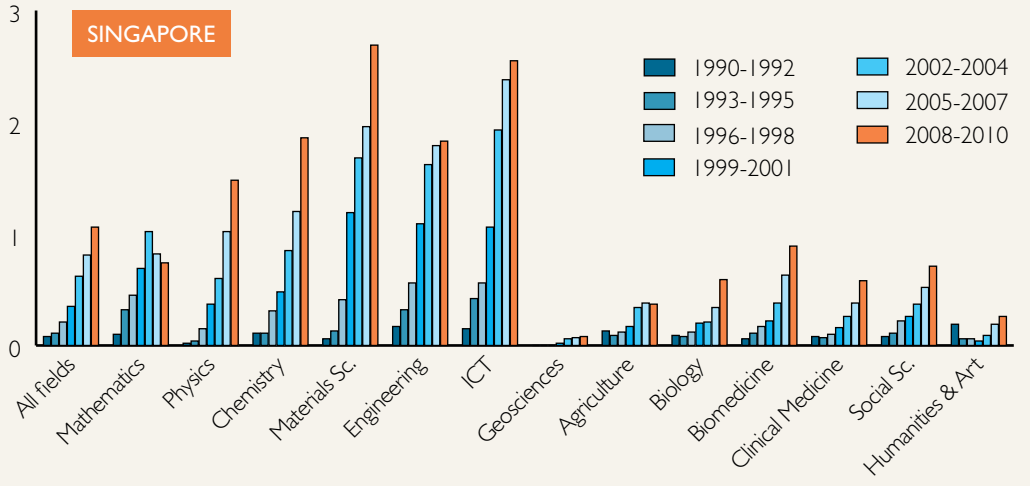
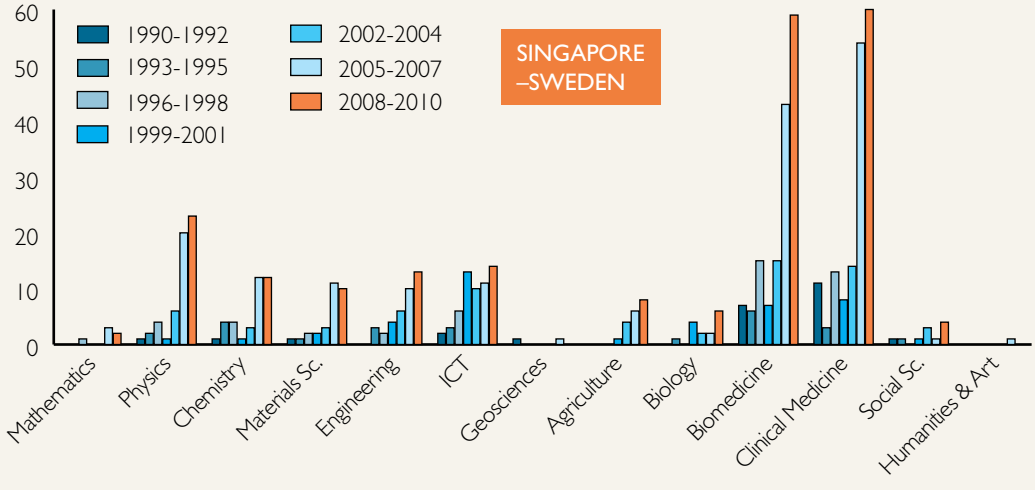


Figure 57: Co-authored publications between Sweden and Singapore by field 1990–2010
Number of artices. Articles with authors from five or more countries excluded.



large investments made by the Singaporean government in Life Sciences over the past decade.

One might have expected Singapore's strong position in Physical and Engineering Sciences to have attracted exchange activity with Swedish scientists, but this seems to have happened to a very limited extent. Instead, co-publications between Sweden and Singapore are heavily concentrated on Biomedicine and Clinical Medicine, fields in which Sweden is regarded as particularly strong and where development has been a priority in Singapore (Figure 57). Although it

Figure 58: Singapore's co-authorship with other countries in All fields, Engineering and Biomedicine
Share of Singapore's internationally co-authored articles (Percent). Articles with authors from five or more countries excluded.

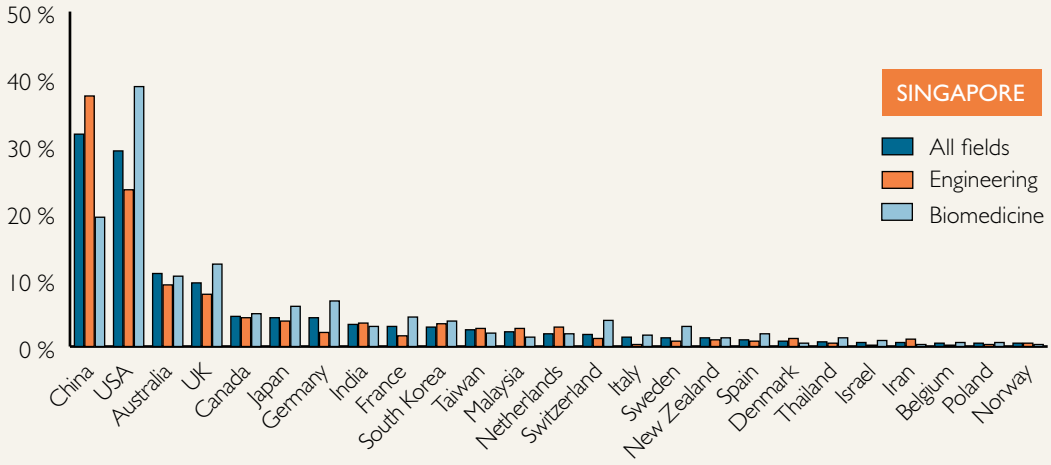
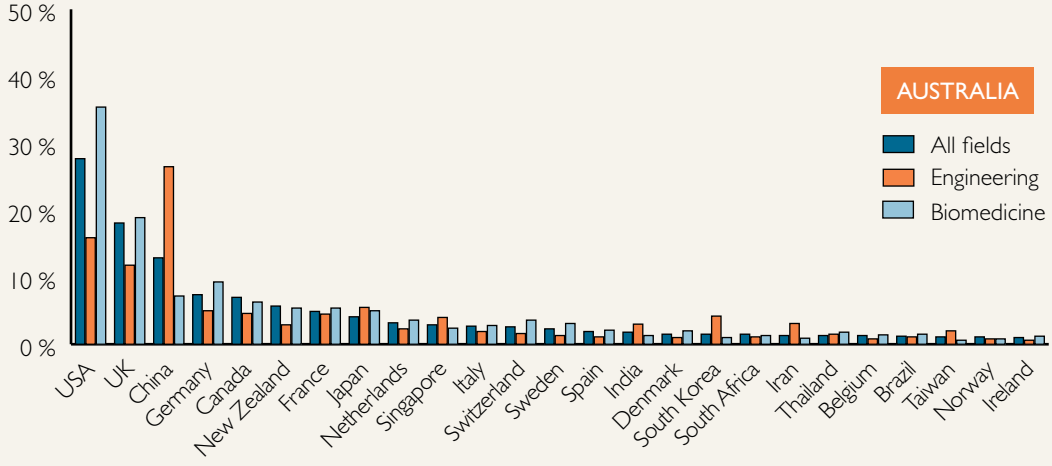
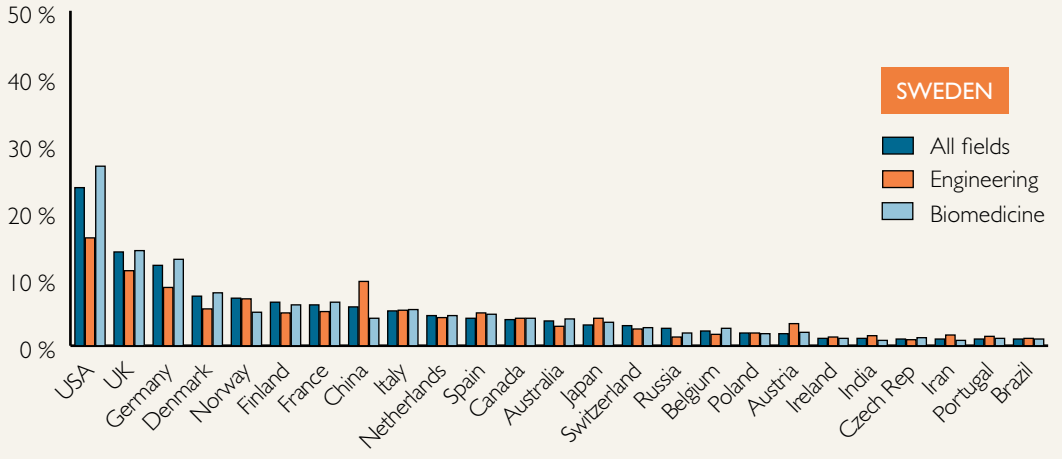


Figure 59: Australia's co-authorship with other countries in All fields, Engineering and Biomedicine
Share of Australia's internationally co-authored articles (Percent). Articles with authors from five or more countries excluded.



is not be regretted that Sweden is developing strong links with Singapore in Life Sciences, it appears that Sweden has neglected to develop exchange with Singapore in that country's areas of particular strength. As argued earlier, and as suggested by Figure 39, actors in Sweden will have to make a much more concerted effort in Physical and Engineering Sciences in order to strengthen co-operation with Asian countries than is necessary in Life Sciences. The Singapore example seems to support this. It may also be argued that the higher profile of Sweden in

Figure 60: Sweden's co-authorship with other countries in All fields, Engineering and Biomedicine
Share of Sweden's internationally co-authored articles (Percent). Articles with authors from five or more countries excluded.



Chemistry and Materials Science in China is, at least to some extent, the result of conscious efforts, especially by the Royal Institute of Technology, to nurture relationships with Chinese universities by investing in connections created through Chinese researchers who have previously studied in Sweden.

Singapore's small size may explain the apparent lack of attention from Swedish researchers. The importance of Singapore as a node in the global research system should not be judged only in terms of the country's size. Just as Singapore historically has served as an important hub in the global circulation of goods, it is today well under way to establishing itself as a hub in the global circulation of knowledge. Its research system is already well-connected with most of the main global players, including very strong relationships with both the USA and China (Figure 58). Its exchange with India is still fairly limited, but its proximity to India suggests that it is likely to develop strong links in due course as India's research system expands and the quality improves.

Like Singapore, Australia is also globally well-connected (Figure 59). Australia's location far away from all other continents may have been a disadvantage in the past, but as globalization has taken hold there may actually be some beneficial effects. Australia's isolated location, combined with high immigration and the limited size of its population and economy, has created a need and a readiness among its actors to develop relationships with other parts of the world. For a long time this was focused on Europe and North America, but over the past couple of decades connections with Asia have come to the forefront.

There is good reason for Sweden to watch how both Singapore and Australia develop their research systems and global research connections in the future, and to make sure that Sweden has strong research connections with these countries.

6. The view from individual universities

This report primarily focuses on the position and connections of Sweden as a whole in the global research system. In this chapter we will present some additional data at the level of individual organizations with a focus on universities. The purpose is threefold:

- to get a picture of the degree of variation among Swedish universities in their to international connectedness
- to get some indication of how well the average statistics for certain countries illustrate the global connectedness of leading universities in the same countries
- to compare Sweden and certain other countries at the level of individual universities

Analysis at the level of individual institutions presents a number of difficulties. To begin with, each country has its own unique research system. Where in Sweden research is highly concentrated to universities, in many other countries, e.g. Germany and France, research institutes play a much larger role. Furthermore, this role may be different for different fields in different countries.

The structure of the university sector itself also varies greatly between countries. In Sweden the largest universities in the fields of Medicine, Engineering and Agriculture are universities which specialize in the respective fields. The same is the case in some other countries, especially in the field of Engineering, while in quite a few countries, comprehensive universities play the leading role in the aforementioned three fields as well. More generally speaking, each university has a more or less unique mix of fields.

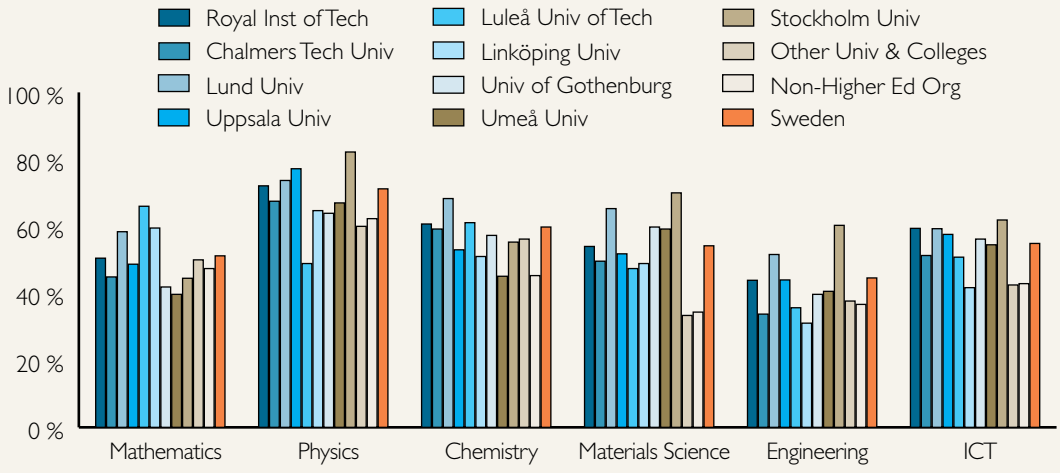
Finally, for the purpose of analysis, it was necessary to select a relatively small number of universities. The admittedly subjective selection of foreign universities was done in two steps. First the following countries were selected: Germany, United Kingdom, United States, Denmark, Switzerland, Canada, Australia, China, India, Japan, South Korea, Taiwan, Singapore and Brazil. Then in each country one or two universities with special strengths in Engineering-related fields were selected. In some cases this meant selecting universities which were not among the leading universities in non-engineering fields in their countries. This limitation has to be considered when interpreting the results later on in this chapter.

INTERNATIONALIZATION DISAGGREGATED TO THE LEVEL OF INDIVIDUAL SWEDISH UNIVERSITIES

Among higher education institutions in Sweden, ten universities produce significantly more scientific articles than the rest (Figure 61). They produce between 5 percent (Chalmers University of Technology) and 20 percent (Karolinska Institute) of all articles in Sweden.[39] While universities and colleges receive a higher percentage of public research funding than in most other countries, there are organizations in Sweden that are outside the higher education sector but that publish scientific articles. The largest categories are various types of research institutes,

Figure 61: Individual universities' and other organizations' shares of Sweden's total production of articles and of Sweden's internationally co-authored articles (two categories) respectively
Share of Sweden Total (Percent).

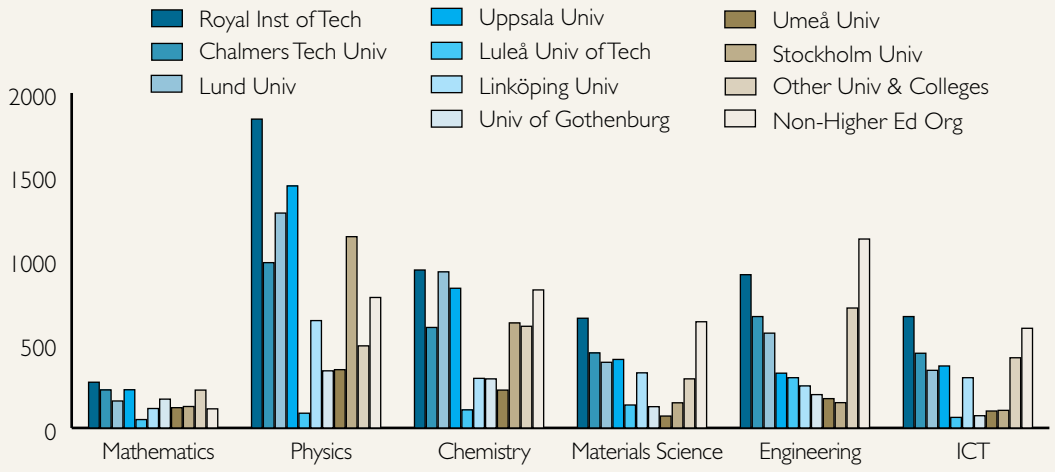
Figure 62: Internationally co-authored articles as a share of all articles in fields of Engineering and Physical Sciences for individual universities 2008–2010
Internationally co-authored articles as a share of all articles (Percent).



hospitals and clinics, other than university hospitals, and companies. When combined, non-higher-education organizations are represented in around 20 percent of all articles with authors from Sweden. A certain, but unknown, portion of these articles are co-authored with universities in Sweden.

For most of the larger universities the share

Figure 63: Total number of articles in fields of Engineering & Physical Sciences for individual universities 2008–2010
Total number of articles.



of Sweden's internationally co-authored publications is fairly close to their share of all publications. The newest universities and the university colleges tend to have a smaller share of internationally co-authored publications than the larger and more established universities. In line with the analysis in the rest of this report, for internationally co-authored articles, a distinction has been made in Figure 61 between those with authors from 2–4 countries and those with authors from 5 or more countries. The latter category, which is particularly prevalent in Physics, Clinical Medicine and Geosciences, on average for Sweden only represents around 8 percent of all internationally co-authored articles, but for a few universities the percentage is higher.[40]

The average percentages of internationally co-authored articles hide what are in some cases rather large variations between fields and for each field between individual universities. These differences are shown in Figure 62 and Figure 64. The relative weight of different fields differs greatly among universities. To illustrate this, the absolute number of articles by fields and individual university is also presented in Figure 63 and Figure 65.

In Figures 62 and 63 data for fields of Physical and Engineering Sciences is presented for the period 2008–2010. Universities are listed in the order of their total production of articles in the field of Engineering. The Royal Institute of Technology (KTH), Chalmers University of Technology (CTH) and Lund University (LU) are the major universities in this field. The same three universities are also among the leading ones in ICT and Materials Science, but in these fields they are joined by Uppsala University (UU), each with total efforts of about the same size as the first three universities. KTH, CTH, LU and UU are also the main players in Chemistry, Physics and Mathematics. In Physics and Chemistry, Stockholm University has a major presence as well.

When comparing the percentages of international publications between universities, it appears that there are few consistent differences across fields. This suggests that the degree of internationalization is not strongly linked to factors or conditions pertaining to a university as a whole.

Stockholm University has a significantly higher percentage of international articles than all the other universities in three of the six fields.

Figure 64: Internationally co-authored articles as a share of all articles in life science and some other fields for individual universities 2008-2010
Internationally co-authored articles as a share of all articles (Percent).

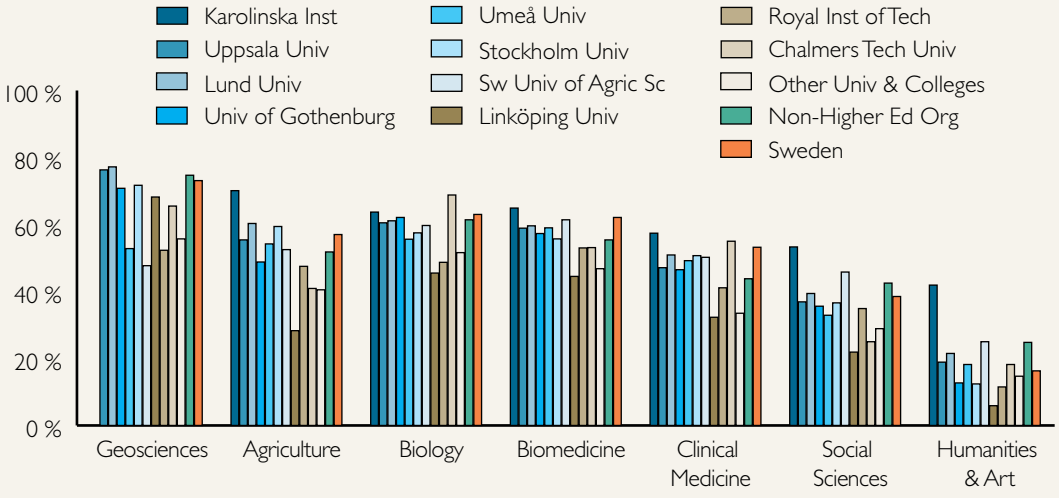
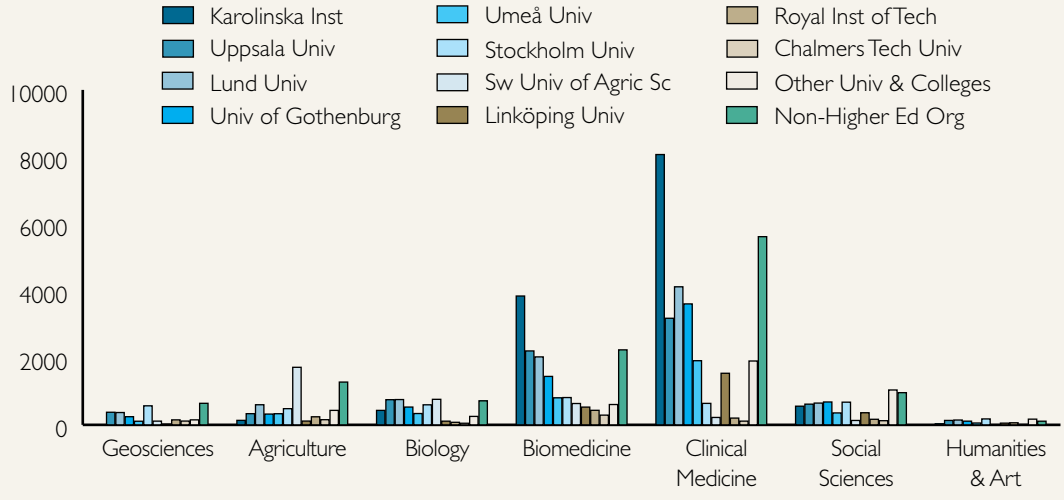
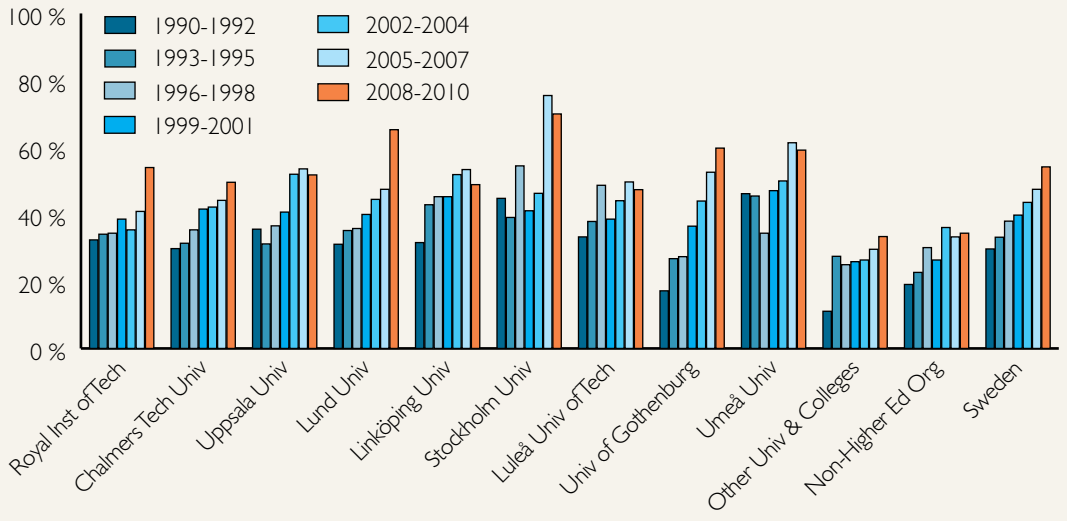


Figure 65: Total number of articles in Life Science and some other fields for individual universities 2008–2010
Total number of articles.



