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AKADEMIRAPPORT

Fostering breakthrough research: A comparative study

Gunnar Öquist och Mats Benner

December 2012

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FÖRORD | FOREWORD

Med tanke på dagens globala utmaningar kan man utan överdrift säga att världen aldrig tidigare har haft så stort behov av banbrytande forskning för att öppna upp för nya lösningar. Det är därför oerhört oroande om svensk forskning trots de betydande nationella satsningar som görs tappar i konkurrenskraft på nivån genombrottsforskning med stort internationellt genomslag. Under 2010 visade Vetenskapsrådet i en rapport ("Den Svenska produktionen av högt citerade vetenskapliga publikationer", SRC 2010) författad av docent Staffan Karlsson, att Sverige har en sämre utveckling på nivån genombrottsforskning än vad som är fallet i Danmark, Nederländerna och Schweiz. Begreppet genombrottsforskning definierades som de 10 procent internationellt mest uppmärksammade vetenskapliga uppsatserna i jämförelse med världsgenomsnittet (Topp 10 index). Det underlag som användes var den databas som tillhandahålls av Thomson Reuter och den definierar cirka 250 ämnesområden. Samtidigt visar olika rapporter att Sverige beträffande medelciteringar hävdar sig relativt väl internationellt. Sverige ligger för närvarande på sjunde plats med en lång rad nationer hack i häl.

Sammantaget innebär detta att svensk forskning håller god klass men att dess internationella betydelse tenderar att försvagas. Utvecklingen oroar. Därför beslutade Kungl. Vetenskapsakademien (KVA) att göra en jämförande analys av forskningssystemen i Sverige och ovanstående länder i syfte att söka identifiera skillnader som kan förklara varför vi i Sverige har en svagare utveckling på

Given the current global challenges, it is no exaggeration to say that the world has never before been in such great need of groundbreaking research to yield new solutions. This makes it extremely worrying if Sweden's competitiveness weakens in terms of breakthrough research with a major international impact, despite the substantial national initiatives under way. In 2010 the Swedish Research Council showed ("Den Svenska produktionen av högt citerade vetenskapliga publikationer", SRC 2010), in a report by Staffan Karlsson of the Swedish Research Council's Department of Research Policy Analysis, that Sweden's production of breakthrough research had fallen below that of Denmark, the Netherlands and Switzerland. 'Breakthrough research' was defined as the 10% of most highly-cited scientific papers worldwide (the top decile of global output by citation rate) compared with the global mean. The documentation used to compile this 'top-decile index' was our database, provided by Thomson Reuters, which defines some 250 subject areas. Nevertheless, various reports show that Sweden is holding its own relatively well internationally in terms of average citation rates: Sweden currently ranks seventh, with a large number of nations close behind.

All in all, this means that Swedish research is maintaining its high quality but that its international importance is tending to decline: a worrying trend. The Royal Swedish Academy of Sciences (KVA) therefore decided to carry out a comparative analysis of research systems in Sweden and the above-mentioned countries, and attempt to identify

kvalitetsnivån definierad som Topp 10 index. Perspektivet var att med ett cirka 20-årigt historiskt perspektiv söka förklaringar till dagens skillnader i forskningens internationella genomslag. I jämförelsen togs, utöver Danmark, Nederländerna och Schweiz, också Finland med. Med detta mål sökte och erhöll KVA medel för utredningen hos Knut och Alice Wallenbergs Stiftelse.

Arbetet påbörjades hösten 2011. Utredningen har genomförts av undertecknade som också står som ansvariga för slutresultatet. Bibliometrin har uppdaterats och fördjupats av docent Staffan Karlsson, Vetenskapsrådet, och professor Olle Persson, Umeå universitet. Bibliometrin publicerades på Vetenskapsrådets hemsida under november 2012. Den bär namnet "The Swedish production of highly cited papers" (SRC 2012a). Bibliometristudien återfinns också som appendix i föreliggande rapport. Bibliometrin har varit en central utgångspunkt för analysarbetet. Under våren insamlades också publicerat faktaunderlag om forskningssystemen i jämförelseländerna. Vidare besöktes referensländerna av undertecknade för intervjuer av personer på departementsnivå och av företrädare för universitet och forskningsfinansiärer. Perspektivet har som nämnts varit att söka förklaringar till dagens situation genom att gå cirka 20 år tillbaka i tiden och då särskilt se på policybeslut tagna på regeringsnivå samt på utvecklingen av universiteten och finansieringssystemen.

I utredningen har vi koncentrerat oss på forskningens villkor och kvalité. Även om vi är väl medvetna om att utbildning på olika nivåer också påverkar ett lands förutsättningar för forskning på längre sikt, har tiden och resurserna inte räckt till för att också beakta dessa frågor i en jämförande analys länder emellan. Vi har heller inte beaktat den effekt som doktorandutbildningens kraftiga expansion under 90-talet har haft på forskningens utveckling och kvalité, då expansionen varit rätt så likartad i Sverige och i jämförelseländerna. Eventuella skillnader i administration har inte heller beaktats i utredningen.

differences that may explain why this country is performing less well at the quality level defined by the 'top-decile index' described above. Our approach is to seek, in a historical perspective of some 20 years, explanations for present-day disparities in international research impact. The comparison includes Finland, as well as Denmark, the Netherlands and Switzerland. With this aim, KVA applied for and received funding for the study from the Knut and Alice Wallenberg Foundation.

Work began in autumn 2011. The survey was conducted by the undersigned, who also bear responsibility for the final result. Docent Staffan Karlsson of the Swedish Research Council and Professor Olle Persson of Umeå University updated and extended the bibliometric data. This bibliometric study, published on the Council's website in November 2012 with the title *The Swedish production of highly cited papers* (*Vetenskapsrådets lilla rapportserie* 5:2012) is annexed to the present report. Bibliometrics has been a crucial starting point for the analysis. During the spring, published factual information was collected about the research systems in the countries selected for comparison. The undersigned also visited these reference countries to interview people in the ministries concerned and representatives of universities and research funders. As mentioned above, the aim was to seek explanations for the current situation by going some 20 years back in time and examining, in particular, policy decisions taken at government level and developments relating to the universities and funding systems.

Our work has been concentrated on the conditions for high-quality research. We are well aware of the close relationship between education (on different levels) and research, but time and resources have not allowed us to penetrate this relationship in the different countries in more detail. Nor have we ananalysed in greater detail the impact of the expansion of PhD training in the 1990s, as this has been a common feature for all the countries under scrutiny. Neither have differences in administration been considered in this study.

Vid vår sida har vi haft en analysgrupp bestående av ledande företrädare för forskning i jämförelseländerna. Ledamöterna har utsetts av respektive lands vetenskapsakademi. Analysgruppen har kompletterats av framstående svenska forskare och har haft två sammanträden. Det första mötet hölls 12–13 januari 2012 för att analysera bibliometrin och för att dra upp riktlinjerna för det fortsatta arbetet. Ett andra möte hölls den 6–7 september 2012, där insamlat material analyserades ingående i syfte att söka förklaringar till forskningssystemens utveckling över tiden i Sverige och i jämförelseländerna. Fokus låg på att söka förklara varför vi i Sverige trots att vi hävdar oss relativt väl på nivån medelciteringar tappar konkurrenskraft på nivån publicering med stort internationellt genomslag, definierat som Topp 10 index. En hearing, där utredningens slutsatser presenterades och diskuterades med företrädare för svensk forskning, hölls också på KVA den 8 november, 2012.

Analysgruppen har bestått av följande personer: Thierry Courvoisier, Schweiz, Ole Fejerskov, Danmark, Eila Helander, Finland och Jos van der Meer, Nederländerna, samt Christian Broberger, Gunnar von Heijne, Arne V. Johansson, Anna-Karin Tornberg och Barbro Åsman, alla från Sverige.

Rapporten är skriven på engelska med en svensk sammanfattning. Orsaken till detta är att också jämförelseländerna skall kunna ta del av resultatet. Det ger också en möjlighet för KVA att bidra till den internationella diskussionen kring vad som krävs för att skapa framgångsrik forskning av genombrottskaraktär. Det är vår förhoppning att denna rapport skall bidra till en fördjupad dialog, och resultera i konkreta åtgärder i syfte att stärka förnyelsepotentialen i svensk forskning och därmed ge Sverige en än mer framträdande ställning som internationellt ledande kunskapsnation.

Vi riktar ett varmt tack till Staffan Karlsson och Olle Persson, som med stor kompetens för uppgiften svarat för bibliometriarbetet. Ett varmt tack går också till medlemmarna av analysgruppen, som med stor entusiasm och engagemang bidragit

For our part, we have had an Analysis Group comprising leading representatives of research in the reference countries. The group members, each appointed by their respective country's Academy of Sciences, were supplemented by leading Swedish researchers. The Analysis Group has met twice. The first meeting was held on 12–13 January 2012 to analyse the bibliometric data and draw up guidelines for subsequent work. At the second meeting, on 6–7 September 2012, the group analysed material collected with a view to finding explanations for the trends with reference to the research systems in Sweden and the other countries over time. The focus was on attempting to explain why Sweden, although holding its own relatively well in terms of mean citation rates, is losing competitiveness at the level of publications with a major international impact as defined by the 'top-decile index'. A hearing was also held on 8 November 2012, with representatives of the Swedish research system, when the main conclusions of the report were presented and discussed.

The Analysis Group members were Thierry Courvoisier from Switzerland, Ole Fejerskov from Denmark, Eila Helander from Finland, Jos van der Meer from the Netherlands, and Christian Broberger, Gunnar von Heijne, Arne V. Johansson, Anna-Karin Tornberg and Barbro Åsman, all from Sweden.

The report was written in English with a Swedish summary, to make the results accessible to the reference countries. This also gives KVA an opportunity to contribute to international discussions about the requisites for successful research of a breakthrough nature. Our hope is that this report will foster a more profound dialogue and culminate in practical measures to boost the potential for renewal in Swedish research, thereby giving Sweden an even more prominent position as a world-leading nation in terms of knowledge.

We owe a debt of gratitude and appreciation to Staffan Karlsson and Olle Persson, who tackled the bibliometric work with great specialist proficiency. Hearty thanks also go to the members of the

med sina erfarenheter och kompetenser, och till Julia Holmvik som skött alla praktiska frågor. Vi riktar också ett varmt tack till alla som bidragit som uppgiftslämnare och tålamodigt svarat på våra frågor (cirka 40 intervjuer har genomförts), och inte minst de som läst och kommenterat våra texter. Till sist tackar vi också Knut och Alice Wallenbergs Stiftelse som finansierat utredningen och Kungl. Vetenskapsakademien som anförtrott oss uppgiften.

Umeå och Lund den 15 november, 2012

Gunnar Öquist
Ordförande

Mats Benner
Huvudsekreterare

Analysis Group, who shared their experience and skills with keen enthusiasm and commitmentand, to Julia Holmvikt who cared for all practical matters. We cordially thank, too, all those who provided information and patiently answered our questions (in total about 40 interviews). Finally, we would like to express our thanks to the Knut and Alice Wallenberg Foundation for funding this survey and the Royal Swedish Academy of Sciences for entrusting the task to us.

Umeå and Lund, 15 November 2012

Gunnar Öquist
Chairman

Mats Benner
Principal Secretary

Professor Gunnar Öquist var professor vid Institutionen för fysiologisk botanik, Umeå universitet, 1981–2003. Han var generalsekreterare för Naturvetenskapliga forskningsrådet 1993–1999, och ständig sekreterare för Kungl. Vetenskapsakademien 2003–2010. Han har varit styrelseledamot i European Science Foundation och European Research Advisory Board. Professor Öquist har suttit i styrelserna för många forskningsfinansiärer och universitet, och har lett flera nationella och internationella granskningar av vetenskap och forskning.

Professor Mats Benner är vicedekan för Ekonomihögskolan vid Lunds universitet och professor i forskningspolitik. Han har en omfattande publicering inom utformning och implementering av forskningspolitik och har deltagit i många utvärderingar av forskningsfinansiärer och universitet.

Professor Gunnar Öquist has been professor at the Department of Plant Physiology, Umeå University, 1981–2003. He was the Secretary General of the Swedish Natural Science Research Council 1993–1999, and Permanent Secretary of the Royal Swedish Academy of Sciences 2003–2010. He has been member of the Board of the European Science Foundation and the European Research Advisory Board. Professor Öquist has also served on boards of research funding organizations and universities and he has lead several national and international reviews of science and research.

Professor Mats Benner is a vice dean (research) at the Lund University School of Economics and Management and a professor in science policy studies. He has written extensively on science policy formation and implementation and has participated in several evaluations of funding organizations and universities.

SAMMANFATTNING | SUMMARY

Målsättningen med studien har varit att förklara varför Sverige under de senaste 20 åren har haft en svagare utveckling av forskning med stort internationellt genomslag än vad som är fallet i Danmark, Nederländerna och Schweiz. I dag ligger Sverige 15 % över världsgenomsnittet vad gäller de 10 % mest citerade publikationerna medan Danmark och Nederländerna ligger 35 % över och Schweiz hela 40 % över. Finland å sin sida ligger 5 % över världsgenomsnittet ("The Swedish production of highly cited papers", Vetenskapsrådets lilla rapportserie 5:2012). Vidare visar bibliometrin att kategorin unga forskare som tillkommit under senare år och som presterar på nivån högt citerade mätt som Topp 10 index är lägre i Sverige än i Danmark, Nederländerna och Schweiz. Skillnaden mellan länderna kan inte förklaras med andelen publikationer som aldrig citeras, med olika balans mellan ämnesområden med olika publiceringstraditioner, med olika grad av internationellt samarbete och med olika grad av självciteringar.

Vad motverkar forskningens kvalitetsutveckling i Sverige?

Först kan man ställa sig frågan om det är viktigt för en mindre nation som Sverige att jämföra sig med de mest framträdande nationerna när det gäller att bidra till den mest banbrytande forskningen. Kanske

The study has sought to explain why, over the past 20 years, Sweden's research with a major international impact has undergone a relative decline compared with that of Denmark, the Netherlands and Switzerland. Today, Sweden exceeds the world average for the 10% most highly cited publications (the top decile) by 15%, while the figures for Denmark and the Netherlands are 35%, and for Switzerland as much as 40% above. Finland, on the other hand, achieves 5% above the global mean ("The Swedish production of highly cited papers", *Vetenskapsrådets lilla rapportserie* 5:2012). Bibliometrics also shows that the category of young researchers starting their careers during the last years who have performed at the 'highly cited' level, defined as being in the 'top-decile index', is lower in Sweden than in Denmark, the Netherlands and Switzerland. The difference between countries cannot be explained by the proportion of publications that are never cited, variations in the balance among subjects with differing publication traditions, different degrees of international collaboration or varying rates of self-citation.

Counteracting the relative decline

First, one may ask whether it is important for a small nation like Sweden to compare itself with the most outstanding nations regarding their contributions to the most groundbreaking research. Perhaps,

strategin i stället skall vara att låta andra nationer göra grovarbetet och sedan dra nytta av detta i "efterföljarforskning" och teknisk utveckling fokuserad på landets intressen mätt i termer av ekonomisk avkastning? Den strategin är emellertid vansklig eftersom den uppenbara risken är att nationen då dräneras på sitt intellektuella kapital, både genom att de mest framstående forskarna flyttar utomlands till mera vetenskapligt utmanande miljöer och genom att det blir svårt att rekrytera framstående forskare på den globala marknaden. Vidare skulle en sådan utveckling innebära att nationen sannolikt skulle bli mindre intressant för framtida investeringar i en alltmera kunskapsbaserad industri. En nation som inte ger sitt bidrag till den mera banbrytande forskningen kommer också att bli marginaliserad då det gäller att ta fram nya lösningar för ett i längden hållbart samhälle.

Vetenskapsrådets bibliometriska rapport är därför en larmklocka som måste tas på allvar om Sverige skall förbli en forskningsnation i den högsta divisionen. Att orientera om svensk forskning så att den blir mera banbrytande måste bygga på en stark betoning av akademisk excellens med korrektiva åtgärder på olika plan.

Vår utgångspunkt för att förklara varför Sverige har en förhållandevis svag utveckling på nivån genombrottsforskning är att söka på tre nivåer:

- prioriteringar på nationell nivå,
- styrning och finansiering av forskning,
- finansiering, ledning och organisering av universiteten, inklusive rekrytering

De skillnader som särskilt framträder när vi jämför utvecklingen av forskningssystemen i Sverige (och Finland) med de mera framstående jämförelseländerna Danmark, Nederländerna och Schweiz är följande:

- Medan utbildning och forskning förenar alla universitet noteras att Sverige avviker från de mera framgångsrika jämförelseländerna genom att på samma nivå betona samverkan med

instead, the strategy should be to let others do the spadework and then benefit by way of 'successor research' and technical development focusing on national interests, measured in terms of financial yield. However, this strategy is a tricky one, owing to the obvious risk of a brain drain. Sweden might be drained of its intellectual capital both by leading researchers moving abroad to more academically challenging environments and because recruiting prominent researchers on the global market might be difficult. Such a development would also probably make the nation less attractive for future investments in an increasingly knowledge-based industrial sector. A nation that fails to make its contribution to groundbreaking research will also become marginalised in terms of coming up with new ways of bringing about a sustainable society in the long term.

The Swedish Research Council's bibliometric report is therefore a warning bell. It must be taken seriously if Sweden is to remain a research nation in the top division. Reorienting Swedish research in a more pioneering direction must build on a strong emphasis on academic excellence, with corrective measures at various levels.

Our points of departure for explaining why Sweden's trend of breakthrough research is relatively slack are threefold:

- priority-setting at national level
- direction and funding of research
- governance of universities

The most salient differences that emerge when we compare the development of Sweden's (and Finland's) research systems with the more outstanding reference countries — Denmark, the Netherlands and Switzerland ('DN&S') — are as follows:

- While all universities have education and research in common, Sweden deviates notably from these more successful reference countries by giving equal emphasis to collaboration with

omgivande samhälle och näringsliv. Sådan samverkan är förvisso viktig, och även av betydelse i de mera framgångsrika länderna men det är inte ett primärt mål för alla typer av universitet och akademiska miljöer. Skillnaden understryks också av att Sverige har betydande inslag av s.k. sektorsforskning inom det akademiska systemet, där relevansen ofta sätts före vetenskaplig kvalité. Den nationella policy som vuxit fram för svensk universitetsforskning har därför svagare fokus på kvalitetsnivån banbrytande forskning än vad vi ser i de mera framgångsrika jämförelseländerna.

- I de mera framgångsrika jämförelseländerna Danmark, Nederländerna och Schweiz förfogar universiteten över merparten av resurserna för forskning medan externa finansiärer står för merparten av forskningsfinansieringen i Finland och Sverige. Därmed får externa finansiärer med olika mål och medel en förhållandevis starkt styrande effekt på forskningens inriktning. Universitetens egna prioriteringar kommer i bakgrunden och fokus läggs på hur medel skall erhållas snarare än på vilken forskning som skall prioriteras. Vidare är det uppenbart att de betydande resurser som tillkommit efter nerdragningen av forskningsresurserna på 90-talet har avsett stora miljöer, nätverk och strategiska områden medan stödet till individer med nya idéer fått allt mindre utrymme. Samma utveckling ser vi i Finland medan de mera framgångsrika jämförelseländerna, även om de också gjort betydande strategiska satsningar, inte gjort dessa på bekostnad av de individuella stöden.

- De mera framgångsrika universiteten i jämförelseländerna har utvecklat system för en rigorös, egen kvalitetskontroll som underlag för fördelning av fakultetsresurser. I Sverige ser vi inte samma utveckling, utan här förlitar man sig i stort sett på de bedömningar som görs av externa finansiärer och i många fall fördelas fakultetsresurserna i relation till förmågan att dra in externa resurser snarare än på en

the local community and business sector. This kind of collaboration is indeed important; it matters in DN&S too but is not a primary objective. The difference is also underlined by the fact that Sweden's academic system contains a substantial element of 'sectoral research', where relevance often takes precedence over academic quality. The national policy that has emerged for Swedish university research therefore has a weaker focus on the quality level of groundbreaking research than we see in DN&S.

- In DN&S, the universities have most of the resources for research at their own disposal. In Finland and Sweden, in contrast, external funders provide the bulk of research funding and thus, with various aims and by different means, exert relatively strong control over the direction of research. The universities' own priorities are therefore overshadowed and emphasis is laid on how to obtain funding rather than which research priorities to select. Moreover, the substantial resources that have been added since the cuts in research resources of the 1990s have clearly related to large environments, networks and strategic areas, while the scope for supporting individuals with new ideas has steadily decreased. We see the same trend in Finland, while DN&S, although they too have made substantial strategic investments, have not done so at the expense of grants for individuals.

- The more successful universities in the reference countries have developed systems of rigorous in-house quality control as the basis for distributing faculty resources. In Sweden, this trend is not discernible: here, broadly speaking, dependence on the assessments carried out by external funders prevails. In many cases, too, faculty resources are distributed in relation to the universities' capacity to attract external funding, rather than being based on an independent appraisal of academic quality. What is more, as the universities' own resources

självständig bedömning av vetenskaplig kvalité. Det är vidare uppenbart att i takt med att universitetens egna resurser urholkats så har också universitetsledningarna förändrats mot att administrera ett konglomerat av uppgifter ("management") snarare än att utöva ett tydligt, och för framstående forskning legitimt, akademiskt ledarskap som främst syftar till vetenskaplig förnyelse ("leadership"). Som kontrast betonar de mera framgångsrika universiteten i jämförelseländerna det akademiska ledarskapet, vars främsta uppgift är att genom rekrytering stärka kvalitén i utbildning och forskning. Därmed läggs starkt fokus på att skapa miljöer för banbrytande forskning.

- En annan alarmerande och välkänd brist i det svenska forskningssystemet är avsaknaden av tydliga karriärvägar och bra villkor för unga forskare inom svenska universitet. I dag är de flesta för sin karriär helt beroende av fluktuerande externa finansiärer och beroendet sprider sig även bland mera seniora forskare med fakultetstjänster. Särskilt Schweiz och Nederländerna utmärker sig genom att ha väl utformade "tenure-track"-anställningar för unga forskare som dessutom får god basfinansiering för sin forskning. Till skillnad från svenska universitet avstår också de mera framstående universiteten i jämförelseländerna helt från att inrätta fakultetstjänster med externa medel.

Slutsatsen är att trots att Sverige utmärker sig genom att ge förhållandevis generösa budgetvillkor för forskning så presterar inte de svenska universiteten på samma nivå som universiteten i de mera framgångsrika jämförelseländerna. Som framhålls beror detta på en rad orsaker som närmst är av systemkaraktär och som bygger på policybeslut på nationell nivå, på finansieringssystemens utveckling och på universitetsledningar som inte med tillräcklig kraft byggd på akademisk legitimitet ges möjlighet att prioritera mot vetenskaplig kvalité på högsta nivå. En starkt bidragande orsak är det stora beroendet av extern finansiering. Universiteten som forskarhotell är i dag en realitet.

have been eroded it is evident that their leaders' work has also changed towards administering assorted functions (management), rather than exercising genuine academic authority aimed mainly at academic renewal (leadership). By contrast, the more successful universities in the reference countries emphasise academic leadership, whose principal function is to strengthen quality in education and research through recruitment. By the same token, they lay great emphasis on creating environments for groundbreaking research.

- Another alarming and well-known shortcoming of the Swedish research system is the universities' documented inability to provide clear career paths and good conditions for young researchers. Today, most academics depend for their careers entirely on fluctuating contributions from external funders, and this dependence is also spreading among senior researchers with faculty positions. Switzerland and the Netherlands, in particular, are distinguished by having appropriate tenure-track positions for young researchers, who also receive good basic funding for their work. Moreover, unlike Swedish universities, the more outstanding universities in the reference countries refrain entirely from setting up faculty positions with external funds.

The conclusion is that, although Sweden distinguishes itself by applying relatively generous budget conditions to research, the Swedish universities do not perform at the same level as the universities in the more successful reference countries. As argued above, this is due to a range of reasons that are virtually systemic in nature, based on policy decisions at national level; on the ways in which the funding systems have developed; and on university managements capable, with sufficient strength based on academic legitimacy, of steering priorities towards top academic quality. One highly significant reason for this is the heavy dependence on external funding. In Sweden today, universities acting as 'research hotels' is a reality.

Förslag till åtgärder för att stärka kvalitén i svensk forskning

Vad vi kan lära oss av Danmark, Nederländerna och Schweiz är att vetenskaplig kvalité främjas genom stabilitet och långsiktighet beträffande nationell policy för finansiering, och ett akademiskt ledarskap som målmedvetet och med fast hand styr mot kvalité med högt ställda internationella krav. Särskilt viktigt är att finansieringen tillgodoser inte bara strategiska behov utan att den primärt ger bra stöd till individer med nya idéer. Framgångsrika universitet tar ett särskilt ansvar för rekrytering med högt ställda krav på kvalité och att tillhandahålla bra karriärvillkor för unga forskare. För att ett universitet skall kunna ta ett större egenansvar för sin kvalitetsutveckling tyder våra jämförande observationer att kvoten egenfinansiering/extern finansiering måste ligga på lägst nivån 60/40 .

Vi föreslår följande åtgärder:

- Forskningspolitiska beslut och avtalsmässiga regleringar med betydelse för universiteten skall vägledas av målet att minst säkerställa men framför allt att höja kvalitén på svensk forskning.

- Stärkt nationell finansiering av individer med nya, djärva idéer för att skapa en bättre balans till olika strategiska satsningar.

- Betona särskilt betydelsen av ett akademiskt ledarskap präglat av hög akademisk legitimitet och djärva visioner vid val av ledare på olika nivåer.

- Tillämpa ett transparent och ansvarigt styrsystem där externt dominerade styrelser hanterar ramvillkoren medan akademiska senater fungerar som beslutsfora för inomakademiska angelägenheter.

- Återinför ett system med fakultetstjänster för professorer och lektorer med full lön och med basfinansiering som möjliggör riskfylld,

Proposed measures to boost quality in Swedish research

What we can learn from Denmark, the Netherlands and Switzerland is that scientific quality is promoted by stability and a long-term approach when it comes to national policy for funding, and by academic leaders who single-mindedly and firmly pursue quality to meet stringent international requirements. It is especially important for funding not only to meet strategic needs but primarily to provide good support for individuals with new ideas. Successful universities take particular responsibility for recruitment of a high quality standard and for providing favourable career conditions for young researchers. For a university to be capable of assuming more responsibility for its own quality development, our comparative observations indicate that its ratio of in-house to external funding must be at least 60/40.

We propose the following measures:

- Policy decisions about research, and labour market agreements, should be guided by the aim of preserving, but first of all, by strengthening the quality of Swedish research.

- Reinforcing national funding of individuals with bold new ideas, to create a better balance for various strategic initiatives.

- Laying special emphasis on recruiting leaders at different levels with strong academic identities and bold visions.

- A transparent and responsible governance structure should be applied. This would involve boards with external representatives setting planning frames and articulating goals for delivering quality, while leaving academic priorities in the charge of relatively small academic senates.

- Reintroducing a system of faculty positions for professors and lecturers, with full salaries and

långsiktig forskning. Ett första steg är att identifiera fakultetens ledande forskare och genom kontrakt ge dem denna status. Fakultetstjänster inrättas inom de områden där universiteten vill vara forskningsledande och vid nyrekrytering söks tjänsterna i konkurrens.

- Etablera ett "tenure-track"-system för unga forskare med basfinansiering på en för ämnet relevant nivå. Den höga angelägenhetsgraden motiverar inledningsvis ett nationellt system som sköts av Vetenskapsrådet i samverkan med universiteten, förslagsvis efter nederländsk modell.

- Rekrytera med internationell öppenhet till fakultetstjänster oavsett nivå. För att nå framgång är det angeläget att de villkor som erbjuds är internationellt konkurrenskraftiga. Lägg vikt vid att genom rekrytering skapa miljöer med komplementära kompetenser. Lägg också vikt vid mobilitet för att motverka vetenskaplig inavel.

- Använd "peer review" för regelbunden (förslagsvis vart 5:e år) kvalitetskontroll på institutionsnivå och som vägledning vid fördelning av individuella basresurser för forskning till dem som har tillsvidareförordnanden på fakultetstjänst (professor/lektor).

- Forskningsråden upphör med att på projektbasis bevilja lönemedel till fakultetens karriärtjänster och fakultetsprofessorer/fakultetslektorer.

- Externa finansiärer förväntas ta hela löneansvaret för de forskare som inte har fakultetstjänster erhållna i konkurrens.

- Det sammanhållna universitetssystemet måste brytas upp för att möjliggöra forskningsintensiva universitet som håller högsta internationella standard och som är finansierade och styrda för att göra detta möjligt. Sådana universitet skall kunna ge ett adekvat basstöd

also basic funding that permits risky long-term research. An initial step is to identify the faculties' leading researchers and confer status by contract. Faculty positions should be set up in the areas where universities seek to lead research, and at the time of recruitment these positions should be applied for on a competitive basis.

- Establishing a tenure-track system, with basic funding at relevant levels for the various subjects. The high degree of urgency initially prompts a national system administered by the Swedish Research Council in tandem with the universities, according to the Dutch model.

- Recruiting internationally for faculty positions, irrespective of level. To achieve success, it is vital for the conditions offered to be internationally competitive. Weight should be given to using recruitment to create environments with complementary skills, and also to the need for mobility to counteract academic 'inbreeding'.

- Using peer review for regular quality control (every five years is recommended) at department level and to guide distribution of basic research resources for tenured professors at various levels.

- The research councils should stop approving salary funding on a project basis for faculty career positions and for professors and lecturers belonging to faculties.

- External funders are expected to assume full responsibility for funding the salaries of researchers who lack faculty positions obtained in competition.

- The unified university system should be unlocked, to foster research-intensive universities of the highest international standard, funded and governed accordingly. Such universities should primarily in tandem with competitive

för forskning, vilket kompletteras med medel sökta i konkurrens hos forskningsråd och stiftelser, i syfte att skapa internationellt attraktiva miljöer.

★ Dessa forskningsintensiva universitet bör bilda en association efter modell av den brittiska organisationen "The Russell Group" för att verka för bästa möjliga villkor för genombrottsforskning i Sverige.

Ovanstående förslag till åtgärder genomförs inte i en handvändning. De innebär ett djupgående systemskifte och det är tveksamt om universiteten klarar av detta på egen hand. Regeringen måste därför vara beredd att ge riktade, ekonomiska stöd för förändringsarbetet med målet att kvoten egenfinansiering/extern finansiering inte underskrider 60/40. Det är angeläget att de förstärkningar till universiteten som föreslås i den senaste forskningspropositionen riktas mot att påbörja förändringar i den riktning som föreslås. Internationella erfarenheter visar att om en reformering av universitetens forskning sker enligt nämnda principer så kan ett universitet under en 10-årsperiod påtagligt nå betydande framsteg och till och med nå en internationell topposition.

research council and foundation support rely on their own resources, in tandem with research council support, in accomplishing research environments of international attractiveness.

★ Such research-intensive universities should form an organization, modelled after the UK Russell Group, to advocate for the best possible conditions for high-quality research in Sweden

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The above proposals cannot be implemented overnight. They represent a profound systemic shift and whether the universities can achieve this unaided is doubtful. The Government must therefore be prepared to provide specific financial support for reform aimed at ensuring that the ratio of in-house to external funding does not fall below 60/40. It is urgent to use the suggested increase of university funding in the latest research bill to initiate the reforms suggested in this report. International experience shows that if university research is reformed according to the aforesaid principles, over a ten-year period a university can make striking and substantial progress, and even reach a leading international position.

Introduction

Why has Swedish research shown a trend of relative decline at the international breakthrough level over the past 20 years? With this relative weakness, Sweden's research stands in contrast to that of other European countries of roughly similar size and with similar aspirations to be leading knowledge-based societies or economies (Denmark, Switzerland and the Netherlands). This report compares research governance at government, university and national funding levels, identifying factors that may explain the divergent trends.

Two aims underlie the study: to elucidate generally which conditions are conducive to high-quality research, and to explain specifically why some nations are more successful than others in producing scientific papers of exceptionally high impact. Our assumption is that variations in research excellence — as measured in countries' shares of highly cited papers (and other quality measures) — may be associated with governance of research, ranging from conditions for individual researchers to national funding and organisation of research. Accordingly, we have looked for systemic differences in the reference countries' research governance and reasons why such variations have led to disparities in the quality of research itself. We hope that the conclusions and recommendations derived from this comparative study will provide some useful, evidence-based guidelines on how to foster research of the highest quality characterised by high impact on science and society.

Our starting point was a series of bibliometric studies conducted by the Swedish Research Council (e.g. SRC 2010) that indicated falling shares of high-impact Swedish research, while other nations (in particular Denmark, the Netherlands and Switzerland) appeared to be maintaining or even increasing their shares of highly cited publications. Similarly, we find bibliometric evidence that renewal among Swedish researchers in selected areas has fallen behind those of comparable nations. Other nations — again, notably Denmark, the Netherlands and Switzerland — have been far more successful in fostering new generations of researchers who produce high-impact publications. In Sweden, these new generations have thus failed to maintain the impact of their predecessors.

For this report, the aforesaid bibliometric studies have been updated and extended by the Swedish Research Council, SRC. The Nordic funding agency NordForsk has also recently carried out a bibliometric comparison of the Nordic countries that supports the observations outlined above (Nordforsk 2011). The latest SRC study is annexed to this report. It contains the core data for our analysis of why Swedish research, at the high-impact

level, is falling behind some more successful European nations. This study can also be downloaded from the SRC webpage. At a more aggregate level, bibliometric studies of European universities confirm the finding in the most recent (2012) Leiden Ranking that Swedish research has a relatively meagre impact in terms of its share of the top 10% (decile) of publications.

All these observations prompt us to consider conditions for high-impact research in Sweden and possible explanations for the laggard performance of Swedish research. We should not, of course, disregard the relatively healthy status of Swedish research on an aggregate level, where Sweden is currently among the world's top ten countries in terms of overall citation impact. The disaggregated figures for top publications are what gives cause for some alarm.

Whether the citation rate, measuring international recognition (or impact) of research results, is a good indicator of research quality is debatable. Examples of other variables that may be considered in the context of defining quality of research performance are numbers of PhDs obtained, how far an environment is conducive to postdoctoral education, the number and size of research grants and other awards provided, and regional and national impact in economic or social terms. However, the steadily growing demand for international dissemination of research results and differing degrees of international recognition that publications receive, reflected in varying scientific or social impact, lead us to believe that the aggregate citation analyses used in this study are indeed a prime indicator of research quality. This applies especially with reference to changes over time and to the emphasis laid on education and research for wealth creation in countries of roughly comparable size.

Another question is whether the databases used do justice to all research fields. Traditions for dissemination of research results vary. The humanities, social sciences, engineering and mathematics are examples of fields that may be disfavoured in bibliometric studies compared with the natural sciences and medicine, both of which have a tradition of more standardised and easily accessible channels for international publication. However, such pitfalls should have been largely avoided in this study, where comparative studies in defined fields have been carried out on the assumption that the publication strategies within these fields are broadly similar in Sweden and the reference nations.

A caveat should be stated. We are aware of the potentially negative effects on research at the high-quality breakthrough level of the increasing use of worldwide publication impact analyses at the individual level. It is highly likely that the rising international use of these analyses in staff recruitment and promotion and in distribution of research grants brings about relatively safe but highly productive, incremental research in line with established paradigms. This happens at the expense of more challenging but riskier groundbreaking research that is more time-consuming, and therefore less productive in the short to medium term. Moreover, the increasing demand for publication in high-impact journals also places growing pressure on young scientists that may jeopardise their willingness to pursue a scientific career, thus impairing the quality of future recruitment (Marder et al. 2010).

The present report is part of the involvement of the Royal Swedish Academy of Sciences in conditions of top-level, breakthrough research, as part of the renewal of research as such, but also of society in a wider and more inclusive sense. The Academy has made several efforts,

on which this report builds and extends, to highlight conditions for high-quality research. In 2010, the Academy's Strategic Research Committee published 'Universities and Research: Challenges and Problems' (KVA 2010). This report focused on organisation and resources for research, with a particular emphasis on how to create research environments suitable both for long-term basic research and for more targeted and strategic research aimed at more or less well-defined deliverables. The report (which can be downloaded from the Academy's website), highlights three challenges for universities:

1) The rapid increase in undergraduate education without adequate funding: in many cases, this has brought about increasing separation of education from research.

2) The ongoing shift towards more strategic research with more utilitarian aims and the increase in short-term external funding have emphasised productivity and measurable deliverables in the short to medium term: this shift has weakened the sector's more challenging, investigator-driven basic research, which calls for a longer-term view.

3) Although external funding from the Swedish Research Council has enhanced research quality, the rapid rise in external funding of university research motivated by strategic and utilitarian considerations has made the universities financially unstable, thus hampering their long-term planning.

The report recommended that the Swedish research universities take the following steps to improve conditions for research with a variety of goals and time frames:

a) give the universities more independence from government regulations and thus greater freedom to formulate and implement long-term strategies;

b) secure the universities' long-term block funding for core, basic research and develop new association forms for externally funded research units (such as research centres) that facilitate inclusion of successful activities after research programmes end;

c) develop more efficient administration systems for four operational sectors: undergraduate education, independent long-term academic research prioritised by the university, externally financed, targeted research and externally funded commercialisation;

d) establish internationally attractive research chairs and increase researchers' national and international mobility;

e) handle issues of intellectual property rights (IPR) more professionally.

Recent reviews in Finland propose changes in funding organisation and conduct of research to strengthen the quality and international impact of national research. We have used other European countries' reports of a similar kind to inform our work.

