Links between research policy and national academic performance

- A comparative study of Denmark, Sweden and the Netherlands

Background report

Research Group

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1. Introduction

This is the background report to a study commissioned by The Danish Council for Research and Innovation Policy (DFiR) under the heading 'World Class Knowledge' (Viden i verdensklasse). The report consists of 9 chapters. The first chapter outlines the objectives and the key questions of the study. Furthermore, the chapter discusses the methodology, the data and the overall approach of the study. Chapter 2 presents a brief literature review examining state of the art of our (limited) knowledge of the relationships between research policy and research performance. Particular attention is paid to six selected factors brought forward by DFiR. Chapter 3 presents three brief country descriptions covering the period 1980 to 2015 for Denmark, Sweden and the Netherlands. In the descriptions the overall research policy development of the three countries are outlined and potential links to the development in research performance are discussed as the outset of a number of more detailed analyses carried out in the subsequent chapters. These are carried out in chapter 4-9 where the six selected hypotheses are examined in a cross country perspective. The overall integrative analysis is found in the main report of this study.

The function of the present background report is first and foremost to document the foundation of the conclusions presented in the main report. As few will read the entire report, the individual chapters have been written to allow readers to focus on selected issues. As a consequence, the same text pieces do in several instances appear in more than one chapter. This is in particular the case in relation to the text written to the literature review in chapter 2: substantial parts of this chapter are repeated in the introduction of each of the chapters from 4-9. For the same reasons each chapter has its own reference list. Similarly, previous relevant studies carried out by the authors of this report are used directly in the analyses in chapter 4-9. Also here substantial text pieces can be found which have been published in other works. In all cases we do however explicitly mention when the material in this report builds on previously published analyses.

1.1. Research policy and performance: the study in context

The relationship between research policy and national research performance has high policy relevance and has been discussed extensively in academic, administrative and political circles in recent years. In particular the Danish case has attracted attention lately as Denmark currently stands out among the top performing countries of the world in terms of academic performance measured by bibliometric indicators. Not least a report by Öquist and Benner (2012) has highlighted the so-called "Danish Miracle" and has raised the question: why is Danish research performing so well when we measure performance in terms of publication volume and citation impact?

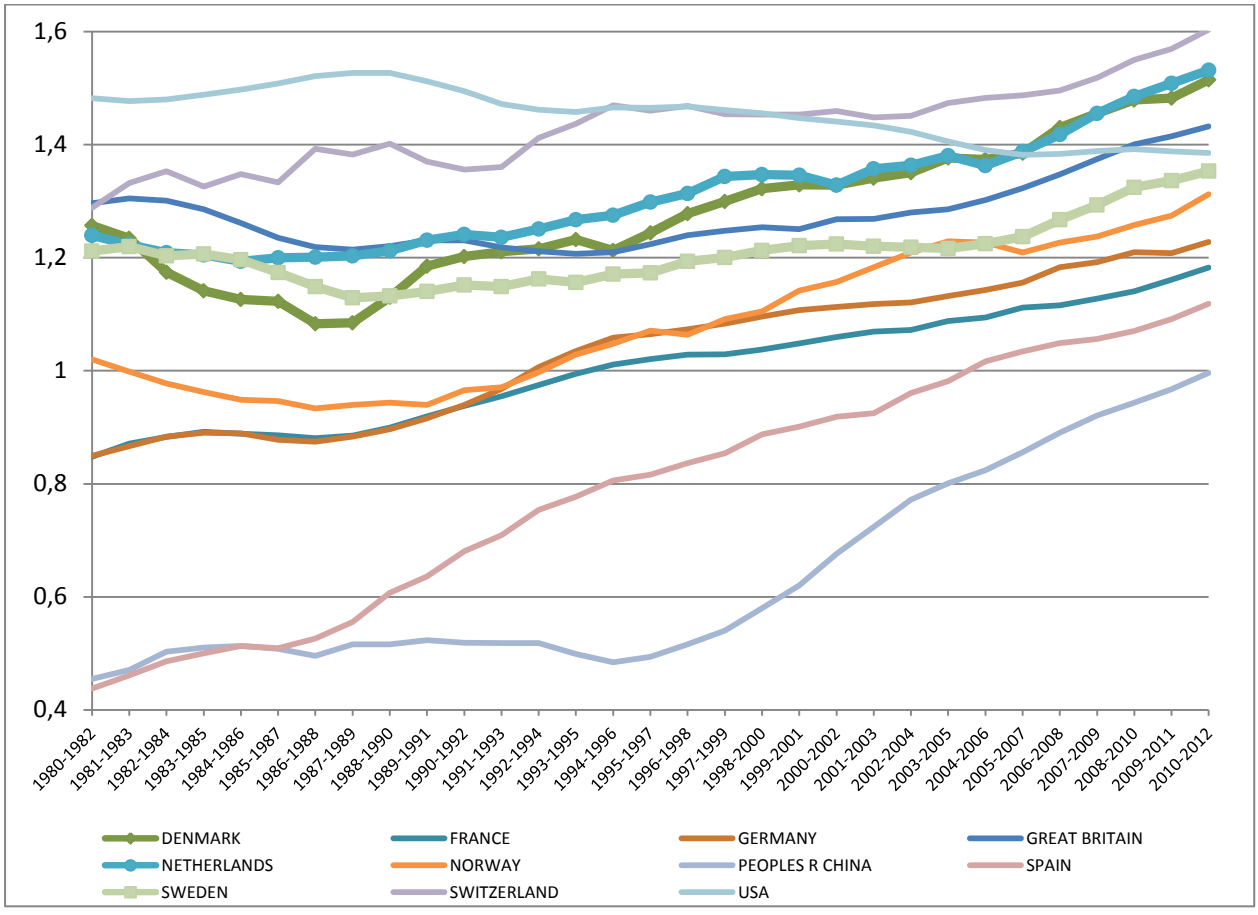
Based on these discussions DFiR has initiated a project aiming to improve our understanding of the long term development of Danish research performance. As a first step, a 'Scientometric mapping of developments in Danish research performance in the period 1980-2013 at macro- and meso-levels' was carried out (Schneider and Aagaard 2015). By examining a variety of indicators and comparing the current standing of Danish research to a selected group of comparable countries (The Netherlands, Sweden, Norway and Austria) this report investigated the robustness of the performance claims and the consistency of the long term trends. Furthermore, the report examined to what extent the overall development in Danish research performance was mirrored at the levels of the major scientific fields. And finally, it examined whether Denmark showed different developments in terms of collaboration, internationalization and journal impact behavior than the benchmark countries.