As already mentioned, the high percentage in Physics is primarily due to the dominance of large-scale multi-country research which tends to result in a large number of publications, each with many authors.[41] There is, however, no such explanation for the Engineering and Materials Science fields. Lund University has a consistently high percentage of international articles.

Figure 66: Share of internationally co-authored articles in the field of Materials Science for individual universities and other organizations in Sweden 1990–2010
Internationally co-authored articles as a share of all articles (Percent).



Chalmers University of Technology, Luleå University of Technology and Linköping University have significantly lower percentages of international publications than other major universities in Engineering, and this is also the case for Linköping University in the field of ICT. The reader will be able to add her or his own observations from the graphs.

The same type of data as the data just discussed is shown for Life Sciences and other fields in Figure 64 and Figure 65. In this case, universities are listed in the order of their total publication volume in Biomedicine. In Biomedicine and Clinical Medicine, Karolinska Institute is represented in around 35–40 percent of all Swedish publications and Lund University, Uppsala University and University of Gothenburg each in 13–20 percent. Umeå University and Linköping University, which also have medical schools, appear in 7-9 percent of all Swedish articles in Clinical Medicine. Umeå University and Stockholm University have the same share in Biomedicine.

The field of Biology is more evenly distributed, with each of five universities appearing in 11–19 percent of all Swedish publications. The situation is similar in Social Sciences, with five universities each making up 12–15 percent of all Swedish publications. Not surprisingly, the Swedish University of Agricultural Sciences dominates the field of Agriculture with around 40 percent of all publications. Stockholm University produces around 25 percent of all articles in Geosciences, followed by Uppsala University and Lund University, each making up 15–16 percent.

Among the major players in Biomedicine and Clinical Medicine, Karolinska Institute has a significantly higher share of international publications. The low percentages of international publications for Linköping University in both fields also stand out.

We have seen that there are large variations in the degree of international co-authorship between fields and within each field as well as between universities. The variations between universities are, however, only to a rather limited extent consistent across different fields. The problem with making simple generalizations becomes even more apparent if we introduce

Figure 67: Share of internationally co-authored articles in all fields combined for individual universities and other organizations in Sweden 1990–2010
Internationally co-authored articles as a share of all articles (Percent).

changes over time. Figure 66 shows the dynamics of international co-authorship in the field of Materials Science for Swedish universities and other organizations. Universities are listed in order of their total number of Materials Science publications in the period 2008–2010.

Today Stockholm University and Lund University have the highest percentages of international articles after a large increase in recent years. In contrast, Uppsala University and Linköping University, which in the beginning of the previous decade had the highest share of international articles, have seen no growth in their share of international publications. The most dramatic development has occurred at the University of Gothenburg which increased its share of international articles from only 25 percent in the late 1990s to 60 percent a decade later.

Figure 67 shows the development of the relative weight of international co-authorship for individual universities for all fields combined. The pattern is quite similar for most of the universities. Linköping University does, however, stand out as having a lower share of international publications than other major universities. This in particular reflects the situation in Biomedicine and Clinical Medicine as these fields have large publication volumes, but is also true for several other fields as has been noted. Chalmers University of Technology, which had a higher share of international publications than most other universities at the turn of the century, has since then seen only marginal growth in its degree of internationalization. It can also be noted that new universities and university colleges viewed as a group exhibit a much smaller degree of internationalization than the major universities and that this difference has tended to grow over time.[42]

SWEDISH UNIVERSITIES' CONNECTIVITY WITH LEADING ASIAN COUNTRIES

In Chapter 5 we analyzed Sweden's connectivity with six leading Asian countries: China, Japan, India, South Korea, Singapore and Taiwan. We found that in some areas, especially Chemistry and Materials Science, Sweden had very strong

Figure 68: The number of co-authored articles with six Asian countries for individual Swedish universities 2008–2010
Number of articles. Articles with authors from five or more countries excluded.

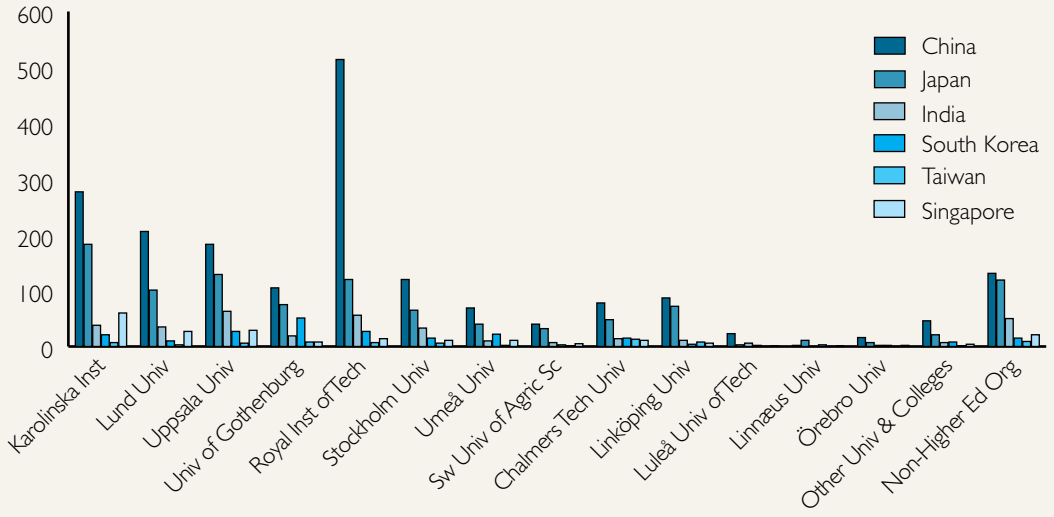


Figure 69: Co-authored articles with six Asian countries as a share of all internationally co-authored articles for individual Swedish universities 2008–2010
Share of university's internationally co-authored articles (Percent). Articles with authors from five or more countries excluded.

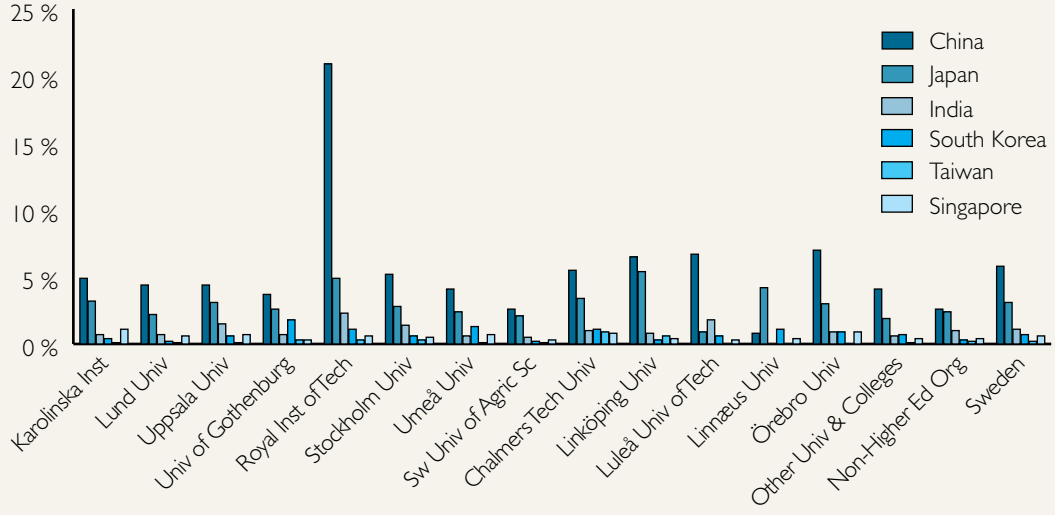


Figure 70: Swedish universities' co-publications with six Asian countries in Biomedicine as a share of all internationally co-authored articles in the field by the respective university 2008–2010
Share of university's internationally co-authored articles (Percent). Articles with authors from five or more countries excluded.

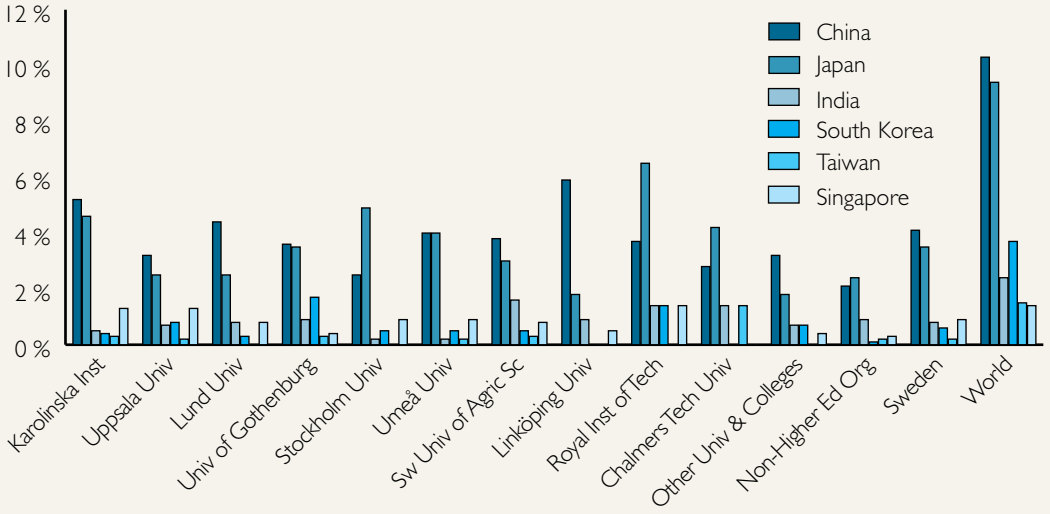


Figure 71: Swedish universities' articles co-authored with China in Physical & Engineering Sciences as a share of all internationally co-authored articles in the field for the respective university
Share of university's internationally co-authored articles (Percent). Articles with authors from five or more countries excluded.

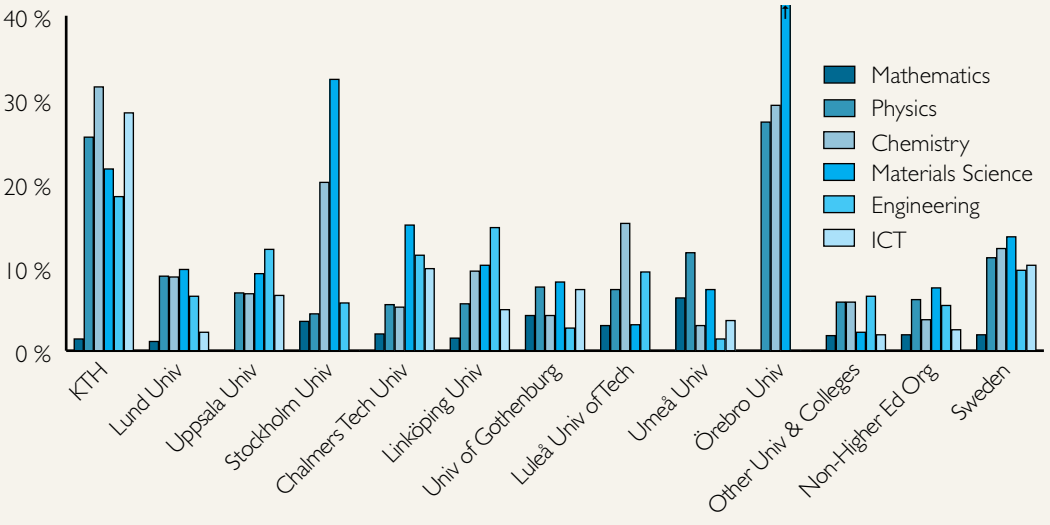
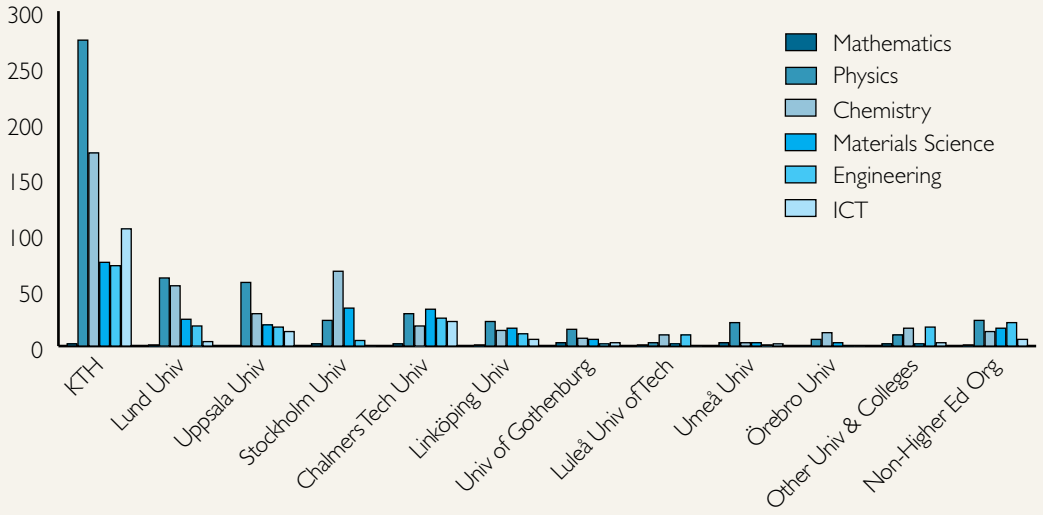


Figure 72: Swedish universities' co-publications with China in Physical & Engineering Sciences 2008–2010

Number of articles. Articles with authors from five or more countries excluded.



links with China. Connections with the other countries were much less remarkable, and with Singapore and Taiwan they were conspicuously weak in those countries' fields of strength.

Earlier bibliometric studies of Sweden's co-publications with China have indicated that the connections are highly concentrated to a few universities, and within these they are dominated by a handful of research groups.[43] These results for China are also verified in this study.

Figure 68 and Figure 69 give an overview of Swedish universities' co-publications with the Asia 6 countries 2008–2010. Importantly, articles with authors from five or more countries have been excluded. The argument for this is the same as before, that co-publications involving many countries do not really indicate close co-operation with any one of the countries involved, although such co-operation cannot, of course, be ruled out. Data is provided both in the form of the absolute number of articles and in the form of the respective university's share of all internationally co-authored articles.

For most Swedish universities, China and Japan today are the two major partners for co-authored articles, with China being the larger of the two (Figure 68). By far the strongest connection is the one between KTH and China, which accounts for more than 20 percent of all KTH's internationally co-authored articles (Figure 69). For Sweden as a whole the corresponding amount is around 6 percent, which is the about the normal level for most other universities in Sweden.

KTH's co-authorship with Japan is about one fourth of that with China, which translates into 5 percent of all KTH's international co-publications. Only Linköping University has a stronger relative emphasis on Japan with 5.4 percent of all international co-publications. For Sweden as a whole, Japan accounts for just over 3 percent of international co-publications.

The relative emphasis on China and Japan differs among universities and is heavily dependent on whether a university has a medical school or not, as Japan still maintains an edge in Life Sciences over China. In Biomedicine, Japan is still

Figure 73: Swedish universities' co-publications with Japan in Physical & Engineering Sciences
Number of articles. Articles with authors from five or more countries excluded.

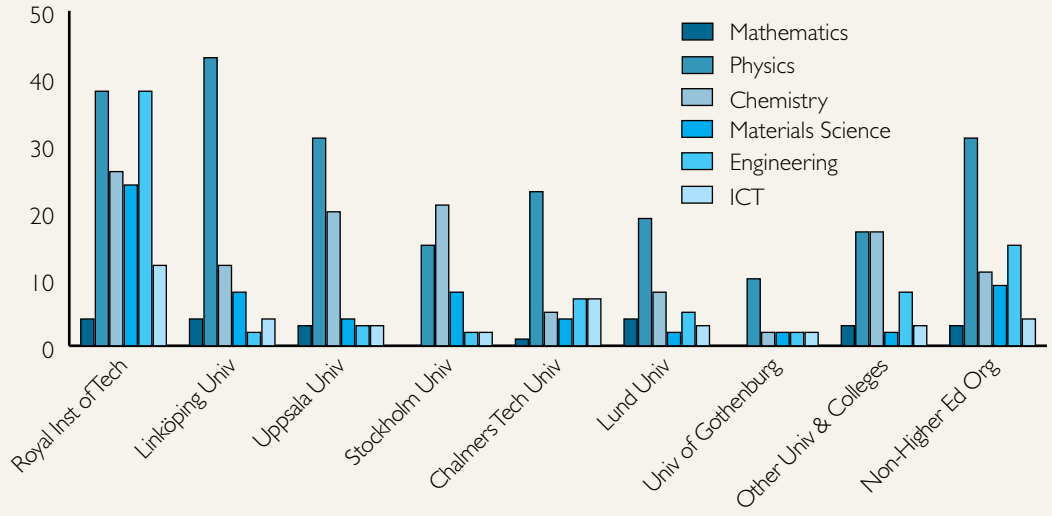
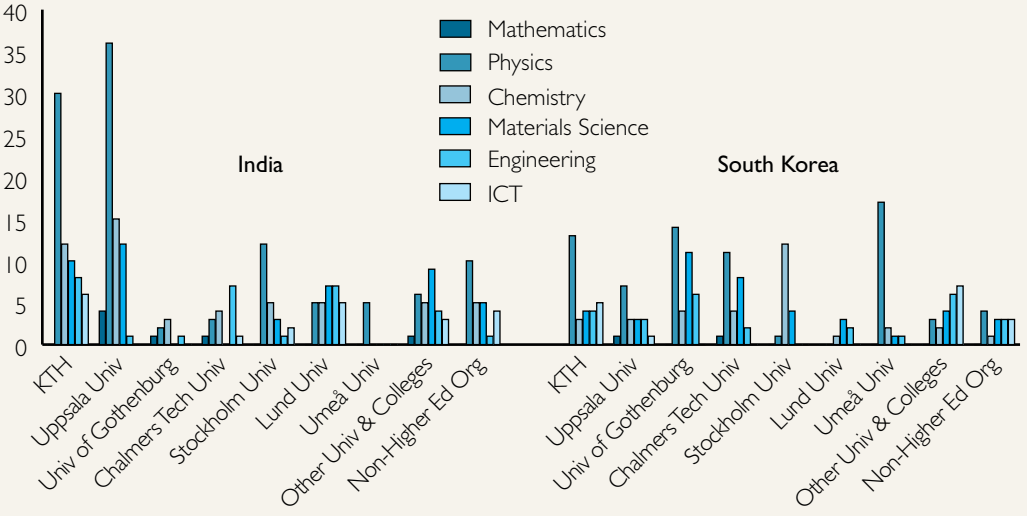


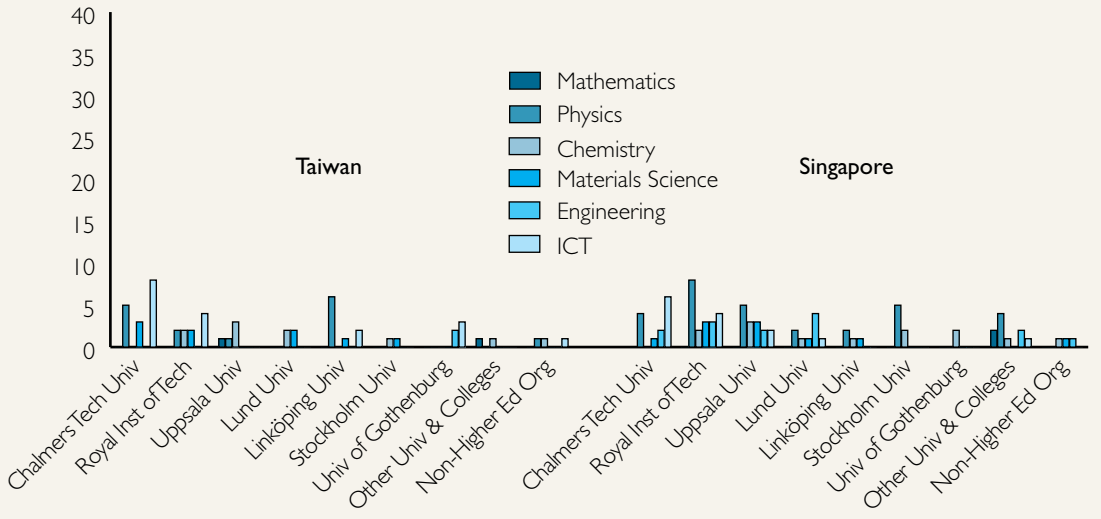
Figure 74: Swedish universities' co-publications with India and South Korea in Physical & Engineering Sciences
Number of articles. Articles with authors from five or more countries excluded.



comparable in size as a partner to China (Figure 70)[44], while for most universities in Physical and Engineering Sciences China has overtaken Japan as a co-authorship partner. The relative weight of connections in Biomedicine with both China and Japan in most cases varies in the range of

Figure 75: Swedish universities' co-publications with Taiwan and Singapore in Physical & Engineering Sciences

Number of articles. Articles with authors from five or more countries excluded.



3–5 percent and the differences among universities are not remarkable.

The differences are much bigger in Physical and Engineering Sciences, especially in the case of exchange with China (Figure 71). For Sweden as a whole, China's share of Sweden's international co-authored articles is in the range of 12–16 percent in all the Physical and Engineering Science fields, except in Mathematics where it is only a miniscule 2 percent or an average of five articles per year. KTH, in all fields except Mathematics, and Stockholm University in Chemistry and Materials Science, are the only universities with a significantly greater emphasis on China than the Swedish average.

KTH's dominance of Sweden's presence in China in Physical and Engineering Sciences is indeed striking, with KTH's share of Sweden's co-publications with China ranging from around 40 percent in Engineering and Materials Science to 70 percent in ICT, with Chemistry at close to 50 percent and Physics at just under 60 percent (Figure 72). Sweden's relatively strong presence in China compared to many other European countries, as discussed previously, is thus largely an effect of the strong presence of KTH in China.

Exchange with Japan is more evenly distributed among Swedish universities but only KTH has connections across a broad range of fields (Figure 73). Physics and Chemistry, both being large fields, are, for all universities except KTH, the only fields for which at least 10 articles were co-authored with Japan during the three year period 2008–2010. A high presence in Japan in relation to overall international co-authorship can be noted for Linköping University in Physics and Chemistry, with 11 and 8 percent of all international publications, and for KTH in Engineering with 10 percent.