Throughout the ongoing process of Horizon 2020, the next EU Framework Programme

for Research and Innovation, there is also a clear focus on frontier research of the highest quality, as supported by the European Research Council. The ERC, which has become a huge policy success, has triggered a reorientation in many European nations and universities. They have recalibrated their activities and devised more transparent career systems and recruitment patterns — the very idea underlying the ERC. This underlines the growing international awareness of the need to support research of the highest quality that opens up new frontiers of knowledge. In line with this trend, the Danish EU Conference *Excellence 2012* emphasises requirements for attaining top quality in research and innovation. It requires confidence and freedom, long-term perspectives, creative and dynamic research environments, interactions beyond and across disciplines, recognition and nurture of talent, and state-of-the-art technologies.

Another factor underlying the achievement of excellence has a different set of motives. The research assessment exercises initiated in the UK in 1986 have since been taken up in the Netherlands and Finland among our reference countries (Sweden is due to introduce such a system in 2018). These assessments are part of a New Public Management model of governing public organisations, and may thus be seen as instances of an 'instrumentalisation' of science. The overall conclusion is that such schemes have contributed positively to quality control by redirecting resources towards more viable areas and environments (Geuna & Martin 2003). However, evidence from the UK and the Netherlands suggests that, to maximise their efficacy, such assessments must be supplemented by generous support of investigator-initiated projects and career development.

While our study focuses on research excellence, it fully recognises the dual nature of academic research as both a tool for incremental problem-solving within the basic knowledge framework and a way of seeking breakthroughs that generate new, unforeseen opportunities. It is vital for us, in our work, to avoid placing basic research in opposition to targeted (strategic or applied) research. Neither can excel without being underpinned by the other. Our assumption is that we need to strengthen not only basic research, but also targeted and also more applied research and innovation at the most challenging level. The focus must be on developing research and innovation systems that, irrespective of goals or time frames, are capable of being more creative and producing more groundbreaking results with far-reaching implications.

This emphasis on groundbreaking research and innovation is prompted both by global environmental challenges and by the need to secure economic growth and improved health worldwide. We need to sharpen research as an instrument for achieving new discoveries and understanding that will yield innovations of a technical or social nature. Societies in which inventiveness flourishes point the way to the future (Homer-Dixon, 2000).

In summary, the aim of this review is to identify, by comparative means, differences in national research systems that may explain why Sweden is steadily losing ground at the level of pioneering, high-impact research, compared with leading European nations. Based on this assessment, we also seek to recommend steps to be taken by the government, universities and funding organisations to reverse the present trend and make Sweden more competitive in the high-impact segment of research. On a more general level, we discuss the relationships between policy, organisation and quality in research in different national contexts.

Analysing research quality

Although many factors impact (directly or indirectly) on research performance, we should at least be able to pinpoint the factors that favour high-quality research and may serve to explain the above-mentioned countries' divergent patterns of research performance, as revealed by the bibliometric data.

Preconditions for breakthroughs in research have attracted increasing interest in science studies. Regarding individuals, studies of research breakthroughs have highlighted the significance of socialisation in creative environments, from elementary school on. Hence, individuals' research accomplishments partly depend on the social conditions surrounding them (Törnqvist 2009). Tentative results at research-group level indicate that high-quality research is the outcome of interaction among several factors, especially a combination of intellectual competition and institutional stability (Heinze et al. 2009). This suggests that funding stability and intellectual stringency in academic environments are important. Studies of the dynamics of research fields also indicate that research breakthroughs emerge at intersections between fields and in the tension between different knowledge domains. Rodgers Hollingsworth and colleagues have carried out several important studies of conditions favouring major breakthroughs in research: examples are scientific diversity, communication and integration, leadership capacity, organisational adaptability and flexibility. Fragmentation, excessive bureaucratic control and organisational hierarchies, on the other hand, impede major breakthroughs in research (Hollingsworth 2008). At the level of university governance, similar exercises show a correlation between the recruitment of esteemed academics as presidents or vice-chancellors, on the one hand, and aggregate performance (as measured in ratings in UK Research Assessment Exercises) at the university level (Goodall 2006, 2009, 2010) on the other. Goodall emphasises that accomplished academic scholars have the requisite legitimacy to lead and take steps towards improving universities' academic performance. This would indicate that universities that place a higher value on research accomplishments than on, say, general management capability are also the ones that perform best in terms of high-quality research. As mentioned, this study targets an even more aggregate level: a country's relative share of 'breakthrough research'. This has the advantage of also enabling us to evaluate (or at least analyse) the aggregate impact of national research policies. The choice of relevant factors to account for research quality at this aggregate level is, of course, based on studies of breakthrough research at five levels (individuals, research groups, departments, subject areas and universities) that jointly compose a national research system. However, interfaces among these levels should also be considered, to identify systemic effects that may produce patterns of research excellence.

This, in turn, necessitates a survey of how science has been governed, i.e. organised and funded. Factors concern configuration of research support, governance of research in universities and laboratories, patterns of promotion and recruitment of researchers, and connections with relevant research networks. It is our task to clarify the internal relationships among these factors on a national level and how they combine to affect the global impact of a nation's researchers.

As a yardstick for our analysis, we seek an understanding of conditions for research in our reference countries. This can help to explain our bibliometric data through qualitative assessments and validations of the current research systems.

Analysing research governance

The factors we assume to account for variation in the countries' research quality can be tentatively grouped in the following broad categories: policy regimes, funding models, governance mechanisms, and patterns of recruitment and mobility at university level.

One factor is research governance at national level. This comprises resource appropriations for research in relation to GDP; formulation of policies for research; policy-shaping interests; and distribution of resources between basic and applied research, ring-fenced and competitive funding, monopolist and pluralist organisation, the proportions of resources allocated to different types of universities (and other public research organisations), and the mechanisms used for ex ante and ex post evaluations of research in different research organisations. In sum, then, we examine resource allocation in terms of size, distributional impact and use of mechanisms for discussing and setting priorities among fields, organisations and purposes.

A second factor is governance mechanisms at the mesolevel (research funding in particular). In virtually every country, research resources are increasingly allocated in competitive processes, with funding from research councils and other external sources providing a growing proportion. The exact meaning of 'competitive' varies: it may take the form of grants for projects, programmes, centres and individuals (*ad hominem*) or direct appropriations to universities. The balance between internal ('floor' or block-based funding) and external funding is also analysed.

The relative importance of fixed and flexible funding thus varies significantly among countries. We look at the composition of funding, the relative importance of different schemes in terms of size, duration and priority-setting, the mechanisms deployed to support high-risk projects, whether they are controlled by funders or the universities themselves, and the structure of support for researchers at various stages of their careers (junior, senior etc.).

Micro-governance mechanisms include, in particular, universities' authority structure, organisation and resource allocation. We examine the structure of resource allocation within universities (and other organisations), proportions of fixed and flexible funding, allocation criteria, uses of internal evaluations and assessments, distribution of resources to different bodies and levels in universities and powers of university leaders at various levels to set and implement priorities at their own discretion. Our study also includes universities' recruitment patterns, not only with respect to academic teachers and how they are recruited and appointed, but also to their scientific standing and background, and the composition and mandates of universities' governing bodies.

Overall, our focus on micro factors is intended to highlight differences in nations' research infrastructure in terms of decision-making and organisational models, allocation of resources and authority in research organisations, forms of academic leadership, and recruitment and career patterns.

Sweden
The research policy system, 1990–2012

Sweden is not only important as the analytical benchmark of this investigation but also because of its historical evolution from scientific preeminence to a more ordinary position, positioned around the world average impact and visibility.

In the postwar period, Sweden was a leader in European science with global pre-eminence particularly in the natural sciences (Garfield 1986). While maintaining a respectable position in production of highly cited papers and university rankings, Sweden is now unexceptional among the many small and medium-sized nations of the global research system. Denmark (with its remarkably growing presence), Switzerland and the Netherlands, which have been able to maintain and raise their international positions (Appendix), stand out in contrast. We therefore seek to explain the relative decline of Swedish research in international comparisons.

In this section, we describe the development of the Swedish research system over the last 20 years in order to explore, in comparison with the development in some other European nations, some plausible explanations of the relative decline of the impact of Swedish research.

One key explanatory factor is the fuzziness of Swedish research policy. In all our reference countries research policy has multiple goals, and some devote less public resources to research than Sweden. But this country is notable for its jumble of different policy goals and tendency to keep adding new ones, with an apparent disregard for how this may affect the universities' ability to stay at the forefront of knowledge renewal in terms of new discoveries and understanding. Consequently, conditions for high-impact research have been overshadowed by other policy concerns. Even where high-impact research has been the primary goal of policy initiatives, it has tended to clash with other measures and goals.

Another key factor explaining the relative decline lies in Swedish universities' increasingly complex and multifaceted governance over the past three decades. The universities' structure, governance, funding and career systems have been radically transformed. Similarly, the structure of the Swedish funding system has been transformed and reinvented over time: not only has external funding of university research been a growing share, but funding streams have also become more complex. Overall, Swedish research is relatively well endowed with resources, but weakly governed.

Swedish research governance, 1990–2000

Overarching policy priorities

Sweden has a history of a multi-pronged science policy, with many different (and sometimes contradictory) goals pursued simultaneously. This has increasingly shaped our research funding and university governance. Swedish universities' endowments were relatively generous throughout the postwar period thanks, in particular, to their 'floor funding', which remained at high levels (around 70–80%) until the early 1990s. Block funding, supplemented by the research councils' support, largely constituted the foundation of the research system. The relatively few professorships were mainly established and awarded by the Government after consulting the universities. Sweden never developed an extensive institute sector but instead numerous sectoral research agencies to support applied research, especially in medicine, engineering and the social sciences, and created research groups within the universities based on 'soft money'. Thus, the research system was twofold in the sense that basic research environments, with distinctive models of organisation and funding, existed alongside applied research environments — sometimes even in the same departments. Adding further to the complexity, the university system was formally unified in the late 1970s ('H77') when professional training became integrated with it. In fact, however, the professional areas operated in a system parallel to the core academic fields, with their limited research resources and primarily educational remit.

The mix of goals persisted in the 1990s with, for example, the 1997 amendment of the Higher Education Act. This placed 'collaboration' on par with teaching and research as one of the universities' three missions. The purposes of professional training and sectoral research were thus extended to the *entire* spectrum of research. Concomitantly, Swedish universities were transformed: autonomous governance by academic elites gave way to direction by the state, with representatives of public interest groups, trade unions and students forming a majority on university boards (see below).

To sum up, we find a very broad spectrum of goals for the Swedish research system. It combines a wide range of areas within a single organisational set-up. Equal commitment to international excellence and practical utility is intended. Universities are expected to function both as bastions of basic research and as arenas for applied research, innovation and development. They are expected to serve the interests of diverse stakeholders, including industry, politicians, students, trade unions and the academic community. In effect, Swedish universities have become multifunctional conglomerates designed to support our knowledge-based society. However, governance of these conglomerates is not optimal. We see examples of more successful conglomerate strategies elsewhere, particularly in Denmark, where universities have seen an extension of their organisational mandate but remained committed to stringent scientific standards.

This complex mix of goals and missions was, in retrospect, bound to impede the universities' capacity to pursue high-quality research. This is an important factor in our explanation of the relative decline of Swedish research. We perceive a functional overload and an excessively complex array of interests and governance attempts by organisations outside academia.

The complexity is partially explicable as an outcome of the Swedish state's fiscal crisis in the early 1990s. Sweden underwent a dramatic economic downturn after the credit-based boom of the late 1980s. The collapse in 1990–91 brought falling housing and office property prices, negative growth, interest-rate spikes and a banking crisis. Initially, the recession was interpreted as a crisis of the postwar Swedish economic growth model, and a new layer of research funding instruments (the 'research foundations') was added in the early 1990s to support regeneration of the Swedish economy. These foundations added considerably to the financial underpinnings of Swedish research, but functioned differently from the research councils or universities. The foundations, especially the Swedish Foundation for Strategic Research (the flagship foundation for the natural sciences, medicine and engineering), supported postgraduate studies and research collaboration in nationwide networks, rather than creation of distinct centres focused on a novel approach, as in the Danish counterpart, the Danish National Research Foundation (see Sörlin 2005 for an overview). This was aligned with the national policy goal of doubling the number of PhDs, from 1,000 to 2,000 annually (Benner 2001). Hence, research funding was increasingly geared towards the goal of expanding PhD training rather than propelling investigator-led research. This curtailed risk-taking in Swedish research.

As sovereign debt continued to mount in the mid-1990s, more radical measures were taken to curb the budget deficit. No area of public expenditure was spared. For research, the consequences were particularly dire, since the cuts affected not only the volume of funding but also its composition. Budgets for research councils, mission-oriented agencies and universities' floor funding were slashed by up a fifth of pre-1995 appropriations. Some cuts were offset by the research foundations set up a few years earlier, but some — notably in core provision for individual projects from research councils and universities' floor funding — were never recouped. Although the aggregate impact was neutral, the outcome was a severe weakening of universities and research councils alike.

Making matters even worse, university floor funding has not been adjusted for inflation. Floor funding has been constrained by the 'wage and price factor', introduced in 1993: universities have received small increases (0.8% annually), well below the level of inflation and wage rises, in their direct appropriations (Sundqvist 2010).

In parallel, governance of research opportunities underwent radical transformation. For example, universities virtually abolished assistant professorships to save costs, and recruitment of new researchers largely fell to research funding organisations, primarily through project funding, instead. At the same time, to cater for ever rising student numbers and regional knowledge interests, the 1990s and early 2000s saw the expansion of 17 new higher education institutions (HEIs/*högskolor*) established since 1977, some of which have now gained university status, primarily to meet labour-market requirements and practical knowledge interests. Gradually, these HEIs have received funding for postgraduate studies and research. This development makes Sweden somewhat unusual, although a similar development may be observed in Finland (with universities of applied science forming a distinct sector, but with numerous, often fairly small regional universities). Nations like Denmark, the Netherlands and Switzerland, on the other hand, have largely refrained from this proliferation of academic institutions.

Career system

The Swedish system of academic careers has always been distinctive by international standards. Until the 1990s, it retained some features of the chair system in continental Europe, with few and well-endowed professorships. At the same time, the rapid increase in the size and complexity of Swedish universities entailed partial replacement of the chair system by a departmental structure, with professors seldom heading departments and their power shifting to the swelling category of university lecturers instead. The position of lecturer was established in the 1950s to fulfil the expanding remit of higher education. Lecturers were not intended to engage in research (Andrén, ms). Those who wished to establish their own research groups (by no means the norm or expectation) had to rely on external funding or limited internal funding quotas allocated within the faculties. The research function, besides that of the professors, became primarily the responsibility of associate professors (*docenter*), who lacked permanent tenure, or assistant professors. The latter were not part of a tenure track system; instead, they had time-limited appointments with no guarantees of future employment. While this created a certain degree of flexibility and pluralism, it also circumvented the career prospects of many scholars. In international evaluations of Swedish research, this pattern was repeatedly identified as detrimental to quality and renewal (e.g. Swedish Natural Science Research Council 1995a, b).

Assistant professorships were thus primarily research-based positions with limited teaching duties. This made them increasingly unpopular with the universities after the cutbacks in floor funding in the mid-1990s. Instead, positions based on external funding became the norm for postdoctoral employment, and since this funding was normally allocated for three years (often with fairly small grants for new entrants), the first rung on the research ladder was often a temporary (three-year), paid position. Research councils continued to provide career grants based on a two-plus-two-year model, but these positions were rare and did not compensate for the dismantling of positions based on faculty funding. Even those who managed to get four-year temporary appointments often found their careers hampered by limited research funds unless they leaned towards senior research staff with external funding. This hampered the renewal of research that should be entrusted to each younger generation of researchers, to explore new directions and address new questions.

Reductions in floor funding also reinforced another aspect of the decline in long-term risk-taking in Swedish research: the funding of professorships. Formerly enjoying full support (with extra resources for research assistance), this funding was steadily eroded owing to the floor-funding cuts. One particularly harmful circumstance was that the erosion of professorship funding coincided with the transformation of the professorial appointment system in 1999. Until then, professorships had been relatively rare, but the reform entitled lecturers to apply for promotion to professorial status. Soon the number of professors rose dramatically, by 45% in 1998–2002 (National Agency for Higher Education 2002), placing enormous strains on funding allocation in universities. As described below, the effect was to erode funding of professorships and compel even holders of professorial chairs (who are appointed, rather than promoted) to find external sources to safeguard their own salaries. The promotion system was thus not backed by any rise in funding but, rather, became a 'paper reform' providing professorial titles but not conditions. Worse still, the model of self-organised funding of professorships spread in the ensuing decade, when conditions for

promotion to professor became normal rather than exceptional for all professorships, at least in experimental fields.

Overall, the 1990s saw the onset of a dismantling of the postwar career system in Swedish universities: research opportunities became confined largely to full, associate and assistant professors, with supplementary external funding. The result was a system in which guaranteed research opportunities decreased and success on the 'funding market' became a precondition for research positions. Once again, this created a certain flexibility and rising competition and productivity, but at the expense of long-term funding allowing for risk-taking and renewal.

University governance

Until the late 1970s, Swedish universities were governed by academic representatives. University boards comprised faculty leaders; tenured staff selected academic leaders in collegial processes; and university departments were headed by professors. However, the expansion of Swedish universities in the 1960s and '70s created a new kind of power structure in which non-tenured teaching staff, university bureaucracy and university teachers' associations were increasingly important. Significantly, there was also a surge in students' decision-making participation. By the late 1980s, Swedish universities had been effectively transformed from an academic oligarchy into an arena of pluralist interest mediation. This process continued, with further reforms, in the 1990s. In 1992, university boards were reconfigured and external board members gained the majority on the boards. In 1997, university vice-chancellors were replaced as university board chairmen by external representatives; at the same time, university boards took over the responsibility to propose the appointment of vice-chancellors.

Research governance, 2000–2012

The 1990s was a turbulent decade for Swedish research, in which many of its pillars — funding of university research, the relationship between external and internal funding, the career system and the universities' governance — were dismantled or transformed. From being relative stable, if not entirely coherent, the system became pluralist and market-driven. Internal direction and governance gave way to an opportunities-driven and flexible, but also destabilised system. How, then, has Swedish research governance developed in the last decade?

At one level, as resource cuts in the 1990s were superseded by resource hikes and a reinforced policy focus on conditions for basic research, the trends have been positive. A unified research council was established in 2001 to offset the fragmentation of funding and serve as the 'jewel in the crown' of Swedish research policy (Benner 2001: 150). Several schemes were initiated to support major research undertakings. Very recently, although much later than in the reference countries, improving conditions for young scholars and international appointments has been added as a policy goal. University governance has been streamlined and university leaders' power has been reinforced. This has not necessarily met the challenges, we argue: many of the old problems persist and have indeed become more severe in the last decade. Among these we would highlight, in particular, the lack of a proper career structure, but also a gradual deterioration in academic appointments at professorial level. Internal promotion accounts for the great majority of appointments, with only a fraction of new professors

being recruited from outside the universities concerned and an even smaller fraction from outside the country (sources show that only some 10% of faculty members at the larger universities are non-Swedish). The insecure funding of university positions generally is a more pervasive, generic problem, to which we find limited solutions. Although the universities themselves are now responsible for appointing staff and devising career structures, their limited financial control makes this autonomy illusory. And while university governance has been streamlined, the role of university leaders remains diffuse and promoting research quality is only one of many often contradictory missions.

Since 2000, marked attempts have been made to reduce the impact of the swift, massive crisis measures of the 1990s, partly through a continued shift from universities to external funders as the engines of scientific renewal and change. This is reflected primarily in the design of Swedish universities' funding. The parameters for external research funding have become increasingly complex and heterogeneous, evolving into a multilayered system (Edqvist 2003). The three public layers are the research council system, the mission-oriented agencies and the strategic research foundations. Each layer is relatively autonomous and caters to its own constituency and ideal role. Purpose-oriented agencies' programmes are tailored to the interests of their communities of practice, while research councils' structure and interests closely replicate those of their corresponding scientific communities, and strategic foundations operate in between, seeking specific (task- or goal-oriented) roles to fulfil. In terms of size, the layers are relatively uniform, although the research council system has expanded (from a modest level) since 2000, with a particular focus on large research environments, cooperative networks and predefined strategic areas. However, project funding for individuals with novel ideas has received less attention.

Assessing impact is a daunting task. There are some notably positive features. The funding system is pluralist and affords many opportunities of funding. Decoupling of positions and funding has stimulated competition and some successful individuals and groups have been able to expand their activities considerably, with multiple funding sources to back them, while chair holders with limited productivity have been phased out. Securing abundant funds has become an important sign of success in the Swedish research system. In lieu of a genuine tenure-track system the pluralist system has evolved into a 'shadow career model', with researchers at various stages able to secure funding for their work and evolving into 'quasi-firms' (cf. Etzkowitz 2003).

Nevertheless, we identify some severe drawbacks of the system. One is the risk of resource bottlenecks in some areas and inadequate funding in others, owing to a lack of coordination. Another is uneven conditions resulting from successful outcomes in the 'funding market' (not always due to applicants' contributions to scientific progress, but rather to their capacity to exploit funding opportunities). A third is growing marginalisation of universities in terms of responsibility for quality assessments and guaranteeing the academic mandate by appointing, evaluating and appraising academic staff. This function has increasingly been taken over by the 'funding market' and funding organisations, with their priorities, *de facto* structure and hiring procedures. Our qualitative evidence suggests that many leading scientists have lost faith in the universities' internal organisational capacity to foster highly competitive research, and therefore argue that research funds

should be distributed primarily by the research councils rather than through the formal university structure.

The Swedish Government has moved to reverse this development by making the universities more autonomous in developing their own operational structures and functions. But the heavy dependence of universities and their research staff on external funders, with their various missions, persists. Swedish universities have never been as dependent on external stakeholders as they are today, and the most recent research bill (October 2012) actually reinforces the process rather than mitigating it. Not surprisingly, the academic leaders' role and function have been diluted and, simultaneously, vice-chancellors' profiles have evolved into summaries of administrative merits rather than of scientific stature (see Engwall & Lindvall Eriksson, 2012, for clear indications of a transformation of academic leadership in Sweden). The results indicate that vice-chancellors are less academically experienced than before, and that they are increasingly promoted on the basis of their (ostensible) administrative capacity rather than of their scientific stature. The investigation has made bibliometrical studies of the academic standing of Swedish vice-chancellors, and it has on average gone down in the last decade. As mentioned, Goodall's studies (2006, 2008) show a positive correlation between academic standing of vice-chancellors and recognition of academic institutions. Hence, the declining scientific position of Swedish vice-chancellors is a major cause of concern.

Other attempts to reduce the complexity and fragmentation arising from this multilayered system have included schemes for large groups and networks. Examples are the Linnaeus environments, supported by the Swedish Research Council (with counterparts sponsored by other public funders); the Strategic Research Centres supported by the Swedish Foundation for Strategic Research (again, with similar schemes for other foundations); and recently the Strategic Research Areas, with funding of up to €5 million annually allocated to large groups of researchers in areas deemed to be of strategic importance both to society and to Swedish research. These laudable attempts to reduce the fragmentation of funding seem, however, to have played less of a part in creating conditions conducive to the establishment of independent scholars at the outset of their scientific careers. Instead, they often function as funding consortia for several research groups, rather than starting-points for new undertakings (cf. SRC 2012b).

Programmes for medium-sized groupings are rarer. The Research Council has boosted its funding (although average annual grants remain below €100,000, including university overheads), and some of the research foundations have reintroduced generous grants for small groups (such as framework grants awarded by the Foundation for Strategic Research). Some funders also support excellent individuals, as in the Wallenberg Academy Fellows programme programme. This kind of support, like the European Research Council's (ERC) advanced grant, may indeed be highly productive but comes late in a recipient's academic career. However, the main challenge is not the limited extent of medium-sized grants but rather the function they currently fulfil — to secure basic funding for scientists and their groups (in response to shrinking floor funding) — rather than serving as a top-slice funding stream that allows for more adventurous research programmes.

Career structure

The lack of a well-defined career structure and adequate project funding for young researchers probably explains why the emergence of new generations of scientists achieving an internationally high impact level is comparatively limited in Sweden (see appendix). As we have seen, the career system was gradually dismantled in the 1990s. The process has been stepped up in the last decade, and the current practice is a fairly idiosyncratic mix of *de jure* positions (assistant, associate and full professors until 2011; now only the full professorship is regulated by law, and only as a title) and *de facto* conditions where the universities do not even provide full funding for professorial chairs. Indeed, with the growing number of promoted professors, the professorial chair system has been more or less abandoned. Of recently appointed professors, a majority have been promoted and most are obliged to obtain at least parts of their salary from external sources. Junior and senior scholars alike are thus dependent on the fluctuations of the 'funding market' to safeguard their activities.

Arguably, some attempts were made in the early 2000s to alleviate the situation for junior scholars. Examples are the INGVAR programme (for the advancement of potential research leaders) sponsored by the Swedish Foundation for Strategic Research (from 2006), the assistant professor programme of the Swedish Research Council (now terminated) and Wallenberg Academy Fellows (WAF), which is run by the Swedish Academies and funded by the Knut and Alice Wallenberg Foundation. WAF is a major initiative, replacing the former Wallenberg programme for Academy Fellows. It supports young scholars, and was announced very recently by the Foundation, with up to 125 positions in 2011–16. This is, however, a limited number and serves primarily to compensate for the virtual abolition of assistant professorships funded by the universities themselves.

The position of assistant professor was phased out with the reform of the employment system in 2010. However, this represented only a *de jure* manifestation of the *de facto* dwindling importance of this position (especially in its original form, when it was established and funded by university floor funding alone). A genuine tenure-track system is still lacking. Instead, the advancement of younger researchers in Sweden is heavily contingent on multiple sources of funding being available. Some attempts have been made to regulate the process of promoting and empowering younger researchers. The long-term impact of these attempts remains to be seen, but the danger is that they will add to the bewildering diversity of young researchers' career options in Sweden, especially if support for the start-up phase is not matched by equally good conditions for scientists in senior positions.

This leads us to the staffing of Swedish universities and the relatively opaque, decentralised system of appointments and empowerment of university teachers in Sweden. Sweden arguably no longer has a proper career system, but merely a range of opportunities. Following the string of deregulation measures begun in the mid-1980s, the right to recruit university teachers has been decentralised to the universities themselves. Appointments can now also be tailored to existing conditions by filling gaps in undergraduate teaching, responding to research grants or endowments and so forth. Appointments less often reflect a balanced notion of the departments concerned or the areas these departments (or similar) cover.

As a result, nominally equivalent positions as lecturer or professor may entail very different

conditions in reality, from full-time teaching to full-time research. Conditions relate primarily to the 'success' of the individual faculty in the funding system and the department's pragmatic stance. For each faculty, precise conditions are normally decided at the lowest level in the university hierarchy, i.e. the department, which acts according to the logic of student demand and funding success.

In parallel, university departments may appear to be the outcome of externally funded projects, rather than of a coherent vision. The project groups have *de facto* responsibility for recruitment into the system, reducing the department's attention to recruiting for such purposes as fostering renewal of disciplines or promoting interdisciplinary cross-fertilisation. The 'research hotel syndrome', an effect of the skewed funding and authority structure, is evident in many, if not all, academic environments in Sweden today.

University governance

After the university funding cutbacks of the mid-1990s, the universities' research funding was transformed. Previously, floor funding had predominated. Now, funding from external sources expanded (and is currently at 51 per cent of total funding). While this change may, again, have boosted competition and Swedish scholars' 'animal spirits' (and enhanced their productivity), it has arguably weakened quality control at university level. Instead, the reform may have yielded a 'Balkanised' university system where individual researchers and groups compete for resources and there is little or no supervision or strategic oversight for the universities' part (cf. Karolinska Institutet 2010). It has also reduced the importance (other than symbolic) of formal levels of university leadership in the inception of research strategy.

Some studies indicate that floor funding is used primarily to match external research incomes and seldom, if ever, to underpin research activities (Jacobsson & Granberg 2008, Jacobsson & Rickne 2004). Swedish universities have therefore rapidly turned their attention outwards, to the point where the output and impact of university research are often beyond the influence of the university management. Again, while circumvention of the university leaders has reinforced competition and the sense of resource dependency among researchers and research groups, it has exacerbated the fragmentation of the Swedish research system that was already under way, and reduced the universities' own scope for control. Instead, they increasingly function as assemblages of various functions and stakeholder groups, where the mission of the academic leadership is to create a balance among these groups and interests rather than to pursue academic goals as such.

The reforms may also have stifled the creativity of Swedish researchers and discouraged them from entering breakthrough areas. In our quest to explain the relative decline in impact of Swedish research we find this to be at least a plausible hypothesis.

Summary and concluding assumptions

In the case of Sweden, what needs explaining is the relative decline in international visibility of our research, especially work that attracts high levels of attention and represents potential breakthroughs. The overarching explanation is the split, patchwork structure of research policy after the economic crisis in the 1990s, when policy initiatives were added (and

removed) with no clear focus on the impact on research quality but, rather, as a result of power configurations and opportunistic decisions. We thus identify a critical lacuna in political understanding of the conditions for high-quality research, as well as fragmentation and weakening of the institutional underpinnings of Swedish research. While these factors create some opportunities, they also spell a risk of resources and authority going to entrepreneurs rather than bearers of originality and renewal.

We highlight the following factors in Swedish university governance:

- The universities are very broad and comprehensive, unlike our counterparts in the reference countries, where the division of labour between universities and universities of applied science has been maintained, with mutual benefits.
- The goals adopted for Swedish research and universities are too complex and contradictory, with an inadequate focus on highly innovative research.
- The universities' broad-based mandate means that mission-oriented, applied research forms a large part of their remit, and this hampers internal quality auditing according to strict quality criteria.
- There has been a shift of resources from university control to a medley of flows with disparate goals and forms of accountability.
- University governance, with its multiple decision points and unclear division of labour among individual researchers and groups, departments, centres and university management in terms of appointments, resource allocation and planning of research activities, is opaque.
- Patterns of academic leaders' recruitment reflect the universities' unclear mission, and the university leaders' academic standing has declined in conjunction with the erosion of universities' internal resource and reputation control.
- A career system with clear entry points, promotion mechanisms and corresponding extra resource allocation (either by the universities themselves or in tandem with research councils) is lacking.

For research funding, we highlight the following factors:

- Research groups and individual researchers are excessively dependent on external funding. This creates flexibility but also makes development of fields and research environments highly uneven, and not always related to the quality of research.
- There is dependence on a funding system that fails to guarantee long-term conditions for junior or senior researchers but, rather, exposes them to the vagaries of the 'funding market' for their continued activities. This has created a culture of caution and tactical manoeuvring, rather than of a quest for innovative research.
- The patchy, fragmented career system, especially for junior scientists, can hamper renewal and create a culture of opportunism among new entrants.

Denmark
The research policy system, 1990–2012

Background

Until the 1980s, Danish research was loosely organised and on a small scale. While some areas and environments (such as theoretical physics and biophysics) were internationally renowned and operated in well-organised structures, quality was arguably more variable elsewhere. The institutional structure of Danish research, too, was modest in scale and scope. Well into the postwar period, there were only two universities. The new universities established in the 1960s were fairly small and focused primarily on educational needs (Aagaard 2010). The universities' research appropriations were tied to their educational remits, and grants from the research councils, awarded to supplement the faculty appropriations, were small. Resources and powers were widely dispersed in the system, and the authority of the university leadership was weak in matters of recruitment and resource allocation, which were, instead, managed by various committees with professors in a minority (Andersen 2001). Postgraduate education remained traditional in nature and expectations, and very limited in scale. Danish research, also a small-scale activity, was primarily self-governed in small academic communities; there were some exceptional bastions, but tolerance of quality variations and institutional idiosyncrasies was high.

Modest reorientation of research governance began in the 1980s, when some universities and other research units began raising their expectations of publications and international orientation. 'Floor funding' was freed from educational remits and there were several (unsuccessful) attempts to modernise and expand the research councils (Olesen Larsen 2010). A more fundamental reorientation of Danish research governance began in the 1990s, as part of a general shift in Danish politics. A deep political and economic crisis in the 1980s forced through a regeneration of Danish politics, with major investments in basic research and an overhaul of the institutional structure of Danish research organisations, to create new scope for economic growth and reinvigorate the lacklustre research system.

Over time, the drive to remodel the research system by a combination of resource infusions and governance reforms has continued and intensified, transforming Danish research policy into a politically profiled area characterised, for better or worse, by recurrent political intervention. In the past two decades, the international impact of Danish research has clearly grown and, despite controversies about research policy, it is evident that policy changes have contributed to this positive development.

In this section we identify the various stages in this process, their relative importance and interplay, and discuss some future prospects of Danish research governance.

Danish research policy, 1990–2000

Setting policy priorities

In the late 1980s, Denmark adopted a new model for growth and employment, where investments in science and technology featured prominently. Changes in multiple directions ensued. Programmes for technological development predominated in the 1980s, while conditions for universities, basic research and postgraduate education came to the forefront in the 1990s. A ministry for research was established as part of a political reshuffle in 1991. National strategies for research and the universities were drawn up, new funding streams were established, the postgraduate education system was reformed and the research councils were modernised. Other changes included an infusion of new resources, transformation of the governance system and reform of work modes.

Danish research received its first major influx of resources in 1992 with the inception of the Danish National Research Foundation (*Danmarks Grundforskningsfond*, DNRF). Its resource concentration was modelled on Germany's Max Planck Institutes. The DNRF's objective was to focus resources on curiosity-driven research that neither the research councils nor the universities themselves were seen as capable of providing (Olesen Larsen 2010). Funded with profits from privatisation of an insurance company, the DNRF was thus set up to challenge the alleged inertia of the universities and research councils. From these quarters, it received some criticism; but it was also widely welcomed as a driver of renewal and concentration in Danish research (OECD 1995).

From 1993, reformed postgraduate education supplemented the old doctoral degrees (which were retained) with streamlined three-year research programmes, some of which were run in graduate schools. All the programmes imposed clear-cut requirements that students should publish their work within a short period (Ministry of Science, Technology and Innovation 2006). In parallel, the structure of the research council system was modified slightly and its close relationship with the university faculties was broken (Grønbæk 2001). Finally, as discussed in detail below, the university governance model was transformed.

Research funding in the 1990s

After prolonged resource stagnation, new resources were infused into Danish research in the 1980s. These resources catered primarily for industrial and public interests in programmes promoting industrial clusters and technological development. Basic research did not figure prominently in these efforts, but came to the fore first with the DNRF (founded in 1992), which represented a major policy innovation. The DNRF successfully targeted small to medium-sized research groups, making them more internationally visible and inducing them to join collaborative national and international networks. The hike in resources continued into the 1990s, when the trend slowed and levelled off (as a percentage of GDP, but also in relative terms) until 2006.

The establishment of the DNRF, with its focus on individuals with challenging ideas and provision of generous, long-term funding for successful applications, pinpointed the need for creative university environments that were amply qualified and equipped to address difficult questions well beyond other funders' capacity at the time. To meet the requirements, the universities were gradually induced to create environments through recruitment and departmental reorganisation (see below). Today, they provide ample supplementary funding for externally supported Centres of Excellence, and our evidence suggests that these Centres are now generally harmoniously integrated into the faculty structure. The DNRF (and subsequently other major research and innovation programmes) has thus become instrumental in helping the universities to develop their research priorities towards academic excellence. Universities' key international recruitments have also notably assisted this development process. In continuing to fund investigator-initiated projects and support individual careers, the Danish Council for Independent Research (*Det Frie Forskningsråd*, DFF) has also been paramount in paving the way for the DNRF's Centres of Excellence.

Universities in the 1990s

The 1993 university reform represented the first departure from Danish universities' tradition of decentralised decision-making. It changed their internal governance structure, and was later supplemented by a change in universities' relationship with the state whereby they gained more organisational autonomy, but also entered into detailed contracts with the state regarding performance indicators and impact assessments. While no comprehensive evaluation took place at the time, evidence suggests that the change in university governance clarified internal decision-making, empowering department heads in particular, but also vice-chancellors (Olesen Larsen 2010). These positions had become increasingly fuzzy and ill-defined as a result of the University Act of 1973, which had entrusted decisions on recruitment and other strategic issues to committees with broad representation. While the 1973 Act may have served various purposes, it is generally agreed that it fostered cronyism and impeded an overall focus on quality.

Research governance since 2000

Setting policy priorities

The central role of research policy in economic growth policy generally has persisted since 2000. Research and innovation have been identified as key elements in the adaptation of Danish research to the perceived demands of a 'knowledge-based, global economy' (the exact meaning of which remains disputed). The Globalisation Strategy, adopted in broad political consensus in 2006, was formulated with the manifest aim of securing Denmark's position in this knowledge-based economy. The Strategy has entailed investments of DKK 42 billion (€4bn) in research, education, innovation and other forms of professional development, to enable Denmark to reach the goal of spending 1 per cent of GDP on public research funding. About half of the resources have been spent on research: university floor funding has been expanded by about DKK 5 billion (approximately DKK 1bn annually). Some DKK 1bn altogether has also been invested in postgraduate education and roughly 400 additional postdoctoral positions. Moreover, the DNRF and DFF have received additional funding for their own unrestricted use, as has the Danish Council for Strategic Research (*Det Strategiske Forskningsråd*) for its programmes in food, energy, education etc.

Decision-making in Danish research governance, while clearly becoming more streamlined over the past few decades, remains multifaceted and therefore somewhat erratic. The political system tends to adopt bold political initiatives but its systematic follow-ups of decisions and their consequences are limited. (However, see Danish University and Property Agency [*Universitets- og bygningsstyrelsen*] 2010 for an exception: an evaluation that also resulted in amendments to the University Act.) Some policies clearly target the quality dimension of Danish research: examples are the inception of the DNRF, modernisation of the Danish Council for Independent Research and resources devoted to prizes and awards for 'elite scientists'. Other policies may indeed hamper the same ambitions: merging universities or incorporating institutes into the university system, for example, resulted in greater organisational complexity.