Overall, the report showed a very robust and consistent picture with a very strong Danish performance documented by a variety of indicators (including MNCS, PPtop10%, PPtop5%, PPtop1%) and with regard to the share of uncited publications. Furthermore, the majority of the analyses were carried out based on both full counts and fractional counting to ensure that differences between the two methods did not distort the overall results. The strong Danish position was documented in comparison with both the four benchmark countries and a wider set of countries (see Figure 1.1 and Figure 1.2 below). The mapping also showed, however, that the performance of Danish research showed a remarkable drop during the 1980s. This trend was reversed by the end of the 1980s and since then few other countries have shown the same rate of improvement as Denmark.

As can be seen from the figures the two benchmark countries included in this report, Sweden and the Netherlands, can also both be labelled as high performing research-nations. The science system of the Netherlands has displayed a consistent high performance level for more than three decades, while the Swedish system during the period under examination has faded somewhat from a strong starting position.

The first figure below shows a selection of countries including the highest performing research nations of the world (countries such as USA, UK, Switzerland and the three benchmark countries). A number of more modest performing countries (such as France, Germany and Norway) as well as some upcoming nations (Spain and China) are also included to provide for the broader context.

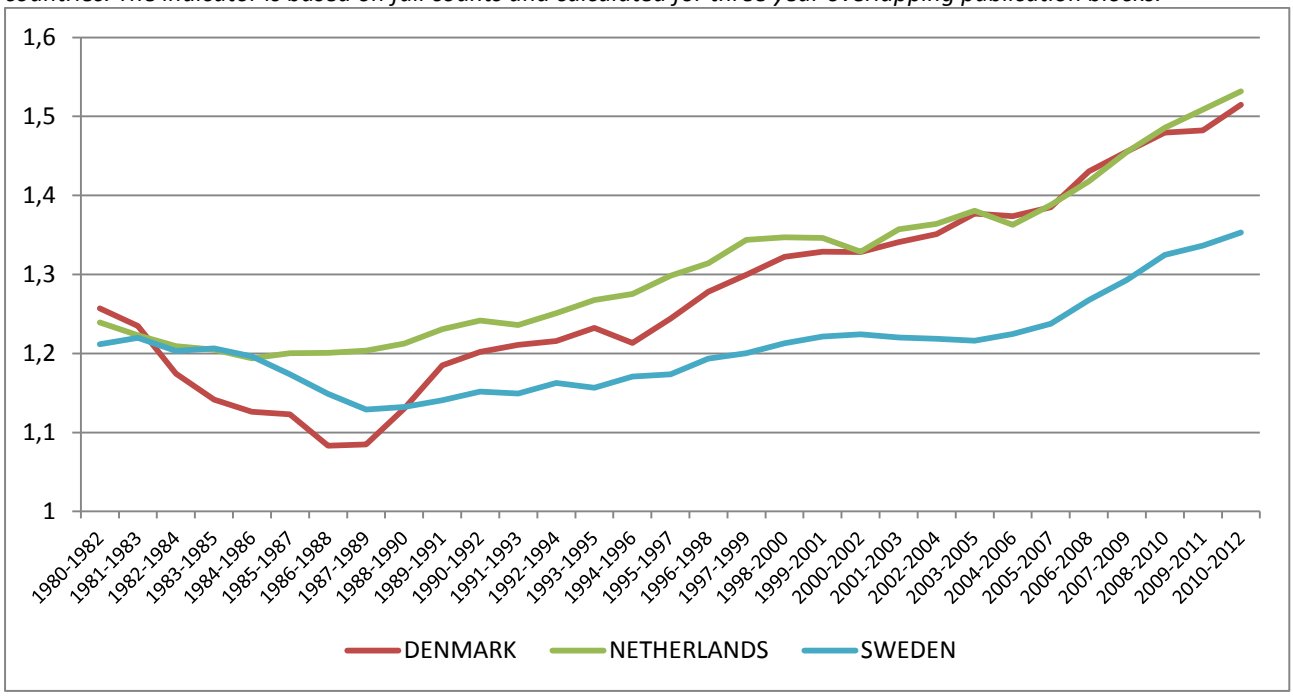
Figure 1.1: Development in mean normalized citation scores (MNCS) based on full counts for 11 countries; three year overlapping publication blocks.