Sweden's research connections with India in Physical and Engineering Sciences are dominated by KTH and Uppsala University (Figure 74). The latter university devotes almost twice as large a share of its international co-authorship in Physics, Chemistry and Materials Science to India as Swedish universities on average, while KTH's share is close to the average. If we turn to Sweden's exhange with South Korea, the University of Gothenburg stands out in relative terms, espe-

cially in Materials Science where South Korea represents 15 percent of the university's international co-publications and a third of all Sweden's co-publications in this field. South Korea is also an important partner for the University of Gothenburg in Physics and Engineering, as well as for Umeå University in Physics. In Chemistry almost all of Sweden's exchange with South Korea is concentrated at Stockholm University.

For the sake of completeness, data for Swedish universities' co-authorship with Taiwan and Singapore in Physical and Engineering Sciences is shown in Figure 75 even though the number of articles is quite small. Apart from the small number, what stands out most is Chalmers University of Technology's connection with Taiwan in the ICT field.

COMPARING GLOBAL CONNECTIVITY BETWEEN SELECTED UNIVERSITIES IN SWEDEN AND ELSEWHERE

As a complement to the comparisons made at the national level in this chapter, we will present some data comparing international co-authorship at the level of individual universities. Such comparisons avoid some of the problems associated with comparing countries that vary greatly in size.

For practical reasons it has been necessary to make selections among foreign universities. A total of 19 universities were selected from Denmark, Switzerland (2), Germany, United Kingdom (2), United States (2), Canada, Australia, China, Japan (2), India, South Korea, Taiwan, Singapore (2) and Brazil. One of the key selection criteria was that the university has an engineering school that is among the leading ones in its country. The universities selected are therefore not necessarily leading universities in their country in other fields, e.g. Life Science fields.

The field profile varies greatly between universities. Figures 76–78 show the profiles for MIT and ETH, which are generally recognized as being among the leading technical universities in the world, and for KTH, Sweden's largest technical university.

Both ETH and MIT exceed KTH in terms of publication output. This is partly due to their scope being broader. Geosciences and Biomedicine are represented at almost the same level as core Physical and Engineering Sciences at both ETH and MIT and Biology at ETH and Social Sci-

Figure 76: Field profile of MIT
Share of World Total (Percent).

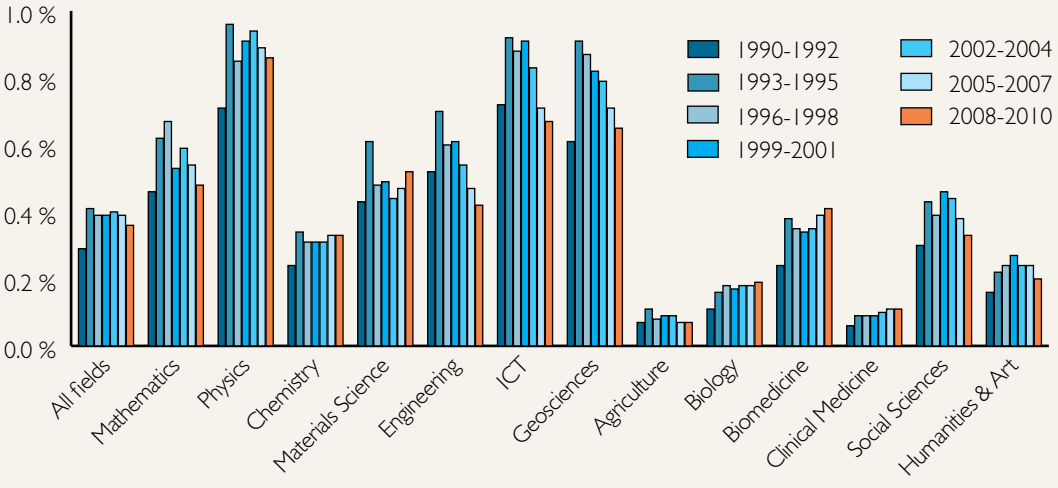


Figure 77: Field profile of ETH
Share of World Total (Percent).

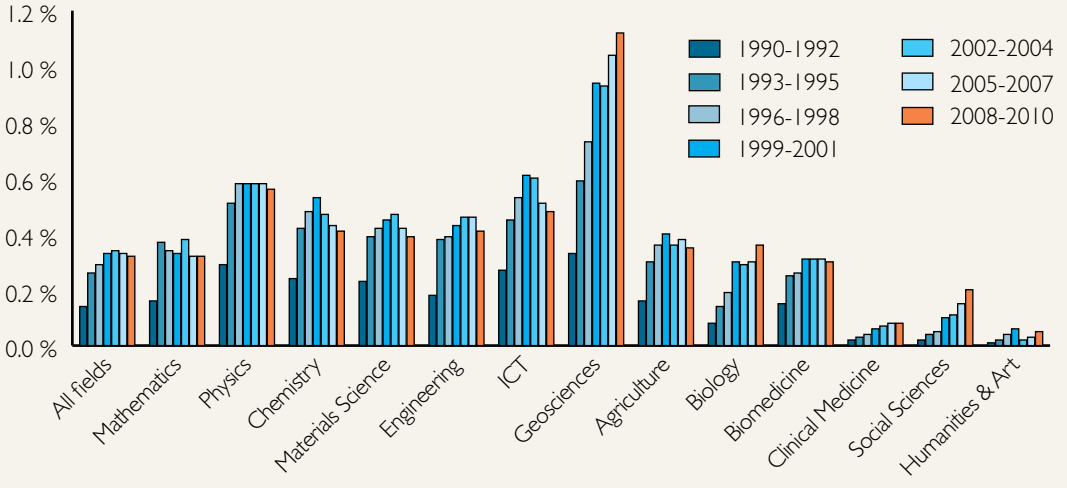
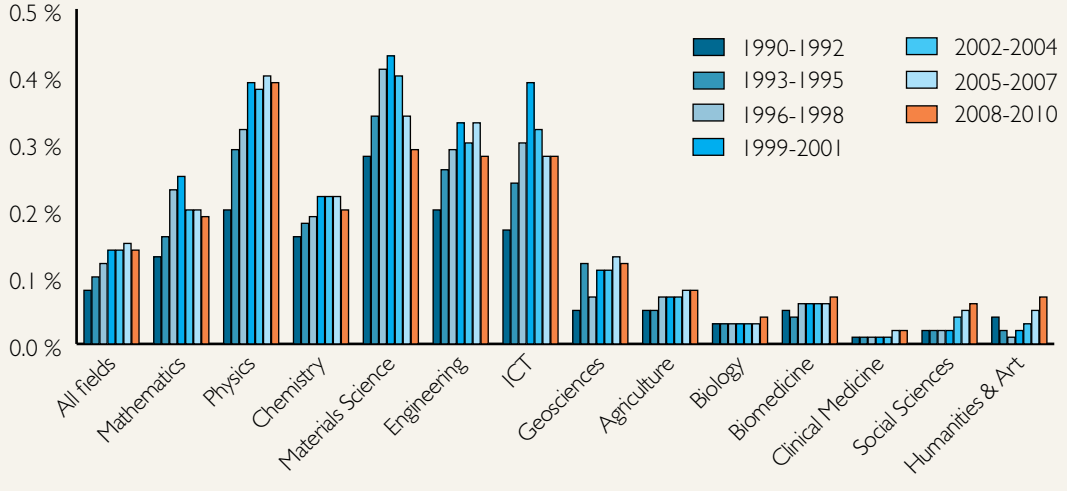


Figure 78: Field profile of KTH
Share of World Total (Percent).



ences at MIT are also surprisingly strong. If we limit the comparison to Physical and Engineering Sciences, ETH and MIT publish 30–130 percent more articles than KTH depending on the field. Ten years ago KTH's publication volume in Materials Science was more or less the same as that of ETH and MIT, but KTH has since lost ground in relation to both universities in this field, especially in relation to MIT. KTH has gained significantly on ETH in Chemistry and on MIT in Engineering, but there is still a considerable difference in size in the case of the former.

Figure 79: Highly cited articles as a percentage of all articles for KTH, ETH and MIT in selected fields 1999–2010
Number of articles. Articles with authors from five or more countries excluded.

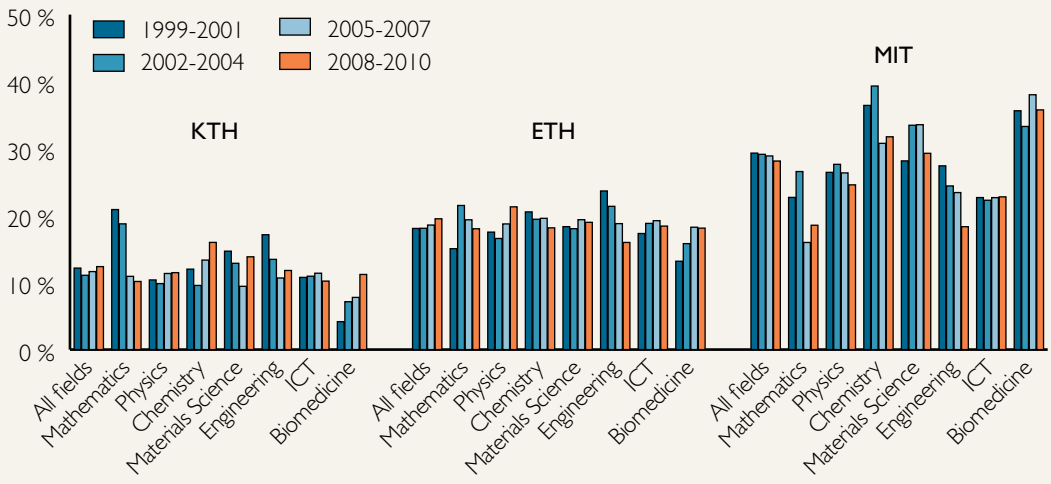
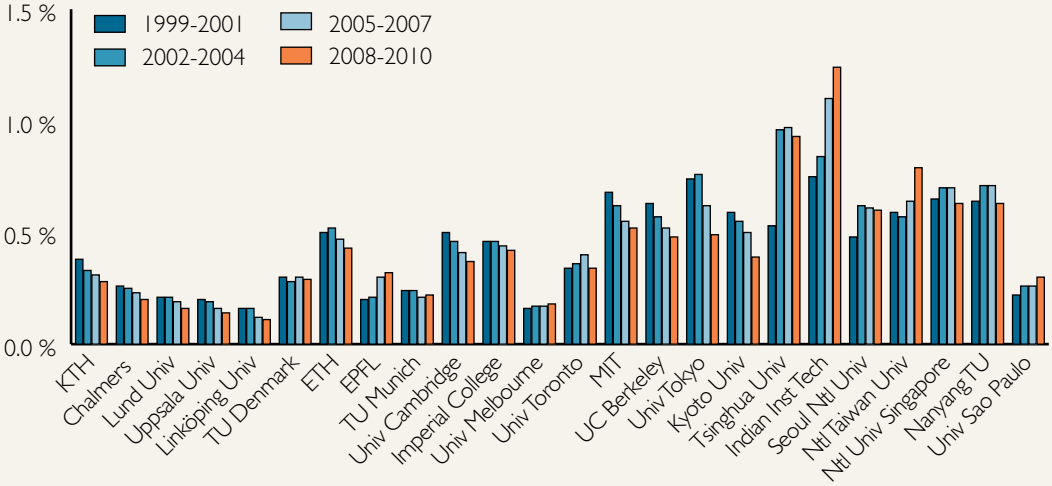


Figure 80: Share of World Total of articles in Engineering+ICT+Materials Science for selected Swedish and foreign universities
Share of World Total (Percent)



In other fields it is more difficult to detect any clear changes in the relative size of the publication volume.

What is perhaps more important than the difference in total publication volume is the difference in the quality of publications as indicated by the share of highly cited articles. On average almost 30 percent of all articles published by

Figure 81: Highly cited articles as a share of all articles in Engineering+ICT+Materials Science for selected Swedish and foreign universities
Share of articles among world's 10 % most cited articles (Percent).

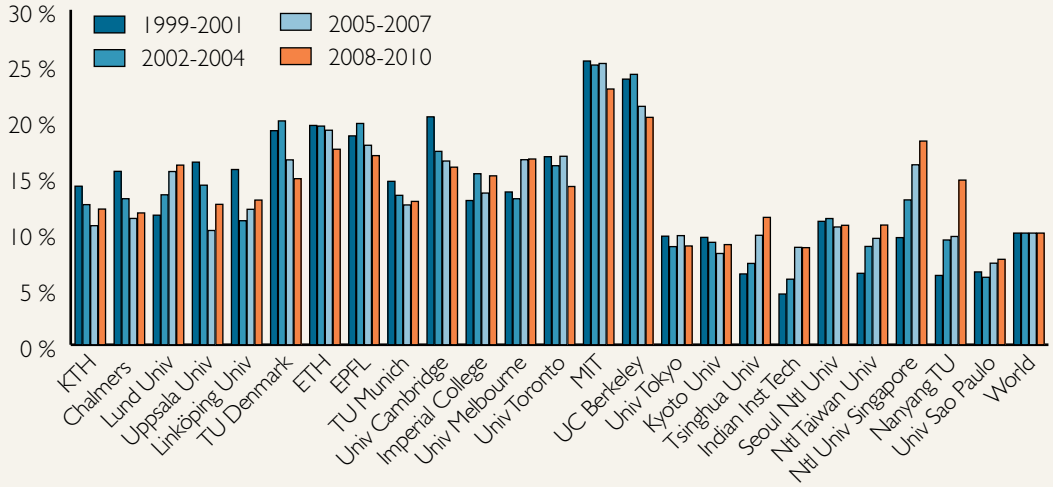
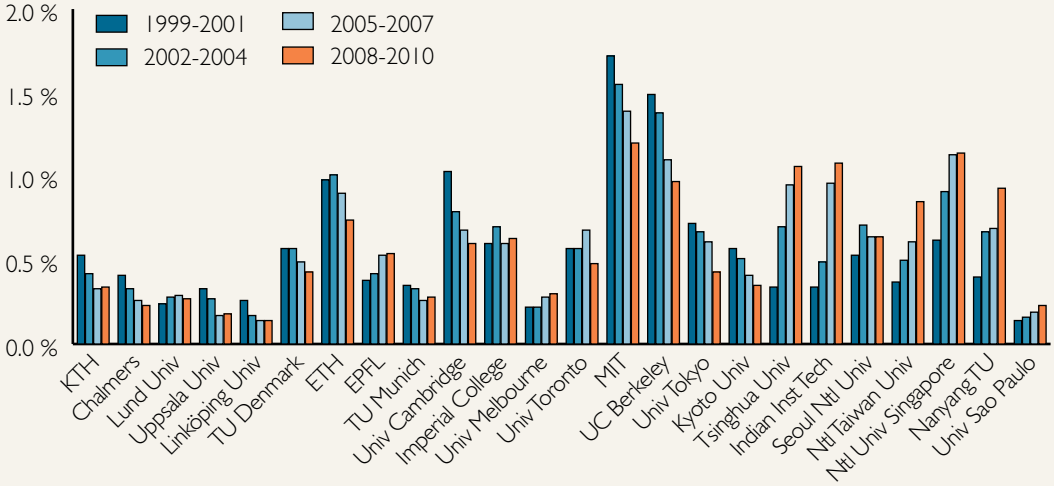


Figure 82: Share of World Total of highly cited articles in Engineering+ICT+Materials Science for selected Swedish and foreign universities
Share of World Total (Percent).



MIT are among the 10 percent most highly cited articles in their respective fields, while the figure is around 12 percent for KTH and 20 percent for ETH (Figure 79).[45] There are differences between fields, with Chemistry and Materials Science showing the best relative quality at KTH. There are also some changes in relative citation rates, with all three universities experiencing a relative

decline in their quality level in Engineering. The sharp decline in MIT's share of highly cited articles in Mathematics resembles the trend at KTH, while ETH has been better able to maintain its level in this field. Regardless of such differences between fields and changes over time, the main observation is that KTH's articles are, on average, cited significantly less than articles from ETH and MIT.

The combined effect of a broader portfolio of fields, a larger publication volume and a stronger average citation performance for each article means that KTH's perceived presence on the global stage is considerably smaller than that of both ETH and MIT.

We will now extend the comparison to additional foreign universities, but in doing so limit ourselves to Engineering-related fields. More specifically we will look at the sum of three fields: Engineering, ICT and Materials Science.[46] Our comparison will include, in addition to KTH, four additional Swedish universities with the largest number of articles in the abovementioned combined field and 19 foreign universities, including ETH and MIT.

In comparing the total publication volume of the selected universities, the most conspicuous feature is the large size of the universities in Asia (Figure 80). In the case of Indian Institute of Technology (IIT), which has the largest number of articles, the comparison may be somewhat misleading as IIT is a system of universities with several campuses across India. In Europe, the University of Cambridge and Imperial College are of a size similar to that of ETH, which is also the case for the University of Toronto. EPFL, the newer and smaller in size of the two technical universities in Switzerland, has grown significantly in recent years and is presently comparable in size to KTH in Engineering-related fields.[47] The same is true for the Technical University of Denmark. The Technical University of Munich and the University of Melbourne are, however, both significantly smaller than KTH in Engineering-related fields. The Munich case reflects a combination of a rather fragmented university system and a large institute sector in Germany. Most universities have a declining share of the world's total production of articles. As discussed in the analysis of national level data, this is a natural effect of the rapid growth in emerging research nations.

While the universities in Asia have large publication volumes, in general they tend to perform less well than Western universities when citation levels are compared (Figure 81). The difference in the percentage of highly cited articles has, however, been greatly reduced, and the National University of Singapore has even reached the same level as ETH and MIT. Tsinghua University, Seoul National University of National Taiwan University have all moved ahead of the top Japanese universities and today have about the same share of highly cited articles as KTH in Engineering-related fields.

The combination of large and rapidly growing publication volumes and improved citation performance has in a short space of time catapulted several of the Asian universities towards the top as producers of highly cited articles (Figure 82).[48] In Engineering-related fields, only MIT published more highly cited articles in the period 2008–2010 than Tsinghua University and the National University of Singapore.

The degree of internationalization varies greatly among the selected universities (Figure 83). Asian universities, with the exception of the universities in Singapore, show by far the lowest share of internationally co-authored articles, with the figure for National Taiwan University being only 15 percent. Lund University along with ETH and EPFL in Switzerland have the highest percentages at more than 55 percent, but KTH and Uppsala University also have among the highest percentages of internationally co-authored articles. Most of the universities have increased their share of international publications over the past decade with a noticeable recent acceleration. However, the Technical University of Denmark, University of Toronto, University of Sao Paulo as well as some of the Asian universities have not noticeably changed their degree of internationalization.

For most universities, citation performance tends to be better for articles that are internationally co-authored than for those with only domestic authors (Figure 84). For the two universities in the USA in our selection, MIT and UC

Figure 83: Internationally co-authored articles in the field of Engineering+ICT+Materials Science as a share of all articles for selected Swedish and foreign universities 1999–2010
Internationally co-authored articles as a share of university total (Percent).

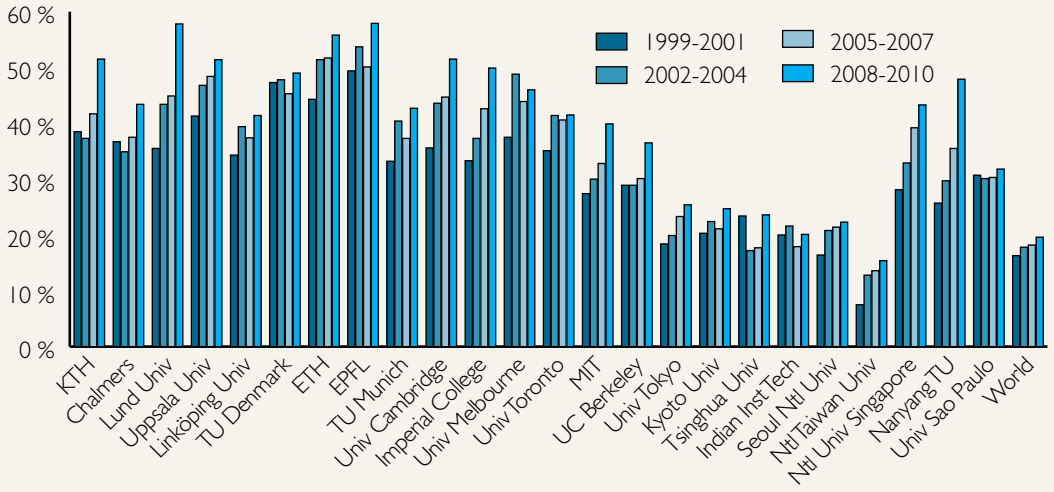
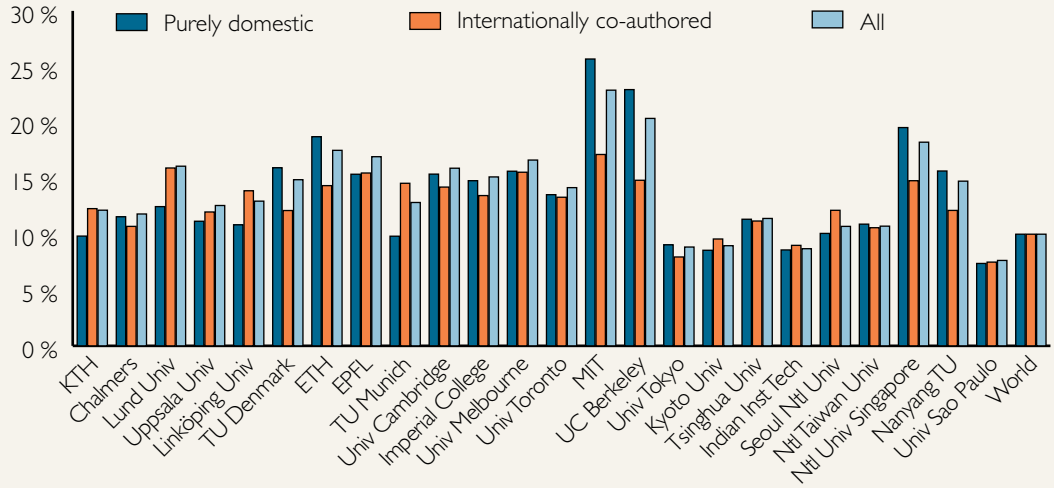


Figure 84: Highly cited articles as a share of all articles for purely domestic and internationally co-authored articles 2008–2010 in the field of Engineering+ICT+Materials Science
World's 10 % most cited articles as share of all university's articles (Percent).



Berkeley, the opposite is the case. This probably reflects the fact that MIT and UC Berkeley not only have excellent researchers in-house, but can also find partners at many other universities in the USA whose research level is very high. The high recognition of these two universities and their researchers may also in itself cause other researchers to pay close attention to their arti-

Figure 85: Different measures of relative presence in the world of selected Swedish and foreign universities in the field of Engineering+ICT+Materials Science 2008–2010
Share of World Total (Percent).