Nevertheless, the relative lack of policy consistency seems to be offset by a tight network of elite stakeholders that transcend the boundaries between government, universities, funding organisations and committees. A few influential people appear to have shaped several of the key changes in Danish research governance, from the advent of the DNRF to transformation of the university system, although not always consistently (several different stakeholder groupings underlie the policy initiatives; Olesen Larsen 2010). These individuals include not only leading figures in the Ministries but also people from industry, especially the Danish Academy of Technical Sciences (*Akademiet for de Tekniske Videnskaber*, ATV), which has been highly influential in shaping policy priorities, especially the university reform. What is lacking is a more permanent forum for policy deliberations. The two arenas established for this purpose, the Coordination Committee and the Research Policy Council (*Forskningspolitiske Råd*), were primarily forums for debates and deliberation (Danish Agency for Science, Technology and Innovation [*Forsknings- og innovationsstyrelsen*] 2009). The Coordination Committee was later scrapped, while the Research Policy Council has become more powerful in recent years, but remains primarily a forum for debate rather than policy deliberations. The Agency for Research and Innovation is arguably, in essence, an organisational umbrella for policy implementation, although its power seems to have grown over time. The policy system thus appears to be somewhat top-heavy and more dependent on political whims rather on long-term plans. Nonetheless, a culture of academic excellence seems to be broadly accepted. This culture underpins Denmark's research system and has served the Danish research system well during periods of transformation since 1990.

The main policy changes along these lines in the past decade have been incorporation of research into the bipartisan agenda of the Globalisation Strategy and the ensuing investments in new positions, floor funding and research programmes. These programmes have focused on strategic research through, for example UNIK (*Universitetsforskningens Investeringskapital*, Investment Capital for University Research), and on commercialisation, mainly through the Danish Agency for Science, Technology and Innovation. Issues of globalisation and competitiveness, where raised, have been framed in terms of modernising the science base and enhancing conditions for Danish universities. This has been done in broad political consensus. The political system thus appears capable of fitting research policy into its broader agenda, which has resulted in considerable budget hikes, especially since 2006. While conditions for basic research share attention with strategic and commercial aspects of research, it nevertheless seems clear that governance of basic research remains benign in Denmark, and that securing the international visibility of Danish research is a major policy concern.

Increasing funding

Denmark's strong commitments to increasing resources in the early 1990s focused particularly on early career support for promising researchers. This continued in the 2000s, especially with the Globalisation Strategy in 2006 and the ensuing hikes in research appropriations. Evidence suggests that the DNRF has been instrumental in raising the international profile of Danish research. It has adopted rigorous models of assessment and long-term support, and in terms of excellence it has — through its continuous support — established expectations and modes of operation in the Danish research system.

The research council system had traditionally been run in a fairly conservative and traditional form, with many small grants and the risks associated with insular selection criteria. In the 2000s it was modernised and became better resourced. At the same time, university floor funding increased, primarily as a result of the Globalisation Strategy and the tandem reforms of the university governance system and the structure of the university sector. Young researchers have been particularly targeted — by the research councils, through funding and by ring-fenced portions of basic appropriations to universities. In addition, specific measures to highlight and reward younger scholars have been implemented.

In 2003 the research council system was reformed, this time with a more profound impact than in the previous rounds. Six previously independent research councils were subsumed under a single council entitled to reallocate resources and instigate new schemes. One such initiative has been the Sapere Aude ('Dare to Know' in Latin) award, set up in 2010 to support researchers from postdoctoral to professorial level in a manner similar to the Dutch Veni, Vidi, Vici scheme.

The Danish Council for Strategic Research was also established, mainly to channel resources into large-scale centres and networks in areas primarily identified by the political system. Similarly, the UNIK scheme channels resources to universities for major undertakings in four areas deemed to be strategic in both scientific and social terms (the human mind, synthetic biology, lifestyle diseases and catalysis, all with multimillion-euro budgets annually over five years).

At the other end of the spectrum, several schemes have been initiated to support young researchers. The DNRF's focus on mid-career leaders is one example. Another is the Sapere Aude programme of the Danish Council for Independent Research, where proficient younger scholars (up to eight years after gaining their PhDs) can receive up to DKK 86 million. Every year, the Danish government also awards a number of Young Elite Researcher (*EliteForsker*) prizes, amounting to DKK 1.2 million, to scholars below the age of 35.

Reforming universities to strengthen academic leadership

With the new University Act of 2003, a major overhaul of university governance was carried out. The Act represented the final dismantling of the decentralised, bottom-heavy governance system in Danish universities, where either professors or corporatist bodies had held the upper hand in all major university affairs. Now, instead, responsibilities were centralised to university boards (with predominantly external members) and vice-chancellors appointed by the boards. Internally, the responsibilities of vice-chancellors, deans and

department heads were further specified, and the authority of the vice-chancellor, dean and department heads was restructured (with the vice-chancellor appointing the dean, who in turn appoints the heads). Arguably, the reforms reduced nepotism and cronyism in appointments; created scope for international recruitments; and streamlined internal decision-making (Danish University and Property Agency 2010). Today deans, in particular, have a much stronger role in recruitment issues, organisational affairs (setting up and closing down departments) and the allocation of internal resources, and they may control several million Danish kronor for recruitment and other plans. This financial latitude is viewed as necessary if universities are to recruit internationally: some extra support (PhDs etc.) is needed to attract the best applicants (ibid.).

The career system in Denmark has thus increasingly been complemented by a stream of postdoctoral positions, and the number of positions based on external funding peaked in the 2000s (http://www.fi.dk/publikationer/2011/evaluering-af-forskerkarriereveje/researchers-career-directions). How this will impact the career opportunities of younger Danish researchers remains to be seen: the influx of resources may lead to segmentation of career opportunities, and the rise in external funding has not been reflected in more permanent positions. At the same time, professorial positions remain relatively scarce in Danish universities and vice-chancellors have opposed a promotion system, to retain performance and selection incentives.

In 2006 there was another wave of reforms. This time, the ambitions were to reduce the number of universities and align the sectoral research institutes (for energy, housing and building, foreign affairs etc.) with the universities. This reform also corresponded closely to the ideas outlined in the early 2000s by ATV, which had called for a unified university structure in the Copenhagen area. The merging of universities is generally considered reasonable, although this has made some faculties cumbersome in structure and somewhat like small universities in their own right (Copenhagen now has four life science faculties which are to be merged into two 'superfaculties' with over 3,000 faculty members and other staff). Aligning the sectoral institutes seems to have been less successful to date: it created unwieldy structures instead of resulting, as expected, in better management of financial and intellectual resources. Reversing the bottom-heavy governance model to obtain a much more hierarchical system has also had negative side-effects, including administrative overload and a stifling of academic values of openness (Danish University and Property Agency 2009).

The broad reform of the research system, university mergers and integration of the sectoral research institutes have been fairly controversial, although the overall assessment seems to be that these changes have reinforced the culture of academic excellence that now permeates Danish academic life. The mergers and, in particular, the institutes' integration appear to have functioned relatively poorly. Initially, the purpose of the mergers was to integrate research into the universities, connecting it better with education and other research, while outsourcing investigative and regulative functions to other agencies. However, these functions have been integrated into the universities, which seems to have caused organisational overload and weak integration of the institutes. What was a reasonable idea appears to have been haphazardly executed.

Another systemic change in Danish science has been the reform of postgraduate education. Support for postgraduate education has been an integral part of the Globalisation Strategy, as has the refinement of the postdoctoral career system. The latter should be seen in relation to the large sums devoted to the research system since the mid-2000s.

The system of university governance is shaped by the remaining significance of floor funding, at around 60 per cent of total revenues for research. A substantial share of project-based funding is available, with project grants typically in the order of DKK 1.5 million. However, in response to the emergence of larger, centre-based funding (through the DNRF) and broader groupings through the Council for Strategic Research (which supports strategic projects, alliances and centres, with budgets up to DKK 50 million over five or six years), the scale of research activities has increased.

The reformed PhD system has been further emphasised by the Globalisation Strategy, which projected a forthcoming 50 per cent increase in PhDs. While this goal seems laudable, it may risk overemphasising the role of postgraduate education in Danish research (as in Sweden and Finland, where postgraduate education is a central undertaking). This is another example of the fairly loosely connected goals of Danish research policy. Here, postgraduate education primarily serves extra-scientific goals, possibly to the detriment of quality.

University mergers and integration of sectoral institutes into universities are related only indirectly to the other changes in research governance, although they have also been carried out with the expectation that a structural change in how universities are governed and resourced will enhance the international standing of Danish research and education. Four major universities remain — Copenhagen, Aarhus, Southern Denmark (SDU) and the Danish Technical University (DTU) — and these account for two-thirds of research and education in the country. They are, in turn, increasingly specialised, with Copenhagen emerging as hub of the life sciences (with no fewer than four former faculties now merged), DTU specialising in engineering, and Aarhus and SDU with a more mixed structure. SDU seems particularly successful in its integration of various tasks and organisations under a single organisational umbrella, whereas the other universities are still struggling to integrate their various functions synergistically (Danish University and Property Agency 2009).

Danish miracle?

Over the past two decades, Denmark has made a commitment to boosting resources, adopting new modes of operation and providing dedicated support for renewal, international recruitments, structural change in the university system, resource concentration and career opportunities for younger scholars. These policies have been enacted in political consensus and have generally met with support from industry, politics and academia alike (except for the controversial University Act). This holds true despite the current economic impasse in Denmark. Clearly, the policy has paid off and contributed to propelling Danish research from a modest performance into a globally leading position.

A key element behind the rise in Danish visibility seems to be the resource increase. Rather than being evenly distributed, the boost has been channelled through highly competitive

schemes with clearly defined goals (career advancements [DNRF, Sapere Aude], investments in infrastructure and large groupings [UNIK], and business plans [DNATF]). This has been paralleled by large investments from a plethora of foundations in Denmark — the Novo Nordisk Foundation, Lundbeck Foundation, Villum & Velux Foundation, Carlsberg Foundation and others — supporting both small activities and large-scale programmes and centres. Together, these have led to a massive increase in the number of scientists in Denmark, with a doubling of the number of postdoctoral researchers and PhD candidates.

The challenges concern the long-term viability of the resource increase, but also its impact on recruitment of researchers. The hike has primarily been channelled through external funding schemes, which has increased the number of researchers funded with 'soft money'. If this pattern continues, it will push Denmark in the direction of Sweden and Finland, where even tenured staff rely on external funding for their employment. Today, 40 per cent of Denmark's university research depends on external funding and this figure is expected to rise (Danish Agency for Science, Technology and Innovation 2012). Even today, a growing number of researchers are employed outside the established career system and their future opportunities will depend on their success in a volatile funding market.

In addition, many of our informants suggest that a focus on clear-cut models of university governance should not be conflated with top-down steering. The tendencies in this direction should be offset by continued reliance on academic staff to plan and execute their work (cf. Gregersen & Rasmussen 2010). The well-intended university reforms should, similarly, focus on quality rather than scale and scope. The initial idea was indeed to enhance quality by integrating sectoral research and assigning priorities, and this remains a valid goal. We also note a growing focus on University Colleges and their research capacity. Expanding these Colleges' mission and status, laudable as that might be, should be seen as supplementing the focus on excellence rather than being a competing goal.

Finland
The research policy system, 1990–2012

Right up to the late 1980s, the Finnish research system was relatively small. Its international orientation was limited, and it was based on hierarchical academic environments (cf. OECD 1987). Top Finnish scientists were frequent migrants, which benefited countries like Sweden and the US when many prominent Finnish researchers (such as Ragnar Granit, a Nobel Laureate) left for universities elsewhere.

Following the Finnish economic recession of the early 1990s, science investments became crucial in a new economic growth model (the 'innovative society'), along with large-scale programmes for commercial exploitation of research. This made the Finnish model renowned. Notably in Sweden, it was often cited in public debates as a policy model to follow, with its close integration between support of basic research and commercial exploitation. This integration took place under the auspices of the Science and Technology Policy Council, chaired by the Prime Minister. Indeed, the model seemed effective: despite economic hardships in the 1990s, it prompted large investments that propelled Finland from a marginal position in science and innovation to a global leader in information and communication technology, and reinvigorated Finnish science. However, after peaking in around 2000, the impact of Finnish research seems to have stabilised at around the world average and the new policy initiatives taken since then appear to have had little or no effect to date on its international visibility.

With the new model of research and innovation governance that emerged in the 1990s, universities were increasingly dependent on external funding to align them with the dual pressures of quality orientation and innovation networking. There was an overall rise in external funding linked to a ceiling, set at 50 per cent, for 'floor funding'. External funding was based on a dual model. First, funding from the Academy of Finland was awarded to 'cutting-edge environments' (*spetsforskningsenheter*); second, the Finnish Funding Agency for Technology and Innovation (Tekes) provided dedicated support of systemic interaction and cluster-based collaboration in and around various technologies. Ideally, these measures were intended to reinforce one another and culminate in large-scale integrated science-innovation centres like BioCity in Turku, the Oulu Biocentre and the ICT cluster in Espoo.

In this process the Tekes funding, at roughly double that of the Academy, came to dominate Finnish research and innovation policy. Grants from Tekes increasingly served as 'signposts' for research in engineering, medicine and to some extent also the natural sciences (Lemola 2002). The Academy has a broader remit: it supports research in the humanities and social

sciences as well, and geared its support to scientific merit alone. The Academy has been operating with Centres of Excellence as a key instrument for over a decade now, while Tekes has experimented with a variety of measures.

University governance

The Finnish university system developed in waves in modern history. Helsinki University was founded in 1640 (in Turku, but it relocated to Helsinki in 1829) and long remained the sole comprehensive academic institution in the country. In the early 20th century, universities were founded in Helsinki (economics) and Turku by the state, and a Swedish university in Turku was founded with private resources. A college of education in Jyväskylä was given university status in the 1930s. In the postwar period university developments proliferated, with new universities established in Lapland, Oulu, Vaasa, Joensuu and Kuopio. In addition, Finland developed a range of polytechnics for areas like nursing and education (more than 30 of these altogether were founded in the 20th century). Moreover, a sizeable institute sector emerged: one notable institute is the VTT Technical Research Centre of Finland in Espoo but there are also several in public health and social sciences clustered around Helsinki, accounting for about a tenth of research expenditure and half the size of the university sector (Statistics Finland, Science and Technology Statistics).

Until the 1980s, Finnish academic research was largely funded and organised by the universities themselves, with floor funding meeting around 80 per cent of total costs. However, a growing shift of resource provision to external bodies had already begun in 1980. This shift reflected a conviction that Finnish research had become insular and that academic environments were in need of external guidance, international collaboration and resource competition to enhance the status of Finnish research (OECD 1987). This aim seems, moreover, to have been achieved: international visibility and collaboration increased remarkably between the mid-1980s and 2000 (Persson, Luukkonen & Hällikä 2000). Finland seems to have achieved this progress primarily by changing the form and direction of university funding, while leaving career and authority structures largely intact. The main innovation was the use of research assessment exercises (begun in 1999 in the University of Helsinki with followers throughout the country in the coming decade), which showcased areas of excellence (as well as exposing those of an inferior standard).

Overall, our evidence suggests that the transformation of funding caused a weakening of the formal organisational levels (especially faculties and departments) while empowering the research centres, which became the spearheads of the research system, instead. Altogether, these changes have obviously had a major initial impact on academic quality by shifting power from inefficient academic environments to internationally oriented areas. The unresolved issue was the interplay between external impetus and internal organisation, and this remains the most pressing issue in Finnish research governance today.

Research governance since 2000

Policy formation and implementation

One recurrent feature of Finnish science policy-making in recent decades has been its

articulation with innovation policy. This has continued since 2000. Innovation policy figures prominently in formulation of science policies in Finland, while strategies to boost scientific quality tend to be combined with other measures and goals.

The still influential Research and Innovation Council of Finland operates with a vision of Finnish science as a building block in national economic strategy. The following excerpt from its recent report on priorities for the period 2011–15 clarifies its stance:

> 'One of Finland's biggest challenges is to create and maintain world-renowned clusters that can act as nodes that attract innovation actors, businesses and capital. Finns need to be proactive in their areas of strength in transnational cooperation networks. Large, multidisciplinary centres have the best capacity to become global poles of excellence and innovation, encouraging creative and open research environments, dynamic labour markets and high-quality business services. A rich variety of expertise and a critical mass provide the conditions for creating innovations at the interfaces of various fields of knowledge and strengthen the ability of the operating environment to innovate' (*Research and Innovation Policy Guidelines for 2011–2015, p. 41).*

This summarises well the stance of research policy, as well as the interests it reflects, but also a general conviction that the shape and form of Finnish research and innovation are good overall and that research governance is in no immediate need of reform.

Arguably, the Academy of Finland is also influential. For example, its comparative reports on research systems and its inputs into the work of the Council are acknowledged (in, for instance, its 2009 report *State and Quality of Scientific Research in Finland*, a new edition of which is due in December 2012). The most recent report concludes that Finland remains a top spender on research, spending some 1 per cent of GDP on public research. The report also concludes that Finland has not made significant improvements in global scientific visibility since 2000, with only world-average presence in high-impact.

The overall structure of the research governance model is therefore under discussion. In concrete policy measures and discourses, however, the innovation paradigm still looms large. Scientific quality, on the other hand, it is associated with utility and exploitation rather than as a goal in itself.

For research funding the twofold strategy has remained in place, with research and innovation programmes as the two pillars. The Academy of Finland has a more proactive profile than other research councils, making regular profiles and assessments of developments in its various areas, and carrying out penetrating overviews of the Finnish research system in its entirety (Academy of Finland 2009, 2012). The Academy is currently reviewing its activities and contemplating a more integrated way of collaborating with the universities. Overall, the level of external funding is still high by international standards. The purpose of the recently formed, large-scale Strategic Centres for Science, Technology and Innovation (SHOKs, defined by their funder, Tekes, as 'public-private partnerships for speeding up innovation processes') is to unite research, innovation and exploitation of knowledge in areas like health, ICT, forestry, metal engineering and energy.

Governing the universities

Recently, university governance has been a central political issue in Finland. The university governance reform in 2010, which separated universities from the state, was couched primarily in terms of economic efficacy rather than impact on universities as academic institutions (or on individual researchers' independence). It should be noted, however, that this autonomy has been accompanied by changes in interaction between the state and the universities. Criteria for resource allocation have been redefined, with larger shares of floor funding based on university strategies and publication rates (25 and 9 per cent respectively).

At the level of university strategy, we find evidence of a more proactive strategy of appointing and promoting faculties in response to the reform. However, these systems are still relatively patchy and do not cover all areas or appointments. Reflecting the balance between external and internal funding, positions based on 'soft money' continue to form a large share of appointments and reduce the impact of the tenure track models. The capacity for institutional reinvigoration is thus stifled by the skewed funding balance of Finnish universities.

Some universities, such as Aalto University, have been singled out as heralding a new kind of interaction between high-quality research and innovation:

> 'Recent assessments e.g. by the Academy of Finland and the Research and Innovation Council chaired by the Prime Minister, have identified key actions to develop the Finnish strategy for research, innovation and higher education. These reports highlight the requirements for an internationally competitive research system, where the role of high-risk and top-quality fundamental research is increased, better academic career systems are created, the division of labour in the university system is clarified, the research and education infrastructure is improved, and integrated development of technological and social innovations is promoted. The creation of Aalto University is one action that provides an opportunity to restate and embed these core academic values.' (*Strategic Development of Aalto University,* January 2012 edition, p. 6).

The impact of such new organizational models remains unclear. Internal audits of research quality and educational innovation indicate that Aalto has not yet become the harbinger of international excellence and utility as intended but, rather, that it has been circumscribed by excessive dependence on external funding and a certain degree of over-bureaucratisation. The ambitious goal adopted by the Aalto University management to match the Swiss EPFL and Danish DTU in academic impact therefore seems remote at present. (In the most recent Leiden Ranking, EPFL comes first in Europe in terms of impact at the 10% level, DTU seventh and Aalto, albeit the highest-ranking Finnish university, 97th.)

The 2010 reform of university governance (the University Act) has recently been appraised (http://www.minedu.fi/OPM/Julkaisut/2012/yolakiarviointi.html?lang=fi&extra_locale=sv). The tentative conclusion is that the Act gave Finnish universities administrative autonomy from the state, making them independent legal entities and no longer government bodies. The political motives underlying the reform were a mix of administrative rationalism, economic efficacy and international trends. The reception of the governance reform has been mixed: in the old universities, certain staff are reluctant to change and many mechanisms work against the aim of reinforcing the central leadership, while the new universities and

university colleges are more enthusiastic. The reform has also led, at least in the short term, to a centralisation of power relations in Finnish universities and has apparently strengthened the policy-university leadership axis, thus clarifying the delegation of authority in Finnish universities (including internal resource allocation and the recruitment of deans and department heads with concomitant responsibilities and resources available). Despite these efforts, Finnish universities, like their Swedish counterparts, appear to be relatively fragmented and weakly governed, as an effect of their great reliance on external funding.

The share of postgraduate education in research is also considerable. Finland produces about 1,500 PhDs annually — a high figure that reflects the high proportion of R&D activities that are geared towards postgraduate education. The growing importance of external funding has led to massive concentrations of PhD-intensive research environments in some areas, notably parts of biomedicine and engineering. These have been given priority by governments and funders, while other areas may have received only marginal infusions and had their support from floor funding cut. Development towards more autonomy-based (and therefore contract-based) relations with the state may strengthen this trend.

Several shortcomings still appear to be reducing the impact of academic activities in Finnish universities. These include low levels of international networking and collaboration (despite concerted efforts to enhance internationalisation), a high proportion of postgraduate education in relation to other research activities, and unclear career paths with extensive reliance on external funding for research positions. Finland and its universities therefore seem stuck in a difficult position. Promises of autonomy have primarily strengthened their political and managerial aspects, but not yet created a more productive system for innovative research.

Conclusions: no longer a shining example?

To sum up, the Finnish research system has developed tremendously over the last decades, in both qualitative and quantitative terms. Massive resources have been injected in the system and a plethora of programmes have been initiated to support concentrated research efforts, in tandem with innovation measures. Over a long period, these measures attracted great international attention and were viewed as constituting a new and more sustainable path for small, peripheral research systems. They were cited as a policy model in, for example, Swedish policy debates. They contributed to the international exposure of Finnish research and caused a swift rise in international visibility and contacts. However, and more recently, we find indications that this development path has encountered some serious limitations:

- Universities have developed extensive autonomy, but their financial underpinnings and dependence on external funding curtail their strategic capacity. Their resource base is weak and their dependence on external support is growing, despite efforts to enhance their autonomy.

- The expansion of resources and programmatic support for research released the productive forces of Finnish research in the 1990s. However, it overshadowed efforts to foster individual initiatives and groundbreaking efforts, as well as to improve the universities' own capabilities. Instead, researchers' efforts seem to have been geared

towards the formation of research consortia, while universities have become enmeshed in external resource dependency and criteria fulfilment. This situation has been exacerbated by the widespread use of research assessments in Finnish universities: at an early stage these helped to raise scientific standards, but in the long term they may have led to a culture of risk aversion.

- The academic system is still hierarchical in structure, and recent reforms may actually have reinforced the position of a few 'elite scientists', rather than creating a dynamic and open system where new entrants are gradually introduced and empowered. The tenure track system that has been established may rebalance the structure of the Finnish academic community, but this will probably be a long drawn-out process.

- Generally, Finland has developed a streamlined and coherent system of policy formation and implementation. However, policies are shaped and formulated primarily in networks comprising industrial interests and their counterparts in public administration, while the role of academics and their representatives is less pronounced. Recent attempts to formulate a national research strategy and efforts to reinvigorate universities may alter the pattern but, again, this will take time and is probably contingent on changes in the funding profile of Finnish research.

The Netherlands
The research policy system, 1990–2012

The Netherlands is something of an enigma. The country's investment in research is lower than Finland and Sweden (at about 0.95% of GDP in public expenditure) and, following a rise in funding in the late 1990s and 2000s, cuts in state expenditure are now under way. Hence, resource scarcity has been a defining feature of Dutch science policy. Nonetheless, Dutch science and universities hold leading international positions: there are no fewer than seven Dutch universities among the world's top 100 in the latest Leiden Ranking (Switzerland has six, Denmark one, Sweden one and Finland none). Unlike two other successful reference countries, Denmark and Switzerland, where resource hikes and sustained high investment levels have underpinned research quality, the Netherlands seems to perform well despite relatively meagre resource inputs. In contrast to Switzerland, excellence has not been achieved on the basis of resource abundance in a culture that cherishes elitism; rather, the Dutch university and research system, which is relatively uniform in structure, is shaped by an egalitarian tradition. The paradox is thus that here, research impact cannot be explained by elitism and a funding cornucopia (as in Switzerland and Denmark). Instead, a relatively meagre system has succeeded in rationalising its resources and using them for productive purposes.

Science governance: continuity and change

In the 1980s, path-dependent allocation of fixed resources to Dutch universities was questioned. Instead of large shares of block resources being allocated to the universities without strings, predefined units (primarily disciplines) were to be assessed in advance and resources distributed according to the outcomes. These assessments were indeed conducted, but the resource redistribution proved harder to implement. What emerged, for assessing and evaluating the research performed by universities, was a system initially based on a nationwide standard protocol with predefined assessment units. Despite the reduced resource reallocation, the assessments had a major impact and several departments were closed down, resulting in a more clear-cut division of labour in Dutch academia and a pervasive focus on international publications.

The 1990s saw the notion of excellence gaining a hold on the policy system, partly owing to the impact of the assessment system on the structure of Dutch universities and the reorientation of Dutch research towards areas and activities with international exposure. Science policy was defined as 'pushing excellence'. Another key element in the focus on internationalisation and excellence was the professionalisation of postgraduate education

through the introduction of graduate schools. This generated a much stronger impetus for PhD students to publish internationally, which has led to a very strict and formalised system of calibrating impact factors for completed PhD theses (such as a journal impact factor of 12 for a PhD). Today, there are about 120 such graduate schools — far more than initially expected.

Somewhat paradoxically, these changes took place under relatively tight financial constraints, and expenditure on research has been more or less flat since the late 1980s. One recurrent theme has been the relatively paucity of resources allocated to research. Essentially, since it has proved difficult to motivate the electorate to make large investments in research, funding has been reshuffled to support new initiatives. This trend began in earnest in the 1980s, when the historically high proportion of 'floor funding' (almost 90 per cent) was gradually lowered; conditional funding was introduced; and initiatives were taken to enhance universities' profiling (cf. van der Meulen 2007). The next step was the introduction of the graduate schools: this forced universities to collaborate, and enhanced the quality of PhDs (which are still relatively few in the Netherlands, but as mentioned subjected to a stringent control of their publication status). A typical example of how research priorities have been set by reallocations rather than by the influx of new resources is the Innovational Research Incentives Scheme (Veni, Vidi, Vici) for talented young researchers, which was funded by reductions in university funding and a concurrent shift of resources into the Netherlands Organisation for Scientific Research (NWO).

Superficially, Dutch policy-making appears relatively volatile and politicised — subject to the vagaries of political change and political intervention in issues of priority-setting and governance. The Netherlands also seems more inclined than other European countries to make bold policy statements (most recently pledging to become one of the top five 'knowledge economies' worldwide by 2020; 'Netherlands pushes for innovation', *Nature*, 15 November 2011). Critics claim that such initiatives have been coupled with real cuts in university funding by up to 8 per cent in the last three years (ibid.). Concerns have also been expressed about plans to gear the NWO's funding portfolio more towards industrial collaboration.

Beneath the surface, however, what characterises Dutch policy-making is continuity rather than change. Key stakeholders are involved in policy formation on a consultative basis. One key factor explaining the policy reforms within restricted means lies in the decision-making structure of Dutch research policy. The Netherlands has a tradition of mediation in science policy that distinguishes it from the incremental system in Switzerland and the politicised systems of Denmark, Finland and Sweden (Rip and van der Meulen 2001). Moreover, the Royal Netherlands Academy of Arts and Sciences (KNAW) occupies a premium position thanks to its role as advisor on research policy. Besides this important advisory role, KNAW regularly issues reports and carries out investigations of policy inputs, and exerts influence as a cautious critic of the policies devised. The Netherlands also has a highly advanced system — probably the most highly developed of any country in the world — of research evaluation and science systems analysis. Altogether, this means that reforms are well thought-out and supported before they are introduced, and that their outcomes are monitored over time.

Research funding

The NWO is an omnibus organisation, covering all areas except industrial innovation. It was formed by the amalgamation of previously independent research councils. Historically, its two main vehicles have been floor funding of eight 'basic research' institutes and project funding of university-based research, typically totalling some €100,000 annually. The NWO's role has grown substantially over time, especially in recruitment to universities and restructuring of postgraduate education.

Governing Dutch universities: internal steering and external pressure combined

The Netherlands was an early adopter of New Public Management techniques for its universities, with funding based on their publishing activities in particular (van der Meulen 2007). Arguably the most significant change in the governance of Dutch universities was the introduction of a Research Assessment System in the 1980s. Assessments were carried out, with resources linked to their impact, to strengthen national policy-making and priority-setting. However, this was never implemented as intended.

In 2000, the system of research assessment was taken over by the universities themselves. They run it with only marginal intervention from the government (which, however, expects universities to carry out assessments every five years without national coordination). The standardised, discipline-based structure has also been abandoned and the universities now define the assessment units themselves. While the impact of assessment has declined over time — most units today score high on the four-grade list — its deterrent effect is large. There has thus been a strong emphasis on scientific impact, as measured in international publications, and a clear-cut relationship between quality assessments and resource allocation.

This ties in with the universities' governance structures, which combine external evaluations with internal leadership discretion. Dutch universities are relatively well endowed and less dependent on external funding than their Swedish counterparts, although in the past few decades an increase in support through various types of programmes and centres has empowered their leaders. Nonetheless, the relative importance of block grants and the influence of vice-chancellors and faculties in recruitment issues offset the impact of growing external funding (in contrast to the Swedish case, where the influx of external resources has been paralleled by an erosion of floor funding and weakened university authority over recruitment issues). As mentioned, external funding is used only for temporary positions (with the exception of the University of Twente) and, instead, supports areas already identified and empowered by the universities in their internal deliberations.

Research governance since 2000

The drive towards excellence continued in the 2000s, and increasing revenues from oil and gas have been primarily channelled into research where excellence is a central criterion. With the global economic slowdown, the Eurozone crisis and stagnation of the Dutch economy, a reorientation of Dutch science policy was announced. The centrepiece of this reorientation was the programme to support 'Top Sectors' (defined basically as the country's areas of industrial specialisation), which are, similarly, to be funded mainly by reductions in funding

to universities and the NWO. This is another instance of resource reshuffling that may impair the impact of the initiative. We obtained ample evidence of the capacity of the Dutch research system and funding organisations to cope with such reallocations of authority and resources.

The current crisis is pressuring universities to enhance their educational portfolio, and the quality of education continues to be discussed, while research is seen as less problematic and less of a policy issue. Gas revenues, which have been crucial for resource inflows in the last decade, will be used to cover budget deficits in future. As a consequence, floor funding to universities may be expected to remain intact but will be distributed in new forms, as will external funding. Funding agencies are currently engaged in addressing industry's needs and shaping research priorities accordingly (jointly with KNAW). The Top Sector initiative was devised within the Innovation Platform (an important advisory body modelled on the Finnish Science and Technology Policy Council), but KNAW decided that its own support for and influence on the process were necessary. Here again, we find the typical Dutch pattern of interest mediation and consensus-based compromise, rather than the unidirectional top-down strategies typical of Scandinavian policy-making.

Politically, science is otherwise less firmly embedded. The strength of Dutch science appears to be something of a mystery to the Ministry of Education and Research, which seems to concern itself primarily with the structure and volume of education, and operates with a lighter touch when it comes to research. For instance, it has no specific stance on the universities' structure and governance. The Ministry seems content to summarise the many factors in the Netherlands supporting its science performance — strong publishing houses, good ICT infrastructure, universities operating in relative autonomy from direct state steering, a long-standing system of quality assessments, R&D-intensive firms etc.

One illustration is that the Ministry for Education and Research appears to lack 'ownership' of the recent initiatives to develop priority areas (Top Sectors). Instead, its flagship programme is an evaluation of the universities' strategic planning in which their plans for education, in particular, will be scrutinised and 7 per cent of their resource allocation based on the outcome of the evaluation. The overall impression is that the Ministry is relatively passive in matters of research, with its light regulation of the universities' priority programmes largely initiated by other bodies (the Ministry of Health, Welfare and Sport and the Ministry of Economic Affairs), and that the NWO is a relatively autonomous agent.

Research funding

As we have seen, the Netherlands was an early adopter of a three-stage support scheme (Veni, Vidi, Vici) for young researchers following their career paths. This seems to have been particularly successful in fostering scientific renewal. Support is provided in these three stages at a maximum of €250,000, €800,000 and €1.5 million respectively. Interestingly, universities tend to recruit only holders of Veni positions (stage 1) to their tenure tracks, which means that the career system is the shared responsibility of the universities and the NWO. Similarly, the NWO's Centres of Excellence have served to launch national groupings for collective postgraduate education — an effect that has lingered on even after support for the Centres was abolished. The Dutch funding system appears well calibrated for the task of enabling young scholars to establish themselves and successively develop their skills, and

for reforming the fragmented nature of postgraduate education. Thus, despite its limited investments, the NWO has played an important part in the reform of Dutch research over the past few decades.

Research governance at university level

Overall funding for universities has been relatively stable since the 1980s, with floor funding accounting for 70–80 per cent and the remainder provided on a competitive basis. The universities act accordingly and generally refrain from granting tenure to faculty members on the basis of external funding. The aim of avoiding a mix of internal and external funding for senior positions seems likely to have enhanced research quality, at least compared with the extreme flexibility of employment conditions that has emerged in Sweden.

Nonetheless, the past few decades' proliferation of programmes and centres has had an impact on the authority structure in Dutch universities. University governance is increasingly geared towards the leaders of large centres and programmes, although the assessment systems and persistence of formal organisational levels when it comes to resource allocation and recruitment serve as counterweights to external dependence. Leaders of research programmes have become very influential and, in parallel to the formal leadership structures, play a central role in shaping policies. Such informal leaders have benefited from the increase in external funding and the design of priority programmes, especially in medicine, agriculture and engineering. They may be expected to remain highly influential, too, in the system that is emerging, with its new initiatives and strong voice for industry. Thus, although the tensions between different governance models appear relatively limited to date, the structure of research governance in the Netherlands is less stable than in Switzerland, for example.

Beneath the coherent surface we find a bewildering variety of conditions for research in the Netherlands. The dominant and (in bibliometric terms) most successful field is biomedicine. It forms a very powerful bloc in the Dutch research system and has grown on the basis of a threefold funding system: direct government grants, support from the Ministry of Health, Welfare and Sport and programme-based appropriations. The funding category that ranks second comprises the flourishing parts of the social sciences, especially economics and psychology, with their large inflows of students, considerable shares of external funding and relatively generous internal funding, given the areas' strong academic performance. For both these subject categories, there seems to be a fairly stable balance between internal and external resources, and between education and research. Third, engineering and the sciences show increasing dependence on external funding, with floor funding covering the basics (infrastructure, buildings etc.) but not the main activities. Accordingly, these three categories show a pattern resembling Sweden's in their dependence on third-party funding, although the practice of granting tenure on the basis of external funding is less widespread. The remainder of the social sciences and humanities fall into a fourth and last category, where student recruitment is uneven, external funding is relatively limited and the outcomes of university research assessments are more average. Thus (in contrast to the Swiss case), the Dutch research system is run not in a coherent but, rather, a highly variable way.

The Netherlands: success against the odds?

Overall, the Dutch case seems to indicate that sustained excellence in research is not merely a matter of money and increased funding. It has also involved stepping up quality assessments at all levels of the research system, from postgraduate education to recruiting young scholars and assessing and arranging university research programmes. These assessments are ingrained in a culture where research excellence is expected and in a policy system based on long-term goals adopted in relative consensus and with elaborate follow-up mechanisms. Despite the increasingly complex funding and steering techniques, university self-governance has largely been retained and there seems to be a productive tension between internal quality control and external governance. The universities and funding organisations alike appear coherent and clear-cut in their support of research at the level of individuals, subjects and universities. A culture of competitive excellence awareness therefore seems to have pervaded Dutch universities, to good effect.

To sum up, the Dutch have carried out some important reforms of their research system that have enhanced the international visibility of national research and strengthened the quality culture even further. There have been reforms of postgraduate education, fostering international publications of a high standard; a careers programme for young scholars, which has set the standard for recruitment and promotion in the entire university system; quality assurance within the universities; rigorous but voluntary mechanisms for resource allocation; and, finally, mildly interventionist academic leadership, paralleled by entrepreneurial leadership of centres and programmes. The case of the Netherlands shows that egalitarian and consensual research systems, too, can be highly productive and innovative.

Switzerland
The research policy system, 1990–2012

Ever since 1945, the international impact of Swiss research has been considerable and Switzerland has hosted some of the world's most reputed research universities. The country's sustained excellence in higher education reflects its strong political commitment to well-resourced prestige universities and academic self-governance. This commitment has not declined significantly over time; if anything, as we argue below, governance of the Swiss research system has improved further. Spectacular examples of institutional innovations have been introduced and disseminated, with profound effects on research conditions in the country.

In this section, we explore some factors that explain Switzerland's capacity to maintain and consolidate its scientific strength. We find a commitment to upgrading of scientific skills, based on stringent quality requirements in tandem with considerable academic autonomy. The result has been a clear-cut division of labour within disciplines and the university system as a whole. Universities are generally well-endowed, with an internal culture and governance mechanisms that support and sustain high-quality research and strong quality drivers. Some of the historical features of Swiss research governance, such as its tradition of academic autonomy, may entail a certain localism (Benninghoff & Braun 2010). In recent decades, however, this has been successfully counteracted by international recruitment, proactive university leadership, mild state steering attempts and appropriate external research-funding models. Nonetheless, even successful universities are susceptible

Research governance, 1990–2000

Overarching policy priorities

In the postwar period, Switzerland's state expenditure on science remained relatively stable at an average European level (0.65% of GDP around 1990). Despite the average figure, conditions for Swiss research are remarkable in a European comparison: the number of universities is comparatively low and funding has therefore been distributed to relatively few (two federal universities and ten cantonal ones, two of which are also fairly small). Tiny by international comparisons, the government research institute sector is embedded in the federal university system. In addition, Switzerland has some 50 universities of applied science, educational sciences and fine arts that lack research mandates. Almost 80 per cent of research funding goes directly to the universities, while the remaining is obtained externally. External funding comes primarily from the Swiss National Science Foundation (SNSF), a federal

body set up in the 1950s with extensive autonomy and stringent selection mechanisms for primarily bottom-up project funding. Ring-fenced funding is marginal and channelled primarily through the Commission for Technology and Innovation (CTI), a government agency for technical development also set up in the 1950s. Nonetheless, Switzerland emerges as a recurrent 'innovation leader' in various scoreboards and comparative overviews of corporate expenditure on research and development. Public research in the country has long been fairly selective and heavily dominated by four areas: clinical medicine, biomedicine, physics and chemistry. Industrial research is strong in pharmaceuticals and food technology, with several companies heavily engaged in basic research as well.

Thus, research funding has historically been selective, with a narrow focus, clear-cut goals and selection processes, and a uniquely privileged position for initiator-led research conducted in academic settings. The Swiss commitment to research dates far back in history and reflects the country's lack of raw materials and the concomitant drive to develop a knowledge-based economic growth strategy, spearheaded by federal and cantonal universities.

Other characteristic features of the Swiss research policy system are shaped by a tradition of small scale and decentralisation. Student numbers in Swiss universities are also fairly small and, owing to selection (currently only about 20 per cent of students in an annual cohort are eligible for university studies and free to apply nationwide), there are still no mass universities. As a result, universities compete for students and, overall, the quality of students is fairly high. Another factor underlying the remarkable development of Swiss science is the universities' tradition of recruiting faculty members and students alike from abroad. As one informant put it, 'The Swiss are not enough.'

While Switzerland has a tradition of consensus on research policy decisions (as in many other areas, given its permanent coalition government), it has nevertheless established policies and steering mechanisms with selective effects (Braun & Benninghoff 2003). Chief among these is the uneven distribution of resources. Two universities, the Swiss Federal Institute of Technology (ETH) and the Ecole Polytechnique Fédérale de Lausanne (EPFL), serve as showcases for the federal government and receive very generous 'floor' or block funding (estimated at CHF 1 billion and 500 million respectively, with almost automatic annual increases). The other universities — well provided-for as they are — share their funding from the federal and the cantonal levels, and are also generously endowed (the University of Zurich with its 25,000 students and 4,000 employees, for instance, has a budget almost double that of Sweden's Lund University). All the universities are relatively small by European standards and Switzerland has no mass universities of the typical European kind, although admission is open to all students with high school leaving certificates. Another striking deviation from other European countries is Switzerland's investments in undergraduate education, where resources per student far exceed those of the other countries in this study.

Although research funding has always been relatively generous, it stagnated in the 1990s in response to a protracted economic downturn (OECD 2006: 33). It was later accompanied by a profound shift in Swiss research funding, achieving national coordination of research activities rather than uncoordinated cuts. This shift, associated with Charles Kleiber (Swiss State Secretary for Education & Research, 1999–2007), placed productivity pressure on

Swiss research (Kleiber 1999). Backed by influential scientists with international experience, Kleiber took steps to foster institutional competition, but also division of labour and collaboration, among the universities by founding the National Centres of Competence in Research (NCCRs, Benninghoff & Braun 2010). This initiative had a profound impact on the structure and orientation of Swiss universities. In the Romandy region, for instance, chemistry, physics and biomedicine were fundamentally restructured, with chemistry and physics becoming clustered in Geneva and EPFL, and biomedicine in Lausanne.

Another effect of Kleiber's reforms was a restructuring of the relationship between internal and external funding. Before Kleiber, external funding was not essential (nor always seen as advantageous) to the pursuit of research, and the same applied to external steering of universities' research conditions and reform of the uniquely privileged positions of Swiss holders of university chairs. With the reforms and associated change of mindset among Swiss scientific elites, having funding from the SNSF (and the EU) to supplement floor funding from the universities has come to be seen as both necessary and legitimate.

Kleiber's policies did not emerge out of the blue. Rather, they were carefully devised in collaboration with elite scientists who thought that Swiss research and universities had become somewhat insular and needed pushing to take systematic action to promote excellence and inter-university competition. This illustrates another striking feature of Swiss research governance: the lack of permanent bodies for research planning and policy deliberations. Instead, policy is largely the aggregate outcome of historical legacies (independent universities, strong funders, international recruitments etc.) and network-based interventions.

Research funding

Switzerland is a top-ranking investor in research and development as a percentage of GDP (3 per cent in total, of which roughly a third is public expenditure). As mentioned above, large shares of funding goes primarily to the universities themselves, either through federal funding for the two federal universities or with the regions as primary funders, and external funding is dominated by the Swiss National Science Foundation (SNSF). The Foundation, which has always been dominated by academic interests and primarily operates through project support, was established in 1952. Historically, the success rate for project grants has fluctuated around 50 per cent, with relatively large median grants. External funding has thus been an add-on and not always necessary, given the generous funding of professorial chairs set up and controlled by the academic community. This is also reflected in the SNSF's capacity to incorporate programmes oriented towards applications (like the NCCRs) and extensive support for research centres. This has made the SNSF the core of third-party funding in the country and curbed the development of a new funding organisation of the kind typical in Sweden, for example.

University governance

Switzerland has only a few institutes although the ETH structure includes a number of quasi-institutes, such as the Paul Scherrer Institute. In Switzerland, two universities (ETH Zurich and EPFL) account for a large share of public research expenditure. The outstanding performance of these two federal universities has prompted the cantons to adopt similar strategies to enhance their flagship universities. This ties in with the governance structures of the university systems, in which a tradition of autonomy for professorial chair holders has been slightly

modified over time, with the introduction of external evaluations and internal leadership discretion (and great variation among universities). Traditionally, academic leadership was largely symbolic and real power resided with the collegiate, but gradually this has been altered and academic leaders now control larger shares of resources and recruitment.

The primary function of the academic leadership has been to control appointments, especially for the federal universities. The two federal universities, and in particular ETH, are renowned for their rigorous recruitment strategy:

> 'Appointment of professors is one of the major responsibilities of the ETH management team. The presidents of the two ETHs have full responsibility and participate in all strategic decisions. They decide upon the call for the professorship according to the long-term strategic plans of the ETH and then appoint a delegate who organises the recruitment procedure. Next the ETH Board nominates the recruitment committee, which includes external members. The detailed job description is advertised internationally. The recruitment committee also actively searches for and contacts candidates. Applications are screened by the commission, and candidates are chosen for an interview and to give a lecture. The commission then makes its recommendation on the appointment to the president, who remains free to look for another candidate. The president must also obtain the funding and the infrastructure needed for the new professor. In addition to the strong role of the president and the "headhunting" which ensures a long-term, proactive recruitment policy, the institution provides various services for its academic staff, e.g. it assists in finding a job for the professor's spouse, in arranging schools for the children, etc. This approach has allowed ETH Zurich to attract successfully international faculty of high quality.' (*OECD* 2006: 82).

As we shall see, the federal universities, especially EPFL, have continued to refine their recruitment in the last decade and broadened it to include assistant professorships (the procedures outlined above are valid only for full professors) as well.

According to our information, the cantonal universities' appointments have also been selective. They follow peer-to-peer logic, since discipline-based needs (departments) are the foundation and recruitment has therefore been subject to the departments' own prerogatives. This is presumably a risky strategy, since it may bring about nepotism. However, there has also been a corrective: vice-chancellors, emulating the federal universities' practice, have increasingly intervened regarding the relevance and orientation of recruitment. 'I am aware of every search process,' says one vice-chancellor, while another has delegated responsibility to the deans but monitors their activities closely.

Research governance since 2000

Policy concerns

In the past decade, as before, despite (or perhaps because of?) its lack of a clear-cut policy centre, Switzerland has remained committed to excellence as a driver of economic growth and prosperity, and less inclined than all the other countries in this study to cultivate other policy concerns (innovation, strategic research etc.). Switzerland has had its fair share of policy initiatives focusing on innovation and private research investments, but this share has

been much smaller than in all the other reference countries, and the SNSF's dominance in the research funding system has been retained (OECD 2006: 31, OECD 2012). The Swiss political dedication to university autonomy, long-term funding and a select number of well-endowed universities stands out by European standards and can probably be matched only by the USA (where other forces are at play) and some Asian countries. Resource levels have risen rapidly in the last decade but still amount to less than 1 per cent of GDP (0.83% in 2011; OECD 2012). Although external sources have been increasingly important for Swiss research, internal resources still predominate (75/25 according to a recent estimate, compared with the OECD median of 60/40; OECD 2012). Switzerland is thus a quiet and stable corner of a continent where resources and mandates for research have been increasingly constrained and targeted, and there are no signs that this commitment is about to weaken. However, it should be noted that the universities of applied science now has research in their mandates and that the responsibility for education is now with the Ministry of Economics, with a more positive relation with the polytechnics and a more constrained attitude toward the universities.

Research funding

The Swiss National Science Foundation has retained its central role in research governance over the last decade. It has successfully incorporated new functions into a structure headed and dominated by the academic community. One major change in Swiss research funding was the establishment of the National Centres of Competence in 2000. These seem to have been particularly successful in bringing about an overall concentration of research activities and rising ambitions in the fields supported. The programme supports geographically dispersed constellations and is thus no traditional 'centres of excellence' scheme.

The SNSF has continued fine-tuning its external support of Swiss research, and adjusted to a somewhat larger and more proactive role with universities still commanding the bulk of resources. For example, in addition to its three-year project grants, the SNSF is currently considering long-term grants in recognition of the increasing importance of external funding. (It has also raised project overheads to 20%, which acts as a further incentive for universities to seek additional revenues.) It also runs programmes for female researchers and has recently launched an initiative for career development (called 'Ambizione' in addition to the SNSF professorships, which have been in existence since 2000).

University governance and structure

Despite the increasing complexity of external funding, and its growing importance (for some universities it is up to 40 per cent of their research income, a significant share of which comes from EU sources), the universities have retained their internal mechanisms for setting priorities and recruiting staff. Recruitment thus follows an inner logic: it is considered unthinkable to recruit a senior person on the basis of 'soft money'; instead, the strategic considerations referred to above guide the process. External funding and endowments are applied for, especially by the more entrepreneurial universities — EPFL, Zurich and St. Gallen (Benninghoff & Braun 2010) — but even there, external resources must fit in with the overall strategy of the university and serve as additions to already identified areas of specialisation. However (and this is one of the weak spots of Swiss research governance), a tenure track model has only recently been established, and only in some universities. ETH, for instance, has devolved the responsibility to the departments, only half of which have established a

tenure track; EPFL, in contrast, has introduced it throughout the university. Hence, conditions for junior scholars are uneven in Switzerland, although the rise of EPFL and its aggressive global recruitment of young faculty members seem to have triggered responses throughout the system. Steps have also been taken to enhance the gender balance in research, which is also fairly skewed in Switzerland.

Another striking feature of Swiss university governance is the continuing dialogue between management, faculties and departments to appraise the performance of academic units in universities and scrutinise their future recruitment and fund-raising strategies (practices vary, however). This, along with the growing importance of external support via the SNSF and the European Union, seems to have made the already quality-oriented (but perhaps somewhat insular) academic environments in Switzerland highly efficient and dynamic, without losing their internal coherence.

Academic leadership shows an interesting combination of tradition and intervention. Vice-chancellors are primarily recruited from within the universities and on the basis of internal deliberations in the academic senates. Their accountability to the academic community is thereby secured. Nonetheless, university leadership seems to have been strengthened over time, but this change has been based on academic values and orientation, in contrast to the multifaceted direction of university leadership in Sweden and Finland.

Although Swiss universities have external councils, they do not override the recommendations of the senate. This does not mean that the councils are passive in relation to the universities' strategies. The universities' capacity for self-governance is therefore very high — probably the highest among the countries under scrutiny here. There are also, however, examples of academic leaders' more aggressive appointments and strategies, the most celebrated example being EPFL, which has developed a model of organisation and resource allocation that is dynamic and attuned to external interests (and funding), while maintaining and even boosting the university's academic outputs. High levels of internal funding are not conducive to indolence; rather, there are multiple examples of internal and external research reconfigurations on the basis of the universities' internal deliberations rather than by external impetus alone.

Reasons for the persistent excellence of Swiss research

To sum up, Swiss research governance has evolved steadily over time, but its emphasis on a culture of excellence and measures to enhance and sustain focused research efforts have also been reinforced. This emphasis starts at the policy-making level, where priorities are long-term and generally avoid opportunist interventions, concentrating more on the framework conditions. Academic leaders are selected in a traditionalist manner, but this does not rule out vigorous interventionism, especially in the recruitment process. Some leaders have acted very strongly to change the course of the universities and successfully redeployed organisational matrices; others have been less successful (the contrasting cases of EPFL and ETH are instructive). Recruitment is predominantly international and the local inbreeding so characteristic of the Nordic countries, in particular, seems rare in the Swiss case. The funding system focuses on efforts to supplement the generous floor funding and allow scholars to work on long-term programmes of their own design. Academic

governance puts a premium on the discretion of academic leaders and enforcement of rigorous publication patterns; dedicated and well-crafted support schemes for younger researchers; and concentration in highly competitive fields (through the NCCRs). However, Swiss research governance remains weak in one respect: in parts, the career and tenure track system is still relatively deficient. This has triggered a critique from young scholars in the country who call for a more comprehensive career system. Similarly, the privileged position of the universities has recently been questioned and the mandate for the polytechnics widened. Hence, the conditions for Swiss universities are not given but exposed to critique, and how the balance between stability and change will be crucial to the future of Swiss science.

CONCLUSIONS AND RECOMMENDATIONS

Research fulfils many functions in society. It underpins education and technical development, supports policy interventions and enlightens the general public. A distinctive feature of scientific research is that it helps to expand knowledge and open new avenues in human thinking.

A key element in this process is the constant quest for new and groundbreaking research of the kind that leads to new ventures and novel perspectives on nature, culture and society. Such research yields discoveries that generate new and often unforeseen opportunities for humankind. Although the impact of such breakthroughs cannot always be measured in financial terms, they are part of society's constant development and have a crucial bearing on our way of life, material conditions, and understanding and mastery of natural and social processes.

Groundbreaking research is not only a matter of creative individuals. It is a collective and institutional endeavour, and cannot be the responsibility of a few nations alone. Rather, it stems from activities with no clear hierarchy but multiple interacting nodes throughout the world. Especially for smaller nations, this function is essential: if they fail to develop governance mechanisms that allow for breakthrough research, they are in danger of being increasingly marginalised in the global research system, withering intellectually and losing their attractiveness in the recruitment of global talent. Larger nations may also encounter such risks, but they have a much more extensive scientific pool to draw from — a luxury most small nations cannot afford.

The background to this report is concern about the conditions for breakthrough research in Sweden. It also reflects more general concern about research governance in Europe today, and the relative decline of European centres of learning despite the historically central position of universities and research in Europe. Although scientific development has always been accompanied by other goals in science policy, conditions for and involvement in original and innovative research as such are, perhaps, more constrained today than ever before. Breakthrough research has been overshadowed by other policy concerns in recent decades, such as utility to society, relevance and innovation. Such concerns are, of course, important for society too. But to enhance the part played by groundbreaking research in opening up new opportunities, we need to pay much more attention to individuals' creativity and new ideas, and to establishing environments in which scholars, junior and senior alike, can excel at the highest level in their pursuit of new knowledge to underpin innovations of a technical and social nature.

Institutional conditions for scientific creativity and renewal have become more constrained in Europe generally, and Sweden in particular. This is clearly shown in our bibliometric analysis (see appendix). Sweden lags behind other, smaller countries not only when it comes to the output of publications with exceptional impact but also in the renewal of scientific fields. Today, Swedish universities' performance is only at an average international level. In particular, Sweden seems to have achieved a less than optimal 'generational shift' in its research cadre. Our data show a pattern of diminishing impact of Swedish research over time

and a failure to secure the presence of Swedish researchers among the top performers.

To sum up, Sweden exhibits some structural deficiencies, as evidenced by our scientific impact profile, especially the weak renewal and relatively low share of high-impact publications. Our hypothesis is that this reveals a pattern in Swedish research organisation and is not necessarily a resource issue. After a dip in the 1990s, public research expenditure has increased steadily and is now on a high level by European standards and higher than, for instance, Denmark, Switzerland or the Netherlands (the 'reference countries'). We need to look elsewhere to explain the declining trend of Swedish research in terms of the real cutting edge.

Key elements in the understanding of how nations support groundbreaking research are:

- ⋆ priority-setting at national level
- ⋆ direction and funding of research
- ⋆ governance of universities.

For setting of policy priorities at national level, including distribution of resources for various types of operation, we focus particularly on the complexity of science policy; how policy goals are set and how they are interrelated; the degree of long-term commitment to research quality; and the relationship between state and universities. In the 1980s, Sweden pioneered the notion of a coherent science policy with the introduction of three-year research bills, setting policy priorities and resource frames for three (and later four) years at a time. However, while retaining these bills (the current period being the11th), since the early 1990s Sweden has applied a volatile style of policy formation in which science policy priorities primarily reflect short-term, tactical aims rather than long-term commitment. Rapidly and in a relatively uncoordinated manner, drastic austerity measures in the 1990s shifted resources and responsibilities from the university research council nexus (which, although not without flaws and rigidities, had proved durable in the postwar period) to a much more heterogeneous set of actors and interests. This laid down a persistent pattern of resource flexibility, with a declining share of resources going to the universities. This pattern has imposed on Swedish research a growing complexity and an increasing multiplicity of goals and interests that are not always compatible with, or easily converted into, high-quality research practices.

This stands in stark contrast to developments in the reference countries, with the exception of Finland, which embarked on a route similar to Sweden's, with a shift away from university control of resources to a mixture of goals and interests. Although the other countries have carried out several research policy reforms over time, these reforms have not affected the core of the 'research quality nexus' — the interplay between strong and decisive academic structures in the universities and a demanding but complementary set of external interests. Switzerland stands out, in particular, with its consensual long-term commitment to relatively transparent and unidirectional goals; its foundation of university self-governance; the understanding that universities commit themselves to excellence in recruitment and practice; the growing importance of external funding; and an expanded institutional research base, with resources not being directed away from the universities themselves. Denmark has poured resources into research in the last decade, but has done so in a relatively coherent manner, allocating resources on the basis of scientific merit and potential. There, universities have concomitantly been empowered with more resources and stronger internal governance mechanisms (and must report to the state on the outcomes of this combination of resources and self-rule). The Netherlands shares some of the characteristics of both Switzerland and Denmark: universities enjoy considerable autonomy but are also well resourced by the state, and in return are expected to adhere to a recruitment system that is stringent and under national coordination. These features, along with clear requirements on universities to conduct internal assessments and act accordingly, have streamlined research

activities in Dutch universities and focused the use of its relatively scarce resources into areas and environments with strong scientific profiles.

To sum up, fewer and more enduring goals, with means and ends correlated rather than decoupled, seem to be a decisive factor underlying variations in the output of high-impact research. Policy goals are simply too numerous and variegated over time in the Swedish system, and do not form a coherent system of research governance. Rather, there is an opportunistic mixture of goals that direct the research system in too many directions at the same time.

The second major aspect of governance of high-quality research concerns the structure of research funding. In this respect, too, Sweden and Finland stand out with their complexity of research-funding instruments, but also because of the impact of research in relation to universities' block grants ('floor funding'). The share of direct funding to universities is below 50 per cent in both countries, while their funding profiles are a complex array of project-based funding, strategic programmes, centre support, innovation centres and national networks. The share of external funding means that researchers and research groups have been obliged to adapt to the funding policies of external bodies. This has reduced the impact of the universities' internal strategies (including those for recruitment). It has also burdened the funding system with the task of securing the long-term regeneration of the research system — a task that does not dovetail with the funding agencies' traditional remit (which is more short-term and based on evaluation of research proposals).

These features of the Swedish and Finnish systems are in contrast to those of Denmark, the Netherlands and Switzerland, which all commit larger resources to their universities — making intra-academic considerations more influential — while adding external funding to enhance activities in certain fields and for certain work modes. However, these three countries have kept a balance between internal and external governance, and also maintained a stable, predictable system of external funding. The Swiss model, in particular, is distinguished by the dominance of the Swiss National Science Foundation (SNSF), which predominantly supports investigator-led projects. The same is true of the Netherlands Organisation for Scientific Research (NWO), which has a structure similar to SNSF and accords strategic importance to generous project funding for high-quality efforts. In Denmark, the 'institutional competition' in supporting innovative research between the Danish National Research Foundation and the Danish Council for Independent Research has significantly enhanced the conditions for research. All these patterns contrast strongly with the scattered, fragmented nature of research funding in Sweden.

Finally, the universities' internal governance systems have been identified as a critical factor in high-quality research. Universities that have developed internal platforms for quality assessment — in contact with international peers and external funders, of course — are the most significant sites for high-impact research. Of the leading universities in rankings of scientific impact (such as the Leiden Ranking), all have stringent models for self-funded evaluation and empowerment of research, and all use external support to augment their activities. We found clear evidence of such models in universities in Denmark, the Netherlands and Switzerland, whereas universities in Sweden and Finland appear to be more loosely organised, responding primarily to external stimuli and adapting their recruitment and resource allocation to the research-funding market. This is somewhat surprising, since Swedish (and Finnish) universities enjoy considerable organisational autonomy. However, they have been unable to translate this into concrete actions owing to financial constraints, and their strategies are, accordingly, in the hands of external funders' strategies and of the researchers capable of exploiting them.

Nevertheless, external conditions are not solely to blame. Recruitment to top academic positions in Sweden has deteriorated over time, and the

function is now less academic and more based on wide-ranging interests (students, staff, political considerations etc.), at the expense of academic criteria. The role of academic leaders is much more clear-cut in the reference countries, and their mandate focuses clearly on academic performance, with resources and recruitment measures that match stringent quality requirements. This is true not only of the top university management but also of faculties and departments, while those in Sweden have been eroded by circumvention of universities' own resource bases. Other countries show different trends and features: deans and department heads have been increasingly crucial in enhancing quality, while faculties and departments are responsible for appointments and have considerable resources at their disposal.

Moreover, Sweden's academic career system has been virtually dismantled with the changing funding profile of university research. Now, instead, careers depend on the fluctuations of the 'funding market' and even the most senior positions have insecure financial underpinnings. This, too, makes Sweden exceptional; the reference countries (again except for Finland), i.e. Switzerland and the Netherlands, have adopted tenure-track programmes with salaries, supplementary resources and promotion opportunities tied to assistant, associate and full professorships. The more successful reference countries have refrained from appointing faculty staff on the basis of external funds, which appears to be a norm in Swedish universities today.

To sum up, Sweden has a strong financial commitment to research (with currently 1,1% of GDP spent on public research, Sweden is on par with the reference countries), but the inconsistent, uncoordinated nature of resourcing and organisation of research prevents Swedish universities and researchers from attaining the other countries' levels.

What is to be done?

How can the international stature of Swedish science be restored? The overall recommendation arising from comparison of the outcomes and impacts of the various research systems is that the quality ethos must be reinstated. Switzerland, the Netherlands and Denmark have all, in varied but interrelated ways, preserved and enhanced the quality of their research base through a combination of political stability and long-term commitment, high-quality university governance, streamlined funding mechanisms and elaborate models of recruiting and promoting scientific talent. Sweden should take these examples of best practice seriously, learn from them and start overhauling its research governance system as a matter of urgency.

A science policy foundation should be that all policy initiatives should be pre-assessed as to their impact on the quality of Swedish scientific research.

The overarching goal of science policy should be to make Swedish universities strong academically, by reforming the quality of academic leadership, the financial underpinnings of academic research, the career system and decision-making regarding research quality. This should be achieved in bipartisan and long-term agreements to avoid the recurrent waves of research policy initiatives that have so long shaped conditions for research in Sweden. National policy should not involve intermittent meddling and reform. Instead, it should facilitate and enhance division of labour at national level, through peer review and other measures to clarify quality requirements in different locations of the research system. International evaluations should be used to clarify conditions for breakthrough research and inform the state's resource allocation.

Restoring effective leadership at every level of the research system would entail appointing and empowering eminent academic leaders, with solid scientific legitimacy and bold visions for research quality and organisation. It is also necessary to empower interaction between leadership levels within the research system (vice chancellors, deans and department heads) and to tie resources and decision-making power accordingly to these positions.

A transparent and responsible governance structure should be installed. This would involve boards with external representatives setting planning frames and articulating goals for delivering quality, while leaving academic priorities and matching of expectations in the charge of relatively small academic senates. The outcome would, in effect, be a bicameral system with checks and balances between boards and senates that would provide backing for the academic leaders and resurrect collegial responsibility for questions of research quality.

One necessary element in this academic resurrection is a new funding system for university research. The current imbalances between internal and external resources must be remedied. The balance should be at least 60/40 in favour of internal funding versus external resource streams. Thus, if universities wish to expand externally, they should do so on the basis of internal considerations and resource strategy, rather than the other way around as happens today. Floor funding should be tied to internal quality discussions, not to external success.

Research councils should not allow applications for the personal salaries of assistant, associate and full professors. Their funding should be for additional support only. The share of funding for investigator-initiated projects should be increased. Along the same lines, universities should stop filling faculty positions with the use of external funds.

Recruitment is high on the agenda of presidents, vice chancellors, deans and department chairs in the academically more successful reference nations. It is through competitive and often international recruitment that successful universities develop, and a well thought-out and skilfully managed tenure track system is essential if a university wants to excel academically in both research and education. The recruitment process should therefore be thoroughly reformed to create a clear-cut career system. This should be owned by the universities, but the urgency of the situation makes a single national entry point advisable to start with (initially administered by the Swedish Research Council and later delegated to the universities). The Veni, Vidi, Vici model (with progression from assistant professor to associate professor and full professor, as applied by NWO in tandem with the universities in the Netherlands) could serve as a model with distinct promotion points, and salaries and resource allocation tied to the different levels, in Sweden. As in the Netherlands, such a national system could become one of the universities' key resources for recruiting professors. In the hands of the universities, evaluations of candidates' progression from assistant to associate professor should be carried out after four years, whereas promotion from associate to full professor should be voluntary and based selectively on the applicant's merits and the university's strategic considerations. Resources should be tied to position at all stages.

Universities should establish faculty professorships for which recruitment is international, and chair holders should receive generous appropriations over an extended period. There should be faculty-funded positions, well defined and carefully selected, in certain fields where universities seek to excel (KVA 2010). All university professors should be subjected to regular appraisals.

The Swedish university system is currently unified and governed by similar mechanisms irrespective of size, tasks and complexity. We suggest that the system is unlocked and that new roles are enabled, for instance to foster research intensive environments of the highest international standard. They should be funded and governed accordingly. Such universities should primarily rely on their own resources, in tandem with research council support, in accomplishing research environments of international attractiveness. They should form a group of universities aiming at international excellence, along the lines of the Russell Group in the UK (representing the very best of British universities in research, teaching and societal collaboration).

Transforming the research system requires multiple changes — in mindset, responsibilities and resource allocation. These cannot be made

overnight. The process calls for perseverance and patience, as well as an abiding determination to change the course of Swedish research. It can be achieved only by the government, funding organisations and universities in collaboration. It would be tragic if Sweden was unable to rise again and regain its former high position among the world's leading scientific nations.

To be more specific, we propose actions along the following lines:

- Policy decisions about research, and agreements with trade unions, should be guided by the aim of preserving and, above all, strengthening the quality of Swedish research.
- Reinforcing national funding of individuals with bold new ideas, to create a better balance for various strategic initiatives.
- Laying special emphasis on recruiting leaders at different levels with strong academic identities and bold visions.
- A transparent and responsible governance structure should be applied. This would involve boards with external representatives setting planning frames and articulating goals for delivering quality, while leaving academic priorities in the charge of relatively small academic senates.
- Reintroducing a system of faculty positions for professors and lecturers, with full salaries and also basic funding that permits risky long-term research. An initial step is to identify the faculties' leading researchers and confer status by contract. Faculty positions should be set up in the areas where universities seek to lead research, and at the time of recruitment these positions should be applied for on a competitive basis.
- Establishing a tenure-track system, with basic funding at relevant levels for their respective subjects. The high degree of urgency initially prompts a national system administered by the Swedish Research Council in tandem with the universities, according to the Dutch model.
- Recruiting internationally for faculty positions, irrespective of level. To achieve success, it is vital for the conditions offered to be internationally competitive. Weight should be given to using recruitment to create environments with complementary skills, and also to the need for mobility to counteract academic 'inbreeding'.
- Using peer review for regular quality control (every five years is recommended) at department level and to guide distribution of basic research resources for tenured professors at various levels.
- The research councils should stop approving salary funding on a project basis for faculty career positions and for professors and lecturers belonging to faculties.
- External funders are expected to assume full responsibility for funding the salaries of researchers who lack faculty positions obtained in competition.
- The unified university system should be unlocked, to foster research-intensive universities of the highest international standard, funded and governed accordingly. Such universities should primarily rely on their own resources, in tandem with research council support, in accomplishing research environments of international attractiveness.
- Such research-intensive universities should form an organisation, modelled after the UK Russell Group, to be an advocate for optimal conditions for high-quality research in Sweden.

REFERENCES

Aagaard, Kaare (2010). *Kampen om basismidlen* ('The Struggle for Basic Funding'). Aarhus: Center for Forskningsanalyse.

Aagaard, K. & Mejlgaard, N., eds. (2012). *Dansk forskningspolitik efter årtusenskiftet* ('Danish Research Policy Since the Turn of the Millennium'). Aarhus: Aarhus University Press (Aarhus universitetsforlag).

Academy of Finland (2009). *The State and Quality of Scientific Research in Finland 2009*. Helsinki: Academy of Finland.

Academy of Finland (2012). *The State and Quality of Scientific Research in Finland 2012*. Helsinki: Academy of Finland.

Andersen, J. E. (2001). 'Academic Staff in Denmark: The Consequences of Massification in a Small Country', in Enders, Jürgen, ed. *Academic Staff in Europe. Changing Contexts and Conditions*. London: Greenwood Press.

Andrén, C.-G. (manuscript). *Visioner – vägval – verklighet. Beslut som format svenska universitet och högskolor sedan 1940-talet* ('Visions, Crossroads, Reality: Decisions that have Shaped Swedish Higher Education Institutions since the 1940s').

Benner, M. (2001). *Kontrovers och konsensus. Vetenskap och politik i svenskt 1990-tal* ('Controversy and Consensus. Science and Policy in Sweden in the 1990s'). Nora: Nya Doxa.

Benninghoff, M. & Braun, D. (2010), 'Research Funding, Authority Relations, and Scientific Production in Switzerland' In Whitley, R, Gläser, J. and Engwall, L., eds, *Reconfiguring Knowledge Production: Changing Authority Relationships in the Sciences and their Consequences for Intellectual Innovation*, Oxford: Oxford University Press.

Braun, D. & Benninghoff, M. (2003). 'Policy learning in Swiss research policy—the case of the National Centres of Competence in Research', *Research Policy*, 32, 10, 1849–1863.

Danish Agency for Science, Technology and Innovation (Forsknings- og Innovationsstyrelsen, 2009). *Evaluering af forskningsrådssystemet i Danmark* ('Evaluation of Denmark's system of research councils').

Danish Agency for Science, Technology and Innovation (*Forsknings- og Innovationsstyrelsen*, 2012). *Peer-review of the Danish research and innovation system: strengthening innovation performance*. Expert group report prepared for the European Research Area Committee.

Danish Ministry of Science, Innovation and Higher Education (2006). *A Public Good: PhD Education in Denmark*. Report from an international evaluation panel, commissioned by the Danish Ministry of Science, Technology and Innovation.

Danish National Research Foundation (2011). *20 Years of World-Class Research*.

Danish University and Property Agency (*Universitets- och bygningsstyrelsen*, 2010). *Universitetsevalueringen 2009* ('The 2009 University Evaluation').

Edqvist, O. (2003). 'Layered Science and Science Policies', *Minerva*, 41, 3, 207–221.

Engwall, L. and Lindvall Eriksson, K. (2012). 'Leaders of Modern Universities: *Primi Inter Pares* or Chief Executive Officers?' in Staffan Tengblad, ed. *The Work of Managers*. Oxford: Oxford University Press.

Etzkowitz, H. (2003). 'Research Groups as "Quasi-Firms": The Invention of the Entrepreneurial University', *Research Policy* 32, 1, 109–121.

Eve Marder, E., Kettenmann, H. and Grillner, S. 2010. Impacting our young. *PNAS*, Editorial, 107: 21233.

Garfield, E. (1986). 'The 1,000 Articles Most Cited in 1961–1982'. Retrieved at: http://garfield.library.upenn.edu/essays/v9p118y1986.pdf.

Geuna, A. & Martin, B.R. (2003). University Research Evaluation and Funding: An International Comparison, *Minerva*, 41, 277–304.

Goodall, A. (2006). ' Should Top Universities be Led by Top Researchers, and Are They? A Citations Analysis'. *Journal of Documentation*, 2006, 62, 388–411.

Goodall, A. (2009). 'Highly Cited Leaders and the Performance of Research Universities'. *Research Policy*, 38, 7, 1079–1092.

Goodall, A. (2010). 'Raise Your Game', *THES*, 18 February 2010.

Gregersen, B. & Gulddahl Rasmussen, J. (2010). Developing Universities: The Evolving Role of Universities in Denmark: the Changing Role and Challenges for Academic Institutions. In Göransson, B. & Brudenius, C. eds. *Universities in Transition*. Berlin: Springer.

Grønbæk, D. (2001). *Mellem politik og videnskab: reform af det danske forskningsrådssystem 1994–1997* ('Between Politics and Science: Reform of the Danish System of Research Councils'). Copenhagen: University of Copenhagen Department of Political Science (Institut for statskundskab).

Heinze, T. et al. (2009). 'Organizational and Institutional Influences on Creativity in Research', *Research Policy*, 38, 610–623.

Homer-Dixon, T. (2000). *The Ingenuity Gap*. New York: Vintage.

Hollingsworth, J. R., 2008, The Style and Mode of Research Organizations: Innovation in Science. Keynote Address at the Board of Trustees and Members of the Corporation, Neuroscience Research Foundation, Inc., La Jolla, California.

Jacobsson, S. & Granberg, A. (2008). 'Vem styr forskningen vid de tekniska högskolorna?' ('Who controls research in Sweden's universities of technology?'), in Mats Benner and Sverker Sörlin, eds. *Forska lagom och vara världsbäst* ('Swedish research: getting the balance right and being the best in the world'). Stockholm: SNS (Centre for Business and Policy Studies).

Jacobsson, S. & Rickne, A. (2004). 'How large is the Swedish "academic' sector really? A critical analysis of the use of science and technology indicators', *Research Policy* 33, 9, 1355–1372.

Karolinska Institutet (2010). *External Research Assessment at Karolinska Institutet*.

Kleiber, C. (1999). *Pour l' Université*. Bern: Benteli.

KVA (2010). *Universiteten och forskningen – utmaningar och problem* ('Universities and Research: Challenges and Problems'). Stockholm: Royal Swedish Academy of Sciences (KVA).

Lemola, T. (2002). 'Convergence of National Science and Technology Policy: the Case of Finland', *Research Policy*, 31, 1481–1490.

Nordforsk (2011). *Comparing Research at Nordic Universities Using Bibliometric Indicators*. Oslo: Nordforsk.

OECD (1987). Reviews of National Science and Technology Policy: Finland. Paris: OECD.

OECD (1995). *Review of National Science and Technology Policy: Denmark*.

OECD (2006). *Review of National Science and Technology Policy: Switzerland*.

OECD (2012). *Main Science and Technology Indicators*.

Olesen Larsen, P. (2010). Stadier på forskningens vej. Dansk forskningspolitik i går og i dag ('Stages on the Research Road: Danish Research Policy, Past and Present'). Odense: Syddansk universitetsforlag.

Persson, O., Luukkonen, T. & Hällikä, S. (2000), *A Bibliometric Study of Finnish Sciences*. Espoo: Technical Research centre of Finland.

Rip, A. & van der Meulen, B. (2001). 'The Netherlands: Science Policy by Mediation' in Laredo, P. & Mustar, P., eds. *Research and Innovation Policies in the New Global Economy*. Cheltenham: Edward Elgar

Sörlin, S., ed. (2005). *"I den absoluta frontlinjen": En bok om forskningsstiftelserna, konkurrenskraften och politikens möjligheter* ('On the Front Line: A book about research foundations, competitiveness and policy potential'). Nora: Nya Doxa.

Sundqvist, B. (2010). *Svenska universitet: lärdomsborgar eller politiska instrument?* Hedemora: Gidlund.