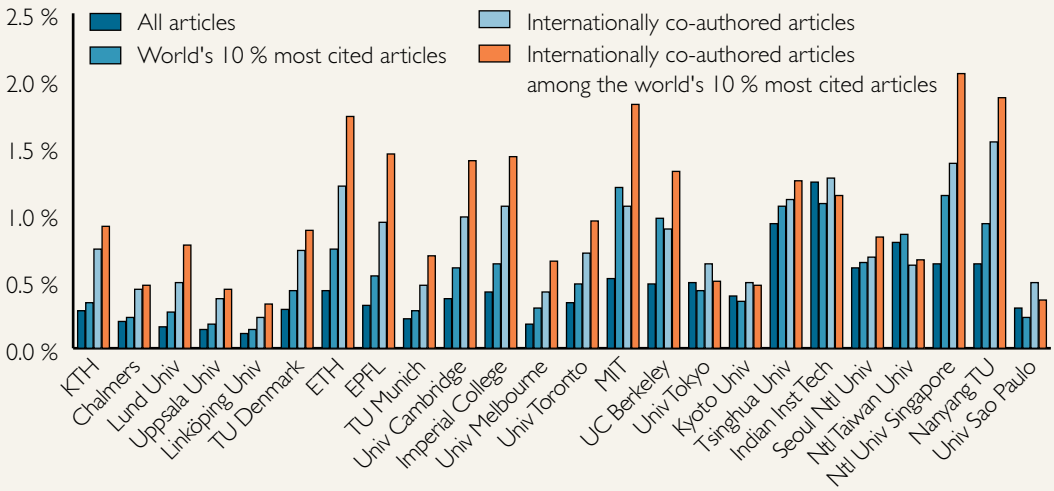
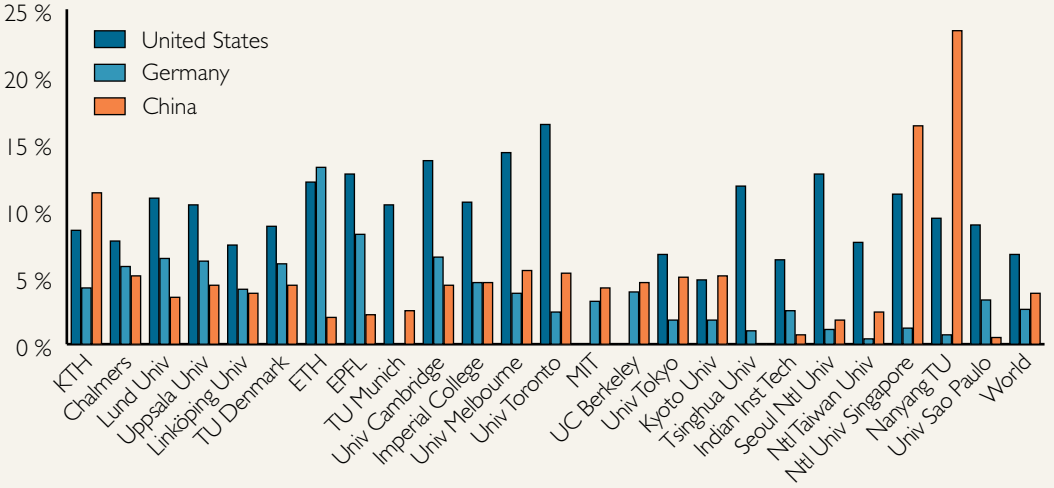


Figure 86: Co-authored articles with USA, Germany and China as a share of all articles for selected Swedish and foreign universities in the field of Engineering+ICT+Materials Science 2008–2010
Country's share of University Total (Percent).



cles, regardless of whether they are produced in international teams or not.

Technical University of Denmark, ETH, National University of Singapore and Nanyang Technological University also exhibit a higher quality in their purely domestic articles than their internationally co-authored articles. Bearing in mind that these are all universities in countries

Figure 87: Articles co-authored by selected Swedish and foreign universities and USA, China and Germany as a share of all of the respective country's internationally co-authored articles in the field of Engineering+ICT+Materials Science 2008–2010

University's share of country's internationally co-authored articles (Percent).

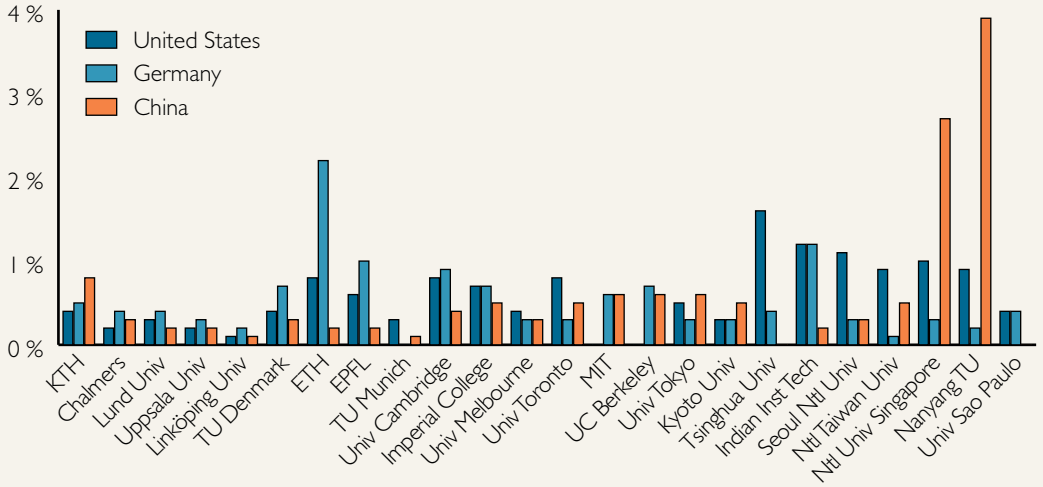


Figure 88: Co-authored articles with Japan, India and S Korea as a share of all articles for selected Swedish and foreign universities in the field of Engineering+ICT+Materials Science 2008–2010

Country's share of University Total (Percent).

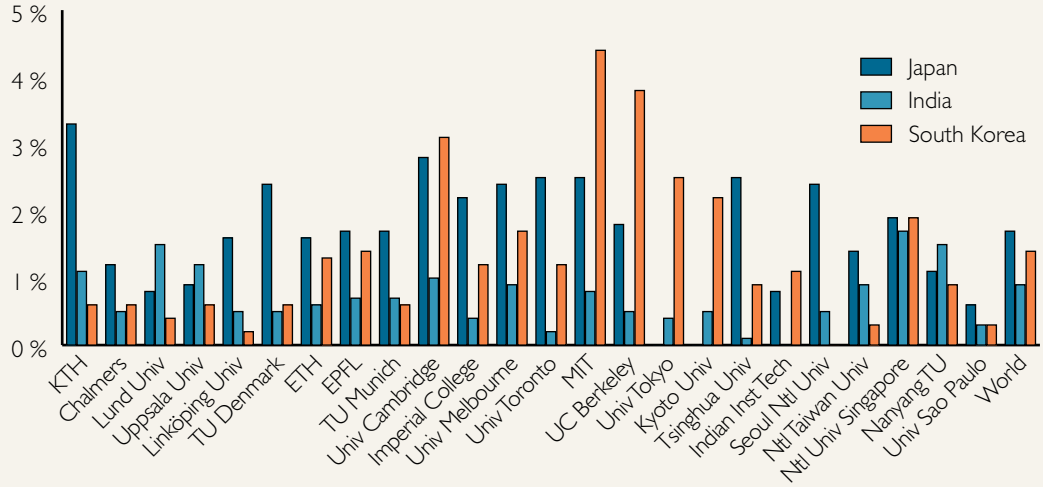
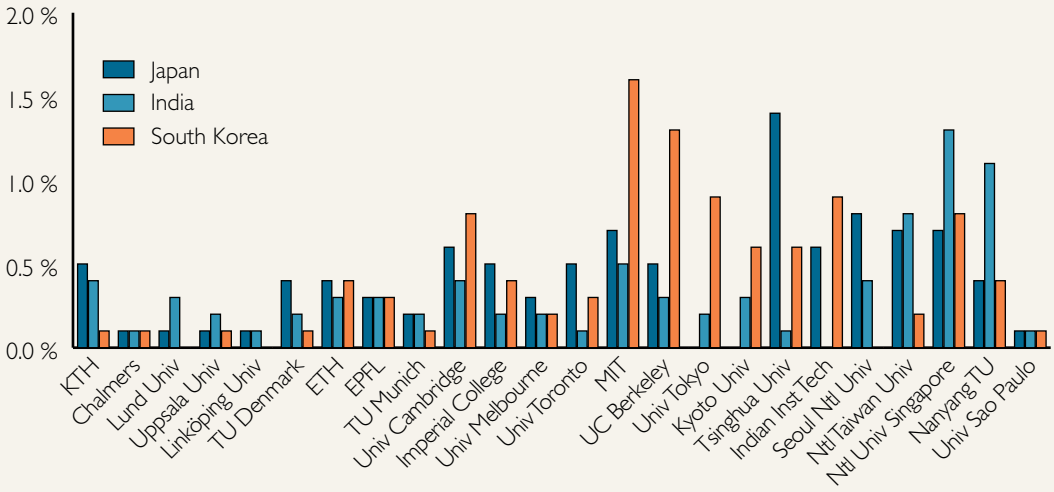


Figure 89: Co-authored articles between selected Swedish and foreign universities and Japan, India and S Korea as a share of all of the respective country's internationally co-authored articles in the fields of Engineering+ICT+Materials Science 2008–2010
University's share of country's internationally co-authored articles (Percent).



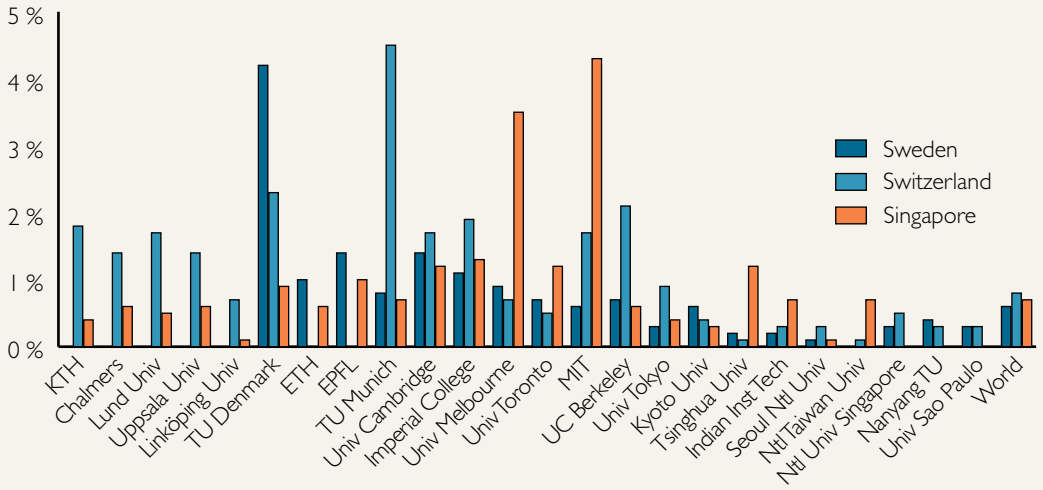
with small populations, the high citation rates for purely domestic articles is indeed remarkable and would suggest the consistently high quality of their research. The University of Tokyo is a contrasting case. It shows a slightly higher citation performance for domestic than internationally co-authored articles, but both are at a low level, in fact a lower level than for most of the universities in our selection. Is this a fair indicator of the quality of research at the University of Tokyo in Engineering-related fields? Or is it, at least to some extent, a reflection of the lack of integration of the Japanese scientific community into the broader international scientific community? A major difference between Japan and its neighboring countries is that a much larger proportion of the leading researchers in China and South Korea than in Japan have recently returned to their home countries from a research career in North America or Europe. As a consequence, many of these researchers have extensive contact networks that include top researchers in Western countries. In any case, it is surprising that the citation rates for internationally co-authored articles by the University of Tokyo are so low.

The low share of internationally co-authored articles in most Asian countries means that the citation performance in these countries is primarily determined by purely domestic articles, which in most cases have lower citation rates than the world average.

Figure 85 represents an attempt to summarize the discussion so far about the relative presence on the world stage of the selected universities.

As emphasized in this report, the term international is in many respects too broad a term. Specifically, we have found that the high degree of internationalization of European countries, especially small countries from a population perspective like Sweden and Switzerland, to a large extent reflects co-authorship with other European countries. The extensive "intra-regional" co-operation seen in Europe does not have any real counterpart in other parts of the world, and as a result, it is not very informative to compare overall degrees of internationalization between countries in Europe and countries in other parts of the world. Making the comparisons at the level of individual universities overcomes some but not all of these problems.

Figure 90: Co-authored articles with Sweden, Switzerland and Singapore as a share of all articles for selected Swedish and foreign universities in Engineering+ICT+Materials Science 2008–2010
Country's share of University Total (Percent).



We will begin with a global perspective comparing the individual universities' research connections with USA, Germany and China and then proceed to look at the connections with Japan, India and South Korea. We will end by looking at the Asian universities' connections with Sweden, Switzerland and Denmark.

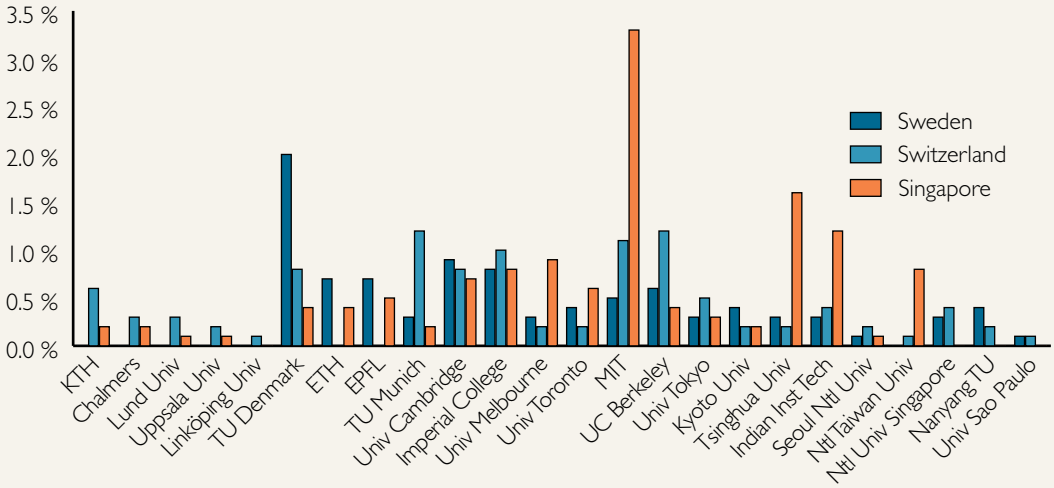
Comparing the connections with USA, Germany and China respectively for individual universities, the USA is, as would be expected, the largest partner for most universities (Figure 86). For the two Swiss and some Swedish universities, Germany is a partner of comparable size to the USA. The two universities in Singapore and KTH stand out by having China as their largest partner for co-authored articles. Other Swedish universities place much less emphasis on China than KTH and the Singaporean universities do, but are comparable to most other universities in their relative emphasis on China. Viewed from the Chinese side, the smaller publication volume of Swedish universities makes their perceived presence in China on the lower side, with the exception of KTH (Figure 87).

When comparing universities' co-authorship with Japan, India and South Korea, the limited exchange between Swedish universities and South Korea is apparent (Figures 88-89). KTH is relatively well-connected with Japan, while the presence there of other Swedish universities is quite small. The relative emphasis on India varies greatly among the universities, with the two Singaporean universities and National Taiwan University having the greatest presence. Apart from these, only the University of Cambridge and MIT have a greater relative presence in India than KTH and Lund University.

MIT and Singapore have built a very strong relationship. Co-authored articles between the two represent almost five percent of MIT's and four percent of Singapore's total publication volume (Figures 90–91). On the other hand and surprisingly, the exchange between UC Berkeley and Singapore is rather weak. Swedish universities put less emphasis on Singapore than their European peer universities do.

The comparisons of co-authorship patterns between universities have all been for the combined field of Engineering, ICT and Materials

Figure 91: Co-authored articles between selected Swedish and foreign universities and Sweden, Switzerland and Singapore as a share of all of the respective country's internationally co-authored articles in the fields of Engineering+ICT+Materials Science 2008–2010
University's share of country's internationally co-authored articles (Percent).



Science. As was shown earlier, there are differences among these three fields when using country-level data as well as between these and other fields. As the difference between MIT and UC Berkeley in their connection with Singapore clearly shows, it is important to be careful when generalizing about individual universities' connections at the country level. A different selection of foreign universities might have changed the picture. Still, it appears that the country-level patterns discussed in the previous chapter are, to a large extent, also reflected in the data for individual universities, while making the differences in scale between universities visible.

7. Navigating in the Global Research Landscape: Conclusions for Sweden

The main purpose of this report is to provide a consistent set of basic facts concerning Sweden's links to the international scientific community as reflected in co-authorship of articles. As the reader will have recognized by now, this is in itself a fairly complex task with many possible pitfalls. Still, this is only one small step towards formulating a policy for what Sweden should do to meet the challenges posed by the rebalancing and increasing integration of the global research system. In order to reach any useful policy conclusions, the facts of Sweden's changing position in the global research system have to be translated into a diagnosis of the Swedish situation. Here it is important to make a distinction between the conditions and changes that must be accepted as the natural course of events and those that are clearly both undesirable and unnecessary, and need to be addressed by active countermeasures. Such diagnosis and development of policy prescriptions naturally requires much more than the analysis of bibliometric data. The necessary work goes far beyond what has been possible here. Bearing in mind the need for much deeper analysis to reach any robust policy conclusions, this concluding chapter will try to identify some of the policy issues raised by the findings presented earlier in the report. The discussion should be seen as merely an outline of the type of analysis needed to arrive at sensible policies.

The chapter starts with a summary of what the bibliometric analysis has revealed. An overall assessment of Sweden's global connectivity is also attempted. Separately some comments are made on Swedish universities' attractiveness on the global stage. Looking ahead, measures that could strengthen Sweden's global connectivity in research are discussed in Section 7.4.

SUMMARY OF FINDINGS FROM BIBLIOMETRIC ANALYSIS

Rebalancing of global research system is at an early stage but impact is already being felt

A large part of the analysis focuses on Sweden's research connections with six countries leading in research in Asia. This focus is motivated by the strong development of scientific research, both quantitatively and qualitatively, over the past 10–15 years in all of the countries except Japan which has a more mature research system. The growth has been strongest in Chemistry, Materials Science, Engineering and ICT ("Engineering-related fields"), but almost as strong in Mathematics and Physics. In Engineering-related fields, Asia-6 today produces as many or more highly cited articles as the EU or North America. While there has been rapid growth in other fields as well, the publication volume in these fields is still much smaller than in North America or the EU. In Life Sciences (Biology, Biomedicine and Clinical Medicine in this report), citation rates of articles produced in

Asia 6 countries are also much lower than those produced in the USA in particular, while there is no such difference in the Engineering-related fields. Indeed the relative quality improvement in Engineering-related fields in most of the Asian countries has been impressive.

One important question is whether Life Sciences in the future will experience a similar rebalancing of the global research system as that which has already occurred in the Engineering-related fields, and if so, in what timeframe that might happen. One might ask if there is some inherent difference between Life Sciences and the Engineering-related fields that would make it more difficult for the countries in emerging research nations to establish a strong position in Life Sciences.

The Asia 6 countries differ greatly in terms of population size. China, while already the largest producer of articles in Engineering-related fields among the six countries, still has a very low production volume on a per capita basis. This suggests that the relative weight of China in the global system will continue to grow for quite some time. The per capita production in India is even lower than in China. The rebalancing of the global research system is thus likely to continue and require commensurate attention.

Decline in Sweden's position in Engineering-related fields

The rapid growth in research capacity and production of scientific articles in a number of emerging economies in Asia and elsewhere has the unavoidable consequence of a relative decline in Europe, North America and Japan, which have much more mature research systems. Data presented in this report shows that Sweden, in all fields except Geosciences and Social Sciences, has experienced a drop in its share of highly cited articles over the past decade. The decline was particularly severe for Mathematics, Chemistry, Materials Science, Engineering and ICT, which all fell by 35–40 percent in the years 1999–2001 and 2008–2010. Some decline would be expected for the reason just mentioned, but the extent of the drop in Sweden's share in Engineering-related fields should be cause for concern.

A comparison with 13 other countries with highly developed economies shows that Sweden's relative loss of position is greater than for most of the countries in each of the Engineering-related fields.[49] The pattern of relative decline varies, however, between fields in terms of the weight of reduced relative quality and slower growth in publication volume compared to the other countries. The pattern also depends on the country with which the comparison is made. In some cases, Sweden, even after its relative decline, maintains a strong position in terms of quality (defined as share of highly cited articles) and/or publication volume per capita relative to leading countries. This is a fact that has to be taken into account when assessing the seriousness of the decline in Sweden's relative position. While a decline in relative quality plays a major role in several fields, e.g. in Mathematics and Chemistry, in other cases, a combination of poor development of quality and volume is responsible for the decline. In the field of Materials Science specifically, the relative decline is almost totally due to a weaker growth in publication volume in Sweden compared to other countries following strong relative volume growth in Sweden in the 1990s. One may speculate that the injection of major research funding in Materials Consortia in Sweden during the 1990s and the lack of special funding for nanotechnology in Sweden during the following decade when many other countries were investing large research funds in this field, may provide some explanation for the pattern we observed in Materials Sciences.

Asia's rise as a favored research partner still mainly in Engineering-related fields

Until recently the dominant pattern of internationalization of Swedish scientific articles was an increase in the percentage of articles co-authored with other countries in Europe and a decrease of almost the same size in purely domestic articles. Although co-authorship with the rest of the world was mainly focused on North America, the connections with North America have grown at a much slower rate than those with European countries. In relative

terms, co-authorship with Asia has grown the fastest albeit from a low starting point. In recent years Sweden's exchange with Asia has accelerated in Engineering-related fields and is today comparable and in some fields even larger than exchange with North America. In Life Sciences, exchange outside Europe is still predominantly with North America. The number of articles with authors from a large number of countries has grown particularly fast. Today, articles with authors from five or more countries represent around 7 percent of all Swedish articles and more than 15 percent of highly cited articles.

Along with other countries of a similar size, Sweden has a higher share of internationally co-authored articles than larger countries. Among European countries this is primarily a reflection of the fact that a large country makes up a larger portion of the European Research Area (ERA) than a smaller country, and as a consequence, researchers in smaller countries will, to a greater extent, have to find their partners in the ERA outside their own country.

Sweden's location at the periphery of Europe reflected in patterns of international collaboration

Switzerland, Austria and Belgium are more fully integrated into the European Research Area than Sweden is, in the sense that a larger percentage of their articles are co-authored with other European countries and a smaller percentage is purely domestic. Sweden shares this feature with the other Nordic countries as well as small countries in other peripheral locations in Europe.