Swedish National Agency for Higher Education (HSV, 2002). *Befordran till professor och lector* ('Promotion to Professorships and Lectureships'). Stockholm: Swedish National Agency for Higher Education (HSV).

Swedish Natural Science Research Council (NFR) (1995a). *International Review of Swedish Research in Fundamental Chemistry 1995*. Stockholm: NFR.

Swedish Natural Science Research Council (NFR) (1995b). *International Review of Swedish Research in Mathematical Sciences 1995*. Stockholm: NFR.

Swedish Research Council (2010). *Den Svenska produktionen av högt citerade vetenskapliga publikationer*. Stockholm: Swedish Research Council (*Vetenskapsrådet*).

Swedish Research Council (2012a). *The Swedish production of highly cited papers*. Stockholm: Swedish Research Council (*Vetenskapsrådet*).

Swedish Research Council (2012b). *Mid-Term Evaluation Report of the 2006 Linnaeus Environments and Doctoral programmes*. Stockholm: Swedish Research Council (*Vetenskapsrådet*).

Van der Meulen, B. (2007). 'Interfering Governance and Emerging Centres of Control: University Research Evaluations in the Netherlands', in Whitley, R. & Gläser, J., eds. *The Changing Governance of the Sciences: The Advent of Research Evaluation Systems*. Berlin: Springer.

Törnqvist, G. (2009). *Kreativitet i tid och rum: processer, personer och platser*. Stockholm: SNS.

APPENDIX

THE SWEDISH PRODUCTION OF HIGHLY CITED PAPERS

Vetenskapsrådet

Vetenskapsrådet

THE SWEDISH PRODUCTION OF HIGHLY CITED PAPERS

VETENSKAPSRÅDETS LILLA RAPPORTSERIE 5:2012

THE SWEDISH PRODUCTION OF HIGHLY CITED PAPERS

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CONTENTS

SUMMARY

Although Sweden is a leading scientific nation many other countries have seen greater progress during the last two decades as measured using bibliometric statistics. Several reports since the late 1990's have pointed out this pattern. This report aims to update the bibliometric statistics and identify potential explanations in the underlying bibliometric data. Thus, various subject fields, the degree of international collaboration, the degree of interdisciplinarity, publications in the foremost prestige journals and other aspects are scrutinised, The Swedish progress is compared with five other European countries; Denmark, Finland, Netherlands, Switzerland and the United Kingdom. All these, except Finland, are ranked ahead of Sweden when using several bibliometric indicators of scientific performance.

Sweden and Finland have lower national mean citation rates and a lower proportion of highly cited papers than the other countries in the comparison. All reference countries, including Finland, have seen greater improvements during the last twenty years in terms of both national mean citation rate and the production of highly cited papers. The cause(s) for the Swedish lack of progress at the same rate as reference countries is difficult to pinpoint using bibliometric statistics. Rather, the causes seem to be spread over the whole research system. In subject fields where Sweden is highly cited, several of the reference countries are even more highly cited. The degree of international collaboration is as high for Sweden as the other countries, while the Swedish and Finnish collaborative publications are not receiving as many citations as the publications from the reference countries. Similar patterns are found for most comparisons made in the report. A fact that supports a system-level cause is found when looking at the different research organisations in the compared countries. Almost all Swiss organisations perform well above world average and 10 out of 11 main universities are classed as high performing. Similar patterns are found for Denmark and Netherlands. Thus it is difficult to identify any major weak spots in the statistics for these countries. Some weak spots in the Swedish (and Finnish) statistics are:

- A low proportion of the author-community that produce highly cited papers
- The recruitment rate of the top scientists tends to be low
- Low citation rates of Swedish national publications (i.e. where all author addresses are Swedish)
- A decreasing proportion of Swedish international collaboration is with the United States.

SAMMANFATTNING

Sverige har en framträdande position bland världens forskningsproducerande nationer Men när utvecklingen mäts med bibliometrisk statistik har flera andra länder visat en bättre utveckling de senaste två decennierna. Flera rapporter sedan slutet av 1990-talet har pekat på detta mönster. Denna rapport syftar till att uppdatera statistiken och söker potentiella förklaringar i den bibliometriska statistiken. Förklaringar har till exempel sökts i olika ämnesområden, graden av internationellt samarbete, graden av tvärvetenskaplighet och publikationerna i de främsta prestigetidskrifterna. Den svenska utvecklingen jämfört med fem andra europeiska länder, Danmark, Finland, Nederländerna, Schweiz och Storbritannien. Alla dessa utom Finland är rankade före Sverige mätt med flera bibliometriska indikatorer.

Sverige och Finland har lägre genomsnittlig citering och lägre andel högt citerade artiklar än jämförelseländerna. Samtliga studerade länder, inklusive Finland, har visat en bättre utveckling under de senaste tjugo åren när det gäller både nationell genomsnittlig citering och produktion av högt citerade publikationer. Orsaken för att uppmärksamheten (citeringarna) till den svenska forskningen inte utvecklas i takt som för jämförelseländerna är svårt att identifiera med bibliometrisk statistik. Snarare verkar orsaken finnas på en ”systemnivå”. Ämnesområde där Sverige är starkt är flera av referens länderna ännu starkare. Graden av internationellt samarbete är lika hög för Sverige som övriga länder, medan svenska och finska samarbetespublikationer inte får lika många citeringar som motsvarande publikationer från jämförelseländerna. Liknande mönster finns för de flesta jämförelser som görs i rapporten. En observation som stödjer att en viktig orsak till skillnaden, mellan Sverige och flertalet av jämförelseländerna, finns på systemnivå ses i statistiken över forskningsorganisationerna. Nästan alla Schweiziska organisationer har citeringsmedelvärden väl över världsmedelvärden och 10 av 11 av de större universiteten klassas som ”high performing”. Även Danmark och Nederländerna visar ett liknande mönster. Det är alltså svårt att identifiera några viktigare svaga punkter i statistiken för dessa länder. Några svaga punkter i statistiken för Sverige (och Finland) är:

- En låg andel av författarna producerar högt citerade publikationer
- Rekryteringen till gruppen författare som producerar många högt citerade publikationer är låg
- Svenska publikationer med enbart svenska författaradresser citeras lågt
- En minskande andel av det svenska internationella samarbetet är med USA.

1. INTRODUCTION

Sweden is among the more successful scientific countries in the world. However, while the impact made by Swedish publications measured as the number of citations they receive has remained relatively stable during the last 20 years, many other countries have seen an increase in the number of citations to their publications. This pattern has been pointed out in several reports during more than a decade (Ingwersen & Wormell 1999, Glänzel 2000, Glänzel, Danell & Persson 2003, Vetenskapsrådet 2006, 2008 and 2010).

Citations offer one of few quantitative *indicators* of scientific quality that easily can be compiled with access to an appropriate database. For individual papers and small sets of publications there could be large deviances from quality as perceived by peers and citation statistics while bibliometrics is considered to provide more robust quality indices for aggregated data based on large publication numbers. Due to the skewed distribution of citations where a few papers receive many citations while most publications receive none or a few, the average citation impact of countries depends relatively strongly on the most highly cited papers (Aksnes & Sivertsen 2004). An alternative measure to citation averages is the proportion highly cited papers (cf. Aksnes 2003, Tijssen et al. 2005). Highly cited is defined as the publications cited more than a certain percentile limit; e.g., the 90th or 95th percentiles. An advantage with this type of measure is that it is unaffected by single extremely highly cited papers that may have a strong effect on the average. In addition, the highly cited papers are often, but not always, perceived as important papers as judged by peers (see reviews in Moed 2005, Tijssen et al. 2005).

In this report we compare the performance of Swedish research, measured though bibliometric statistics, with five European countries; Denmark, Finland, the Netherlands, Switzerland and the United Kingdom. All of these, except Finland, are ranked higher than Sweden in the bibliometric statistics. The main focus of this report is on the highly cited publications; mainly on those cited more than the 90th percentile. These receive almost 60 % of all citations.

Elements of this report are an update of statistics presented in previous reports from the Swedish Research Council (Vetenskapsrådet 2009, 2010) while other parts complement previously reported statistics. The report is produced in collaboration with the study "Fostering break-through research: A comparative study" at the Royal Swedish Academy of Sciences. The Academy study builds on the present report with the aim of explaining why Sweden today is lagging behind more successful nations in Europe when it comes to high impact publications. The Academy report will be published in December 2012.

2. TERMINOLOGY AND METHODOLOGY

Details on the data source and methods used are given in the appendix. Here, only a few key definitions and terms will be described.

The analysis is restricted to articles and reviews.[1] By "highly cited" or the "top 10 %"- publications we refer to those cited higher than the 90th citation percentile (P_{90}) using a three year citation window. P_{90} is calculated for each year, type of publication (article or review) and subject field separately. Thus papers in subject fields with low mean citation rates have the same probability to be included as papers in more highly cited fields. Similarly, articles are as likely to be included as the more highly cited reviews. To be included in the highly cited group a paper must receive at least one citation more than the 90th percentile. Therefore less than 10 % of all papers are included in the group. The exact number varies between years, subject fields and type of publication, but in most cases the group consists of 8-9 % of all publications. In order to more easily compare and interpret the proportion of highly cited publications, this is taken into account by normalizing the number calculated for a country relative to the fraction of the world production (i.e. the entire database) in the same subject field, year and publication type. Thus, a country that has the same proportion highly cited papers as the world obtains the value 1 and e.g. 1.1 means that the value is 10 % higher than world average (analogous to the field normalized citation rate described below). This normalized value is called *top 10%-index*. In a few cases, corresponding statistics for papers among the top 1 % or top 0.1 % in the world are presented.

The publications *not* included in the top 10 % group, i.e. all publications cited at the 90th percentile or less, are called *base publications*.

All citation statistics are based on a three year citation window and self-citations[2] have been removed. Further, the citations are field normalized meaning that the world (database) average citation rate is 1 for each subject field, year and type of publication. A field normalized value of e.g. 1.2 means that the value is 20 % higher than world average. Correspondingly a value of 0.9 means 10 % lower than world average. The top-10 %-index is interpreted in the same way.

Statistics are calculated for different subject fields using two different groupings. The most detailed subject classification in the database is the journal subject fields defined by the database producer Thomson Reuters. Currently 251 subject fields are in use. Each journal issue is assigned one or several (up to 6) subject fields[3]. These fields are in most cases aggregated into 13 SPRU-fields. Publications in multidisciplinary journals, such as Nature and Science, are reclassified based on the subject profile of cited and citing publications.

1 Here the publication types *letter* and *note* are included in the *article* type.
2 Citations where the same last name and initials is found among the authors in both cited and citing paper.
3 These groups were first defined by SPRU at University of Sussex. The SPRU classification consisted of 14 groups. Since the publications in the "other" group mainly consist of papers in multidisciplinary journals which to a large extent have been reclassified into others fields in the database at the Swedish Research council, this group has been omitted in this report.

3. GLOBAL OVERVIEW

3.1 The database, publication and citation behaviour

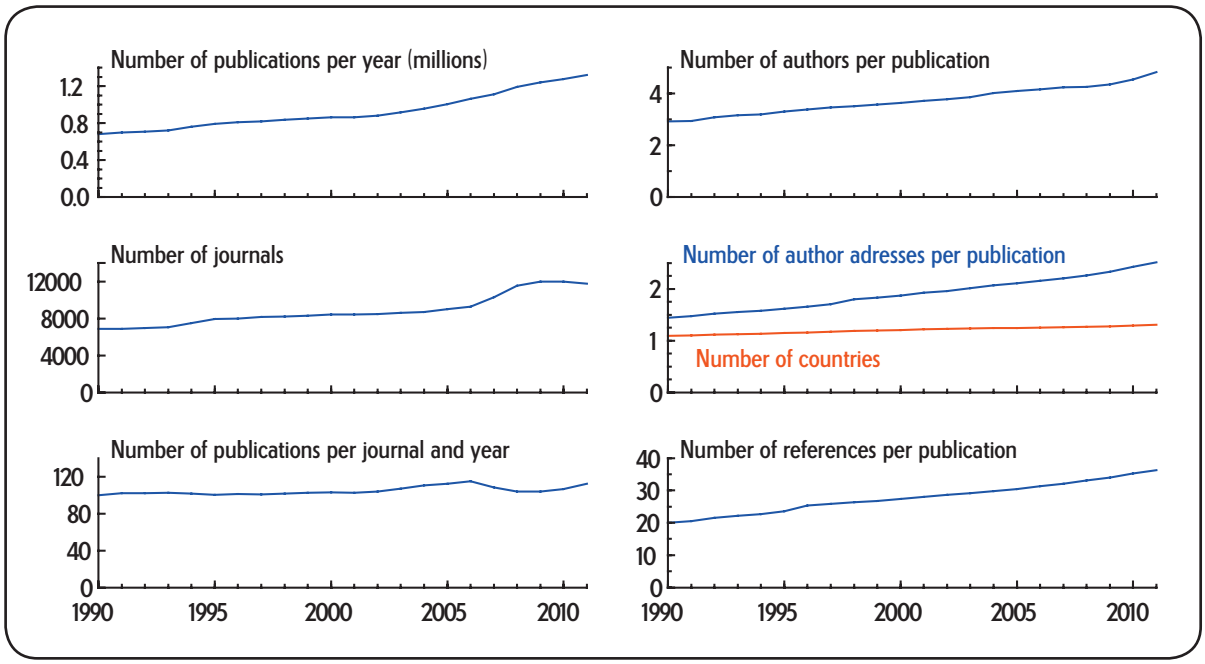
When interpreting changes over the last twenty years, one should keep in mind that the database contents and publication behaviour have changed markedly during this period. Regarding the database contents, the number of articles and reviews indexed in the database each year has increased by 88 %[4] and the number of journals indexed has increased by 74 % (Figure 3.1). Although English-speaking countries and Europe dominate the database strongly, the geographical spread of journals covered has increased over time. For example, during the last ten years many journals from South America and Asia have been added to the database. Currently (2009-2011) 6.1 % of all publications in the database are published in Asia and 1.8 % in South America. English speaking countries contribute with 69 % and continental Europe (i.e. Europe excluding the United Kingdom and Ireland) with 22 %. Between 2006 and 2008 the number of journals increased markedly. The number of articles and reviews published per journal and year has shown a more modest change; +8 %.

Non-English-language journals are commonly cited less than English-language journals in the same fields. Thus the addition of non-English-language journals to the database could affect the citation statistics of some countries negatively. Such a pattern has been described for universities in Germany and France (van Raan et al 2011). Although the geographical distribution of the journals covered by the database has increased, the proportion of English language publications has increased over time; from 92 % twenty years ago to 96 % currently. In parallel with the increase in the proportion of English-language publications, the proportion in Russian has decreased from 2.4% to 0.2 %, in German from 2.1 % to 0.8 % and in French from 1.7 % to 0.7 %. As a consequence of the increase of Asian and South American journals, publications in Spanish and Chinese have increased slightly; currently 0.7 % of the publications in the database are in Spanish and 0.6 % in Chinese.

Also the behaviour of the authors of the scientific publications has changed. During the last 20-years the number of authors per paper has increased by 57 %, the number of author addresses per paper by 68 %. The number of addresses has thus increased more than the number of authors. Partly this could be due to an increasing double affiliation among the authors. The increasing use of bibliometrics has probably also contributed to the awareness of including all relevant addresses in the publications. The average number of countries found among the author addresses has increased by 18 %. Also, the number of publications cited by the average publication in the database also has almost doubled (Figure 3.1). All these inflationary tendencies in the underlying bibliometric data calls for relative indicators (Persson, Glänzel, Danell 2004) which we apply throughout this report.

4 Relative changes are based on comparisons between mean values for 1989-1991 and 2009-2011.

Figure 3.1. Statistics showing changes in database contents (first column) and publication behaviour (second column) during the last 20 years.

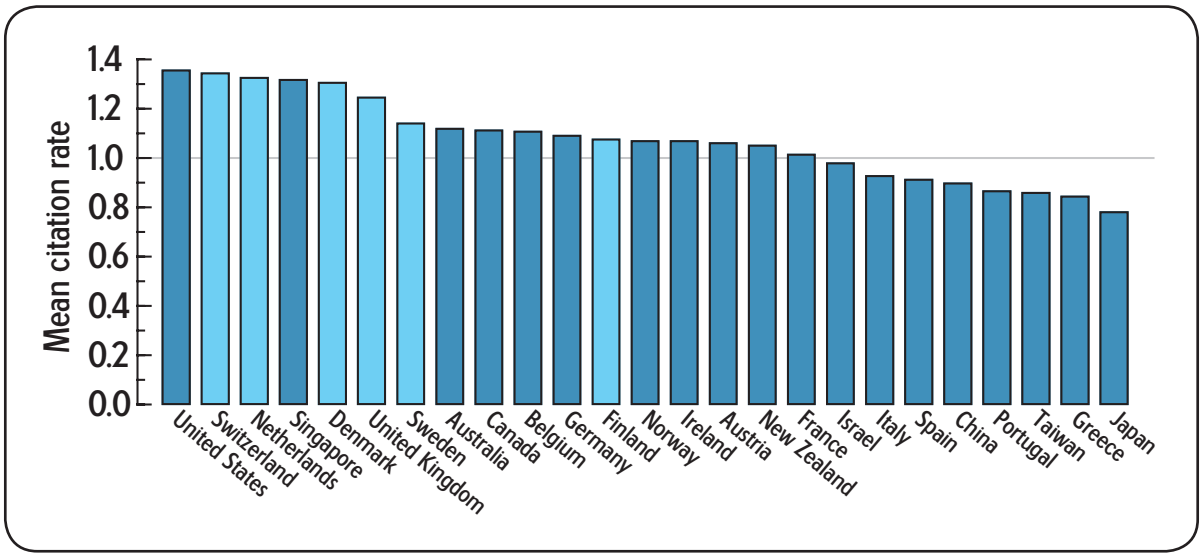


3.2 Global patterns in citation impact

The United States is the world's leading scientific nation in terms of citation impact (Figure 3.2)[5]. However, the distance between the United States and other nations is decreasing (cf. also Figures 3.3 and 3.4). The publications from four countries; Switzerland, the Netherlands, Singapore and Denmark, are cited almost as much as those of the United States. In figure 3.2, only 0.05 units separate the United States in first place and Denmark in fifth place. Any of these five most cited countries could potentially shift positions coming years. After this closely-clustered group of five countries come the United Kingdom and then Sweden. After Sweden follows a tight cluster of nine countries, all with an average citation rate less than 0.1 units below the Swedish rate.

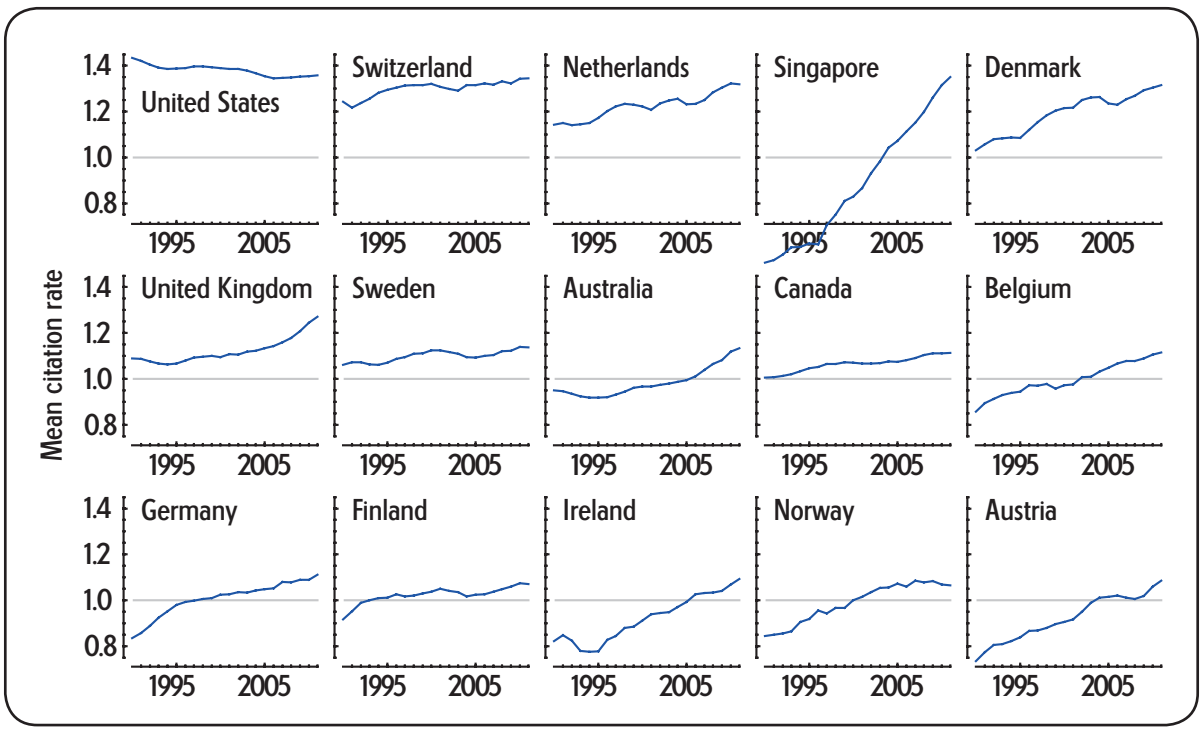
5 In terms of volume United States is by far the world's largest scientific nation, contributing with 23 % of the database content, to compare with 11 % for China, the world's second largest producer of publications. However, twenty years ago the American dominance was much stronger with 37 % of the database contents.

Figure 3.2. The 25 countries with highest mean field normalized citation rate 2009-2011 among the 39 countries with at least 4000 publications per year. The countries in particular focus of this report are marked in a lighter shade of blue.



In Figure 3.3, the trend in the mean citation rate over the last 20 years is shown for the 15 most highly cited countries. The United States is the only country with a declining trend. This decline for the United States is probably not an indication of declining quality of the American publications. Since the world average is 1 by definition, it is more or less impossible for the United States to maintain its very high average from the early 1990's as quality and quantity of the publications from other countries around the world increases. Thus, as the world outside of the United States produces an increasing amount of publications that are of a good international standard, the range of national citation means tends to narrow up around 1.

Figure 3.3. Trend of mean citation rate between 1990 and 2011 for fifteen of the currently most highly cited countries according to figure 1.

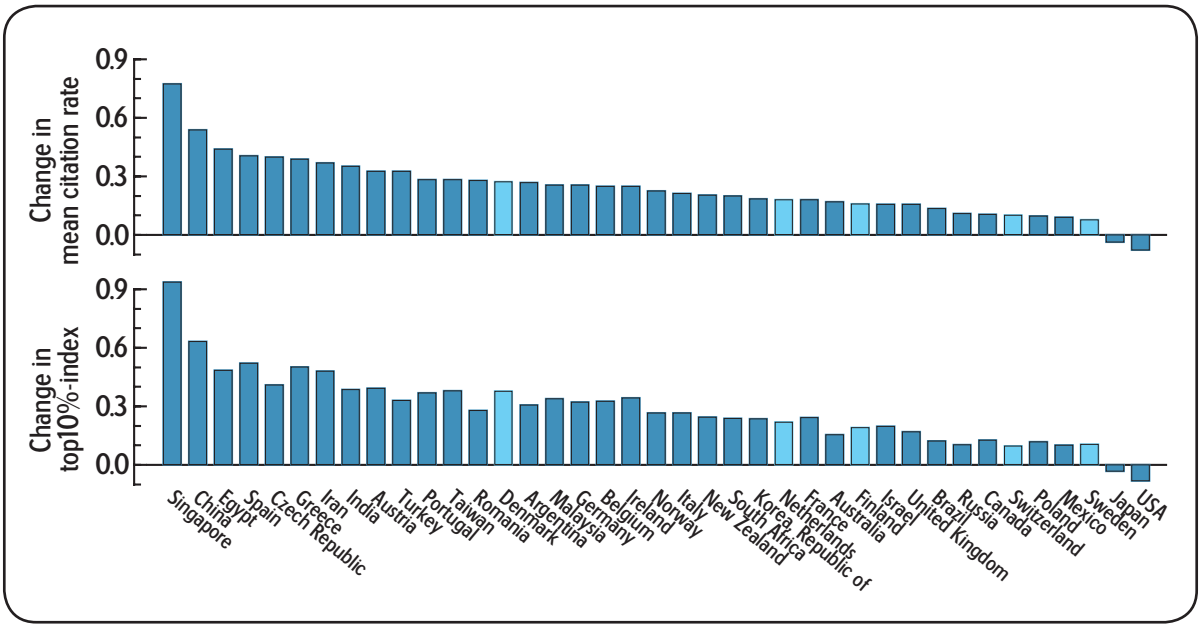


The most dramatic shift in citation impact has been shown by Singapore (Figure 3.3 and 3.4). This development is in parallel with a strong economic development, significant investment in research and development - mainly in engineering and biomedicine - and recruitment of a large number of foreign scientists.[6]

The change in citation averages and the proportion of highly cited publications over the last twenty years is shown in Figure 3.4. As mentioned above, Singapore sticks out as having the most dramatic change among all major producers of scientific papers. Other countries progressing very strongly are China, Egypt and Spain. Since it is much easier to improve from a low starting point, most of the countries showing the largest improvements had very low citation averages in the early 1990's.

Among the countries that are in focus in this report, Denmark has shown the largest increase in mean citation. In the rightmost edge of the chart we find the United States and Japan as the only countries with a declining mean citation rate. There are other, small countries with a negative development but they have a marginal impact on global patterns. The United States, and to some extent Japan, therefore balances out all other countries that show increasing mean values.

Figure 3.4. Change in mean citation rate between 1989-1991 and 2009-2011. The selection of countries is limited to the 39 countries in the world with an annual output of at least 4000 publications during the later period.



Among the world's 39 largest nations in terms of scientific output, Sweden has shown the third weakest development of the mean citation statistic and the fifth weakest with respect to the development of the proportion highly cited publications during the last twenty years (Figure 3.4). Switzerland is also among the countries showing a small change.

In the following sections the Swedish development will be compared with that of five European countries, all of which are better than Sweden in the parameters shown in Figure 3.4. The comparison will include a number of aspects that may help to understand the Swedish development.

6 See eg Sinha 2009

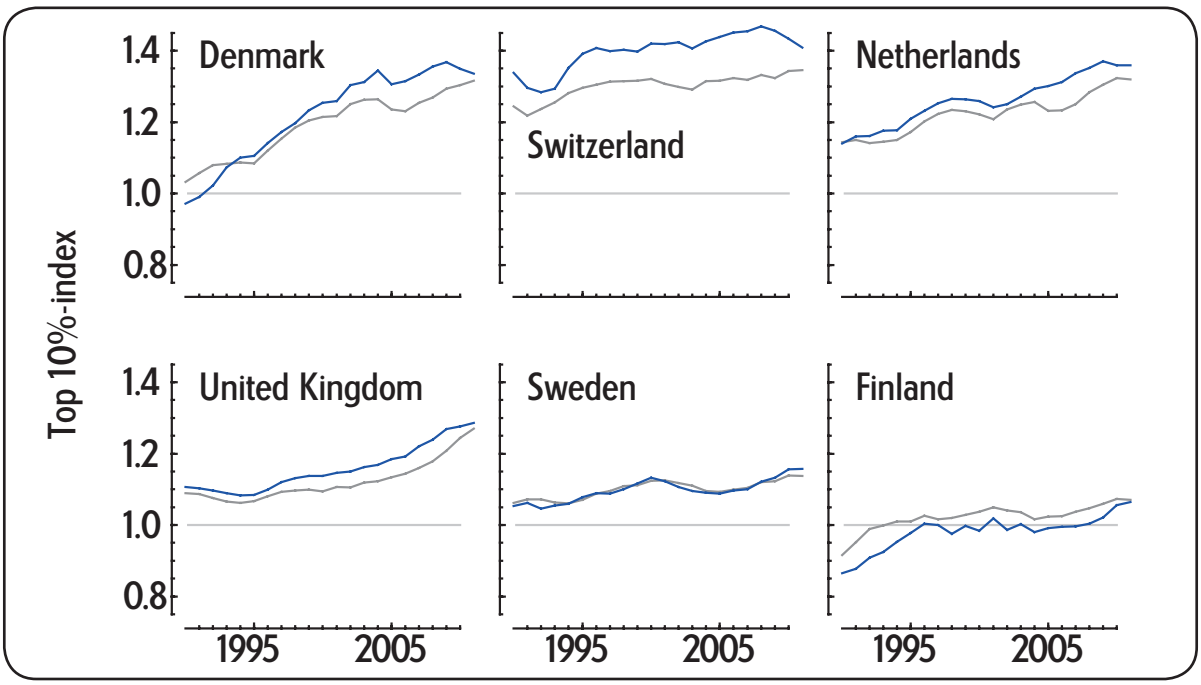
4. THE PRODUCTION OF HIGHLY CITED AND NOT CITED PUBLICATIONS DURING THE LAST 20 YEARS

This section compares the production of highly cited papers (top 10 %, top 1% and top 0.1 %) among the countries in focus for this study and how these highly cited papers contribute to the total number of citations received by each respective country. Furthermore, statistics on the proportion of papers not cited during the first three years after publication is presented.

For several of the compared countries, the development of the proportion of highly cited papers (the top 10 %-index) follows the national citation average relatively closely (Figure 4.1). The only significant exception is Switzerland where the top 10 %-index is considerably higher than the mean citation rate. For Denmark the rise in the top 10%-index is more marked than the rise in the mean citation rate.

For Finland and Sweden the curves has been relatively flat during the last 10-15 years. For Sweden the mean citation and top 10%-index curves overlap for most years. The Finnish top 10 %-index curve is below the mean citation curve. Also the Swiss top 10 %-index curve has been relatively flat for the last 15-years, although at a very high level. The other countries, Denmark, the Netherlands and the United Kingdom, have shown an increasing top 10 %-index.

Figure 4.1. Development of the top 10 %-index between 1990 and 2011 for Sweden and the five reference countries. For comparison the national mean citation rate is shown as a grey curve and the grey horizontal line (with a value of one) shows the world average. The curves are based on 3-year moving averages.

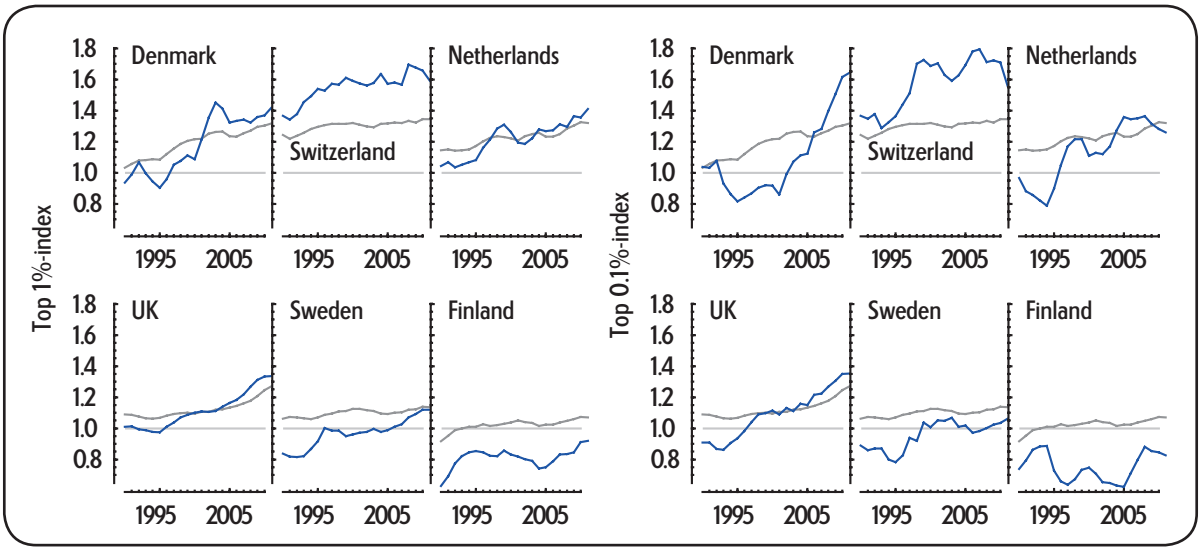


The pattern from Figure 4.1 is largely repeated when the top 1% or top 0.1 %-indices are compared (Figure 4.2). Since curves for the latter two are based on a considerably lower number of publications the statistics become much noisier; most so for the proportion 0.1 %. For this reason the top 0.1 %-index is based on five-year moving averages[7].

7 The mean for 1990 is based on 1988 to 1992, etc. For the last years there is no data after 2011, the means for 2010 and 2011 are thus based, means for four and three years only.

The increasing trend in the Danish mean citation rate curve (grey curve) is enhanced by the large increase in top 0.1% papers (blue line, Figure 4.2). For Sweden and even more so for Finland, the proportion very highly cited papers falls below the mean citation rate curve.

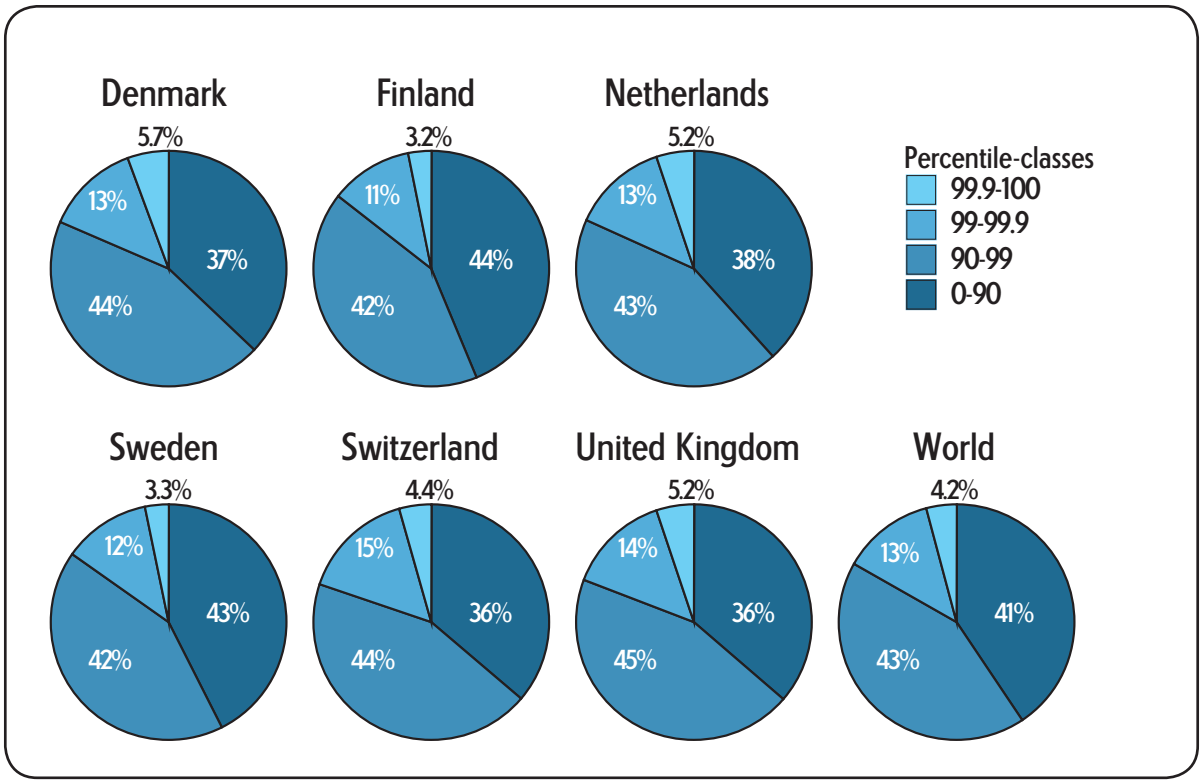
Figure 4.2. Development of the top 1 %-index and 0.1 %-index between 1990 and 2011 for Sweden and the five reference countries. For comparison is the national mean citation rate shown as a grey curve and the grey horizontal line (at 1) shows the world average. The top 1 %-index curves are based on 3-year moving averages while the 0.1 %-index curves are based on 5-year moving averages.



Sweden together with Finland thus has a low proportion of highly cited papers compared to the other countries. The difference is more pronounced for the very highly cited publications (top 1 % and top 0.1 %). The contribution of these groups to all citations to Finnish or Swedish papers is lower than the corresponding number for the other countries in the study and lower than the world average (Figure 4.3). In the world (i.e.the entire database), 4.2 % of all citations are given to the top 0.1 % and 17 % to the top 1 %. Finnish and Swedish publications among the world top 1 % account for 14 % and 15 %, respectively, of all citations to these countries while the Swiss share of the top 1 % publications receives 20 % of all citations to Swiss publications. Switzerland is followed by United Kingdom (19 %), Denmark and the Netherlands (both 18 %).

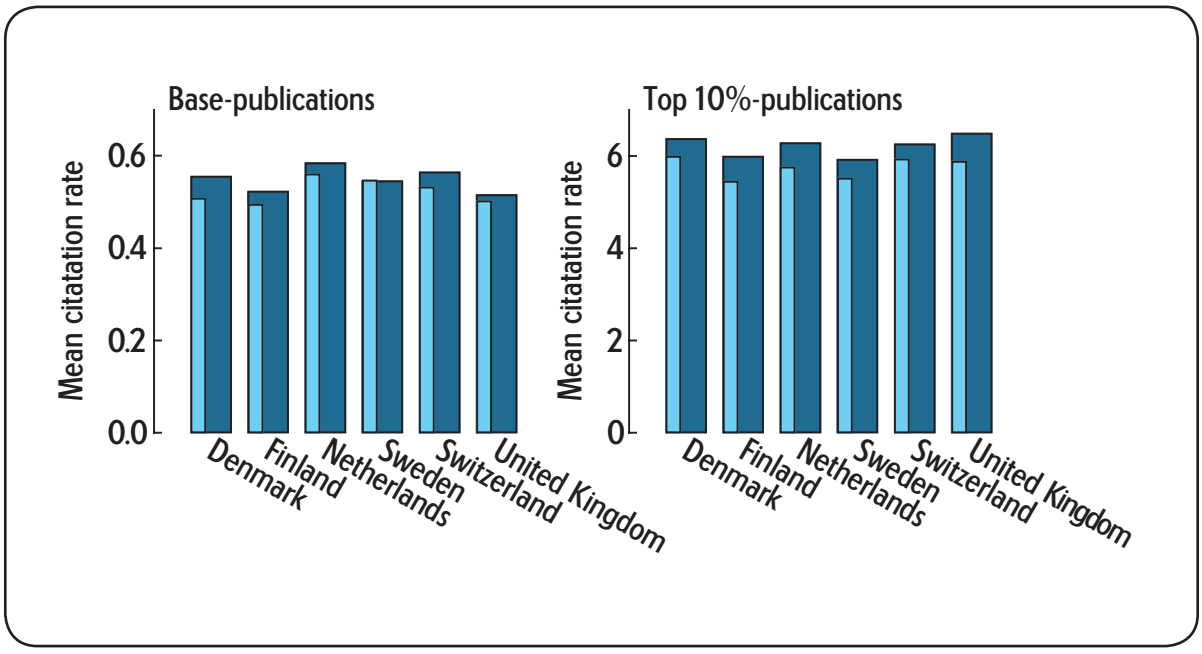
For Sweden to obtain a 10 %-index similar to that of Denmark the number of top 10 %-papers per year needs to increase by 200 per year (currently Sweden produces 1400 fractionated top 10 %-papers per year). Similarly the number of top 1 %-papers should increase by 30 and the number top 0.1 % papers by 8 per year to match the Danish level.

Figure 4.3. Contribution of different percentile-classes to all citations.



The rank order among the compared countries is similar when comparing mean citation rate for the base publications and the top 10 %-publications; the main difference being a relative low mean for the base publications from the United Kingdom (Figure 4.4). The top 10 %-publications citation rate is more than 10-times that of base-publications.

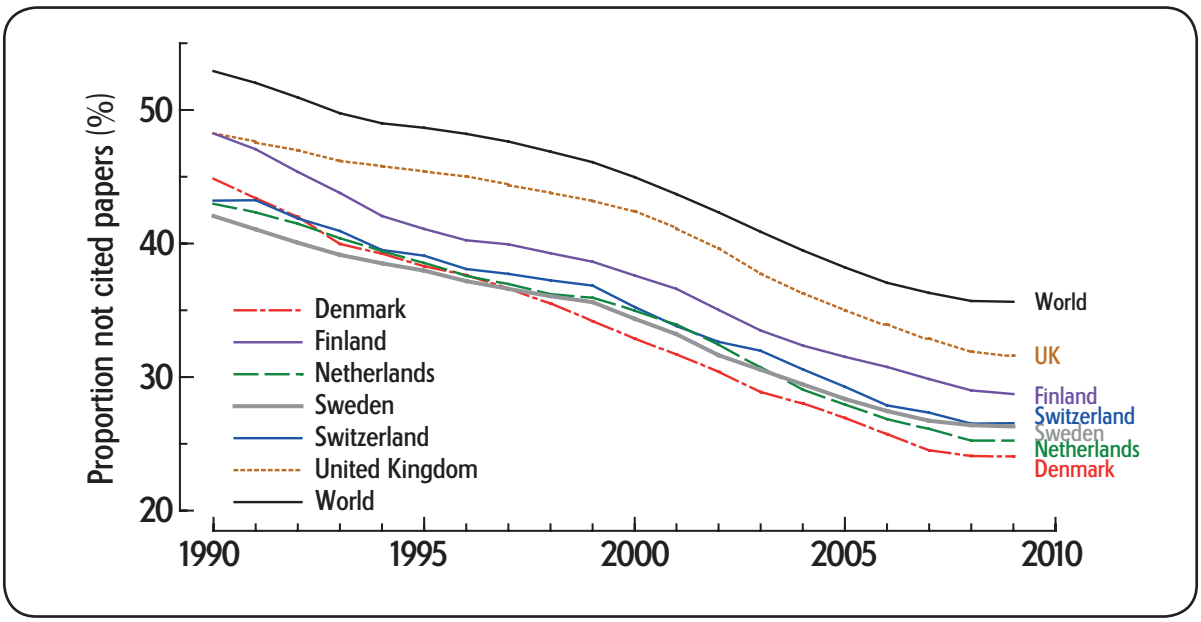
Figure 4.4. Mean field-normalized citation rate for the base and top 10 % publications. Wide bars show mean values for 2009-2011 and the narrow bars mean values for 1989-1991.



If the other extreme of the citation spectrum is considered, i.e., the publications not receiving any citations during the first three years following publication, the pattern changes (Figure 4.5). There is a global trend of a decreasing number of papers not receiving any citations during the first three years after publication; the world proportion of such publications has decreased from above 50 % in the early 1990's to 36 % by 2009. This decline is probably related to the increase in the number of references per paper (c.f. figure 3.1).

Regarding the proportion non-cited papers, Sweden does not differ significantly from the most highly cited nations; the Swedish proportion is at a similar level to that for the Netherlands or Switzerland. The countries that have the highest proportion not cited publications are the United Kingdom followed by Finland. Currently, Denmark has the lowest proportion not cited; 24 %

Figure 4.5. Proportion of the publications not receiving any citations during the first three years after publication. Three-year moving averages.



The statistics presented above indicate that the importance of the highly cited publications for the national mean citation rate is declining; the proportion of papers not cited is declining and the mean citation rate of base publications is increasing, not so for Sweden however (Figure 4.4). Currently around 40 % of citations are obtained by the base publications, twenty years ago this number varied between 20 % and 25 % for the countries in this study.

To summarize, Sweden together with Finland, has a lower proportion of highly cited publications as compared to the other countries in the comparison. In addition, the mean citation rate of the highly cited papers from Sweden and Finland are also lower than for the other countries. Combined, the highly cited publications thus contribute less to the number of citations received by Swedish and Finnish publications. This difference is accentuated for the more narrow definition of highly cited papers used (top 10%, top 1 % or top 0.1 %). However, the rank order between the compared countries remains almost the same when the base publications are compared, the differences in highly cited papers cannot explain all differences in mean citation rate between the compared countries.

5. COLLABORATION AND IMPACT

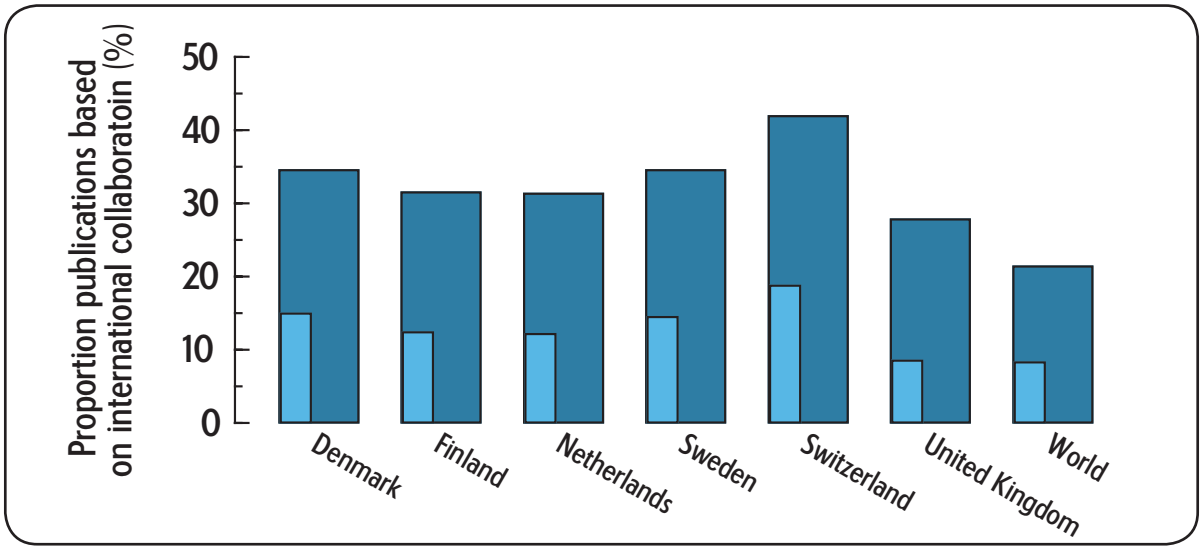
It is well know that publications based on large collaborations on average are more highly cited than publications where the number of authors or adresses are low (eg Aksnes 2003). Further, small countries tend to collaborate more internationally than large countries (eg Luukkonen et al 1992, Gunnarsson 2010); the main reson for this is probably that in small countries it is less likely to find suitable collaboration partners within the country as compared to larger countries. In this section we compare some statistics where collaboration is related to citation rates and the proportion highly cited publications. Statistics on the main collaboration countries are also presented.

5.1 Proportion of publications based on international collaboration

One way to compare the effect of collaboration is to distinguish between papers produced within one country with those based on international collaboration. Publications based on international collaboration, international publications, are here defined as those where the authors represent two or more countries. A small fraction of the international publications are due to double affiliation of a single author. About 12 % of all authors in the database have more than one address; of these one fifth (22 %) have affiliations in more than one country. Thus, at the most a few per cent of the papers produced in international collaboration according to the definition used here, may be the result of a single person affiliated to more than one country.

The proportion of the publications produced in international collaboration has increased markedly during the last 20 years (Figure 5.1[8]). The extent of collaboration is smallest for the United Kingdom which largely can be explained by the size of this country. The largest proportion is found for Switzerland while Finland has a lower proportion than expected for the country size; Finland and Denmark are similar in size but Denmark has a higher proportion of international publications.

Figure 5.1. The proportion of publications based on international collaboration. Wide bars show mean values for 2009-2011 and the narrow bars means for 1989-1991. Based on fractionalised publications.



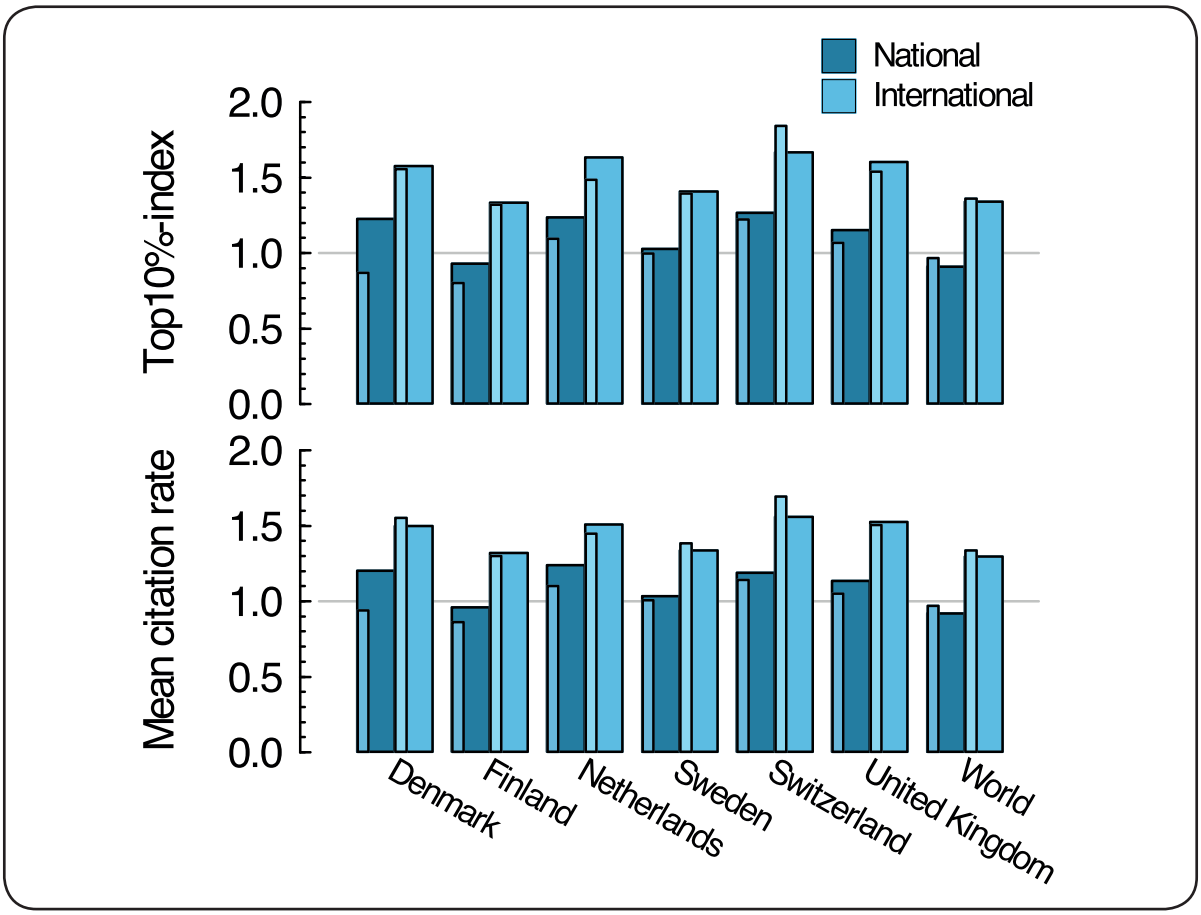
8 Figure 5.1 is based on *fractionalised* publications. The proportion of international collaboration based on whole counts yields higher values (see appendix) but the relative differences among the countries are very similar.

5.2 Collaboration versus impact

Both the proportion of highly cited papers and the mean citation rate are higher for international publications than for national publications, i.e., those where all author addresses are in the same country (Figure 5.2). Among the compared countries, international publications from Switzerland have the highest proportion highly cited papers and received the highest mean citation rates. During the last 20 years, several of the countries (Denmark, Finland, the Netherland and the United Kingdom) have improved their proportion of top-10 %-publications among the national publications. The increase in citation rate of national publications is largest for Denmark.

The change between the two periods for international papers is smaller. Only in one case, the Swiss international publications, shows a marked declined both in terms of the proportion highly cited publications and in the mean citation rate. The Swedish change in the top10%-index for both national and international papers is marginal.

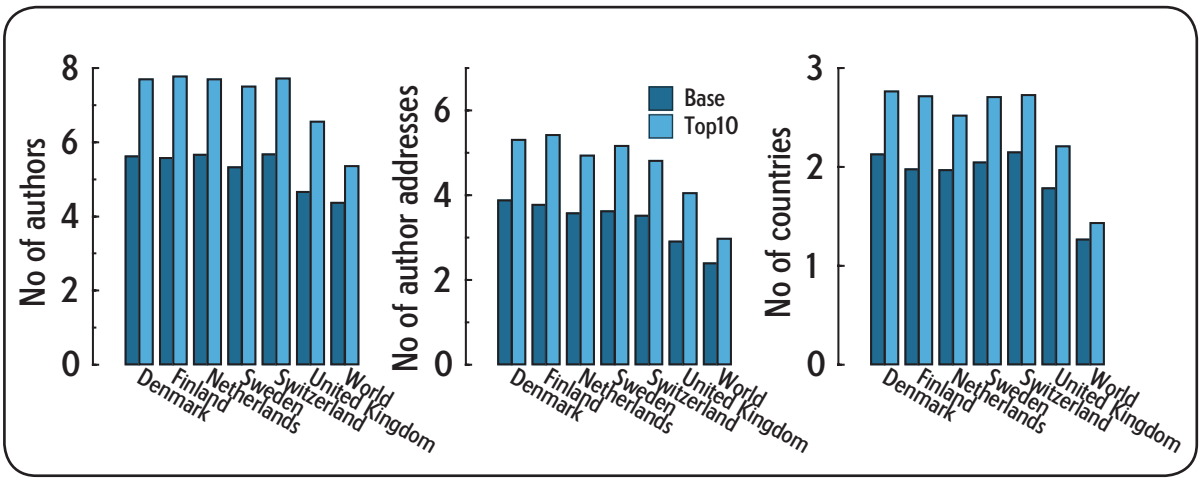
Figure 5.2. Top10 %-index and mean citation rate for national and internationally co-authored publications. Wide bars show average for 2009-2011 and narrow bars 1989-1991.



Another approach to analyse collaboration patterns is to compare the number of authors, number of author adresses or the number of countries represented by the authors. In Figure 5.3, these three measures are compared for base- and top 10 %-publications. In all cases top 10 %-papers are based on collaboration to a higher degree than the base-publications. Differences among the compared countries are

probably mainly related to country size (c.f. Gunnarsson 2010); publications from the United Kingdom are in all cases to a lesser extent the result of international collaboration. Finland shows the highest numbers, but the differences between Finland, Denmark and Sweden are small.

Figure 5.3. Collaboration indices for base and top 10 %-publications. Base publications are those cited less than the top 10 %-publications. The statistics is based on publications with 50 authors or less.[9]



Considering country size, there are, thus, no large differences among the compared countries in the proportion of the publications produced in international collaboration. Switzerland is slightly more internationalized than may be expected and Finland slightly less. The improved citation rates observed over the last twenty years for Denmark, Finland (and to some extent the Netherlands) are mainly due to increasing citation rates of national publications, which is not the case for Sweden.

5.3 Main collaboration countries

For each of the six countries focused in this report, the six most frequent collaboration countries are shown in Figure 5.4. For all countries except Switzerland, United States is the most frequent collaboration partner. For Switzerland collaboration with Germany is slightly more frequent than with United States. From the graph it is apparent that inter-European collaboration has increased substantially during the last twenty years. The percentage of international publications involving collaboration with the United States has been relatively stable over the last twenty years for most of the countries. One exception to this pattern is Sweden where collaboration with the United States has decreased. Twenty years ago 34 % of the international Swedish publications involved collaboration with the United States, the highest proportion among the compared countries. Currently this number has decreased to 28 %. Only Finland has a lower proportion (27%). Also Finland and the United Kingdom show small decreases in collaboration with the United States.

The proportion of highly cited publications among the publications produced with the most important countries does not show any clear patterns (Figure 5.4). For example, the top 10%-index for the Swedish collaborative publications with the United States is only slightly lower (ca 0.10 units) than those for Denmark and the Netherlands, and is similar or higher than those for Switzerland and the United Kingdom.

Statistics on the effect of international collaboration for different subject fields will be presented in the next section.

9 Less than 1 % of all publications are excluded by this restriction.

Figure 5.4. Most frequent collaboration countries. The wide, dark bars indicate mean for 2009-2011 and the narrow, lighter, bars indicate mean for 1989-1991.

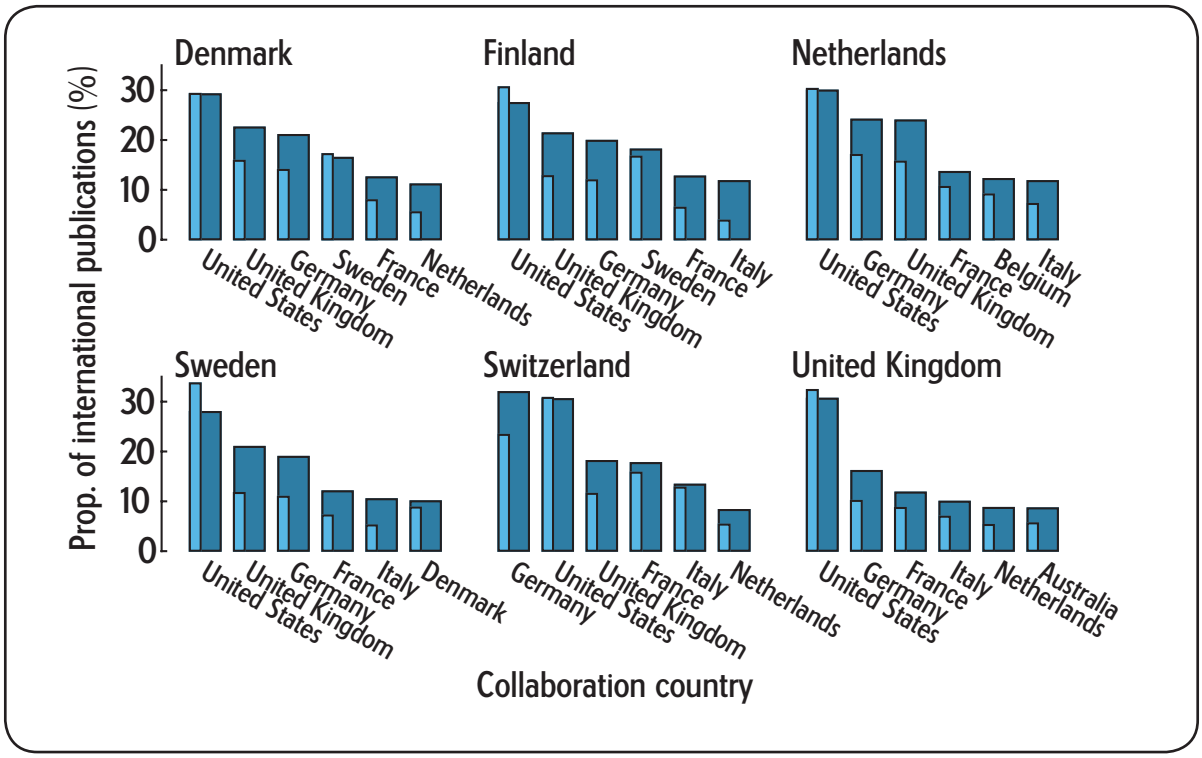
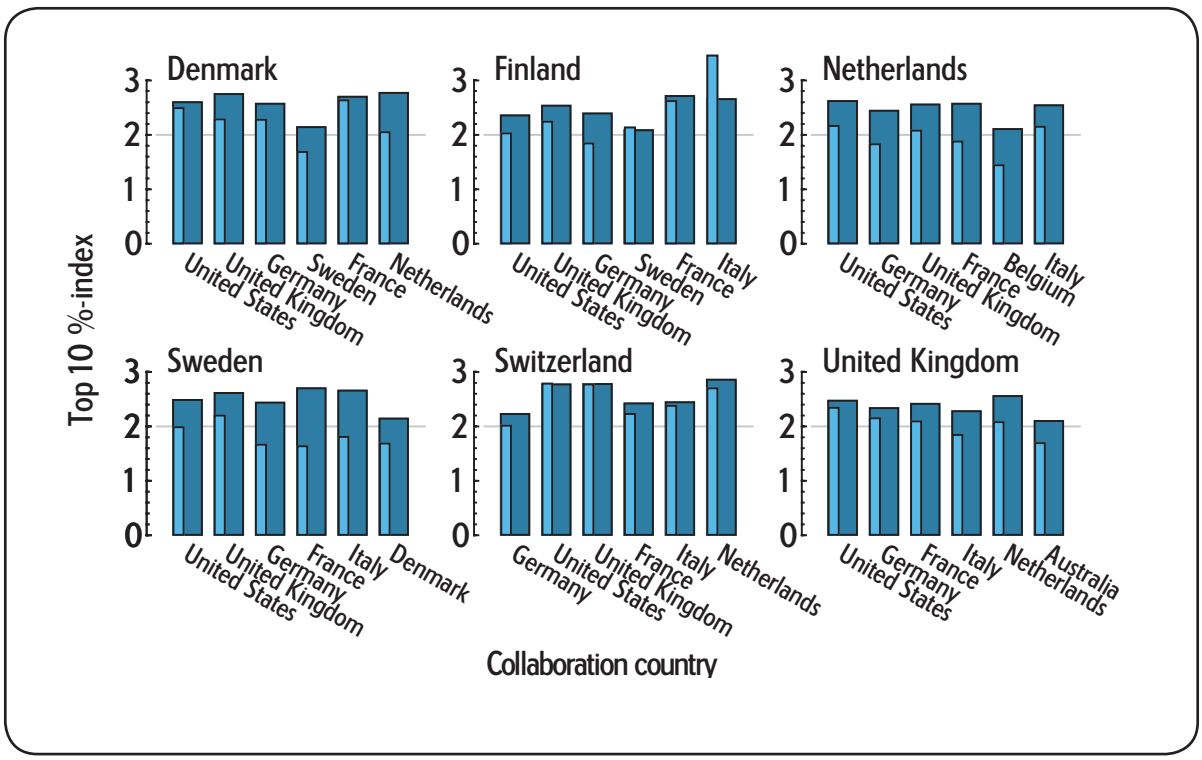


Figure 5.5. Proportion of highly cited publications among the publications produced in collaboration with the most frequent collaboration countries. The wide, dark bars indicate mean for 2009-2011 and the narrow, lighter, bars indicate mean for 1989-1991. The grey horizontal line is drawn in order to facilitate comparisons.



6. PERFORMANCE IN DIFFERENT SUBJECT FIELDS

One argument that occasionally is encountered is that small countries cannot be good in all fields and therefore must specialise in a few fields where they can be both strong and have a significant output. This section will present statistics for different subject fields. The first part of this section is based on 13 SPRU-fields (c.f. section 2) while the second part present statistics based on the 251 journal subject fields.

All subject fields are included in this report. However, it is important to keep in mind that most of the publications for Arts and Humanities as well as for Social Sciences **are not included** in the database used for this report. In these fields other publication channels such as anthologies and books are more important than the international journals indexed in the database used. The prestige publications in these fields are often not found in the international journals. Further, in some technical fields proceedings is an important publications channel. Proceedings are not included in the publication database at the Swedish Research Council.

The statistics presented here thus include publications in international scientific journals only, which is not representative for the entire output in these fields. Further, the distribution of journal publications found in the database is skewed so that some fields are more frequently represented than others; for example, a relatively large fraction of the database publications in social sciences is in psychology and economics.

In Figure 6.1, a number of characteristics are summarized for each country. The X-axis shows the activity index, i.e. the proportion of the national output of publications found in a particular field relative to the world (database) proportion.[10] A value of 1 thus indicates that a country has the same proportion as expected from the world average, a value of 1.5 means that the country has a 50% greater proportion in that field than expected from the world average. The Y-axis shows the top 10%-index as described in section 2. Each of the 13 subject fields are shown as circles where the cicle area is proportional to the number of publications produced and the arrows indicate how the circles have moved during the last decade.

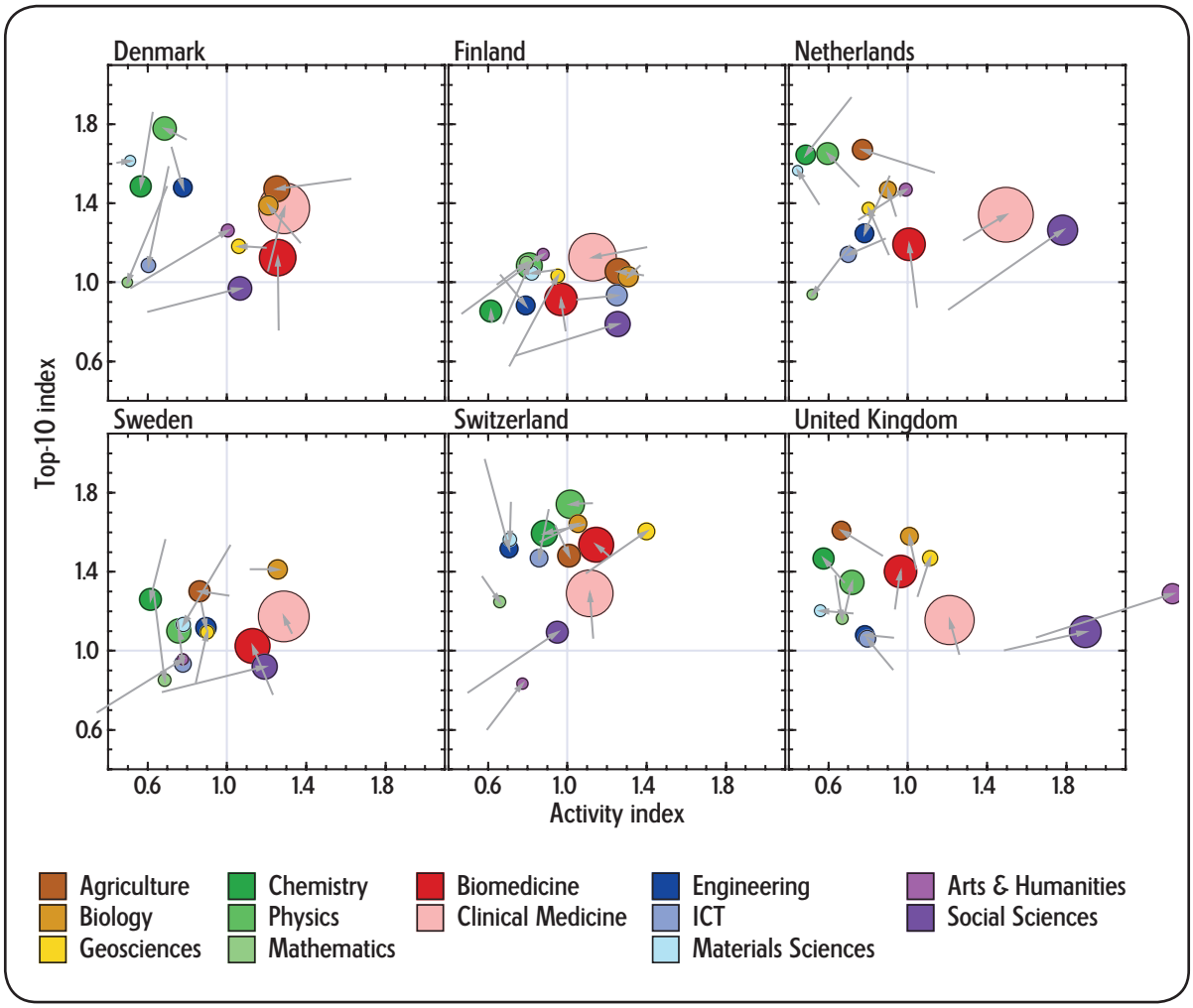
The high proportion in *Arts and Humanities* as well as in *Social Sciences* found for the United Kingdom is probably mainly a language effect, these fields have a more pronounced tradition to publish in their native language than the other fields. Thus, in a database strongly dominated by English-language journals these fields are more visible for English-speaking countries. Among the other countries Netherlands has a high activity index for *Social Sciences* followed by Finland and Sweden. For all six countries the proportion of the publications in *Arts and Humanities* as well as *Social Sciences* increases at the same time as they receive more citations, i.e. all arrows for these fields point up and to the right.

Figure 6.1 clearly shows that *Clinical Medicine* is the largest field (largest circles) in all six countries. All six countries also have, relative to the world production, a high proportion of *clinical medicine* (all circles are located above 1 along the X-axis) and they are all cited above the world average (above 1 along the Y-axis). The high proportion of *Clinical Medicine* for the Netherlands is notable (more than 50% higher than expected from world average). The subject profile for the Netherlands is thus quite strongly focused on *Clinical Medicine* and *Social Sciences*. All other fields have activity indices at or below 1.

10 A more detailed description of the calculation of the Activity Index can be found in Piro (2011), page 42.

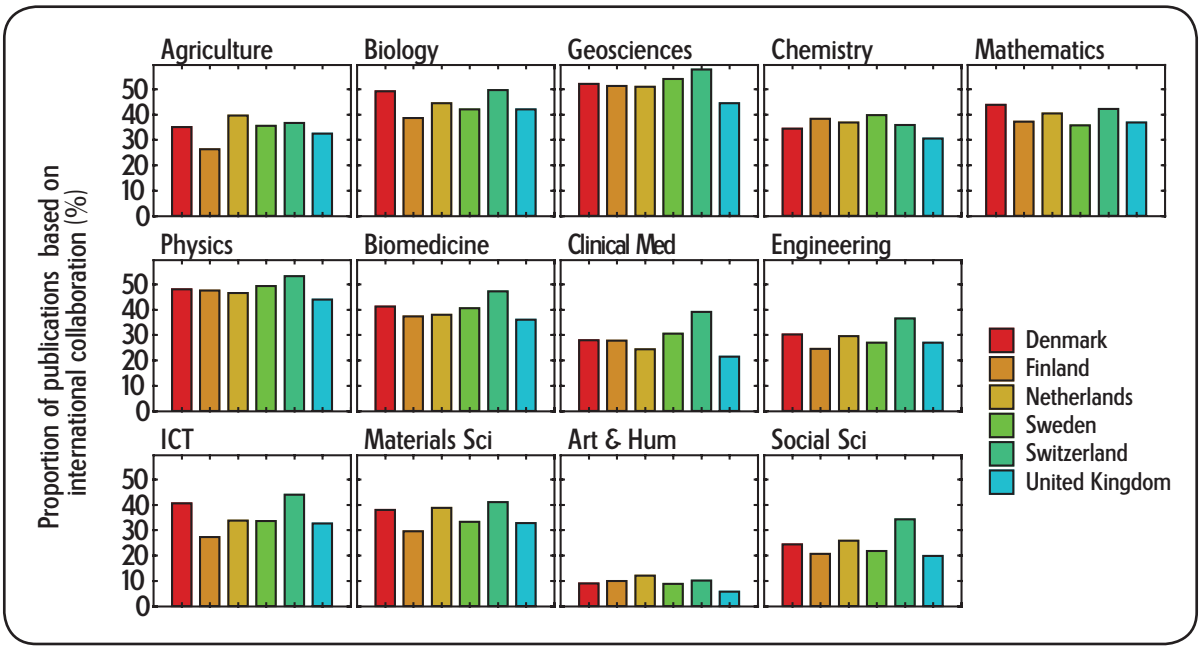
For the United Kingdom all fields have a proportion of highly cited publications above world average, i.e., with top 10 %-index above one. Denmark, the Netherlands and Switzerland each have only one SPRU-field with top 10 %-index below one. Finland and Sweden have four or five fields with top 10%-index below one.

Figure 6.1. Activity index in relation to top 10 %-index. The colours of the circles indicate the subject field and circle size the number of publications produced. Grey arrows show the shift in position of the circles between two five year means (1997-2001 and 2007-2011).



The proportion of the publications based on international collaboration varies substantially among subject fields (Figure 6.2). *Arts and humanities* has by far the lowest proportion based on international collaboration (6-12%). The highest degree of internationalisation is found for *Geosciences* (above 50 % for all countries except the United Kingdom) followed by *Physics*. Switzerland has the highest degree of international collaboration in all fields but three. In two fields the Netherlands are slightly more internationalized (*Agriculture and Arts and Humanities*) while Sweden shows the highest degree in one subject (*Chemistry*).

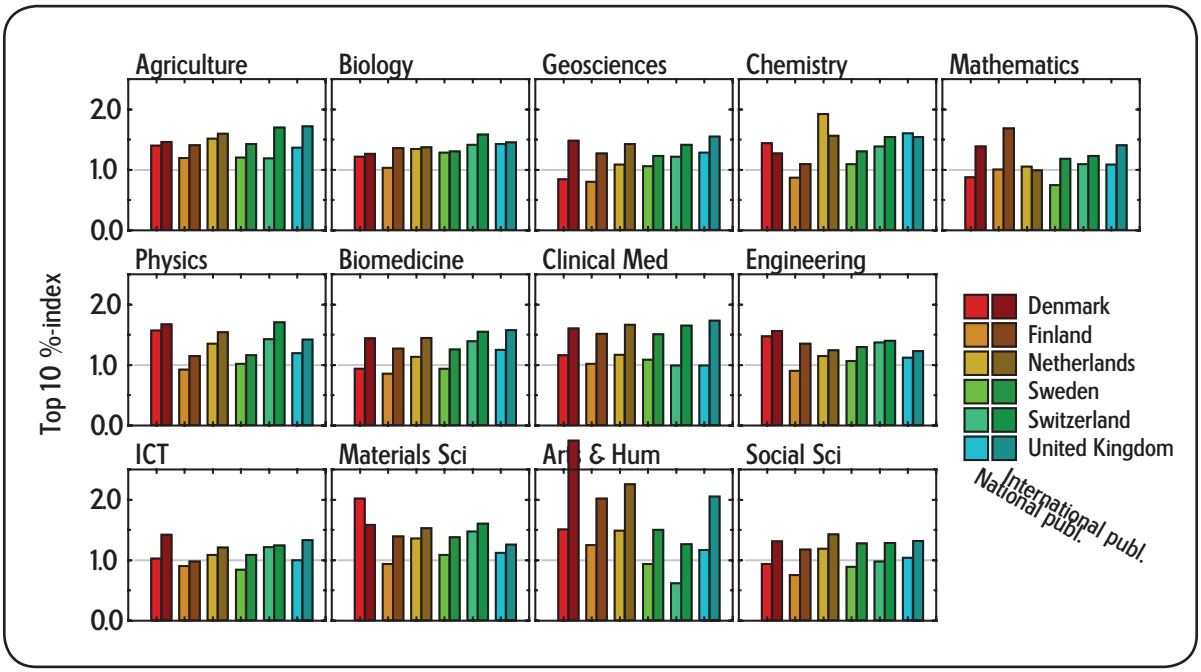
Figure 6.2. Proportion of the publications based on international collaboration in the different subject fields. Based on 2009-2011. ICT = Information and Communication Technology .



In the following graph (Figure 6.3) the top 10%-index is compared among countries, subject fields and national versus international publications. Again, in most cases Sweden is ranked second last among the selected countries and Finland has in most cases the lowest score. In two fields Sweden ranks last (*Mathematics and ICT*) and in three fields is third last (*Biology, Clinical Medicine* and *Materials Sciences*). Even when Sweden performs relatively well, such as *Agriculture, Biology, Clinical Medicine, Materials Sciences* and *Arts and Humanities* (all above 1.3), several of the other countries perform even better.