It is difficult to generalize about Sweden's global connectivity in its production of scientific articles compared to other countries as it greatly varies between fields. For all fields taken together, 43 percent of all articles from Sweden are purely domestic and another 7 percent are articles with authors from five or more countries. The remaining 50 percent is divided evenly between articles co-authored with other European countries only and articles where Sweden includes authors from outside Europe. Of the latter articles, around one third includes authors from at least one other country in Europe besides Sweden. As most of the articles with authors from five or more countries include authors from outside Europe, we can conclude that almost one third of all Sweden's articles have "global connections."

In Europe, the United Kingdom, Germany and France are more globally oriented than smaller countries

While a country's size matters when comparing co-authorship percentages within Europe, outside of Europe the percentage of co-authored articles can be directly compared between European countries regardless of their size. Overall, Germany, United Kingdom and France are equally or more "globally oriented" than Sweden, while Sweden compares favorably with most small European countries, especially in Asia.

The share of globally co-authored articles is somewhat higher for Switzerland, United Kingdom and France but lower for most other European countries. In Engineering-related fields, with the exception of Materials Science, globally co-authored articles tend to represent a significantly lower percentage in Sweden than in several of the other European countries, large and small. This is compensated by Sweden's stronger global orientation, especially in Physics and Clinical Medicine, yielding a fairly high average degree of global connectivity. It is noteworthy that the United Kingdom and France are more globally connected in their articles rather consistently across fields than Sweden is.

Sweden's connections with South Korea and Singapore should be strengthened and its weakened position in Japan needs attention

Sweden's co-authorship with the Asia 6 countries is explored in detail in this report and comparisons are made with Switzerland, Canada and Australia in particular. Sweden's relative presence in China, Japan and India compares fairly well with that of Switzerland, Canada and Australia when we consider differences in population size and geographical location. Sweden has strengthened its relative position in China in Chemistry and Materials Science, but its con-

nections with China in Life Sciences have grown at a slower rate than China's total international exchange. Sweden has not connected with the rapid advancement of Mathematics in China either. Sweden's relative position in Japan has weakened in most fields but particularly in Physics, Chemistry and Materials Science.

Sweden's exchange with South Korea, Taiwan and Singapore is far less well-developed, the major exception being connections with Singapore in Life Sciences. In Physical and Engineering Sciences, Sweden clearly has a weaker relative presence in these three countries compared to Switzerland, Canada or Australia.

Spontaneous mobility of students and researchers between Sweden and Asian countries not enough to build desired research connections

The fact that Sweden has a more uneven relative presence in the Asia 6 countries, especially in Physical and Engineering Sciences, than the three countries with which Sweden is being compared, can be explained by a combination of at least four factors: a) mobility patterns of students and researchers; b) the relative attractiveness of research environments in the respective country; c) special exchange initiatives by individual universities or governments; d) size of the respective country's research system. It appears that Sweden is too small to be able to develop connections with all of the countries. The contrast with Canada – the largest of the three benchmark countries – is striking in this regard. Canada's relative presence is very similar in five of the Asia 6 countries. The exception is China with which Canada, like Sweden, has the strongest relative presence.

Sweden's relatively strong connections with China are, to a significant extent, the result of conscious efforts by some Swedish universities to develop their educational and research exchange with China. In contrast, exchange activity with the other Asian countries has overwhelmingly come about either through the usual spontaneous contacts between individual scientists or, as in the case of Life Sciences exchange with Singapore, through initiatives from the Asian country's side. Spontaneous contacts are strongly affected by the level of mobility of students and researchers. In the case of South Korea and Taiwan outward mobility has leaned heavily towards North America, and mobility into Sweden has obviously not been sufficient to form a basis for stable research exchange on the desired scale. Mobility from Sweden, which has been rather limited into all of the Asia 6 countries, has, on the whole, not played a major role as a mechanism for building research connections. The systems for funding post-doctoral work carried out abroad by researchers from Sweden have very rarely been used to fund a researcher's stay in Asian countries.[50] This is not surprising as research at a famous American or European university is, from a career point of view, a much safer bet than trying to find a research environment in an Asian university. A contributing factor here is that senior Swedish researchers often have only limited knowledge of, and connections with, universities in Asia. This makes it difficult for senior researchers to provide young researchers with good advice and introductions. Another effect is that the reputations of even first-rate universities in Asia are not well-established in the Swedish research community. Cultural and language barriers – real and perceived – also play a role when Asian countries are being considered.

Sweden much more visible as potential research partner for Asian countries in Life Sciences than in Engineering-related fields

Sweden's relative attractiveness as a research partner for Asian countries greatly varies greatly between fields. This becomes apparent when the difference in the volume of highly cited articles is compared. In Engineering-related fields the Asia 6 countries produce 28 times as many highly cited articles as Sweden, while the same ratio is only around four times in Biology and Clinical Medicine and seven times in Biomedicine. This is the combined effect of the strong position of the Asian countries in Engineering-related fields and the still relatively undeveloped research in Life Science on the one hand and Sweden's relative weakness in Engineering-related fields and special strength in Life Sciences on the other.

The situation is, to some extent, similar for other countries with highly developed economies, but the contrast is more pronounced for Sweden than for most countries. A consequence of the asymmetry in the field profiles between Sweden and the Asia 6 countries is that initiatives from the Asian countries for the development of research co-operation with Sweden are much more likely be in Life Sciences field than in Engineering-related fields. In the latter fields, where Sweden has much to gain from co-operation, the onus will be on Sweden to take the initiative. This by no means implies that Sweden should not welcome initiatives in Life Sciences as well.

Singapore favored partner by MIT

To help bridge the gap between the rather abstract analysis at the country level and the practical reality of policy-making at individual research institutions, this report compares data for Swedish universities and 19 foreign universities. The latter were selected in particular with a view to their strengths in Engineering-related fields and this is the focus of the comparison of the universities' co-authorship with Asia 6 countries.

The combination of large and rapidly growing publication volumes and improved citation performance has in a short space of time catapulted several of the Asian universities towards the top as producers of highly cited articles. Among the universities selected for comparison, only MIT published more highly cited articles in the period 2008–2010 than Tsinghua University and National University of Singapore (NUS) in Engineering-related fields. The large percentage of highly cited articles at both NUS and Nanyang Technological University is very impressive.

KTH's research connections in China dominate Sweden's presence in Asia

Our analysis confirms what has been found in previous studies, namely that Sweden's relatively strong presence in China is largely due to activities at KTH.[51] In Engineering-related fields, KTH is also relatively well-connected with Japan, while the presence there of other Swedish universities is quite small. Comparing connections with India, only the two universities from nearby Singapore, the University of Cambridge and MIT have a larger relative presence there than KTH and Lund University. Sweden's limited exchange with South Korea and Singapore is confirmed in the university-level comparisons. Still, there are examples of what seems to be long-term exchange between South Korea and several Swedish universities in Physics and with the University of Gothenburg in Materials Science and Stockholm University in Chemistry. The strong relationship that has developed between MIT and Singapore is striking. Articles co-authored by the two represent almost 5 percent of MIT's and 4 percent of Singapore's total publication volume. Chalmers' connection with Taiwan in the field of ICT is also noteworthy.

A well founded conclusion from the analysis of Sweden's research connections with the six Asian countries studied is that, for each combination of field and Asian country, the exchange is highly focused on very few Swedish universities. In the case of South Korea and Singapore, the connections are less developed than for several countries against which it is reasonable to benchmark Sweden. The significant decline in Sweden's relative position in Engineering-related fields is reflected in weak research links with Asia in the fields of Engineering, ICT and Mathematics, while Sweden's relative presence in Chemistry and Materials Science is stronger, especially in China.[52]

IS SWEDEN SUFFICIENTLY CONNECTED AT THE GLOBAL LEVEL?

The answer to the question naturally depends on Sweden's ambition with respect to its standing as an advanced knowledge society. It also depends on with which reference Sweden is compared.

Switzerland ahead of Sweden on most measures but has weaker connections with China

If a comparison is made with countries with a population size similar to Sweden's, there is one country, Switzerland, that has a uniquely strong research system and is well ahead of Sweden on most measures, e.g. production of highly cited articles in different fields. The international connectedness of its research system rests on two

equally strong pillars: one with Germany and the other with the United States. Its presence in these two key countries is significantly more prominent than Sweden's. On the other hand, Switzerland's exchange with leading Asian countries does not stand out in the same way. Switzerland is placing less emphasis on China than Sweden is in Engineering-related fields, while the picture is more mixed for other fields and for exchange with other countries in Asia.

Australia, Canada and Singapore are suitable benchmarks for global connectivity

Another country which is becoming an important benchmark for Sweden, so far primarily in Engineering and Physical Sciences, is Singapore. On a per capita basis, it outperforms Sweden in most of these fields by a considerable margin. Its international research exchange is dominated by China and the USA. Although Singapore's population is only around half of Sweden's, the country has already become recognized as an important node in the global research system. The government in Singapore is very actively promoting this role by seeking to develop exchange selectively with leading foreign universities. The National Research Foundation (NRF) has, for example, under its Campus for Research Excellence And Technological Enterprise (CREATE) program, so far set up strategic partnerships with the University of Cambridge, ETH and the Technical University of Munich.[53] It is also notable that MIT has made a major commitment to developing relations with Singapore by establishing its first foreign campus there. It should be mentioned that the Karolinska Institute has signed an agreement with Nanyang Technical University for a joint PhD program in Biomedicine.

Other small countries with highly developed research systems, such as Denmark and the Netherlands, do not exhibit a higher degree of global connectedness than Sweden, and Sweden has a much stronger presence in China. Articles co-authored with Asia 6 as a whole, however, make up almost an equal share of all articles for Denmark and Sweden, reflecting a different country emphasis in their exchange with Asia.

Both Canada and Australia have shown strikingly strong development in their research systems in recent years. Today both appear to be truly global players in their orientation, and it might be useful for Sweden to benchmark its international activities outside Europe against these two countries. Both countries are very active in offering higher education on the international market, while they are less impressive in the outward mobility of their students. In the case of Australia, its location, maybe more in terms of time zones than distance, has made it natural to develop research links with Asian countries, especially with China and Singapore.[54]

Benchmarks for Sweden must include regions and institutions in large countries

While several small countries, not least Sweden, tend to rank very highly in international comparisons of knowledge intensity and innovation performance, it is important to note that they constitute a very small portion of the global economy. Even if it is convenient to compare countries of a similar size, an assessment of the global position of the Swedish economy and the Swedish research system must not be limited to small countries, nor to countries in Europe.

Among the large European countries, the United Kingdom is the most globally oriented with Germany not far behind. A major difference is that Germany puts relatively more emphasis on exchange with Russia and other eastern non-EU neighbors. France has more extensive exchange with African countries and Spain with Latin America than other European countries. The regional profile of Sweden's global connections is not very different from that of the United Kingdom, a major difference being that Oceania (Australia and New Zealand) plays a relatively larger role for the UK.

North America has strengthened its position in Asia relative to Europe

In considering Sweden's and other European countries' exchange with Asia, the most relevant benchmark is probably the United States and Canada. Comparing the EU as a whole and North America, exchange with leading Asian countries ("Asia 6") represents almost twice as

large a share of all articles for North America than for the EU. If only highly cited articles are counted, the difference is smaller simply because in the United States the citation rate for purely domestic articles is overall still higher than for articles co-authored with Asia.

The most striking difference between North America and Europe in their exchange with Asia relates to South Korea, Taiwan and Singapore. Outside of Asia these countries have much stronger ties with North America than with Europe. Sweden, in general, has even fewer contacts with these countries than many other European countries. Exceptions include the Karolinska Institute's exchange with Singapore, Chalmers' exchange with Taiwan in the field of ICT and the University of Gothenburg's exchange with South Korea in several fields. These exceptions do not change the overall picture of what can only be characterized as insufficient exchange between Sweden and the three abovementioned countries.

While the EU Framework Programme (FP) has an important role to play in strengthening the integration of the European Research Area, it is crucial that the design and implementation of the FP is such that it pro-actively facilitates the global connectivity of European research. The fact that research links with leading Asian countries appear to play a relatively larger role in North America than in the EU is a warning sign. In FP7, 17 percent of all projects had participants from outside the EU.[55] Considering that a clear majority of all internationally co-authored articles in EU 27+3 include articles from outside the EU, it would seem that the Framework Programme is rather inward-looking.

ARE SWEDISH UNIVERSITIES ATTRACTIVE ENOUGH AS PARTNERS FOR STRATEGIC ALLIANCES WITH LEADING PLAYERS?

Contradictory messages from rankings of nations and institutions

In many rankings of knowledge intensity or innovation capacity based on national level data, Sweden ranks at the very top. This data is typically expressed in relative terms, that is, in relation to the size of the economy or the size of the population. On the other hand, when looking at rankings of individual universities, one has to search much lower down the list to find Swedish universities.[56] While both types of data are in some sense correct, they still yield very different pictures of Sweden's situation. The former inspires declarations to the effect that Sweden should aim to be the most advanced and attractive knowledge-based economy in the world. The latter invites comments to the effect that we cannot expect Sweden to have universities that can really compete on a par with the leading universities in the world. We should instead be content that our universities perform at a decent level.

For policies to be effective they have to be based on a realistic view of the world. It is therefore important for the national level indicators and the view at the level of individual institutions to be harmonized into one consistent assessment. The key to resolving the apparent inconsistency between the two perspectives is, as discussed earlier, recognizing that Sweden's high rankings at the national level reflect a high average level in a small country with relatively small variations among individual institutions.

Why should Sweden have a lower level of ambition than Switzerland and Singapore for its engineering schools?

It is hardly surprising that the top universities in a large country like the USA are able to drum up substantially more resources than the leading universities in Sweden. In a highly competitive environment with a large sum of total resources provided by both public and private sources, the top institutions and their researchers are able to have a large resource per capita ratio, and this is a factor in their ability to attract top talent from all around the world. This argument is, however, not convincing when we compare Sweden with countries of a size that is more comparable to Sweden's. The difference compared to Switzerland and Singapore is most striking. Is there any reason why Sweden should not aim to have engineering schools that can compete at the same level as ETH, EPFL, the National University

of Singapore and Nanyang Technical University? There is one basic difference, namely Sweden's large surface area, which, it can be argued, is a fundamental reason why Sweden has chosen to establish engineering schools in so many locations. Although this may indeed be a valid argument, one of the effects is that each institution's presence will be recognized to lesser extent on the global stage.

Some may argue that ETH and EPFL, along with a few British universities, are extreme cases and that Swedish engineering schools are not doing that badly in comparison with most other European universities. This may be true and a more full-fledged comparative analysis at the level of individual universities than has been possible in this study would be desirable. The one university chosen in Germany, Technical University of Munich, is actually not particularly "impressive" in terms of its global connectivity. This may, however, reflect a weakness in the German research system and should therefore not be something for Sweden to seek solace from.[57]

Using other European countries as the main benchmark may also become less and less relevant. Very significantly, compared to the situation in Europe, more of the university research in the leading Asian countries tends to be carried out at the top universities. These institutions are, in many cases, highly favored in the allocation of government funding to universities. Many of them already have acquired a strong reputation on the global stage and are likely to become even stronger institutions in the future. This will put increasing pressure on European universities.

Joining forces for attractiveness on the global stage

Is the size of a university actually important? Does it matter? One may argue that the important factor for recognition is rather the perceived level ("quality") of the research being conducted. An often-cited example of a relatively small but highly regarded university is the California Institute of Technology (Caltech). It turns out that Caltech's total production of articles in Engineering-related fields in 2011 was around 17 percent lower than that of Sweden's Royal Institute of Technology (KTH). However, in terms of the 10 percent most cited articles, Caltech produced more than twice as many as KTH, and MIT's production was 4.5 times that of KTH.

The question can be rephrased as follows: Does the size of a university matter in terms of its high quality research output? It depends on for whom and in what context. There is reason to believe that it does matter when it comes to strategic decisions on things such as building strategic alliances between institutions or the career decisions of individual students, researchers or faculty. As the number of institutions is growing and the perceived need for strategic decisions is increasing, visibility on the global stage is becoming more important. A combined evaluation of size and quality and, closely related to these, the centrality of an institution's position in a country or region will matter.

The relative size of the top Swedish universities in terms of their research function varies between fields. In this report we deliberately selected foreign universities with strong engineering schools for comparison for reasons that have been explained. To allow for proper comparisons in other fields, other universities will need to be added.

The largest engineering schools in Sweden, KTH and CTH, are focusing almost entirely on Physical and Engineering Sciences. Internationally this is becoming more and more unusual. In particular, a number of renowned technical universities have expanded their research activities in Life Sciences. Although this is, to some extent, happening at KTH and CTH as well, the Life Sciences component is still very small. Once again, the contrast with ETH and EPFL is striking, but the Technical University of Denmark also has significantly more research in Life Sciences than KTH and CTH. A few years ago both Imperial College and the Technical University of Munich merged with medical schools. The largest portion of MIT's research funding today comes from NIH and in the recently published THE World University Ranking, MIT was ranked in first place in "Life Sciences"![58] Most of the major engineering schools in Asia belong to comprehensive universities with significant

activity in the Life Sciences field, Tokyo Institute of Technology, Tsinghua University and Nanyang Technical University being notable exceptions.

It is not clear what would be desirable in terms of developing the structure of the Swedish university system, but the relatively small scale of the research activities of Sweden's technical universities as individual actors on the global stage needs to be recognized and carefully considered. From a governance point of view, there may be many advantages to having relatively small and focused institutions, but their "punching power" on the global stage has to be taken into account as well. It is probably necessary to create new platforms for combining resources across institutions and to aim to become powerful research nodes in the global arena with sufficient visibility and attractiveness. The creation of Science for Life Lab in Stockholm/Uppsala can be seen as an example of a step in that direction. Similar initiatives are needed in areas of relevance for broader areas of Swedish engineering and process industries. Although some of the initiatives under the scheme of the so-called Strategic Research Areas may be seen as small steps in this direction, the scope of each initiative and the added resources have in most cases been relatively small.

The above discussion about the structure of the Swedish university system only addresses what Swedish universities need to do in order to be recognized as important and attractive nodes in the global research system. There are obviously many other aspects that need to be considered in developing the Swedish higher education and research system as a whole. One aspect is the distribution of roles and responsibilities between various types of universities, university colleges and research institutes to meet the need for higher education and research interaction in industry and the public sector in all parts of Sweden. Designing effective mechanisms for research and knowledge exchange and contacts with Swedish society between research institutions with the capacity to serve as nodes in the global research system and other institutions is also an important consideration when developing policy, but one that falls outside the scope of this report.

RESPONDING TO GROWING COMPETITION FOR CONNECTIONS AND TALENT

There appears to be a growing sense of urgency in many countries regarding the need to actively respond to the challenges presented by the growing competition for talented individuals, corporate investment and partnerships in R&D on a global scale. Many of the initiatives are still in an experimental and learning mode. There is reason to believe that Sweden needs to take initiatives too. Merely reacting to initiatives from other countries and their institutions is not enough if Sweden is to benefit from the exchange. As shown by the examples of South Korea and Singapore in particular, spontaneous processes are probably not sufficient for developing exchange.

The expansion and integration of the global research system does indeed present a small country like Sweden with great challenges. One may ask how globally connected a small country like Sweden realistically can be. We have seen that Sweden has very weak links with several Asian countries that today command an important position in Engineering and Physical Sciences. It is not surprising if each individual Swedish university is unable to develop strong links with all of the emerging research powers in Asia. The question is, however, whether Sweden as a whole can afford not to have an active and significant exchange with globally strong research nations in their fields of strength? If the answer is that Sweden needs to nurture such exchange, the conclusion would seem to be that there has to be some degree of coordination as well as joint efforts among universities (and other actors) to develop links with these countries.

Why should Sweden develop its research connections with South Korea and Singapore?

The reasons why Sweden should develop strong research connections with the Asia 6 countries in their fields of strength and on a scale that is commensurate with the size of the respective country's high quality research vary depend-

ing on the country. A fundamental reason is of course that they are all today conducting world-class research in several fields of importance for Sweden. There are additional reasons that vary from country to country. The most populous countries, China and India, represent large, rapidly growing markets as well as a large potential pool from which to recruit students, researchers and engineers. Japan, South Korea and Taiwan have all built up advanced industries, across the broadest front in Japan and highly focused on the IT industry in Taiwan. Outside the USA, Japan is by far the largest source of industrial technology, and among European countries only Germany has more international patenting activity than either South Korea or Taiwan. In spite of its small size, Singapore is emerging as an important node in the global circulation of knowledge. Its research system is already well-connected with most of the main global players, including very strong contacts with both United States and China.[59]

Sweden's attractiveness as a research partner and place to study and conduct research needs to be benchmarked

One necessary precondition for developing research connections with leading research environments anywhere in the world is the attractiveness of Swedish researchers, research groups and research organizations as partners in research co-operation. The quality of the research matters of course, but other factors, such as openness, flexibility, leadership, career opportunities, unique research infrastructure, access to societal actors and their issues can also make a difference. For strategic partnerships to be attractive, the research needs to be performed on a sufficient scale and with sufficient scope. This and related aspects are continuously dealt with in the "normal" development of research and innovation policy, most recently through the new research and innovation bill presented by the Swedish government. The question of to what extent Sweden is sufficiently attractive as a place for foreign researchers to work or as a partner for research co-operation has begun to influence policy development in Sweden. So far the focus has primarily been on the citation performance of research conducted in Sweden. Little has, however, been done up to now to systematically benchmark the attractiveness of Swedish research as perceived by foreign students, researchers or companies in operational terms. Such work, while difficult from a methodology perspective, is badly needed.

Growing competition for strategic alliances

A high degree of global connectivity is, in itself, a factor that strongly influences the attractiveness of a research environment. One critical question is whether such connectivity to a sufficient extent emerges spontaneously through normal contacts between individual researchers, or whether special initiatives are needed. There seems to be a growing belief among university leaders that their institutions need to actively develop strategic partnerships with other research institutions as well as with companies and other societal actors at a global level. Such partnerships are rapidly growing in number. Although it still remains to be seen what their relative importance will be in the development of global connectivity among research and higher education institutions in the end, it may turn out to be a risky strategy to wait on the sidelines while top universities around the world are being pulled into, or themselves initiating, partnerships. There are clear signs that universities in Asia are becoming increasingly selective and quality-conscious in their choice of strategic partner universities.