In most subject fields the proportion of top-10% papers is higher for the internationally produced publications. However, the international-collaboration effect in *Biology* it is marginal and for *Chemistry* the effect is more or less lacking. The strongest effects are found in *Clinical Medicine* and *Arts & Humanities*.

Figure 6.3. Comparison of the top 10 %-index calculated for each subject field. Left (lighter) bar is for national publications and right (darker) bar is for international publications. ICT = Information and Communication Technology. The grey horizonal line indicate world average.



To further elucidate the degree of subject specialisation among these countries another analysis was performed using the journal subject classification made by the database producer Thomson Reuters. Publications in multidisciplinary journals have, however, been reclassified by the Swedish Research Council based on the subject profile in the reference list and citing papers (c.f. Vetenskapsrådet 2011). Currently 251 journal subjects are in use.

For each country, all subjects with an annual volume of at least 10 publications per year (i.e. 50 over the five year period 2007-2011) were identified. Among these subject fields three performance groups were identified as fields that:

1. Perform poorly in terms of producing highly cited papers (top 10%-index < 0.8)
2. Perform at least 50% better than world average (top 10%-index > 1.5)
3. Perform twice as well as world average (top 10%-index > 2)

Also the contribution of the two latter groups to the national production of publications was calculated. The results are shown in Table 6.1.

The number of subject fields passing the size threshold is increasing with country size. Thus the United Kingdom produced at least 50 publications during the five-year period in 242 of the 251 subject fields. The smallest countries, Denmark and Finland, each had about 120 fields reaching the same threshold.

Finland followed by Sweden has the largest number (32 and 27 respectively) of subject fields with a top 10 %-index less than 0.8 while the corresponding number for the Netherlands is 4. Regarding the number of fields with an index above 1.5, i.e., producing at least 50 % more top 10 %-papers than the world average, Finland and Sweden have the lowest numbers (10 and 20 respectively) while Switzerland and the Netherlands are most successful with more than 50 fields each. The pattern is similar if we compare fields with a very high proportion top 10 %-papers (top 10 %-index > 2).

When considering how much the fields with a high proportion highly cited papers contribute to the total national output of respective country, again Finland and Sweden falls out; for both countries these successful fields contribute less than 10 % of the total national output. The successful subject fields for Denmark and the Netherlands contribute with almost one quarter of the national output and with 40 % of the output for Switzerland.

Table 6.1. Number of subject fields where the country publishes at least 10 papers per year, the number of these fields that has low proportion top 10 %-publications

Country	No of fields selected	No of subject fields where			Contribution to total national output of fields where	
		Top10%-index < 0.8	Top10%-index > 1.5	Top10%-index > 2	Top 10%-index > 1.5	Top 10%-index > 2
Denmark	123	14	34	6	24 %	0.8 %
Finland	122	32	10	2	7 %	0.0 %
Netherlands	193	4	53	9	23 %	0.3 %
Sweden	162	27	20	5	9 %	0.1 %
Switzerland	155	15	55	8	40 %	1.5 %
United Kingdom	242	20	43	9	16 %	0.1 %

Thus, there is no support in these statistics that the most successful countries (Denmark, the Netherlands and Switzerland) are better at focusing in a few strong fields as compared to less successful countries (Finland and Sweden). The pattern is rather the opposite the successful countries receive high citation rates in many fields. In fields where Sweden is strong (e.g. Agronomy, Biology and Chemistry, cf. fig 6.3) several of the other countries in the comparison perform even better.

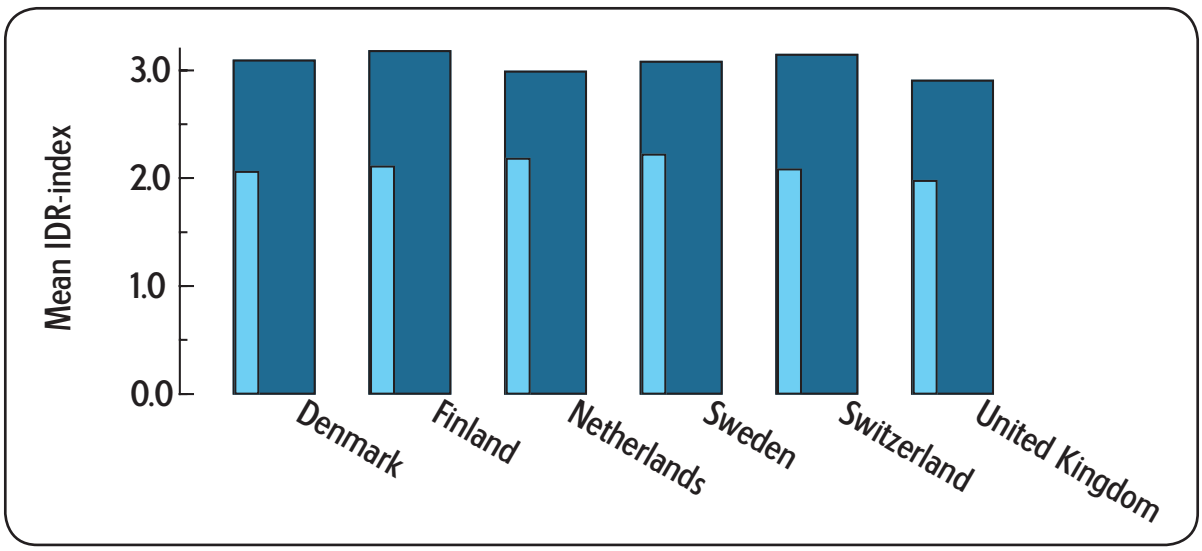
7. INTERDISCIPLINARITY

In recent years there has been a belief in that interdisciplinary research is where the most important discoveries are made (Porter & Rafols 2009, Rafols & Meyer 2010). In parallel with this there has been focus in the bibliometric literature on how to study and quantify interdisciplinary research (abbreviated IDR below, Wagner et al 2011). The quantification of the degree of interdisciplinarity is neither simple nor unproblematic (see e.g. Rafols & Meyer 2010, Wagner et al 2011). Many terms and definitions are in use such as multidisciplinarity, interdisciplinarity, crossdisciplinarity or transdisciplinarity (e.g. ESF 2011). In the bibliometric literature the term interdisciplinary has been used in a broad sense and it has been quantified for individual publications based on the subject diversity found in the reference lists or citing papers (see Rafols & Meyer 2010, Wagner et al 2011).

Several approaches to calculate a measure of IDR for individual publications based on the subject diversity among the cited reference have been presented. Here a very simple measure is used; the number of SPRU-fields (c.f. section 2) represented in the reference list.[11] The IDR-classes used below are the mean number of SPRU-fields present in the reference list. All papers citing five or more fields are grouped into the 5+-class.

The compared countries vary only marginally regarding the average IDR-index (Figure 7.1). The United Kingdom shows the lowest index followed by the Netherlands and Sweden while Finland and Switzerland have the highest indices. For all countries the index has increased substantially during the last 20 years, to some extent due to the almost doubled number of references per publication (cf. figure 3.1).

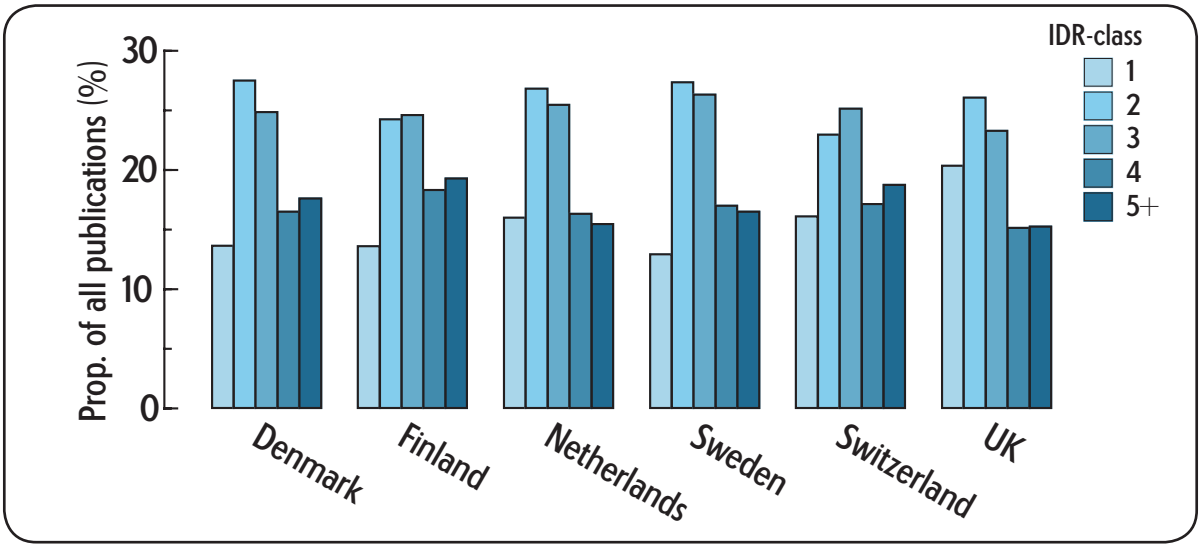
Figure 7.1. Mean IDR-index for all publications from the compared countries. The wide, dark bars indicate mean for 2009-2011 and the narrow, lighter, bars indicate mean for 1989-1991.



When comparing the proportion of the publication in different IDR-classes, class 2 and 3 are the most frequent for all countries (Figure 7.2). The low total average for United Kingdom (in Figure 7.1) is to a large extent the result of a large proportion of the British publications in class 1.

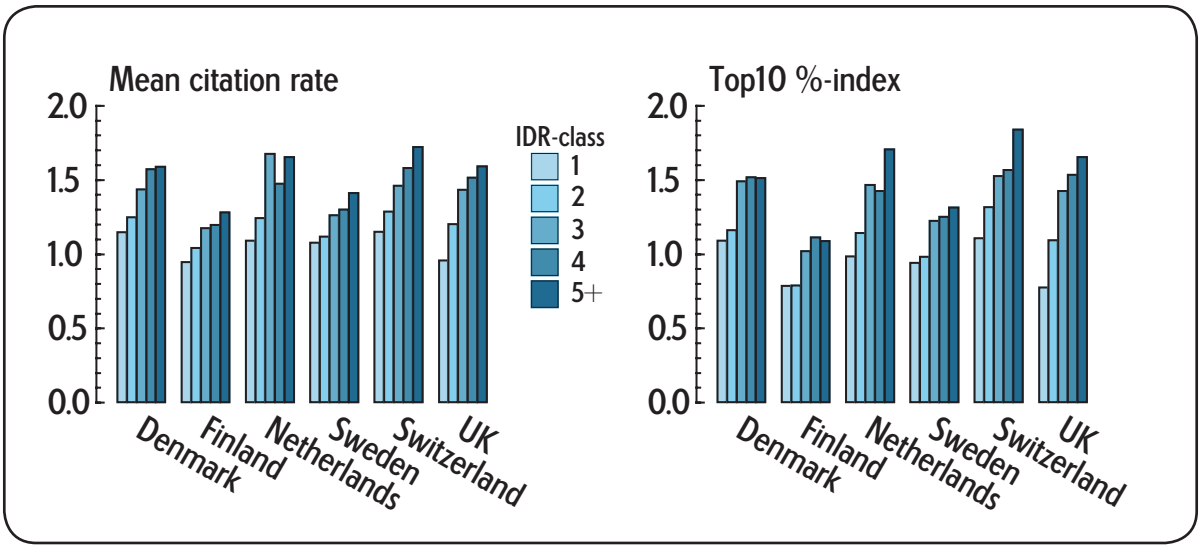
11 Mean of the degree of interdisciplinarity based on this measure is closely correlated to more complex measures based on Shannons or Simpsons diversity indices (pearson r > 0.98 for national means).

Figure 7.2. Frequency distribution of the national output on five classes of interdisciplinarity.



For all countries, the mean citation rate and the top 10 %-index increase with increasing IDR-index, but least so for Sweden and Finland.

Figure 7.3. Mean field normalized citation rate and top 10 %-index for publications of different levels of interdisciplinarity.



It is clear from the graphs above that both citation rate and the top 10%-index increases with the IDR-index. There is nothing that suggests that Finland or Sweden produce publications that are less interdisciplinary than the other countries. Rather, the publications from Finland or Sweden are cited less also when controlling for the IDR-index.

8. JOURNAL PRESTIGE

It is commonly considered important to publish in the best journals. In bibliometric studies, the quality of journals is often evaluated through the journal impact factor (JIF) or similar measures.[12] However, the use of journal impact in bibliometric assessments is also extensively criticized (e.g. Seglen 1997, Moed 2005).[13] Unless based on very large materials mean journal impact can be a poor predictor of the actual impact of the publications (van Raan 2012).

In this section two aspects of the publication pattern of the studied countries in relation to journal prestige are compared. First the mean journal citation rate for all publications is compared; secondly the number of publications in three of the most prestigious journals are compared.

8.1 Mean journal prestige for all publications

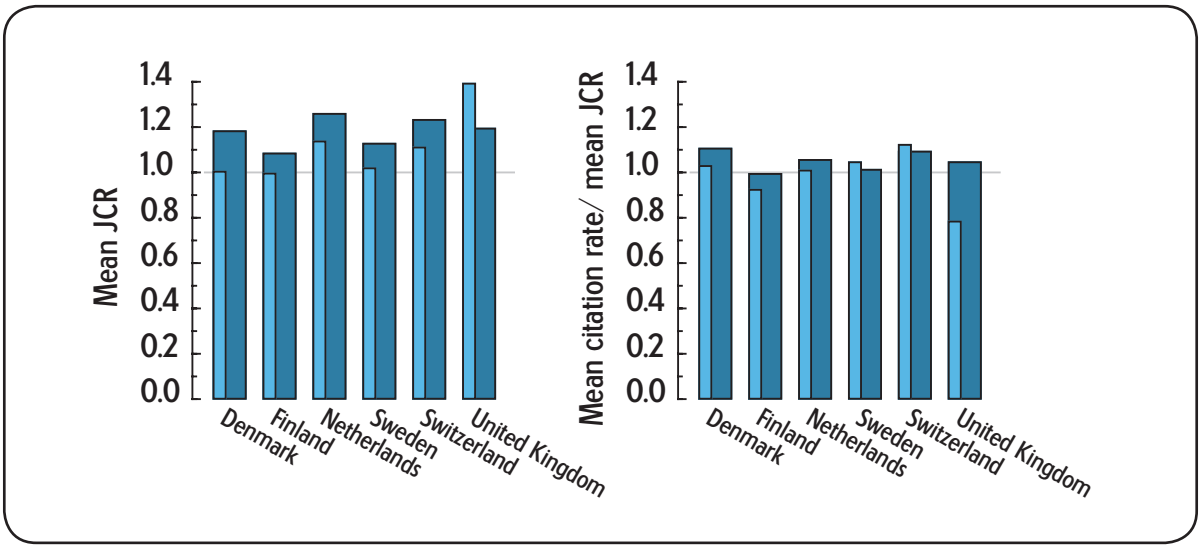
Journal prestige is here estimated as mean field normalized journal citation rate (abbreviated JCR below), i.e. the mean number of field normalized citations of an article in respective journal.[14]

The Netherlands publish, on average, in the most prestigious journals and has a JCR-average of 1.26. Finland has the lowest mean JCR (1.08, Figure 8.1). Denmark and Switzerland have a mean JCR slightly lower than that of the Netherlands, while the Swedish average is just above the Finnish value. All countries, except the United Kingdom, have increased the mean JCR during the last twenty years. The increase could, at least in part, be a result of successive addition of new, relatively poorly cited journals to the database.[15]

The Finnish and Swedish publications get cited to the extent that can be expected from the JCR, i.e. the ratio field normalized citation rate /JCR is close to 1. The other countries in the comparison receive 4 % to 10 % more citations than expected from the JCR. Denmark and Switzerland have the highest ratios (1.10 and 1.09 respectively). These countries thus get about 10 % more citations than could be expected from the journals where they publish.

12 In principle the number of citations per paper in the journal. For a more precise definition see http://thomsonreuters.com/products_services/science/academic/impact_factor/)
13 An entire issue of the journal Scientometrics was recently devoted to discuss the journal impact factor (Scientometrics volume 92 issue2, 2012)
14 JRC is calculated using the similar to mean citation rate; i.e. citations to articles published 1989-1991 and 2009-2011 using a 3-year citation window.
15 Thomson Reuters has the ambition to cover the most important journals. Thus, when adding new journals to the database the new ones tend to be less cited than those already included.

Figure 8.1. Mean journal citation rate (JCR) and the ratio between mean citation rate of respective country's publication and the mean journal citation rate. The wide, dark bars indicate mean for 2009-2011 and the narrow, lighter, bars indicate mean for 1989-1991.



The relative differences among countries found repeatedly in previous sections is found also here when comparing an estimate of journal quality (the JRC); Finland and Sweden publish in slightly less cited journals as compared to the other countries. In addition, the Finnish and Swedish publications get cited at a rate that is similar to the mean value of the journals where the papers appear while the other countries receive more citations than expected from the JCR.

8.2 Publications in high-prestige journals

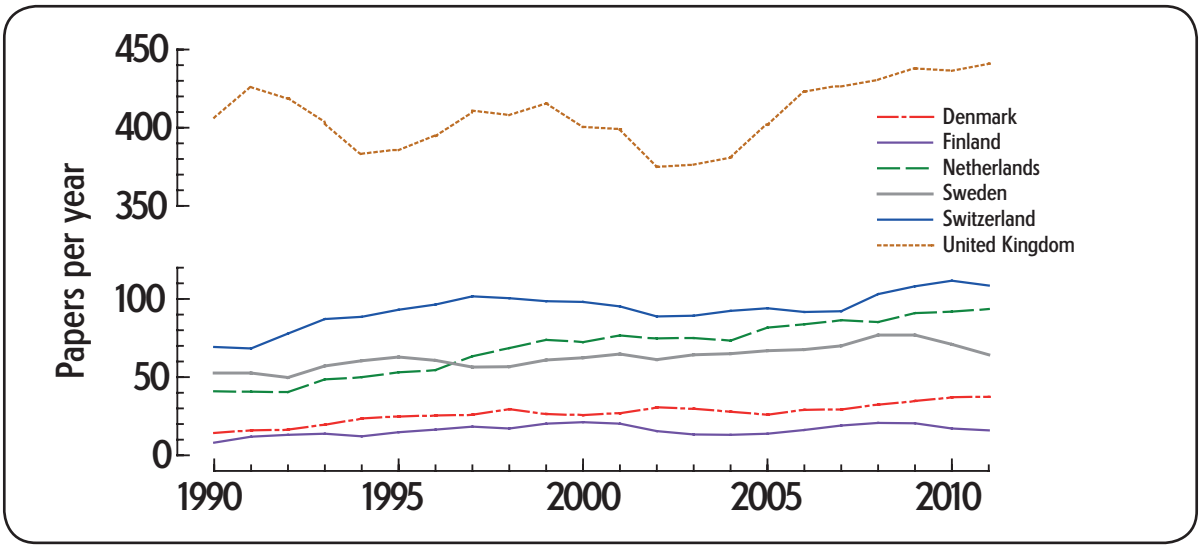
Many important new discoveries are published in a few prestigious journals. In this section, the number of publications by the studied countries in three of the most prestigious journals, viz. Nature, PNAS[16] and Science, are compared. These three journals currently publish about 6000 articles per year, corresponding to 0.5 % of the total database contents. PNAS is the largest with 60 % of these while Nature and Science contributes with 20 % each.

In Web of Science these journals are classified as "multidisciplinary" but in the publication database at the Swedish Research Council, many of the publications in these journals are reclassified into other subjects based on the dominating fields cited by or citing these papers (see Vetenskapsrådet 2011).

The United Kingdom produces 400-450 fractionalized publications per year in these journals. For the other countries, the number of publications per country and year is lower; 20-100 publications per country and year (Figure 8.2). Therefore all statistics in this section are based on three- or five-year moving averages.

16 Full name: Proceedings of the National Academy of Sciences of the United States of America

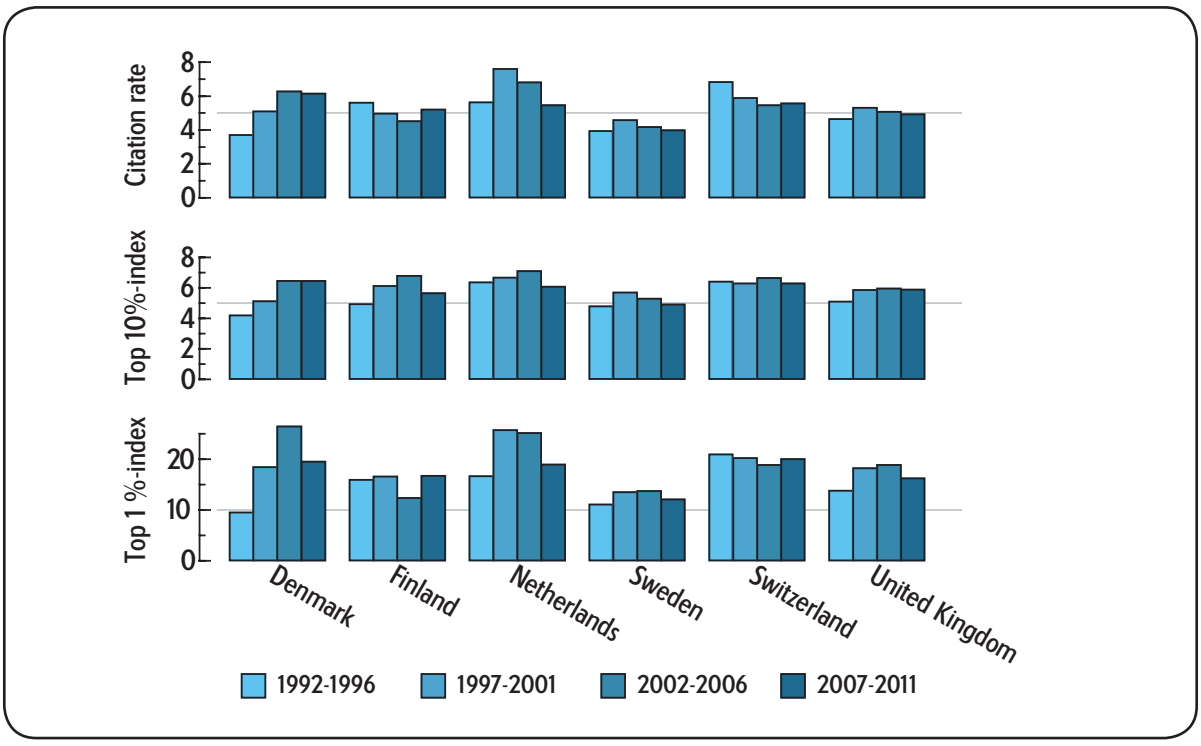
Figure 8.2. Number of publications per year in three prestige journals, Nature, PNAS and Science. The curves are based on three-year moving averages.



Many of the publications in these prestige journals are highly cited, on average about 5 times higher than the world average. Also the top 10 %-index is about 5 times higher than the world average. Thus about half of the publications in these journals belong to the 10 % most cited of the world production while the other half of the publications are cited at more "normal" rates.

Figure 8.3 shows three citation performance statistics for publications in the prestige journals. In all three performance scores presented in figure 8.3, Sweden ranks last among the compared countries.

Figure 8.3. Mean citation rate, top 10 %- and top 1 %-index for publications in the prestige journals during four 5-year periods. The grey horizontal lines are drawn to help compare countries.



The highest proportion of the national output found in these prestige journals is found for Switzerland (0.8 %), followed by the United Kingdom and Sweden while Finland has the lowest proportion (0.3 %, Table 8.1). These prestige journal publications contribute with between 1.5 % (Finland) and 3.4 % (Switzerland) of the national production of top 10 %-papers and 5 – 10 % of the top 1 %-publications.

Table 8.1. Contribution from prestige journal publications to the national output and citations received. Based on last 5-yr period (2007-2011).

Country	Volume	Citations	Top 10 % publ.	Top 1 % publ.
Denmark	0.46 %	2.2 %	2.2 %	6.4 %
Finland	0.27 %	1.3 %	1.5 %	5.3 %
Netherlands	0.42 %	1.8 %	1.9 %	6.1 %
Sweden	0.55 %	1.9 %	2.4 %	6.0 %
Switzerland	0.80 %	3.4 %	3.4 %	9.7 %
United Kingdom	0.62 %	2.5 %	2.9 %	8.0 %

These prestige journal publications are too few for a detailed subject field analysis. Instead they are grouped into three areas: medicine, natural sciences and other (Table 8.2 and 8.3). For all countries more than half of all prestige journal publications are classed as medicine. Sweden has the largest fraction of medical publications (71 %) to compare with Denmark and United Kingdom which have the lowest fraction of medical papers (54 %). Consequently the fraction of Swedish papers in natural sciences and "other" fields are the lowest among the compared countries. Among the total output of Swedish publications medicine contributes with 48 %, natural sciences with 30 % and the other fields with 22 %. Thus, the medical fields are more successful than natural sciences and other fields in getting their publications accepted by these high-prestige publications.

Table 8.2. Prestige journal publications partitioned into three areas, medicine, natural sciences and other fields. Based on last 10-yr period.

Country	Volume			Subject profile		
	Medicine	Natural Sci.	Other	Medicine	Natural Sci.	Other
Denmark	184	130	28	54 %	38 %	8 %
Finland	113	58	10	62 %	32 %	6 %
Netherlands	506	312	92	56 %	34 %	10 %
Sweden	525	172	45	71 %	23 %	6 %
Switzerland	674	308	91	63 %	29 %	8 %
United Kingdom	2446	1413	644	54 %	31 %	14 %

Natural sciences publications in the high-prestige journals are generally receiving more citations than medical publications. In all three subject areas the Swedish publications have the lowest, or second lowest, top 10 %–index. Only one case, British papers in the Other-group, has a lower top 10 %-index than Sweden.

Table 8.3. Impact of prestige journal publications partitioned into three areas. Based on last 10-year period.

Country	Mean citation rate			Top 10 %-index		
	Medicine	Natural Sci.	Other	Medicine	Natural Sci.	Other
Denmark	5.31	7.47	6.58	5.53	7.71	4.61
Finland	4.17	6.03	3.28	5.04	7.48	4.61
Netherlands	4.68	8.99	4.87	5.69	8.18	3.92
Sweden	3.32	6.26	4.43	4.42	7.06	3.37
Switzerland	4.36	8.24	5.62	5.87	7.84	4.39
United Kingdom	4.53	6.82	2.91	5.73	7.33	2.95

To summarize, Sweden has a relatively high proportion of papers in prestige journals; the third highest value among the six compared countries (Table 8.1). However, the impact made by the Swedish publications is relatively low (in particular for Medicine, Table 8.2) and Sweden ranks last in terms of the top 10-index in two of the three areas.

9. PATTERNS AT THE ORGANISATIONAL LEVEL

To what extent do a few successful institutions affect the national values? In this section, size (measured as number of publications) and performance of organizations are analysed to provide some insights in this question. The relationship between size and performance has been addressed by several reports.[17] The size of the individual departments or research labs may in many cases be more important than the size of the university. Nevertheless, in some cases the size of the university is also considered important, for example to afford expensive infra-structure.

First, all universities and university hospitals in the six compared countries producing at least 200 publications per year during the last three-year period (2009-2011) were identified.[18] In total 113 universities and university hospitals fulfilled this criterion. Among these the universities with a top 10 %-index above 1.2 were defined as "high performing".[19] Secondly, the frequency distributions of the top 10%-index for all unique organisation names with an annual volume of at least 50 publications during 3 years were compared.

For both the Netherlands and Switzerland, more than 80 % of all universities and university hospitals reached the threshold to be classed as high performing (Table 9.1). Denmark has the lowest number of universities above the size threshold (7) and five of these were classified as high performing. These high performing universities contribute about two thirds (59-73 %) of the national production of publications in these three countries. In contrast, five of the 14 Swedish organisations reached the high performing-limit. These five contributes with one quarter (28%) of the Swedish publications. For Finland, no university passed the high performing limit. Two of the Finnish universities performed just below the 1.2-treshold; Helsinki University Central Hospital and Helsinki University (1.19 and 1.17 respectively).

17 See e.g. Tunzelmann et al 2003, Evidence 2011.
18 For the Nordic countries the organization names are unified (see Piro 2011). When merges has occurred the new name has been applied also retrospectively. For the other countries the unification is more superficial. No merges has been applied. Therefore the number of universities passing the size threshold and their size may be somewhat underestimated.
19 The Pearson correlation between the top 10 %-index and the mean field normalized citation rate for these universities = 0.92.

Table 9.1. Number of universities (and university hospitals) producing more than 200 publications per year during 2009-2011, and the proportion of these that produce a large proportion highly cited papers (Top 10 %-index > 1.2). The highly cited organisations contribution to the total national output given in the last column.

Country	Selected universities		High performing universities	
	N	Contrib. to total national prod.	N	Contrib. to total national prod.
Denmark	7	80 %	5	73 %
Finland	10	68 %	0	0 %
Netherlands	18	70 %	16	67 %
Sweden	14	78 %	5	28 %
Switzerland	11	62 %	9	59 %
United Kingdom	53	62 %	28	52 %

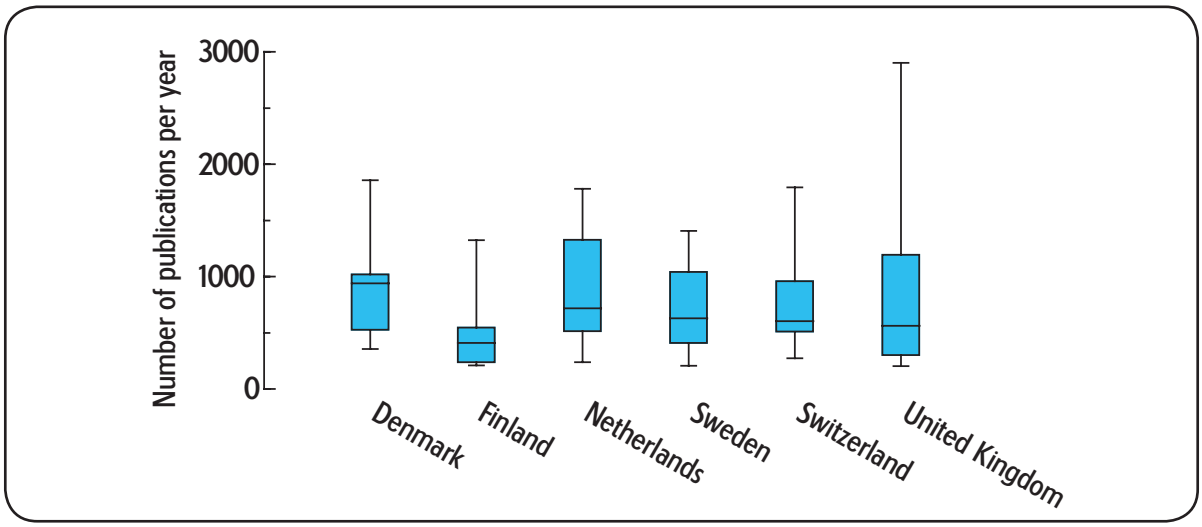
The number of universities with a volume above 200 publications per year is of course strongly dependent on country size. In Table 9.2, the ratio between the number of universities and country size (measured as number of inhabitants) is presented. Thus, relative to county size Finland has the largest number of universities (1.9 universities per million inhabitants) followed by Sweden (1.5) and Switzerland (1.4). The United Kingdom has the lowest number of universities relative to population. Regarding the number of high performing universities, the relative value for Sweden is less than half that for Switzerland and about 40% lower than the numbers for Denmark and the Netherlands. The relative number of high performing universities in the United Kingdom is second lowest after Finland.

Table 9.2. Number of universities and high performing universities relative to country size (universities per million inhabitants). Restricted to universities and university hospital with at least 200 publications per year.

Country	No. of univeristies relative to country population	No. of high performing univeristies relative to country population
Denmark	1.27	0.90
Finland	1.87	0.00
Netherlands	1.09	0.97
Sweden	1.50	0.54
Switzerland	1.41	1.16
United Kingdom	0.85	0.45

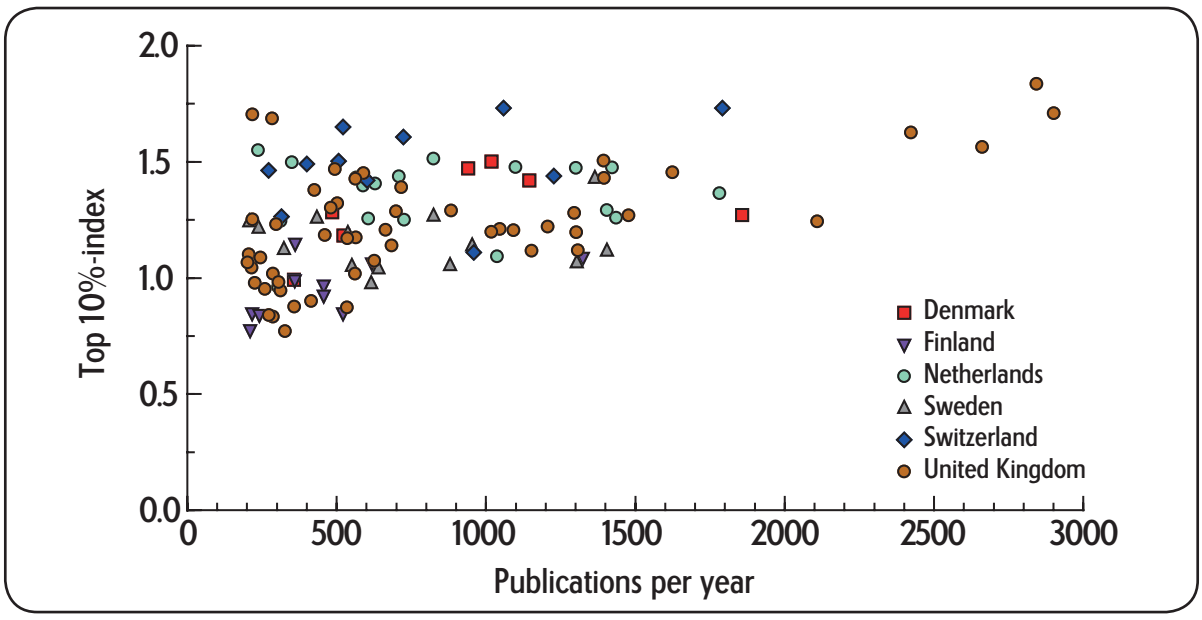
The compared countries also show some variation in the size-distribution of their universities (Figure 9.1). The Finnish universities are relatively small and relatively similar in size. The United Kingdom shows a large spread in size while the remaining countries (Denmark, the Netherlands, Sweden and Switzerland) have a similar distribution.

Figure 9.1. Box plots of variation in university size. Size measured as number of publications produced per year 2009-2011. Restricted to universities and university hospitals with at least 200 publications per year. Boxes indicate the second and third quartile. The whisker endpoints indicate minimum and maximum..



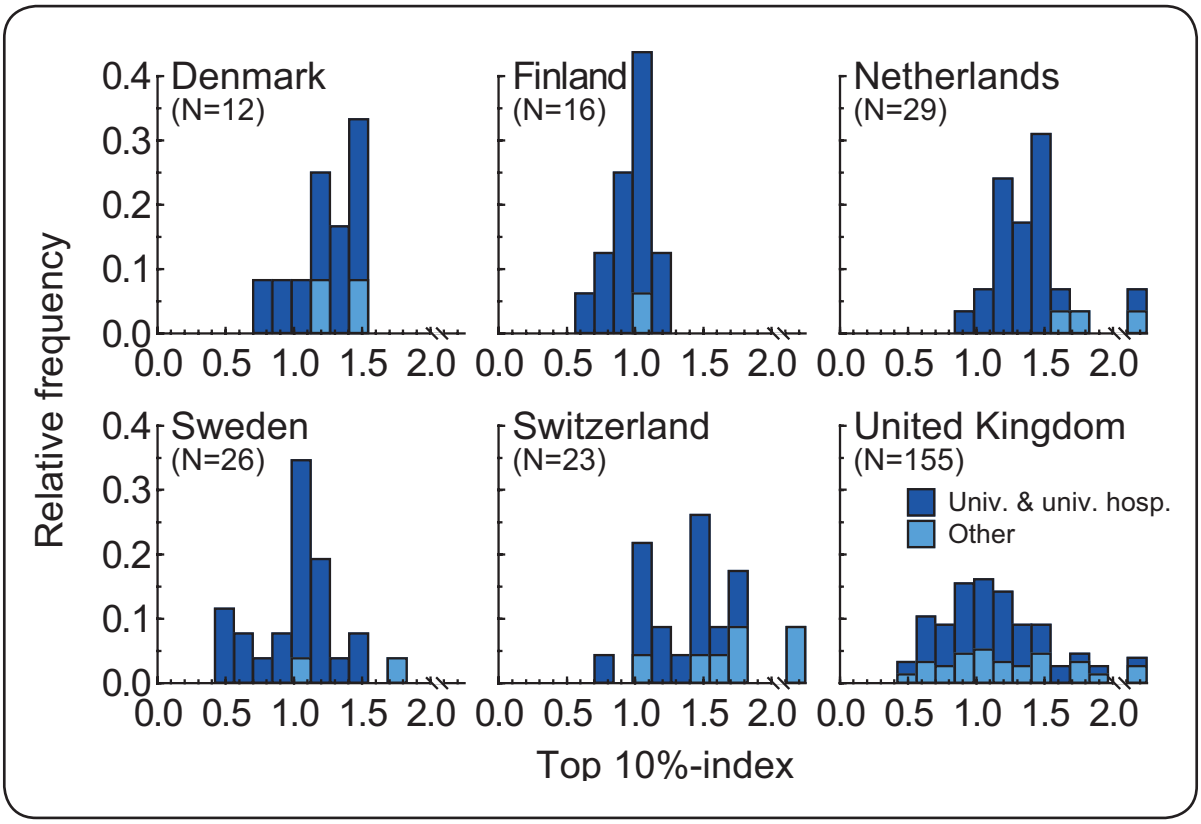
In Figure 9.2 the proportion of highly cited publications (top 10 %-index) is related to size for all 113 universities. From this graph it is evident that universities that perform well are not necessarily large, but all universities with a top 10 %-index below 1.0 are among the smaller (below 700 publications per year). In comparison, almost half, seven of fifteen, of the universities with a top 10 %-index above 1.5 were also relatively small (less than 700 publications per year).