In 2008 VINNOVA launched a program to support the development of "Strategies for global links for strong research and innovation milieus." As a preparation for formulating a call for proposals, VINNOVA invited so-called research and innovation milieus to submit an expression of interest with responses to 15 questions. The aim was to gain a better picture of how various R&I milieus in Sweden regarded the need to strengthen the international dimension of their activity and to assess interest in developing clearer, effective strategies for this purpose. The expression of interest responses and subsequent seminars provided a wealth of valuable information about the state of strategic international connections of many R&I milieus

in Sweden. VINNOVA summarized its conclusions as follows:

- "There is a perceived need and interest amongst R&I milieus to develop clearer strategies for their international exchange.
- International exchange must be integrated into fundamental strategies and working methods in R&I milieus in an entirely different fashion than currently. It is not enough for this to be tacked onto a mainly nationally-orientated activity.
- The development of R&I milieus' strategies for global links must actively involve central players in milieus from both research organizations and companies. Key people with leading competence and comprehensive, valuable international contacts must be motivated to set aside time to take part.
- It is important to be able to gather together relevant players in Sweden (sometimes extended to the Nordic region) as the basis for international exchange. Swedish R&I milieus must have a strong position in Europe if they are to be credible as global players. There must therefore be a subsidiary strategy for participation in the EU's Framework Programme. However, a restriction of international exchange to Europe is seldom sustainable in the long term. Whilst collaboration with the US and Canada is usually regarded as natural, special efforts are required in order to develop exchanges with Japan, China, India and other countries outside Europe and North America. The building up of knowledge about and contact with organizations in these parts of the world should therefore be given particular attention in the strategy development work."[60]

There are some signs that Swedish universities are beginning to see the need to proactively develop strategic international research alliances. Whether this has significantly changed the situation for Swedish R&I environments from the situation observed in 2008 is, however, hard to tell, but the conclusions above are probably still valid.[61]

How to increase the mobility of researchers between Sweden and Asia?

Research exchange and the mobility of graduate students and researchers are closely linked and tend to reinforce each other. The spontaneously occurring mobility between Sweden and Asian countries appears to be far below the desirable level. Although this is especially true for outward mobility from Sweden, in relation to several of the Asia 6 countries, inward mobility to Sweden may also need to be encouraged. The experience is that traditional mobility programs, such as postdoctoral grants, are not very effective mechanisms for promoting mobility from Sweden to Asian countries. This problem has to be addressed. The most promising solution seems to be to promote mobility within the framework of long-term research co-operation between research environments in Sweden and in Asian partner countries. Based on such a platform for co-operation, even short research assignments for graduate students and young researchers can be very productive and valuable in intensifying research co-operation. At the same time they do not require major career decisions on the part of the students or researchers involved. The same mechanism could of course be used to promote inward mobility.

The abovementioned solution for promoting mobility is, however, contingent upon the existence of sustained research co-operation on a significant scale and this can by no means be taken for granted. While there is a fair number of established research connections between Sweden and the Asia 6 countries, the continuity and intensity of co-operation is, in most cases, severely limited by the lack of funding opportunities. It is also probably necessary to develop new connections beyond those that have emerged spontaneously. Most Swedish researchers still have only a limited acquaintance with research environments in Asia and vice versa. There is a difference between registering the specific scientific contribution by an individual researcher in a journal article or at a conference and being able to assess the strengths and weaknesses of an entire research environment. More in-depth exchange through study visits or focused workshops may play a very important role in identifying common interests and complementarities.

Creating opportunities for the development of new research contacts

Organizing activities that can help to establish new, and deepen existing, relationships by creating meetingplaces for in-depth dialogue requires considerable effort on the part of various parties, including leading scientists in the field in question. As there is no guaranteed pay-off for the individual researcher who engages in these efforts, some incentives for contributing to the collective good may be needed. To increase the attractiveness of Sweden as a partner and to match the resources of the Asian partners, it is often useful, and sometimes even necessary, to gather researchers from several Swedish universities and research institutes. Involving companies and public sector organizations that are perceived as innovative in international comparisons may also make the Swedish side significantly more attractive. The direct participation of such actors also has the benefit of increasing the societal relevance of Sweden's global research co-operation.[62]

Arranging study visits and workshops is relatively cheap compared to the cost of carrying out research. The costs are, however, large enough for funding to be needed, at least for "collective costs." The main bottleneck for contact-creating activities is probably not financial resources, although they must be found somehow, but rather the task of identifying promising themes where truly mutually beneficial exchange can be expected to emerge, and to obtain a commitment from leading actors in Sweden and the partner country. Clearly the expertise of individual scientists is crucial. However, the criteria for selecting themes and people should be broader than the immediate concerns of the individual scientist if the objective is to build partnerships of strategic importance to a university or Sweden as a country.

Economic incentives work against the development of global research connections

In order to build and maintain strategic partnerships in research, access to funding is necessary. The Swedish research system is presently not well equipped to handle this requirement for research co-operation outside Europe and the issue has unfortunately not received much attention. Whether individual universities should prioritize their institutional funds for this purpose or whether R&D-funding organizations should play a major role is open to discussion. A combination of both sources of funding may be desirable. STINT (the Swedish Foundation for International Cooperation in Research and Higher Education) is playing an important role although its budget is limited to SEK 40–50 million per year. This can be useful for developing and maintaining contacts but not as a source of funding for actual research co-operation.[63] Another source is Swedish Research Links managed by the Swedish Research Council. It supports research co-operation between Sweden and "low and middle income countries." The grants are small, typically SEK 250,000 per year, and none of the Asia 6 countries highlighted in this report are eligible.

Significant international research co-operation often requires funding for all the partners involved or at least for the research organizations as companies may be able to cover their own costs. In the case of the EU Framework Programmes, this is accomplished by the European Commission providing the funding.[64] For co-operation with actors outside Europe, joint funding by Swedish research funding organizations and their counterparts in partner countries is desirable but usually difficult to organize, except in limited areas where there are special joint funding agreements in place based on open calls for proposals.[65] Presently such funding only covers a small portion of potential areas for co-operation between Sweden and non-European countries.[66] Even if the number of areas for each country were to be expanded, the coverage of joint funding schemes based on open calls would most likely remain rather limited.

There is therefore a need for flexible funding mechanisms that would allow research groups in Sweden to respond positively and within a reasonable timeframe to attractive invitations for research co-operation from abroad. These funding mechanisms need to be designed in a way that ensures the high quality of the research being supported and transparency in decision

processes. It would not be unreasonable for universities to use their own institutional funds to establish such flexible funding. R&D-funding organizations might play a particularly useful role in promoting more complex types of international co-operation, for example cases in which several different organizations join forces on the Swedish side.

Recruitment to build new connections with Asia presents a dilemma

Recruitment of top scientists and talented young researchers from other countries is an important mechanism, both for raising quality and introducing new perspectives in research, but also for expanding a research environment's international contact network. It is currently well recognized that Sweden needs to make a greater effort than in the past to recruit internationally.[67] The significant increase in the institutional funds of universities' in recent years has improved their capacity in strategic international recruitment.[68] The earmarked funding for so-called Strategic Research Areas in particular appears to have been used at several universities to greatly increase international recruitment. In the Swedish government's most recent research bill, special new funds were allocated for the recruitment of top foreign scientists. One important question is to what extent the increase in foreign recruitment will help strengthen research connections with countries in Asia and other parts of the world outside Europe and North America. There is a significant risk that the dearth of contacts with these countries will be reproduced, which would represent a lost opportunity. On the other hand, targeting individual countries or regions in recruitment decisions does not seem very attractive. Here is a dilemma that deserves to be acknowledged.

Sweden a latecomer in the international market for higher education

To ensure the long-term development of research and other connections, an inflow of students from emerging economies is very important. International higher education is in some countries today regarded as a major industry and much effort is devoted to ensuring its competitiveness and growth.[69] After recently being required to charge non-EU students. Swedish universities are now entering the market for higher education in earnest as latecomers. A very large initiative by Brazil to send 100,000 students abroad for education during four years has tested the capacity of countries to accommodate a large influx of students.[70]

Strategic university-industry co-operation at the global level

This report focuses on Sweden's global connectivity in research. While important, it is only one of several factors that will influence Sweden's attractiveness as a place and partner for knowledge production in the increasingly globalized knowledge economy. Closely related to this is the mobility in and out of Sweden of students, researchers and engineers. Another factor is the interaction between research institutions and industry in Sweden as well as in global innovation networks. It is therefore desirable that the idea of strengthening the integration of elements in the knowledge triangle is also applied when considering Sweden's global connections in education, research and innovation. It is noteworthy that several recent initiatives to strengthen research exchange between Western countries and countries in Asia combine graduate education, research and strong involvement by industry.[71]

A first step towards a global perspective in Swedish research and innovation policy

Efforts to integrate a global perspective into Sweden's research and innovation policy are still at a very early stage. In connection with the most recent research and innovation bill, the Swedish government adopted a "Strategy for international cooperation in research and research-based innovation."[72] It outlines on a general level why Sweden needs the strategy and its objectives. The strategy states that more concrete "substrategies" for co-operation with specific countries or regions will be developed in co-operation with the agencies concerned. The first steps in the direction of developing country-specific strategies have been taken in the case of China.[73]

In a new development, the Swedish Research Council, the Swedish Council for Work Life and Social Research and the Swedish Research Council Formas announced in late 2012 that in 2013 they will announce a call for proposals for research co-operation with China.[74] It is noteworthy that one of the requirements mentioned is that the university or college to which the applicant belongs must provide a long-term strategy for its co-operation with China. The announcement indicates that each grant may amount to as much as SEK 5 million per year over five years. This level of support should be a sufficient basis for more strategic co-operation, something which has so far been lacking for Swedish co-operation outside Europe.

Combining European integration and efforts to develop global connectivity

So far, very little special government funding has been earmarked for research co-operation outside Europe.[75] Even without this special funding it is possible for individual research councils and other R&D-funding agencies to provide funding for Swedish actors to participate in international research co-operation. As already mentioned, this has been done to some extent, although so far on only a small scale for co-operation outside Europe.

The funding available through the EU Framework Programmes provides a strong incentive for researchers to seek collaboration partners in Europe. From the start in 2007 until October 2012, the Seventh Framework Programme (FP7) has provided EUR 720 million in funding to Swedish universities and colleges.[76]

Decisions concerning EU-funding have until recently not been directly influenced by Swedish national research or innovation policy. The situation is, however, beginning to change as the use of so-called partnership programs that are co-financed by the member countries and the Commission is becoming increasingly common. In partnership programs funding is provided by the member states in varying degrees. To secure the necessary funding for Swedish participation in new or expanded partnership programs, the recent government research and innovation bill earmarked new funding amounting to SEK 100 million for 2014, increasing to SEK 200 million in 2016. The latter amount is about the same as the amount Swedish R&D-funding councils and agencies were spending on European partnership programs in 2011.[77]

There are good reasons for Sweden to actively participate in the development of partnership programs. There is, however, a risk that the global perspective will receive even less attention both among researchers and in funding organizations than it has up to now. The recent initiative by three research councils in Sweden to provide funding for strategic research co-operation with China is a welcome sign that it may be possible to combine efforts to intensify co-operation in Europe with efforts to increase Sweden's global connectivity in research. Initiatives should, however, not be limited to China.

Increasing commitment to the development of partnership programs will require opportunities for European co-operation to be explicitly considered together with the development of national research and innovation policy initiatives. The real challenge will be how to also include opportunities for collaboration outside Europe in policy deliberations.

FURTHER STUDY

The discussion in this last chapter has attempted to place the analysis of Sweden's international research collaboration in a wider policy context. Many of the issues raised would benefit from more systematic studies – quantitative as well as qualitative – than have been possible in preparing the present report. Some of the possible topics for such studies are briefly described below.

Does the picture drawn using bibliometrics coincide with the actual experiences of Swedish researchers?

An obvious extension of the analysis presented in this report would be to compare and contrast the picture emerging from the bibliometric analysis with the international collaboration experiences of Swedish researchers. For this purpose, an analysis at the level of individual universi-

ties would probably be the most suitable. The fields into which articles have been subdivided in this report are quite broad and within each field there may be large variations between different subfields. A more fine-grained division into subfields might therefore be desirable. The selection of foreign universities for comparison may also need to be expanded.

One basic issue relates to whether or not bibliometric analysis is really suitable for certain fields. The importance of publishing journal articles varies between fields and for some fields other types of publication may be more relevant. In the field of ICT it would, for example, be desirable to include conference proceedings, which were not included in the database used in this report. It would be important to find out if Sweden's position and pattern of international collaboration in the field of ICT would appear in a different light if conference proceedings were included.

What are the benefits of international co-operation in research?

There are many aspects to international research collaboration depending on whose point of view is taken and also depending on the field or research subject.[78] The interests and priorities of different stakeholders may very well differ, even within a university. In order for the promotion of international research collaboration to be effective, it is important for the benefits being sought to be clearly defined and expressed. Much remains to be done to document the benefits and costs of international research collaboration.

A common theme in research and innovation policy developments in recent years in most countries has been the need to address global challenges. If these ambitions are to be fulfilled it would be surprising if it did not influence the patterns of international research collaboration. The effects deserve to be monitored and analyzed.

What is needed to develop and sustain strong research connections?

One conclusion in this report is that Sweden needs to strengthen its research connections in Engineering-related fields with, for example, South Korea and Singapore. Some of the factors that are important for the development of new research connections have been discussed, but more needs to be known about the most effective mechanisms and the extent to, and the way in, which they may differ between countries. Specifically, it is important to better understand the significance of the apparent growth in strategic research alliances. While the "chemistry" between individual research leaders is likely to continue to be an important factor for the development of fruitful collaboration, a crucial question is to what extent more institutionalized frameworks, including significant funding, will determine and shape research collaboration in the future. A better understanding of how successful research collaboration has evolved in the past will be helpful, but may not sufficiently reflect the rapidly changing realities of today and tomorrow.

How can universities, research institutes and companies benefit from each other's global connections?

The increasing globalization of industry is affecting the geographical patterns of co-operation between companies and research organizations. Research organizations here include universities and research institutes. Global corporate groups usually operate R&D units in many different countries. How these R&D units distribute responsibilities among themselves and how they work together varies from company to company. The global networks of research contacts of corporations operating in Sweden can offer valuable channels to new research contacts for Swedish universities and research institutes. There is reason to believe that these opportunities are not being exploited enough today by Swedish research organizations. In other cases, effective co-operation with the Swedish subsidiaries of foreign-owned companies may require Swedish universities and research institutes to develop working relationships directly with the central R&D units of the parent companies abroad. Also more generally speaking, Swedish research organizations need to expand their

co-operation in the fields where they are particularly strong with leading international companies. Presently, there is very little in terms of systematic data and analysis to shed light on how companies and research organizations in Sweden are working together as participants in global networks for research and innovation co-operation.

How can European and global collaboration usefully be combined?

A recurring theme in this report is the need for Sweden to actively develop research links, both within and outside Europe, and that it would be desirable if the two could be combined. The assumption is that a strong position in European research networks should make Swedish research milieus attractive as research partners outside Europe as well and that, in the long run, maintaining a strong position in Europe will require fruitful partnerships to be built outside Europe. It would be useful to identify and analyze examples of how this can work in practice.

Appendix 1: Additional data

Figure A1-1: Engineering articles per capita for top 21-40 countries
Countries in order of their share 2008-2010 of the world's 10 % most cited articles in the Engineering field. Articles per capita. Rebased: Sweden=100

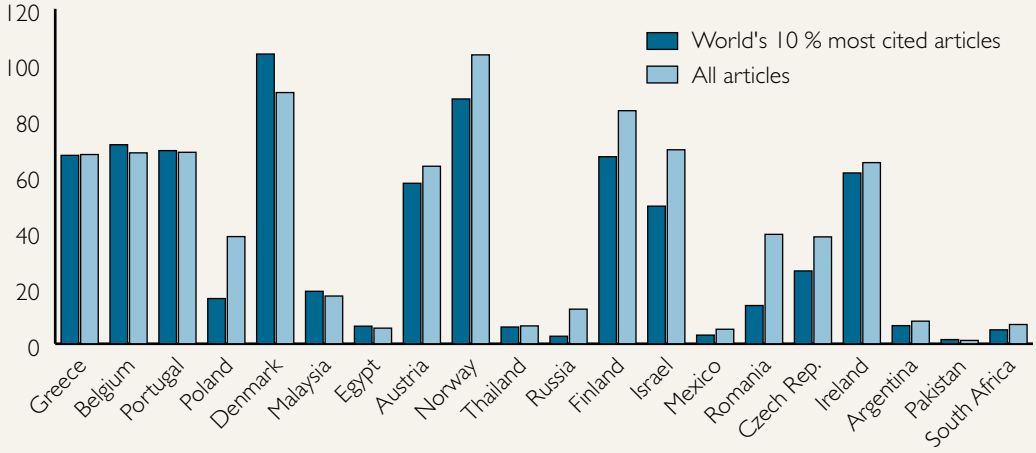
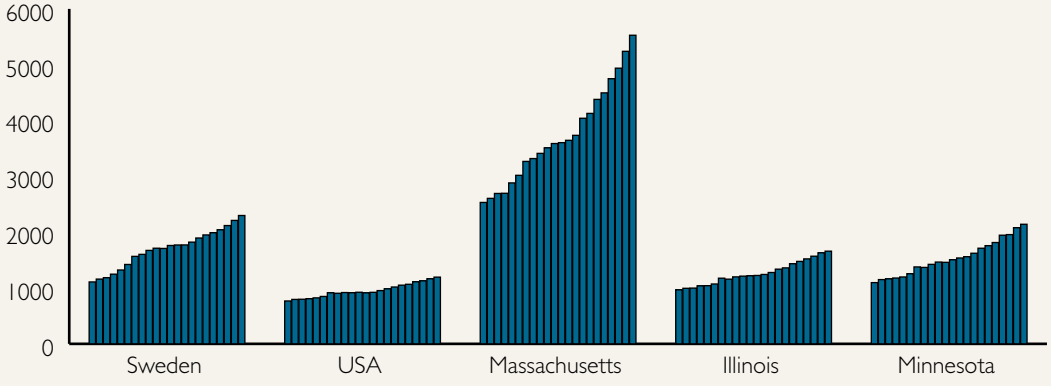


Figure A1-2: Comparison of per capita authorship in Sweden with the USA and three individual states
All fields 1990-2011. Articles per million inhabitants.



Source: On-line search in Thomson Reuters' Web of Science (WoS) database

Figure A1-3: Recent growth in articles co-authored by Sweden and selected non-European countries involving authors from more than two continents and same data for Switzerland
Materials Science. World Top 10 % cited articles in the relevant fields. Number of co-authored articles.

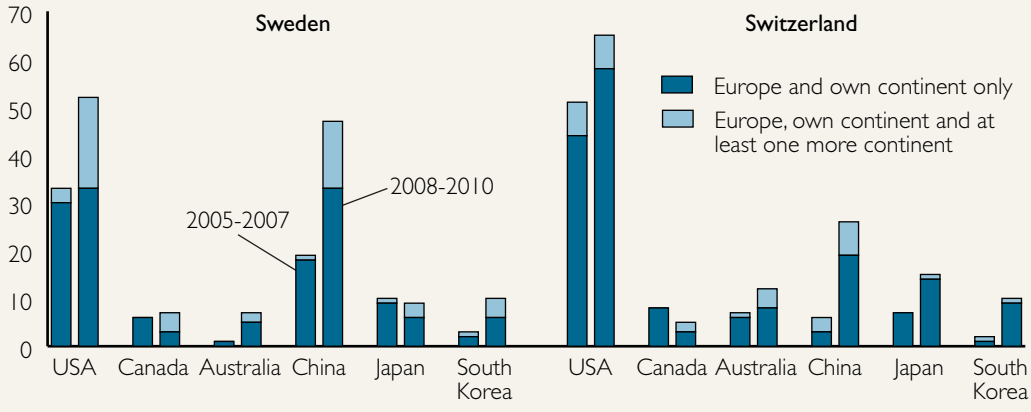


Figure A1-4: Quality of Sweden's articles co-authored with six Asian countries and with all countries in the world in the combined field of Engineering, ICT and Materials Science
Share of articles among World's 10 % most cited articles (Percent). Articles with authors from five or more countries are excluded.

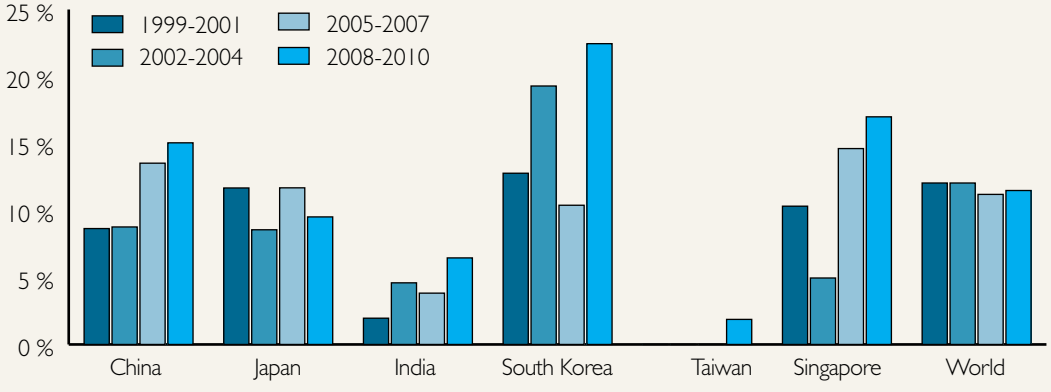


Figure A1-5: Number of articles co-authored with six Asian countries in the field of Biomedicine for individual Swedish universities 2008–2010

Number of articles.

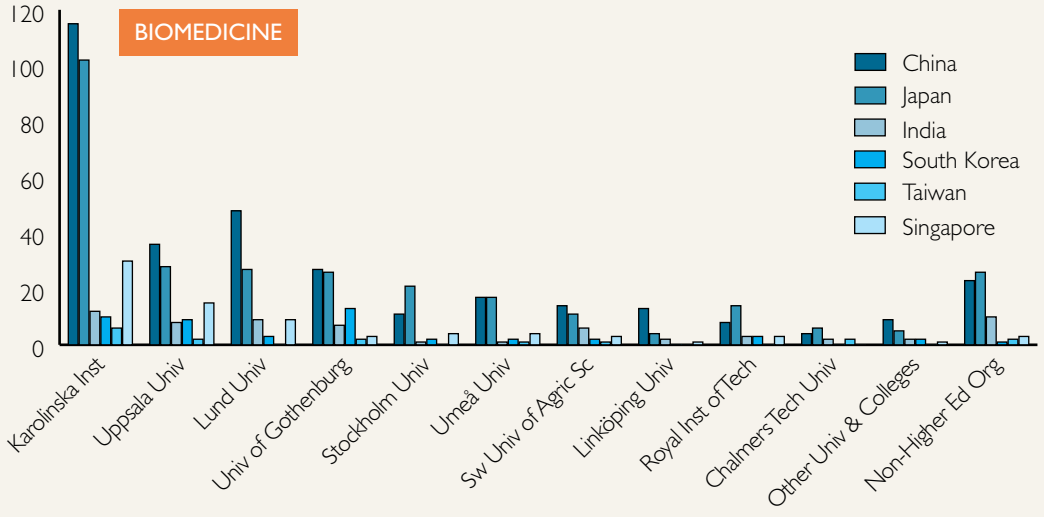


Table 1: World share of highly cited articles for country groups and individual countries in each group (except EU 27+3) 2008–2010 for all fields and five selected fields

	Population 2009 (Millions)	Share of World's 10 % most cited articles					
		All fields (Percent)	Engineering (Percent)	Chemistry (Percent)	Biomedicine (Percent)	Clinical Medicine (Percent)	Agriculture (Percent)
World		**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
EU 27+3		**40.79**	**32.96**	**33.19**	**42.29**	**43.02**	**42.27**
Sweden	9.3	2.28	1.44	1.44	2.60	3.16	2.08
North America		**47.02**	**27.43**	**32.39**	**57.43**	**55.99**	**33.88**
United States	307.7	43.24	24.02	29.43	54.13	51.93	29.45
Canada	33.7	5.98	4.20	3.44	5.96	7.35	6.00
Asia 6		**21.90**	**37.96**	**39.83**	**16.92**	**11.99**	**22.93**
China	1334.9	10.32	19.85	22.54	6.04	3.65	11.17
Japan	126.6	5.25	4.56	6.99	6.09	4.42	4.84
South Korea	48.0	2.67	4.58	4.19	2.15	1.94	2.73
India	1207.7	2.04	5.02	3.65	1.56	0.95	3.00
Taiwan	23.1	1.81	4.00	2.23	0.97	1.10	1.85
Singapore	4.9	1.06	1.83	1.86	0.89	0.58	0.37
Oceania		**4.55**	**3.52**	**2.45**	**3.95**	**5.31**	**6.31**
Australia	21.9	3.99	3.20	2.21	3.53	4.77	5.26
New Zealand	4.3	0.68	0.38	0.27	0.55	0.75	1.17
Middle East & Central Asia		**3.54**	**7.46**	**3.08**	**2.37**	**2.61**	**5.21**
Israel	7.3	1.16	0.55	0.77	1.37	1.13	0.83
Turkey	71.8	1.06	3.36	0.86	0.44	0.81	2.19
Iran	73.1	0.77	2.43	1.00	0.24	0.25	1.25
Pakistan	170.5	0.18	0.39	0.13	0.08	0.11	0.43
Saudi Arabia	26.8	0.16	0.32	0.17	0.12	0.12	0.16
Jordan	6.0	0.06	0.15	0.05	0.03	0.04	0.11
United Arab Emirates	6.9	0.06	0.13	0.02	0.06	0.06	0.06
Lebanon	4.2	0.05	0.06	0.02	0.04	0.09	0.11
Latin America		**2.69**	**2.97**	**1.89**	**2.29**	**2.70**	**5.37**
Brazil	193.2	1.32	1.55	0.92	1.13	1.54	2.53
Mexico	112.0	0.47	0.54	0.38	0.31	0.41	0.93
Argentina	40.1	0.43	0.40	0.33	0.36	0.42	0.91
Chile	17.0	0.29	0.23	0.14	0.17	0.20	0.41
Colombia	45.7	0.13	0.19	0.07	0.12	0.14	0.25
Venezuela	28.5	0.06	0.05	0.06	0.06	0.07	0.08
Peru	28.8	0.06	0.03	0.00	0.06	0.12	0.08
Africa		**1.54**	**2.07**	**0.74**	**1.49**	**1.96**	**2.87**
South Africa	49.8	0.57	0.39	0.21	0.51	0.75	0.68
Egypt	79.7	0.27	0.77	0.28	0.20	0.22	0.60
Kenya	39.5	0.10	0.01	0.01	0.14	0.19	0.23
Tunisia	10.4	0.09	0.26	0.06	0.07	0.07	0.40
Algeria	35.0	0.08	0.29	0.07	0.03	0.02	0.16
Uganda	32.4	0.07	0.00	0.00	0.12	0.18	0.03
Nigeria	154.5	0.07	0.16	0.03	0.05	0.08	0.15
Tanzania	43.5	0.06	0.01	0.00	0.10	0.15	0.06
Morocco	31.6	0.05	0.13	0.04	0.02	0.02	0.15
Russia & Other Europe		**1.27**	**1.26**	**1.07**	**0.75**	**0.53**	**0.73**
Russia	143.1	0.80	0.60	0.64	0.46	0.25	0.29
Serbia	9.9	0.17	0.27	0.15	0.07	0.10	0.18
Croatia	4.4	0.15	0.12	0.09	0.17	0.12	0.22
Ukraine	45.7	0.12	0.20	0.14	0.03	0.04	0.04
South-East & Other Asia		**0.89**	**1.77**	**0.75**	**0.84**	**0.82**	**2.24**
Thailand	68.7	0.36	0.64	0.35	0.44	0.39	0.76
Malaysia	27.9	0.26	0.81	0.34	0.15	0.14	0.70
Viet Nam	86.9	0.08	0.10	0.01	0.09	0.09	0.12
Indonesia	237.4	0.07	0.08	0.03	0.07	0.07	0.19
Philippines	91.7	0.06	0.04	0.02	0.06	0.07	0.23
Bangladesh	147.0	0.05	0.08	0.01	0.05	0.09	0.17

Table 2: Highly cited articles as a share of all articles for country groups and individual countries in 2008–2010 for all fields and five selected fields

	World's 10 % most cited articles as a share of all articles					
	All fields (Percent)	Engineering (Percent)	Chemistry (Percent)	Biomedicine (Percent)	Clinical Medicine (Percent)	Agriculture (Percent)
World	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**	**10.0**
EU 27+3	**10.9**	**9.9**	**10.3**	**11.0**	**10.8**	**11.6**
Sweden	13.8	11.5	13.2	12.9	14.8	14.1
North America	**14.7**	**11.2**	**16.6**	**15.2**	**14.8**	**13.1**
United States	15.2	11.7	17.1	15.9	15.3	13.5
Canada	13.1	9.3	13.2	12.3	14.6	12.1
Asia 6	**8.4**	**10.9**	**9.6**	**6.7**	**6.8**	**9.5**
China	9.6	11.9	10.7	6.7	7.9	11.7
Japan	8.0	8.4	8.4	7.6	7.0	8.7
South Korea	8.1	9.9	9.8	6.5	7.3	9.5
India	5.9	11.1	5.9	4.5	4.3	5.6
Taiwan	8.7	10.6	10.4	6.3	6.5	11.7
Singapore	14.7	16.7	21.4	14.2	11.5	15.8
Oceania	**12.1**	**11.6**	**12.7**	**11.2**	**12.2**	**13.4**
Australia	12.4	11.9	13.2	11.7	12.3	14.0
New Zealand	11.6	9.7	9.7	9.6	12.7	11.6
Middle East & Central Asia	**6.8**	**10.6**	**5.7**	**6.2**	**4.7**	**7.6**
Israel	11.5	8.1	12.6	12.4	10.7	12.9
Turkey	5.5	13.0	5.8	3.8	3.0	7.4
Iran	6.1	9.7	4.9	2.9	2.8	7.3
Pakistan	5.5	14.3	2.7	3.4	4.6	5.0
Saudi Arabia	7.2	9.8	6.4	6.7	4.9	8.3
Jordan	6.3	8.5	4.5	4.0	5.5	6.6
United Arab Emirates	7.1	7.5	6.0	10.4	7.8	6.6
Lebanon	8.6	11.4	5.7	9.2	8.7	18.1
Latin America	**5.5**	**8.0**	**5.0**	**4.5**	**5.8**	**5.4**
Brazil	5.0	9.0	4.8	4.0	5.1	4.2
Mexico	5.9	6.9	5.4	4.4	7.8	6.2
Argentina	7.1	9.1	5.4	4.8	10.0	8.6
Chile	7.2	7.4	5.2	5.3	7.4	7.1
Colombia	6.3	5.5	4.6	7.1	8.5	7.8
Venezuela	5.2	4.2	6.2	5.5	7.4	4.1
Peru	11.1	15.2	3.2	11.4	15.5	8.8
Africa	**7.1**	**10.2**	**3.8**	**6.9**	**9.4**	**7.0**
South Africa	9.0	8.3	5.6	9.6	14.5	6.4
Egypt	6.5	12.8	3.8	5.1	6.5	11.0
Kenya	12.0	9.6	7.0	10.6	15.9	9.3
Tunisia	4.4	9.3	2.6	3.3	3.6	9.6
Algeria	6.4	10.4	3.4	5.0	5.9	9.8
Uganda	14.2	0.0	11.1	17.2	18.2	4.0
Nigeria	3.4	12.2	3.2	1.8	3.6	2.8
Tanzania	13.8	8.9	4.4	15.3	17.9	5.9
Morocco	4.6	11.1	2.5	3.8	2.1	9.0
Russia & Other Europe	**3.7**	**3.4**	**2.0**	**4.4**	**4.7**	**4.8**
Russia	3.4	2.5	1.6	4.0	5.0	4.4
Serbia	5.9	6.8	4.7	3.5	3.8	5.8
Croatia	5.2	4.2	4.2	10.0	5.1	5.4
Ukraine	3.0	3.6	2.0	2.1	11.0	4.3
South-East & Other Asia	**7.4**	**11.4**	**5.1**	**6.7**	**7.6**	**8.9**
Thailand	8.2	10.8	7.0	7.5	8.4	8.7
Malaysia	6.8	12.6	4.6	4.8	5.4	11.2
Viet Nam	8.9	13.4	2.1	10.1	11.9	7.0
Indonesia	9.1	9.4	5.0	8.9	11.8	9.6
Philippines	9.6	10.9	6.9	10.0	12.5	9.5
Bangladesh	6.4	9.2	2.0	5.4	11.3	7.1

Appendix 2: How serious is the decline in Sweden's position in Engineering-related fields?

An issue that has surfaced in the report on several occasions is an apparent decline in Sweden's relative position in Engineering-related fields over the past decade. The analysis of changes in Sweden's relative position is not the focus of this report, but as it affects comparisons between Sweden and other countries of changes in co-authorship patterns, some degree of systematic analysis of this issue seems warranted and such an analysis is therefore presented in this Appendix. The development of Sweden's position in Physical and Engineering Sciences is compared with other advanced research countries. Outside Europe and North America, we will include Australia and Singapore as these are emerging as useful benchmarks for Sweden.

The Swedish research policy debate relating to changes in Sweden's international position in research has focused on a decline in Sweden's citation performance compared to other countries. A recent study by Karlsson and Persson (2012) provides an in-depth analysis of Sweden's citation performance over the past two decades relative to Denmark, Finland, the Netherlands, Switzerland and the United Kingdom. The authors find that, compared to Sweden, all five countries "have seen greater improvements during the last twenty years in terms of both national mean citation rate and the production of highly cited papers."[79]

While changes in relative citation performance are important, there are other aspects that should also be considered when the development of Sweden's research performance is compared to that of other countries. One is the volume of research and, in this regard, changes as well as the absolute level adjusted for differences in country size. When changes in both volume and quality of publications are considered and comparisons made with a greater number of countries and for different fields, a rather complex pattern emerges. The relative weight of changes in volume and quality varies greatly between fields and depending on with which country the comparison is made. In deliberating suitable policies to address what seems to be a weakening of Sweden's position in research, this more complex picture should be taken into account.

Omitting articles involving authors from five or more countries, Sweden's share of the total production of the world's 10 percent most cited articles fell from 2.29 to 1.93 between the periods 1999–2001 and 2008–2010 back to approximately where it was in the early 1990s (Figure A2.1).[80] Considering that emerging research nations, led by China, greatly expanded their research systems over the past decade this may not seem very remarkable. It is noteworthy, however, that Sweden's share fell more than the share for most other countries with highly developed economies and advanced research systems (Figure A2.2). A very important exception was the United States which saw its world share of highly cited articles decline to the same extent as Sweden. The same held true for Israel and Finland, and only Japan' experienced a greater

Figure A2-1: Change in world share of highly cited articles between 1999–2001 and 2008–2010 for selected countries

World share of highly cited articles 2008–2010 as a factor of the same share 1999–2001 (1999-2001=1.00). Articles with authors from five or more countries are excluded.

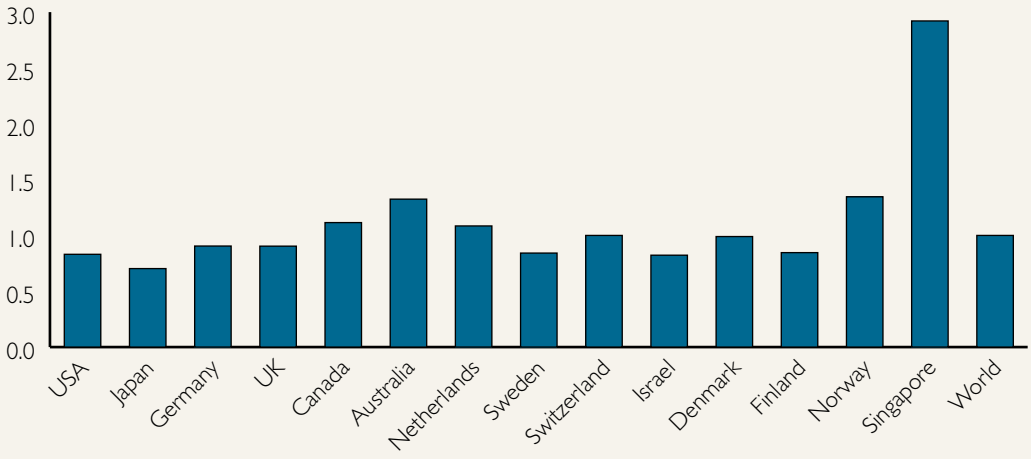
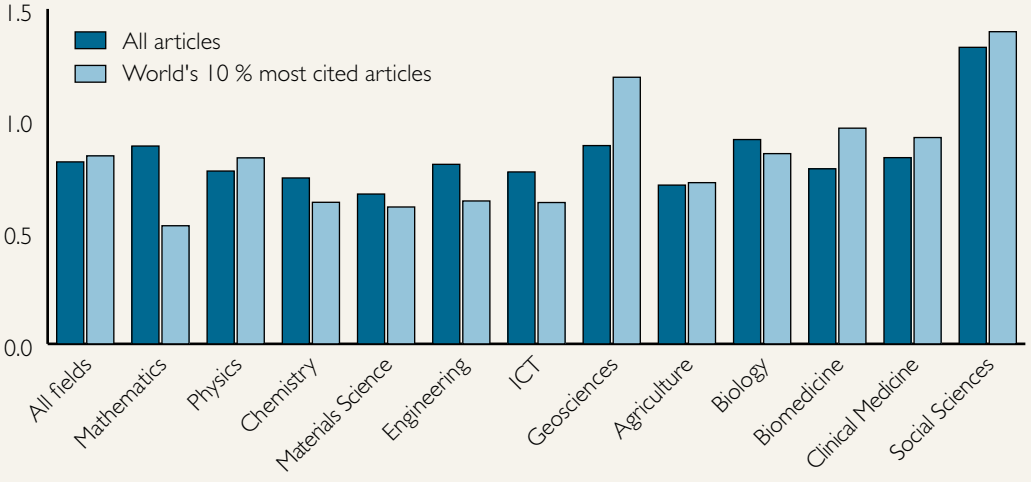


Figure A2-2: Change in Sweden's world share of all and highly cited articles between 1999–2001 and 2008–2010 for different fields

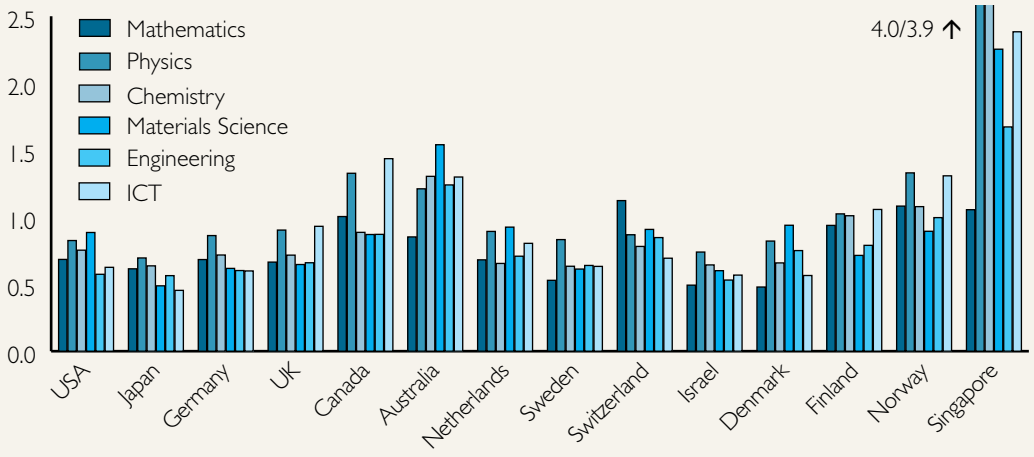
World share in 2008–2010 as a fraction of the same share in 1999–2001 (1991–2001=1.00). Articles with authors from five or more countries are excluded.



decline in its share than Sweden. The main research countries in Europe – the United Kingdom, Germany and France – all saw their world share decrease by around 10 percent, notably less than Sweden's 16 percent decline. Denmark and Switzerland maintained their world share at essentially the same level, while Canada, Australia, the Netherlands, Norway and Singapore all increased their share of the world's total production of highly cited articles.

Figure A2-3: Change in world share of highly cited articles between 1999–2001 and 2008–2010 for selected countries in fields of Physical and Engineering Sciences

World share of highly cited articles 2008–2010 as a factor of the same share 1999–2001 (1999-2001=1.00). Articles with authors from five or more countries are excluded.



As has been discussed at length in this report, the global dynamics of research varies greatly between fields. Figure A2.2 summarizes these differences for changes in Sweden's share of the world's production of scientific articles over the past decade. It shows the change both in terms of all articles and the 10 percent most highly cited articles. Sweden experienced a drop in all fields except Geosciences and Social Sciences in its world share of highly cited articles. The drop was particularly severe for Mathematics, Chemistry, Materials Science, Engineering and ICT, which all reduced their world share of highly cited articles by 35–40 percent. For these fields the decline was larger for highly cited articles than for the total volume of articles, suggesting a reduction in the "quality" level of Sweden's publications measured in citation terms. The development was the opposite for Biomedicine and Clinical Medicine. Both fields experienced relatively modest reductions in their world share of highly cited articles and the average quality actually improved as indicated by the fact that the world share of highly cited articles decreased significantly less than the world share for all articles. The development for Physics, Agriculture and Biology falls somewhere in between the two patterns described above.

One crucial question is how these developments for Sweden, and especially the sharp relative contraction in "Engineering-related" fields, should be interpreted. Changes in a country's overall world share only tell a small part of the story and are not sufficient for a balanced assessment. As the global research system is undergoing substantial structural transformation in which the relative weight and quality performance of different countries are changing and are doing so in an inhomogeneous way across fields, it is necessary to compare Sweden with individual countries while also distinguishing between fields.

Figure A2.3 shows how the world share of highly cited articles changed over the past decade in the fields of Engineering and Physical Sciences in Sweden and 13 other countries. In most fields, Sweden's decline is greater than that of most other countries. Besides Sweden, Japan, Israel and Germany have also seen their relative position deteriorate in several of the fields presented.

The decline in Sweden's relative position as a producer of highly cited articles is the combined result of relative changes in the "volume" and "quality" of Sweden's articles. Figure A2.4 allows

Figure A2-4: Change in the "Volume" (world share of all articles) between 1999–2001 and 2008–2010 for selected countries in fields of Physical and Engineering Sciences
World share of highly cited articles 2008–2010 as a factor of the same share 1999–2001 (1999–2001=1.00). Articles with authors from five or more countries are excluded.

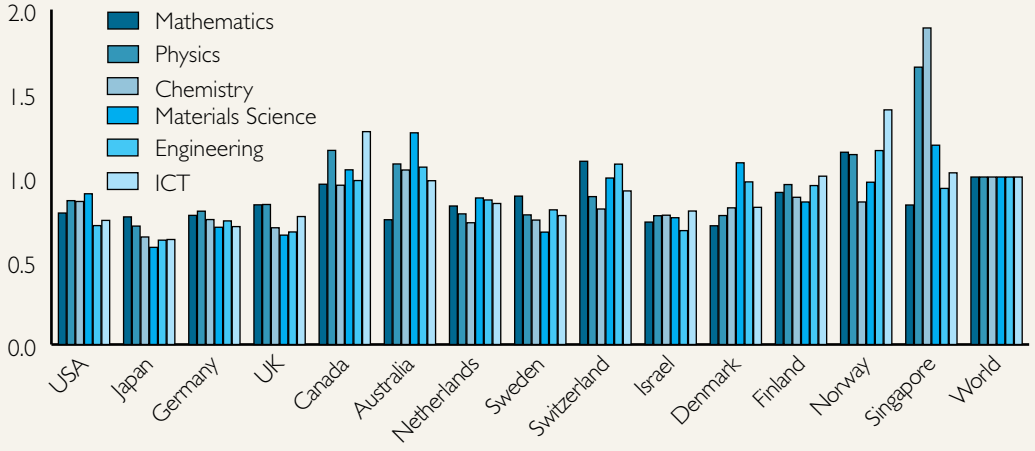
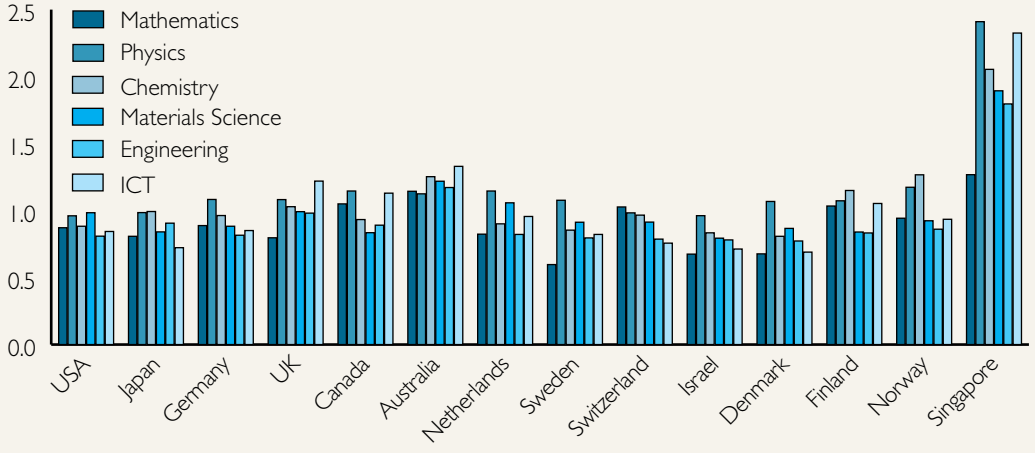


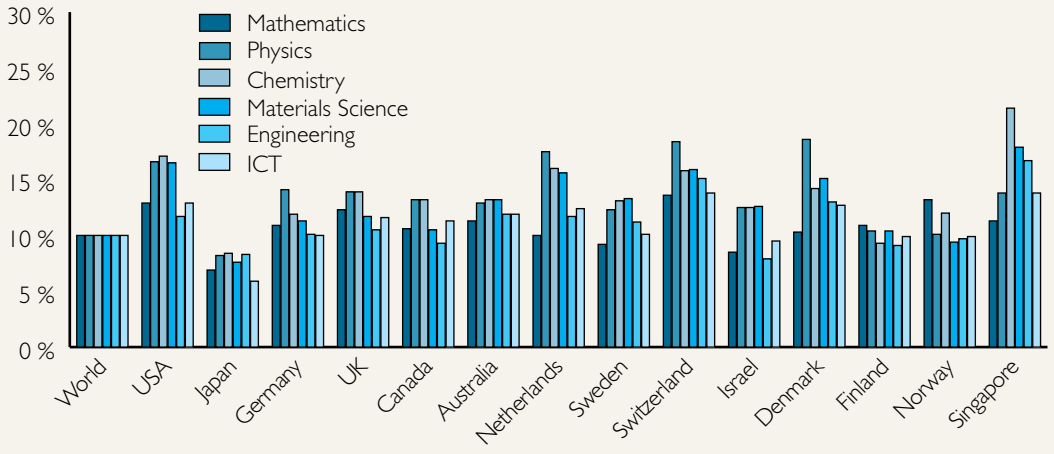
Figure A2-5: Change in "Quality" (highly cited articles as a percentage of all articles) between 1999–2001 and 2008–2010 for selected countries in fields of Physical and Engineering Sciences
Highly cited articles as a percentage of all articles 2008–2010 compared to the same percentage 1999–2001 (1999–2001=1.00). Articles with authors from five or more countries are excluded.



the change in Sweden's volume of articles to be compared with the other 13 countries and Figure A2.5 the change in relative quality. In both cases the values for 2008–2010 are compared with the values for 1999–2001 and the ratio between the two calculated for each field and country. What we find is a very mixed picture in which relative changes in volume and quality are combined in different ways depending on for which field and with which country the comparison is made.