Figure 9.2. Universities top 10% index versus size (number of publications per year). Restricted to universities with an annual volume of at least 200 publications.



The frequency distribution of the performance (top 10 %-index) for all organisations (not only universities) with an annual production of 50 publications per year or more in respective country is shown in Figure 9.3. When including a wider array of organisations, it's apparent that many smaller organisations contribute to the high performance scores for Switzerland; only two out of 23 organisations have averages below 1. Also Denmark and Netherlands have their frequency peaks well above the world average for top 10 % index. The frequency distribution is centered close to the world average top 10% index (i.e. 1.0) for Sweden and Finland.

Figure 9.3. Frequency distribution of the top10%-index for all organisations producing at least 50 publications per year. Dark blue = universities and university hospitals, light blue other organisations (mainly institutes, hospitals and businesses). All organisations with an index above 2 is shown in the rightmost bar.



This section has shown that the strong performance of Denmark, the Netherlands and Switzerland cannot be explained by one or a few excellent universities. For all these countries many of the research organisations have averages well above world average. The Finnish system is remarkably homogenous with respect to the performance of its research organisations and the production of highly cited papers while the United Kingdom followed by Sweden shows the largest variation (measured as the coefficient of variation).

Furthermore the statistics do not give any support for the assumption that a particular (large) size is required for excellent performance. There are several small universities in the studied countries that perform as well as the best large ones. However, universities with a low proportion of top 10 % publications tend to be relatively small.

10. WHO IS CITING WHOM?

Could it be so that researchers in some countries are more likely to cite colleagues from the same country and thereby boost the national citation statistics? In this section the countries from which the studied countries are receiving their citations are presented. For comparison, all the five largest countries in terms of annual production of publications, the United States,China, Germany, the United Kingdom and Japan are included.

Citations commonly follow a geographical pattern; colleagues in the vicinity are more likely to be cited than more distant ones (e.g. Luukkonen et al. 1992, Gunnarsson 2010). To more easily compare citations received from the own country, they are found also in the top row of the Table 10.1, labelled "National citations".

These statistics are based on address-fractionated counts, i.e. each citing publication sums to 1 independent of the number of countries in the author addresses. No field normalization is applied and author self-to national citations are not removed.

Table 10.1. Nationality of citations received by the publications of the studied countries.. All the world's five largest producers of citations are included (above the thin line). Based on publications from 2009-2011.

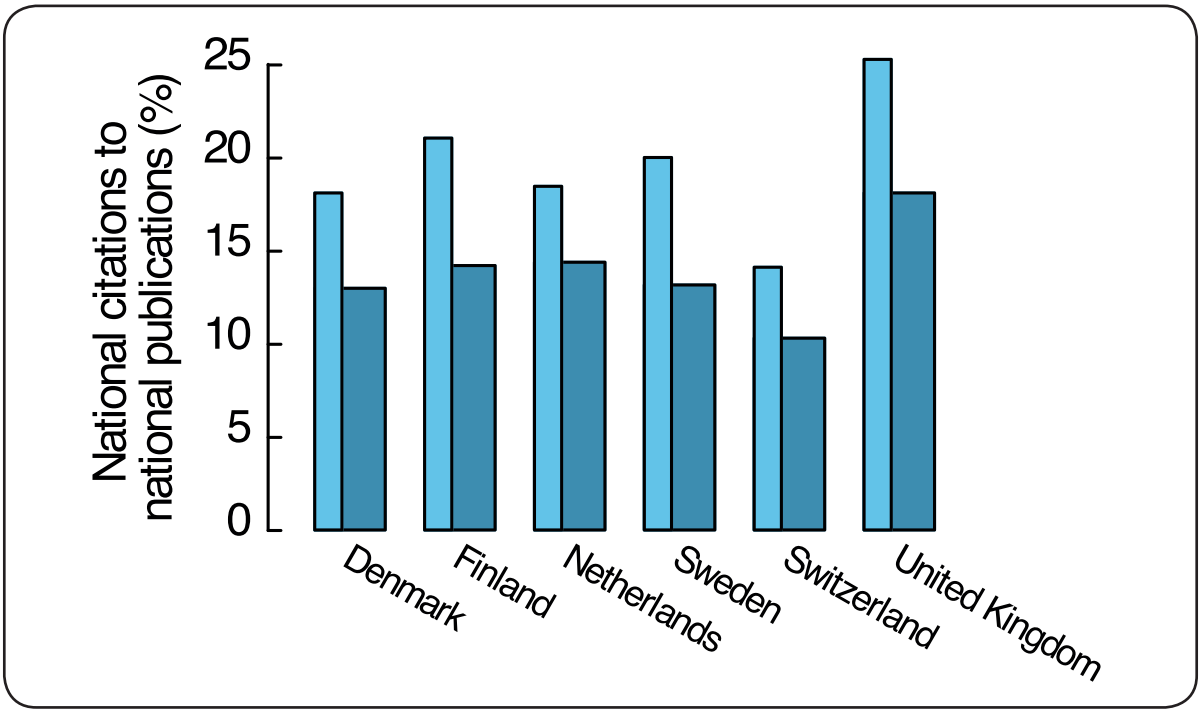
	Cited country							
Citing country	Denmark	Finland	Netherlands	Sweden	Switzerland	United Kingdom	United States	China
National citations	8.8 %	10.0 %	10.7 %	9.3 %	7.4 %	15.0 %	39.1 %	43.6 %
United States	22.0 %	21.2 %	23.0 %	22.8 %	23.9 %	23.4 %	39.1 %	12.7 %
China	5.8 %	5.9 %	5.7 %	6.1 %	6.5 %	6.2 %	7.0 %	43.6 %
Germany	6.7 %	6.1 %	7.1 %	6.3 %	8.5 %	6.0 %	5.2 %	3.0 %
United Kingdom	6.7 %	6.1 %	6.8 %	6.3 %	6.2 %	15.0 %	5.3 %	2.7 %
Japan	3.7 %	3.8 %	3.8 %	3.9 %	4.3 %	3.7 %	4.1 %	3.6 %
Netherlands	2.7 %	2.5 %	10.7 %	2.4 %	2.2 %	2.5 %	1.9 %	0.7 %
Switzerland	1.6 %	1.4 %	1.6 %	1.5 %	7.4 %	1.5 %	1.2 %	0.6 %
Sweden	2.3 %	2.7 %	1.4 %	9.3 %	1.3 %	1.3 %	1.0 %	0.5 %
Denmark	8.8 %	1.2 %	1.0 %	1.5 %	0.8 %	0.9 %	0.6 %	0.3 %
Finland	1.0 %	10.0 %	0.7 %	1.5 %	0.6 %	0.7 %	0.5 %	0.3 %

The most important countries citing the publications from the studied countries show no large variations. For example, 22 % of the citations to Danish publications come from American authors while Sweden received 23 % of the citations from America. Denmark receives 8.8 % of the citations from Danish authors while Sweden obtains 9.3 % from Swedish authors. The high impact of the publications of the three most successful countries, Denmark, the Netherlands and Switzerland, cannot be explained by being successful in receiving citations from any particular countries (including national citations).

In Section 5 it was shown that several of the countries included in this study had improved their citation statistics for nationally produced publications (not so for Sweden, however). It is possible that these national publications are boosted by national citations. In Figure 10.1, statistics on the degree of national citation of national publications is shown.

The degree of national citations to national publications is quite similar among the compared countries; Switzerland has the lowest degree of citations (10 %) and the largest country, the United Kingdom, has the highest (17 %). For all countries the level of citations has decreased during the last twenty years. The decrease over the last twenty years is largest for Finland, Sweden and the United Kingdom (ca 7 %), Switzerland show the smallest change (4 %).

Fig 10.1. Citations to national publications from the own country. Wide darker bars means for 2009-2011 and lighter narrow bars means for 1989-1991.



The marked increase in citation rates of national publications found for some of the studied countries (section 5) is thus not related to national citations.

11. PROPORTION OF TOP SCIENTISTS

Most authors of scientific publications publish few papers while a few scientists are more prolific both in terms of volume and highly cited papers (i.e., top 10 %-papers). Since a small fraction of highly cited papers can affect national mean values, a small fraction of authors that produce many highly cited papers can be important for the national performance. In this section an attempt is made to describe the size of the author community and how many of these that is involved in highly cited papers.

The statistics is calculated for each of the 13 SPRU subject fields and is based on publications from 2009 to 2011. For earlier years the database contains no link between author names and author addresses. The same person may publish in several different fields and one person may be using different spellings or initials in different publications.[20] Assuming that these errors are similar in all countries, the statistics may still indicate differences in the author populations in the compared countries. The statistics in this section is based on whole counts of papers (no fractionalization is applied).

The fraction of highly cited authors, i.e. the authors having at least two highly cited papers during the last three-year (2009-2011) period, is highest for Switzerland (19 %). Denmark, the Netherlands and the United Kingdom have slightly lower proportions (0.8 to 1.4 lower than Switzerland). Again Finland and Sweden have the lowest proportion (14 and 15 % respectively). However, regarding the number of highly cited papers per author or per highly cited author, Sweden performs best or second best. Thus, there are relatively few Swedish authors producing highly cited papers, but those that do so are more productive than the corresponding group in the other countries in the comparison.

Table 11.1. Proportion highly cited authors and number of publications per author.

	Denmark	Finland	Netherlands	Sweden	Switzerland	United Kingdom
No. of papers per author	2.90	2.85	2.50	3.36	2.47	3.54
Prop. authors having highly cited paper	18.0 %	13.6 %	17.6 %	15.3 %	18.8 %	17.4 %
No. of highly cited papers per author	0.35	0.28	0.31	0.36	0.34	0.40
No. of highly cited papers per highly cited author	1.9	2.0	1.8	2.4	1.8	2.3

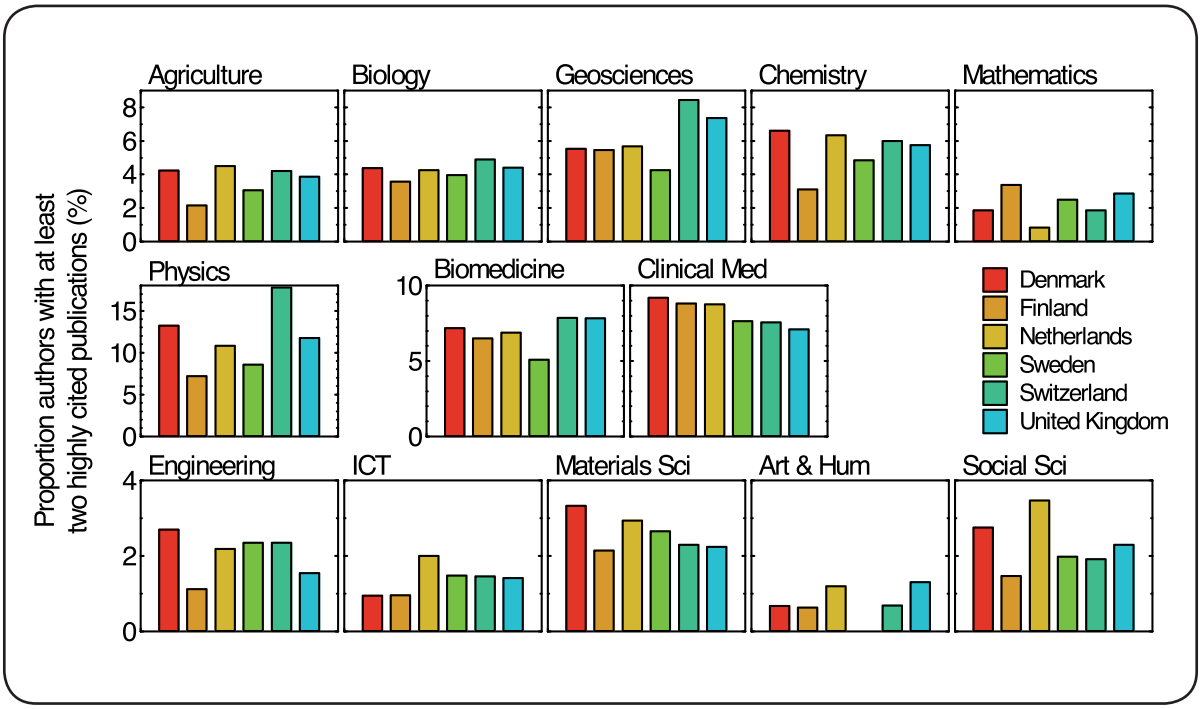
Figure 11.1 shows the proportion of all unique author-names that produce at least two highly cited publications during a three year period. The variation among subject fields in the proportion of prolific authors is probably to a large extent dependent on publication traditions within fields. For example in physics multi-authored papers are common, thus many authors are involved in many highly cited pa-

20 Further, one paper may be associated with more than one SPRU-field. When this occurs, only the most frequent is used here.

pers. In contrast in Arts and Humanities the papers commonly have few authors and thus the fraction of prolific authors is low.

The differences among the compared countries vary substantially among subject fields. But again the familiar pattern is repeated; Denmark, Netherlands and Switzerland have in many cases the highest proportion of prolific authors. In contrast Finland and Sweden tend to be among the countries with low fraction of prolific authors. However, for Finland the fraction is high in Mathematics and Clinical Medicine. Sweden has the second largest fraction prolific authors in ICT and Engineering (together with Switzerland in the latter case).

Figure 11.1. Proportion (%) of all author names that have at least two highly cited (top 10 %) publication during a three year period (2009-2011). Note the different Y-axis scales.



12. RECRUITMENT OF TOP SCIENTISTS

For a country to keep pace with the outside world, it is important to be able to recruit top scientists. If not done sufficiently, we can eventually expect stagnation both in terms of research volume and attractiveness. This question can be illuminated using bibliometric data.

Let us define the scientific elite in a country as the authors in a given field who have written at least five top top 10 %-publications over a fifteen year period. We want to identify the elite author community in each country for three, overlapping 15 year periods: 1986-2000, 1991-2005 and 1996-2010, respectively. Since the database lack a link between author names and addresses before 2008, when there are several countries among the author addresses there is some uncertainty of the nationality of an author. In order to somewhat reduce the number of elite authors with incorrect country affiliation, we restrict our search to the highly cited publications (articles and reviews) where all author addresses are from the country in focus and the publications with up to at most 3 different countries among the author addresses and with at most 10 authors. For each country, each field and each of the three 15 year periods, we identify the year the author wrote his or her first highly cited article in this field. Then we calculate the percentage of authors who made his or her debut during the last five years of the fifteen-year period in question. By this definition it is more difficult to enter the elite group for those starting to publish late in a period as compared to those starting to publish early in the period. This effect is, however, similar for all compared countries. The recruitment statistics was calculated for each SPRU subject field and each of the 250 journal fields. Both these subject groupings resulted in very similar results and only the results based on the SPRU-fields are presented. The calculations are based on the whole counts production of papers (no fractionalization is applied).

These estimates are associated with similar potential errors as mentioned in section 11, and with the restriction to articles with at most 3 countries and at most 10 authors. Again, we assume that errors are similar in all six countries compared. Thus, the recruitment rates presented here are intended to indicate relative differences among the compared countries and should not be interpreted as absolute measures of recruitment rate. Further, since the estimated recruitment-rate can be related to changes in the total output of publications and the growth of the entire author community; the mean annual growth rate of both these are presented in table 12.1.

For all countries, the recruitment rate decreases from period 1 to period 2. Between the two last periods the pattern is not consistent among countries; for four of the countries the rate continue to decline while for the other two, Switzerland and the United Kingdom, the recruitment rate increases the last period (only marginally so for the United Kingdom).

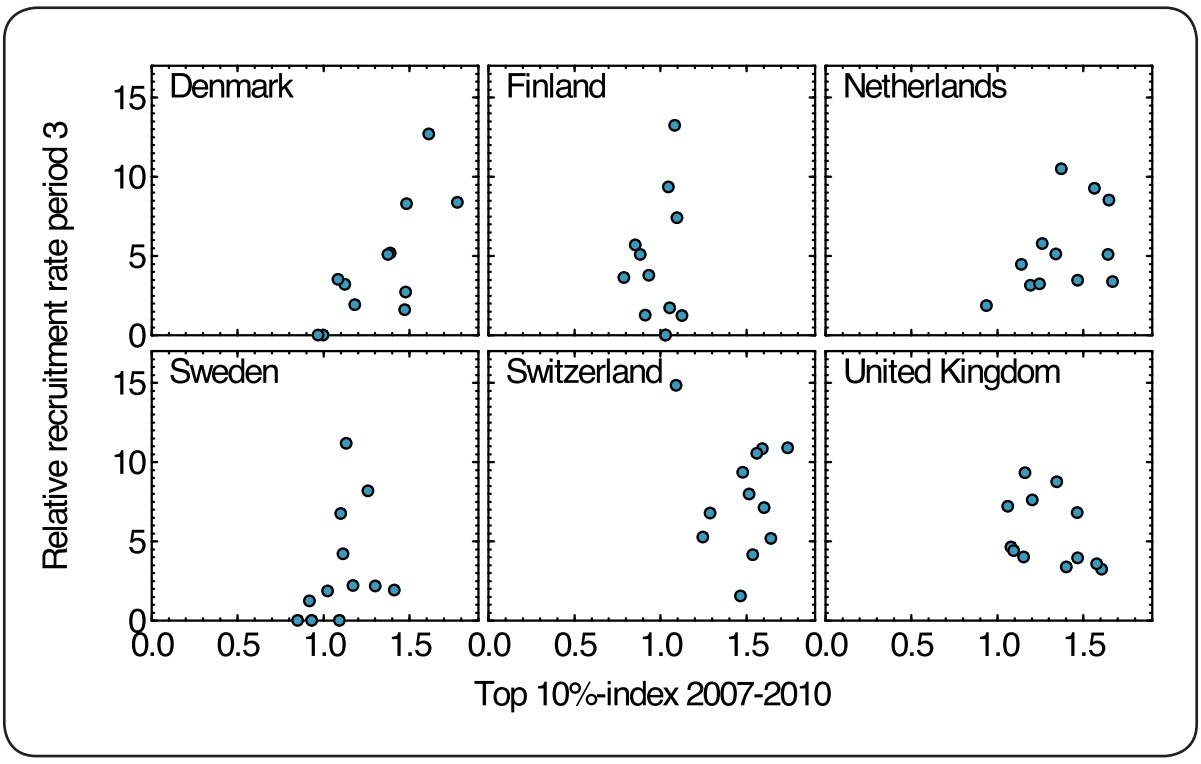
Sweden shows the lowest recruitment rate at the first period and the second lowest rate for the two other. In parallel with relatively low recruitment rates, Sweden also has the second lowest growth rate among the compared countries for the total publication volume and for the size of the entire author community, respectively.

Table 12.1. Recruitment rate: Per cent of elite authors emerging during the last five years of a 15-year period. For comparison the mean annual growth rate of the publication volume and the number of author names are shown in the two last columns.(The restrictions mentioned above for the calculation of the recruitment rate apply.)

Country	Period			Mean growth of publication volume	Mean growth of no. of authors 1986-2010
	1986-2000	1991-2005	1996-2010		
Denmark	8.1 %	5.3 %	5.0 %	2.8 %	5.9 %
Finland	7.7 %	4.0 %	3.1 %	3.2 %	6.2 %
Netherlands	9.5 %	6.5 %	5.2 %	3.5 %	6.1 %
Sweden	5.4 %	4.4 %	3.7 %	1.9 %	5.2 %
Switzerland	10.6 %	6.3 %	7.7 %	3.0 %	6.3 %
United Kingdom	6.6 %	4.7 %	4.8 %	1.4 %	4.5 %

Although the rank order among the compared countries considering the recruitment rate is similar to that found in many other sections of this report, there seems not to be any close relationship between recruitment rate and the top 10 %-index when comparing these indices for different SPRU-fields (Figure 12.1). On the other hand, it clearly shows that Swedish research, more than the other countries', faces both relatively low proportions of top 10 %-papers and slow recruitment of its scientific elite.

Figure 12.1 Recruitment rate versus the top 10 %-index for 12 SPRU-fields. The field Art and Humanities is excluded due to the low number of publications and authors found in this field. (The restrictions mentioned above for the calculation of the recruitment rate apply.)



13. CONSIDERATIONS ON STATISTICAL SIGNIFICANCE

The statistics presented in this report are based on an entire dataset rather than on random sampling. Further the data quality is high with very few random errors. Therefore the statistics presented are an accurate representation of the situation within the limits of the coverage of the database as described below. When comparing universities or countries, there is a degree of randomness in which year a particular publication is printed and thus in annual means. However, all statistics presented in this report are based on three- or five-year means. These means should show very small random components.

There are, however, some cases where the "measuring error" could be larger. (1) For the organisation statistics in section 9 the university names for Nordic countries are unified and corrected (see Piro 2011). For the other countries the unification is more superficial; the number of organisations above the size threshold and university size could therefore be underestimated for the non-Nordic countries. (2) In sections 11 and 12 when using last name and initials to identify individual researchers.

Nevertheless, statistical significance test were performed in some cases. For one of the smallest datasets presented, publications in the prestige journals in section 8.2, some statistical tests were performed using annual averages as "replicates". For example, the top 10 %-index for the last period (leftmost bars in each group, middle row, in Figure 8.2), the Swedish value is not significantly different from the Finnish (P=0.17) but significantly lower than that for all other countries (P=0.013 or less; tested by a generalized linear model in SAS). For the top 1%-index in the same graph the Swedish mean is not significantly different from that for Finland or United Kingdom (P= 0.12 and P=0.14, respectively) but significantly lower than the means for Denmark, Netherlands and Switzerland (P=0.01 or less). With respect to this dataset it should be kept in mind that the number of fractionalized top 1%-publications from each country each year is extremely small in the prestige journals (in the order of 1- 20, except for the United Kingdom with 40-70, c.f., Figure 8.1). Most other statistics presented in the report are based on considerably larger data sets. It is therefore safe to assume that the differences between Finland or Sweden and the other countries are statistically significant (in the above sense) in most cases.

An important restriction to all statistics presented is, however, that the report is based on a commercial database covering a fraction of all scientific publications only; those in ca 12 000 international journals. As stated above (section 6) this restriction is most important for *Arts and Humanities* but significant also for *Social Sciences*. Further, for some technical fields, 'proceedings' is an important type of publication not included in the database at the Swedish Research Council. All statistics should be interpreted in this context; the statistics describe the performance of publications in the journal set indexed by Thomson Reuters. In some fields there are important publications in other publication channels.

14. CONCLUSIONS

In this report, Sweden is compared with five other countries in terms of a spectrum of bibliometric statistics. In almost all aspects the same pattern is found; Finland and Sweden perform less well than the other countries in the study. The differences between Finland and Sweden on one side and the other countries on the other cannot be attributed to particular subject fields, universities or collaboration patterns. The most successful countries (Denmark, Netherlands and Switzerland) have few universities performing below world average. Their whole university systems are, thus, strong and do not depend on a few elite universities (Figure 9.2).

Some patterns indicating causes for the poor Swedish (and Finnish) performance have been identified. All countries, except Sweden, have shown improving citation rates for nationally produced publications. This development has been most marked for Denmark. Thus the difference between papers produced in international collaboration and national papers is declining, but not so for the Swedish publications (Figure 5.3). Among the Swedish publications produced in international collaboration a decreasing proportion has involved collaboration with the United States. Finland and the United Kingdom have shown a similar but less marked trend while the other countries have maintained the proportion of collaboration with the United States. For Sweden and Finland the proportion of the author-community that produces highly cited publication is smaller than for the other countries. However, among the authors producing highly cited papers, the productivity of the Swedish authors (number of highly cited papers per year) is the highest. Thus the Swedish elite is small but productive. Also regarding recruitment of the top scientists (those producing many highly cited papers) Sweden and Finland seem to have lower values than the other countries.

Further, comparing the countries with other types of statistics (Table 14.1) gives no obvious explanations for the differences in performance. Without a more detailed analysis of changes in other statistics and in research policy, it is difficult to understand the causes for the statistics presented here. A few years later the British bibliometric performance started to improve. The British performance have improved at a greater pace during the last 10 years. First, the United Kingdom introduced the Research Assessment Exercise (RAE) in the early 1990's and a few years later the British bibliometric statistics started to improve. The British statistics have improved at a greater pace during the last 10 years. Denmark had a major university reform in 2003 but most of the Danish increase took place during the 1990's, after turn of the millennium the Danish curves have been flatter.

National research systems are very complex and vary in a number of aspects (e.g. Himanen et al. 2009) and it may be difficult to identify the consequences of individual characteristics or find simple causes for certain patterns in the statistics. A more thorough analysis of the research systems and changes in the research policy during the last decades in the compared countries is presented in the report from the Swedish Royal Academy of Sciences mentioned in the introduction.

Although the performance of Sweden and Finland has been pointed out as "poor" in this report, it should be kept in mind that the comparison is made with some of the world's most successful countries, as measured by bibliometric statistics. Sweden and Finland are among the world's most respected nations in science.

Table 14.1. Some general statistics for the compared countries and their research systems. All statistics are for 2010, except Eurostat-data for Switzerland which is for 2008. Bibliometric statistics are based on means for 2009-2011.

Characteristic	Denmark	Finland	Netherlands	Sweden	Switzerland	United Kingdom	Source
A Population, millions	5.53	5.35	16.57	9.34	7.78	62.03	Eurostat
B GDP, billion €	227	178	581	310	378	1 602	Eurostat
C Total R&D, % of GPD	3.06	3.87	1.83	3.42	2.99	1.77	Eurostat
D R&D in extended academic sector, % of GPD	0.98	1.18	0.96	1.07	1.07	0.79	Eurostat
E No of researcher (FTE) in extended accademic sector[22]	10 845	18 521	27 159	18 872	14 810	154 812	Eurostat
F No of fractionalized publications	7 416	6 714	20 311	12 553	12 624	6 415	Swedish Research Council
G Field normalized citation rate	1.30	1.07	1.32	1.14	1.34	1.24	Swedish Research Council
H Top 10 % index	1.35	1.06	1.36	1.16	1.43	1.28	Swedish Research Council
Calculated:							Formula
I R&D billion €	6.95	6.89	10.63	10.60	11.30	28.36	B*C/100
J R&D in extended academic sector, billion €	2.22	2.10	5.58	3.32	2.99	11.05	B*D/100
K R&D in extended academic sector million € /capita	0.40	0.39	0.34	0.36	0.38	0.18	J/A
L Publications / millions € to R&D in the exteended academic sector	3.33	3.20	3.64	3.78	4.23	5.85	F/J
M Publications / year and million inhabitants	1 341	1 255	1 226	1 344	1 623	1 043	F/A
N Publications / year and researcher	0.68	0.36	0.75	0.67		0.42	E/F

The letters in the first column are used in the last column to show how the six bottom rows are calculated. GDP = Gross Domestic Product, FTE = full time equivalents.

21 I.e. the higher education sector, the governmental sector and the private non-profit sector (cf. Jacobsson & Rickne 2004)

15. REFERENCES

Abramo G., Cicero T. & D'Angelo C.A. 2012. *A sensitivity analysis of research institutions productivity rankings to the time of citation observation.* Journal of Informetrics 6: 298-306.

Aksnes D.W. 2003. *Characteristics of highly cited papers.* Research Evaluation 12: 159-170.

Aksnes D.W. och Sivertsen G. 2004. *The effect of highly cited papers on national citation indicators.* Scientometrics 59: 213-224.

ESF, 2011. European Peer Review Guide. *Integrating Policies and Practices into Coherent Procedures* (http://www.esf.org/activities/mo-fora/peer-review.html).

Evidence 2011. *Funding research excellence: research group size, critical mass & performance.* A University Alliance report (www.university-alliance.ac.uk).

Glänzel W. 2000. *Science in Scandinavia: A bibliometric approach.* Scientometrics 48:121-150.

Glänzel W., Danell R. & Persson O. 2003. *The decline of Swedish neuroscience: Decomposing a bibliometric national science indicator.* Scientometrics 57:197-213.

Glänzel W, Schlemmer B. & Thijs B. 2003. *Better late than never? On the chance of becoming highly cited only beyond the standard bibliometric time horizon.* Scientometrics 58: 571-586.

Gunnarsson M. (ed) 2010. *International research cooperation in the Nordic countries.* Nordforsk (http://www.nordforsk.org/no/publikasjoner/international-research-cooperation-in-the-nordic-countries).

Himanen L., Auranen O., Puuska H.-M. & Nieminen M. 2009. *Influence of research funding and science policy on university research performance: a comparison of five countries.* - Science and Public Policy 36: 419-430.

Ingwersen P & Wormell I. 1999. *Publication behaviour and international impact: Scandinavian clinical and social medicine 1988-96.* Scientometrics 46: 487-499.

Jacobsson S. & Rickne A. 2004. *How large is the Swedish 'academic' sector really? A critical analysis of the use of science and technology indicators.* Research Policy 33: 1335-1372.

Luukkonen T., Persson O. & Sivertsen G. 1992. *Understanding patterns of international scientific collaboration.* Science, Technology & Human Values 17: 101-126.

Kostoff R.N. 2007. *The difference between highly and poorly cited medical articles in the journal Lancet.* Scientometrics 72: 513-520.

Moed H.F. 2005. *Citation analysis in research evaluation.* Springer, Dordrecht.

Persson O., Glänzel W. & Danell R. 2004. *Inflationary bibliometric values: The role of scientific collaboration and the need for relative indicators in evaluative studies.* Scientometrics 60: 421-432.

Piro, F.N (ed) 2011. *Comparing research at Nordic universities using bibliometric indicators*. Nordforsk Policy Brief 4, 2011. (http://www.nordforsk.org/files/rapp.bib.2011.pub_21.5.11)

Seglen PO. 1997. *Why the impact factor of journals should not be used for evaluating research*. BMJ 314:497.

Sinha G 2009. *Singapore's science bet. Science, March 2009, pp 773-778* (DOI: 10.1126/science.opms.r0900067)

Tijssen RJW, Visser MS & Leeuwen TN van. 2002. *Benchmarking international scientific excellence: Are highly cited research papers an appropriate frame of reference?* Scientometrics 54: 381-397.

van Raan, AFJ. 2012. *Properties of journal impact in relation to research group performance indicators*. Scientometrics 92: 457-469.

van Raan, AFJ, Leeuwen TN van, Visser MS. 2011. S*evere language effect in university rankings: particularly Germany and France are wronged in citation based rankings.* Scientometrics 88:495-498.

von Tunzelmann N., Ranga M., Martin B & Genua A. 2003. *The effect of size on research performance: A SPRU Review.* SPRU, University of Sussex at Brighton.

Vetenskapsrådet 2006. *Hur mycket citeras svenska publikationer? Bibliometrisk översikt över Sveriges vetenskapliga publicering mellan 1982 och 2004.* Vetenskapsrådets rapportserie 13:2006 (http://www.vr.se).

Vetenskapsrådet 2008. *Betydelsen av samarbete för hur vetenskapliga publikationer citeras. Sverige jämfört med fyra högt citerade europeiska länder.* (http://www.vr.se).

Vetenskapsrådet 2010. *Den svenska produktionen av högt citerade vetenskapliga publikationer.* Vetenskapsrådets lilla rapportserie 1:2010.

Vetenskapsrådet 2011. *Subject classification of publications in the ISI database based on references and citations.* Vetenskapsrådets lilla rapportserie 4: 2011.

Wagner, CS, Roessner JD, Bobb K, Thompson Klein J., Boyack KW, Keyton J, Rafols I & Börner K. 2011. *Approaches to understanding and measuring interdisciplinary scientific research (IDR): A review of the literature.* Journal of Informetrics 165: 14-26.

Appendix: Bibliometric methods

The statistics have been compiled using the publication database at the Swedish Research Council. This database contains the material from Science Citation Index Expanded 1982-2011. [22][23] A detailed description of the database and methods used can be found at: http://www.vr.se/bibliometrics/ and the report Subject classification of publications in the ISI database on references and citations (see www.vr.se)

All statistics are based on:

- The publication types *Article* and *Review*. The publication type article has been extended to include also *Letters*.
- Fractionalised publications i.e. each country or organisation is credited a fraction of each publication in proportion to its share of all author addresses given on the publication. The publication volume is thus the sum of all fractions. (Sections 10-12 are however based on whole counts)
- A three-year citation window, i.e., the citations obtained during publication year and the following years are counted. For the most recent years (2010 and 2011) citations has only been accumulated during one or two years. However for aggregated data also short citation windows give robust averages.[24]
- Self-citations are not counted; all citations where one or more author name (with identical spelling) is found in both the cited and citing publications are defined as self-citations.

Citation averages are calculated as weighted averages where each publication is weighted using the address-weight. In those cases where a publication is allocated more than one subject the publication is also fractionalised among the subjects. For example, a publication that has two subjects, the publication is split between these with 0.5 publications to each field. In this case the statistics is based on the combined address and subject weight. By this procedure the sum of all fractions (of countries, organisations and/or subject fields) always sums to the total sum of publications analysed.

Citation statistics are presented as *field normalised mean citation rates 3* years after publication. For publications less than 3 years old the citation window is shorter. The field normalised citation rate is the number times a publication is cited (C) divided by the average number of citations of all publications in the database from the same year, same publication type (article or review) and in the same subject field(s) (i.e., the field reference value, FRV):

Field normalised citation rate = C / FRV

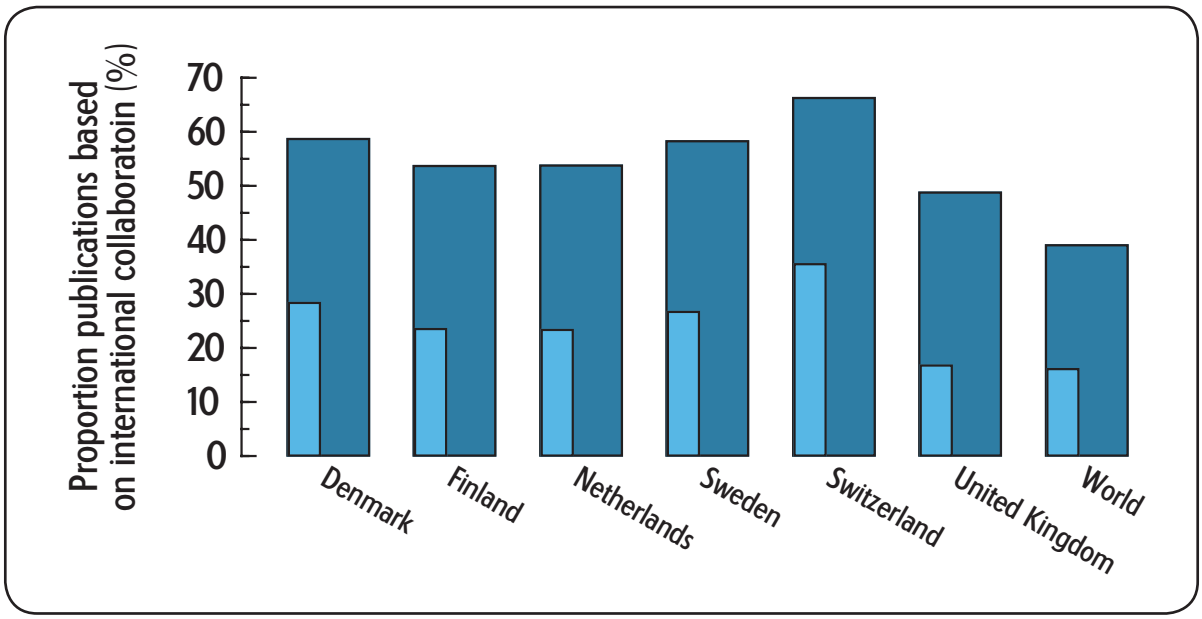
A publication that is cited at the same rate as the world average thus obtains a citation rate of 1. If the number of citations are half that of the world average the rate becomes 0.5 and if the number is 50 % above the world average the rate become 1.5 etc. Citation averages are calculated using the weights as defined under 2) above. Thus a publication where the authors represent four countries (one address to each country) the publication has the weight 0.25 in the calculation of the mean for respective country.

Most publications in journals belonging to the subject field "Multidisciplinary Sciences" have been reclassified into other field based on the subject profile of cited and citing papers.

22 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.
23 The contents of Web of Science and the Science Citation index are very similar but not identical.
24 See Abramo et al 2012.

As stated above all statistics in this report, except for sections 10-12, is based on fractionalized publication counts. This result in relatively low values for the proportion of the publications produced in international collaboration (section 5 and parts of section 6). The figure below shows show the proportion of the publication based on international collaboration when calculated based on whole counts. The values in the graph below are considerably higher than those in figure 5.1, but the relative differences between countries are similar.

Figure Appendix 1. The proportion of all publications that involve international collaboration based on whole counts. (Complement to figure 5.1)



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