Figure A2-6: Highly cited articles as a share of all articles 2008–2010 for selected countries in the fields of Physical and Engineering Sciences

Highly cited articles as a share of all articles 2008–2010 (Percent). Articles with authors from five or more countries are excluded.

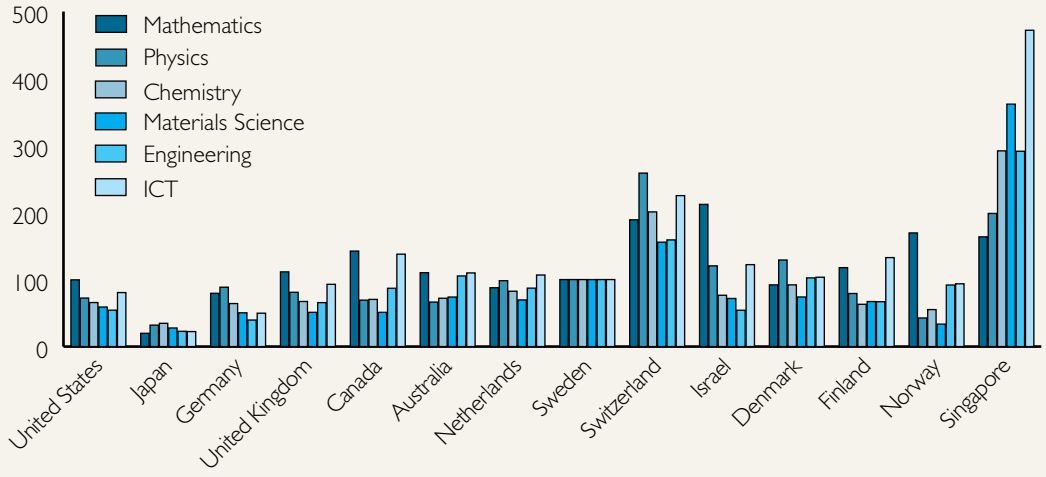


Mathematics and Materials Science represent two contrasting cases in terms of the cause of the decline in Sweden's world share of highly cited articles. The drastic decline in Sweden's share in the field of Mathematics is almost entirely due to a drop in the average quality of Swedish articles. The share of all articles among the world's 10 percent most cited articles decreased from 15.4 percent in 1999–2001 to only 9.2 percent in 2008–2010 (Figure A2.6). While the majority of the countries it is being compared with saw a decline in their quality level relative to the world average, no country performed as poorly as Sweden in this regard (Figure A2.5). Denmark and Israel came closest to Sweden in terms of relative decline in quality. As many as seven countries had significantly higher levels of per capita production of highly cited articles in 2008–2010 (Figure A2.7). Sweden's development in the field of Mathematics is clearly worrisome.

By contrast, Sweden's relative decline in Materials Science was primarily caused by weak growth in the total volume of articles (Figure A2.4). Although the relative quality level dropped in relation to five countries, in three of these cases the relative decline in volume was much greater, the exceptions being the United Kingdom and Singapore. Sweden's quality improved in relation to Denmark and Canada and stayed constant vis-à-vis Switzerland. However, these three countries as well as Australia and Singapore increased their volume of articles relative to Sweden by 50 percent or more. Also, for the United States, the Netherlands and Norway the volume of articles grew significantly relative to Sweden – by between 30 and 44 percent. Even after a decade of weak relative performance in volume terms, only Singapore and Switzerland have a higher per capita production of highly cited articles (Figure A2.7). The difference compared to these countries is, however, very large as in most other fields of Physical and Engineering Sciences. The gap below Sweden is also large. The overall picture of Materials Science is of a field that has rapidly expanded with Sweden not being able to keep pace with the expansion. Compared to this, the relative movement in quality has been very minor. There is, however, much room for improvement in quality relative to those five countries – United States, Netherlands, Switzerland, Denmark and Singapore – all of which had significantly higher quality than Sweden in 2008–2010 (Figure A2.6). It is noteworthy that among Engineering and Physical Sciences fields, Materials Science is the

Figure A2-7: Highly cited articles per capita 2008–2010 relative to Sweden for selected countries in the fields of Physical Sciences and Engineering

Highly cited articles per capita 2008-2010. Index: Sweden=100. Articles with authors from five or more countries are excluded.



field in which the United States has been best able to defend its relative position.

As far as can be judged using bibliometric indicators, Sweden's position in the field of ICT has seriously deteriorated over the past decade. Among the 13 countries being compared, only the United States, Japan, Germany, United Kingdom and Norway today have lower production of highly cited articles per capita than Sweden, and for three of these the gap between them and Sweden is smaller than for all other fields except Mathematics, which we have already identified as the most poorly performing field for Sweden (Figure A2.7). The decline in Sweden's relative position is due to a combination of a drop in relative quality and relative volume of articles in more or less equal measure, but with the mix varying considerable between countries. Only in the case of the United Kingdom is the entire change due to a relative decline in quality for Sweden.

For the remaining three areas – Physics, Chemistry and Engineering – the pattern of relative change is rather mixed. In Physics the relative decline is mainly due to other countries showing better volume growth, while there are almost no cases of loss of relative quality for Sweden. In Chemistry the relative decline has primarily been caused by a decrease in Sweden's relative quality. Sweden's relative position in terms of per capita production of highly cited articles and the share of highly cited articles is still fairly strong, especially on the per capita measure, and resembles that for Materials Science. Sweden's relative position in Engineering appears generally weaker than in Physics, Chemistry and Materials Science but stronger than in Mathematics and ICT. Except for the largest countries and Israel, Sweden's position has weakened relative to all the countries almost entirely due to a weaker performance in volume terms.

Canada, Australia, Norway, Finland and Singapore have most consistently strengthened their position across different fields relative to Sweden. The fact that the three first-mentioned countries have also benefitted from strong growth in their natural resources industries may not be a total coincidence. The Netherlands, Switzerland, Denmark and Singapore in almost all areas show a higher average quality in their articles than Sweden. With the exception of Mathematics, and in the case of Switzerland Chemistry as well, Sweden has improved its quality performance somewhat in relation to Switzerland and Denmark.

Footnotes

1. Some data on the rapidly increasing internationalization of Swedish industry are presented in Stenberg (2011).

2. This point is emphasized in the recent evaluation of Swedish Innovation Policy by the OECD: "The government should: *Use all available means to anchor large firms and their activities in production and research in a world-class Swedish innovation environment*. This includes sharpening the profiles of strong universities, e.g. through larger centres of excellence." (OECD, 2012). In the same review, OECD also calls for Sweden to embrace internationalization more fully than at present and recommends that "The government should: *Continue strengthening links to established and emerging global centres of innovation*. The rise of Asian and other fast-developing economies requires a broader focus on internationalization while not forgetting the continuing importance of maintaining strong links to Europe and North America."

3. The fact that many of the acquired firms are continuing their activities in Sweden bears witness to the competitiveness of Swedish industry. For this to continue, one of the challenges in terms of the research and innovation environment has just been described.

4. "Europe" here refers to EU plus Switzerland, Norway and Iceland.

5. "Certain data included herein are derived from the Science Citation Index Expanded® Social Science Citation Index® and Arts and Humanities Citation Index® prepared by Thomson Reuters®, Philadelphia, Pennsylvania, USA© Copyright Thomson Reuters® 2012. All rights reserved."

6. The Web of Science includes different types of publications. What will be referred to as "article" in this report includes in addition to "article" also the category "notes" in the Web of Science. The categories "note" and "chronology" used prior to 1996 have also been included under the category of "article".

7. The extent to which the nationality of a journal's publisher has any effect on the nationality of the authors contributing articles in the journal is very difficult to judge, but it cannot be ruled out that there is some effect.

8. The original SPRU classification is described in Katz & Hicks (1995). It contained a category "Other" consisting of interdisciplinary journals. Articles in these journals have been distributed among the 13 fields by VR. As new subfields have appeared in the Web of Science, VR has updated the field classification of journals.

9. For the period 2008–2010, 75.5 percent of all articles were classified as belonging to only one major field, 21.0 percent to two major fields, 3.5 percent to three major fields and a negligible share to more than three major fields.

10. The propensity to publish differs between fields. The number of articles published can therefore not directly be used as a measure for comparing the size of the research effort in person-years between fields.

11. Many articles around the world's 10 percent most cited articles have the same number of citations. The dividing line between articles with different citation frequencies does not therefore fall at exactly 10 percent but usually around 8-9 percent. When numbers are given for the share of the world's 10 percent most cited articles, adjustments ("rebasing") have been made to account for the actual "dividing line."

12. Similarly, Karlsson (2010) shows that the main reason Denmark and the Netherlands have improved their citation performance compared to Sweden is that their purely domestic articles have increased their citation rates, while this has not been the case in Sweden.

13. Two different hypothetical explanations will illustrate this point. It has occasionally been argued that the Swedish research system depends too much on PhD students. If this is more the case in Sweden than in Denmark and Switzerland, it could offer a possible an explanation because doctoral student could be expected to be less prone to co-author articles internationally. It has also been suggested that Swedish research projects are often too small to effectively address the complex research questions at the leading edge. If this is really the case, a possible response would be for Swedish researchers to seek collaboration with partners in order to broaden the scope of and total effort expended in their research work. If the partners are primarily sought internationally, the effect would be for international projects to be better able to address pertinent research questions and therefore achieve higher citation rates.

14. The Royal Society (2011) discusses this in great detail.

15. In one sense the percentages of the individual countries are overestimated by the data shown. The reason is that a growing proportion of articles are internationally co-authored. As so-called "whole counts" have been used in this analysis, the co-authored articles are counted for each country appearing on the respective article. The sum of percentages for all of the countries is therefore higher than 100 percent. In the field of engineering the total grew from 108 percent in 1990–1992 to 118 percent in 2008–2010. In Clinical Medicine the corresponding numbers were 113 percent and 147 percent, reflecting a rapid growth in articles with authors from a large number of countries. The relative size of the different countries and the dynamics will, however, only be influenced very marginally by what method of counting is being used.

16. The lowest ranked among the 23 countries in Engineering, Portugal, participates in 1.07 percent of all the top cited articles. In Clinical Medicine India is ranked 23rd and participates in 0.95 percent of the top cited articles.

17. Russia is conspicuous for its relatively low share of publications found among the world's 10 % most cited articles.

18. In addition to Figure 10 see Figure A1.1 in Appendix 1.

19. In this example the analysis is based on all articles rather than only the World's 10 % most cited used previously. Using the latter measure per capita authorship for Sweden is 75 percent higher than that of the USA.

20. The population of Taiwan is very close to that of Australia.

21. Bangladesh, Mongolia and North Korea have been included in the "South-East

and Other Asia" group while Pakistan has been made part of the "Middle East and Central Asia".

22. Looking at all articles regardless of citation level the share is only 0.5 percent on a global level.

23. The slightly higher level for ICT over Engineering is mainly due to Instrumentation being included in the ICT field. Some of the journals in this field report results from high energy physics, a field which tends to have many multi-country articles.

24. The location of CERN in Switzerland is likely to influence the data for physics, but clearly the relative strength of Switzerland is not limited to this field.

25. The total number of top cited articles in Materials Science 2008–2010 was 408 for Switzerland and 312 for Sweden. These numbers are the base for calculating the percentages in Figure 25.

26. Looking at the specific case of USA-China co-authorship there does not seem to be any general trend for the USA to increasingly favor three-continent links. In Materials Science the share of three-continent co-authorship among all USA-China co-authored top-cited articles remained constant at around 10 percent for both 2005–2007 and 2008–2010.

27. At least as far as the fields shown in Figure 31 are concerned.

28. If we, for example, compare Sweden and Baden-Württemberg, which have about the same population, articles co-authored by Baden-Württemberg with other parts of Germany would be considered purely domestic articles as long as other countries are not involved. In the case of Sweden, they would be counted as internationally co-authored.

29. An exception is the country group "Russia & Other Europe," which is expected to have stronger ties with countries in East and Central Europe than with other European countries.

30. Adding the share for the five remaining country groups (Latin America, Africa, Middle East and Central Asia, Russia and Other Europe, South-East Asia & Other Asia) may involve some double counting, but the extent of this is estimated to be very small.

31. The stronger than average links of Germany, Poland, Czech Republic, Austria and Finland with "Russia and Other Europe" is a case where we once again see the effects of geographical proximity, although the share for these countries is still only 1.6 – 2.1 percent. The fact that Portugal's share of articles co-authored with Russia and Other Europe falls in the same range has no obvious explanation.

32. Articles with authors from five or more countries are excluded.

33. The two fields overlap to a considerable extent. For data, see Figure A2.7 in Appendix 2.

34. Journal publications may be less important as a means of communication in the field of ICT compared with many other fields. Conference papers are often said to be more important. This suggests some caution may be needed in interpreting the Sweden's relatively weak publication record in ICT.

35. Share of World Total for individual countries is shown for the same fields in Figures 4 and 6 in Chapter 2.

36. The Rest of the World includes, for example, Turkey, Australia, Iran, Brazil, Malaysia, Egypt, Thailand, Russia, Israel, Mexico, Pakistan, Argentina and New Zealand (Figures 10 and A1.1).

37. Articles with authors from five of more countries have been excluded for reasons explained earlier.

38. Articles with authors from five or more countries have been excluded in calculating the shares.

39. If only highly cited articles are counted, the individual universities' percentages change somewhat. Notably, all the engineering-dominated universities have lower percentages for highly cited articles than for all articles. Higher education institutions other than the top universities when combined are represented in 10 percent of all Swedish articles and in 6 percent of the highly cited ones. The reader should be reminded that some articles have authors from more than one organization in Sweden. The extent of double counting is indicated by the fact that the percentages for the individual organizations and groups of organizations in Figure 62 add up to 135 percent for all articles and 138.5 percent for highly cited articles (not shown in Figure).

40. Stockholm University's relatively high share of articles with authors from five or more countries is mainly due to the university's strong emphasis on extensive multi-country collaboration in the field of physics.

41. Likewise, around one sixth of the articles in ICT are about instrumentation research linked to large-scale, multi-country physics research.

42. This might to some extent and in some cases reflect the fact that the former have placed a higher priority on developing co-operation with local industry and other partners than on expanding their international connections. The situation is likely to differ between individual universities and colleges and requires further study before one can judge whether there is a problem or not.

43. Sandström (2011)

44. The absolute number of publications is shown in Figure A1.5 in Appendix 1.

45. Articles with authors from five or more countries have been excluded in calculating the percentages.

46. Figures 80–85 include also articles with authors from five or more countries, but in the three fields in question, they make up only a small share.

47. The term Engineering-related fields here refers to Engineering+ICT+Materials Science. Earlier in the report, the term also included Chemistry. Chemistry has been excluded here as the number of articles in this field is almost as large as the other fields combined and therefore would dominate the picture too much.

48. The criterion for highly cited articles used in this report is the 10 percent most highly cited articles. If a more severe criterion, say the 1 percent most highly cited articles, is chosen, the relative strength of universities is likely to change towards dominance for leading Western universities.

49. Changes in Sweden's relative position as a producer of scientific research are not the focus of this report. They do, however, influence Sweden's relative position as a partner for international co-authorship. It is therefore considered important to obtain some systematic data on how Sweden has performed relative to other comparable countries. For more details on this analysis, the reader is referred to Appendix 2.

50. Very few of the international postdoctoral grants from The Swedish Research Council during 2010-2012 were for research stays in Asia (The Swedish Research Council, 2012). The same is true for VINNOVA's VINNMER Program.

51. Sandström (2011) provides a detailed account. See also Karlsson (2011).

52. In deriving these conclusions co-authored articles per capita has been used as measure for comparison. On a per capita-basis Sweden, Sweden has a much larger innovation capacity – measured, for example, in industrial R&D-expenditure, patenting or exports of manufactured goods – than Canada or Australia. If this is taken into account, Sweden's exchange in Engineering-related fields would appear even less adequate.

53. National Research Foundation (web site)

54. The need for comprehensive policies to develop exchange with Asian countries appears to be well-recognized and articulated in both Australia and Canada. See for example: Australian Government (2012), Maslen (2012) and Toope (2012).

55. Bouchereau (2012). Among the Asia 6 countries, only China and India are significant participants in FP7.

56. In world rankings of universities by field, Karolinska Institute achieves by far the highest ranking among Swedish universities at places 11and 18 in the ARWU rankings for "Clinical Medicine and Pharmacy" and "Life Sciences & Agriculture" respectively, at place 20 in the QS ranking for "Life Sciences & Medicine" and at place 23 in the THE ranking for "Clinical, Pre-clinical and Health." Other Swedish rankings by subject at places below 50 include Uppsala University at place 34 in the THE ranking for "Life Sciences," The Royal Institute of Technology at place 43 in the QS ranking for "Engineering & Technology" and Stockholm University at place 47 in the ARWU ranking in "Chemistry." In the ARWU and THE overall ranking of universities, Karolinska Institute occupies places 43 and 42 respectively.

57. An adequate assessment of the German research system's global connectivity would need to include not only universities but research institutes as well as the latter play a much larger role in Germany than in Sweden.

58. "Life sciences" in the THE ranking is probably close to "Biomedicine" in the present report. THE has a separate category for "clinical, pre-clinical and health universities."

59. Much the same as has been said about Singapore being globally well-connected can also be said for Australia. There is good reason for Sweden to watch how both Singapore and Australia develop their global research connections in the future.

60. VINNOVA, 2008

61. In 2012 VINNOVA launched a new similar call for proposals for "Strategic internationalization of strong research and innovation milieus".

62. A good example of a forum that has created broad-based contacts between researchers in Sweden and Japan in an emerging field is the Swedish-Japanese Bio-Nano Workshops which have been held on seven occasions since 2002 and have, on the Swedish side, been supported by the Swedish Foundation for Strategic Research (Richter-Dahlfors, 2012).

63. During the period 2008–2012, STINT provided around SEK 12 million to the Swedish side in 41 collaborative research projects between Sweden and South Korea (source: information provided to the author from STINT). The Foundation for Strategic Research (SSF) has announced that it might start funding research collaboration with South Korea in the fields of materials science, ICST (information, communication and systems technology) and bioengineering.

64. As discussed later in this section, Joint Programming Initiatives involve national funding of European co-operation.

65. Tillväxtanalys (2012) discusses some of the issues involved in bilateral joint research funding.

66. VINNOVA, Swedish Energy Agency and the Swedish Foundation for Strategic Research (SSF) are involved in funding research co-operation together with R&D-funding organizations in Japan, China, India, South Korea and Brazil.

67. See e.g. Hellmark Knutsson et al. (2012). OECD (2012) also recommends that "The government should: *Foster international academic openness through stronger inward internationalization*" and "*Make better use of universities' role in hosting foreign students and researchers.*"

68. An example of universities using their institutional funds for active recruitment of foreign students and researchers is the initiative by Stockholm University to allocate SEK 100 million for the recruitment of 25 two-year postdoctoral students and 15–20 guest researchers at a new institute for advanced studies. The initiative also will provide funding for 50 sabbatical semesters abroad for the university's own faculty, give special support to departments that recruit international students and intensify exchange with specially selected partner universities (Stockholm University, 2012).

69. See e.g. (Government of Canada, 2012).

70. According to Internationella Programkontoret (2012), Sweden will accept 2,000 students from Brazil under the program during the period 2013–2014.

71. A joint India-UK program for collaboration in ICT research with total funding of GBP10 million engages a number of universities and companies on each side (EPSRC, 2012). The Danish company Novozymes, a leading producer of industrial enzymes, and the Holck-Larsen Foundation are funding a six-year program for an annual exchange involving around 25 scientists between universities in India and Denmark in the field of industrial biotechnology (Ray, 2012). The Bangalore-Cambridge Innovation Network created to foster links between academics, businesses, researchers and entrepreneurs from both cities was launched in Sept 2012 (The Times of India, 2012). The Swedish security and defense company Saab AB is extending its research collaboration with Swedish universities to leading Brazilian universities by offering scholarships for Brazilian scientists who qualify for grants under the Science Without Boarder program (SAAB, undated).

72. Utbildningsdepartementet (2012).

73. Utbildningsdepartementet (2010 and 2012b); VINNOVA et al. (2011); VINNOVA et al. (2012).

74. Swedish Research Council (2013).

75. Although earmarking in government allocation of budgets to R&D-funding councils and agencies for funding of R&D-co-operation outside Europe has been very rare, one might say that there has been an unspecified expectation on the part of the government that the R&D-funding councils and agencies should use their normal budget for implementing the science and technology agreements which the Swedish government has concluded with several countries, including China and Japan.

76. Source: VINNOVA. According to Statistics Sweden (2012), Swedish universities and colleges in 2011 received SEK 1291 million from the EU in funding for research and development. In addition to the FP7 this also included other EU funding such as from the EU Structural Funds.

77. Andrée et al. (2011) contains data on Swedish funding of the different types of European partnership programs.

78. As an example, Research Councils UK states in its international strategy as the aims of its support for international collaboration: a) increase RCUK influence in international research strategy and policy development; b) provide opportunities for excellent UK researchers to flourish in global research collaborations; c) enhance the value and impact of research through international collaboration; d) show RCUK commitment to key global responsibilities in a world where challenges cross national boundaries (Research Councils UK, 2010).

79. The methodology used by Karlsson and Persson (2012) differs to some extent from the one used in this report and the results are therefore not exactly comparable. Most importantly, the former uses fractionalized data while this study uses "whole counts" and in this Appendix excludes articles with authors from five or more countries. One effect of this difference is probably that internationally co-authored articles have a stronger influence on citation rates in this study.

80. This Appendix is based on data that includes citations in 2011.

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