Source: Schneider and Aagaard 2015

The next figure shows the three benchmark countries only in order to get a clearer overview of the long term developments of these countries.

Figure 1.2: Developments in mean normalized citation scores (MNCS) for Denmark and the two benchmark countries. The indicator is based on full counts and calculated for three year overlapping publication blocks.



Source: Schneider and Aagaard 2015

As discussed below and in more detail in (Schneider & Aagaard 2015) there are however important indicator limitations and database-effects which we need to take into account when we interpret the long-term developments within and between countries. See section 1.3. for further details on the limitations and caveats associated with the data and methods used in this report

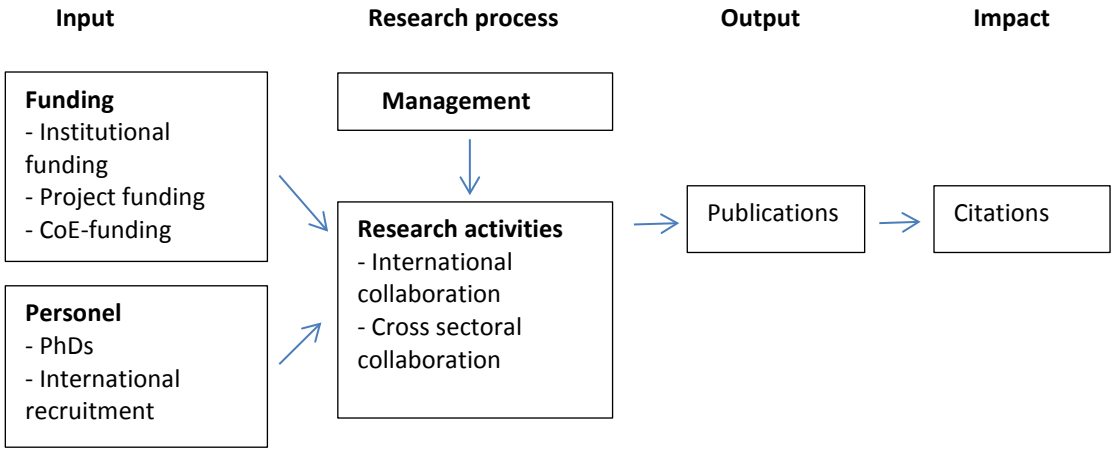
1.2. Objectives and main questions

Based on the abovementioned discussions and the bibliometric examinations the present study was commissioned by DFiR with the aim of examining the Danish relationship between research policy and research performance in a comparative perspective. By exploring the underlying factors contributing to the development in Danish research performance the present study thus aims to strengthen the foundation for future research policy decisions in Denmark. In addition, the project aims to add to the more general, cross-national knowledge of the relationships between research policy and research performance by analysing and discussing systemic factors of importance for well-functioning national research systems.

It shall, however, be noted that the analysis has an explicit focus on academic performance measured by bibliometric indicators only. It does not accordingly address other types of impact directly. It is generally assumed that there is a potential positive relationship between academic research excellence and both societal impact and high quality teaching, but it is also acknowledged that this relationship may not exist under all circumstances. It is highly likely that examples of tradeoffs between these three central university missions can be found. When the results of this study are discussed they must accordingly be placed in this wider context.

From this outset this report presents a quantitative and qualitative based long term analysis exploring the foundation of the development in Danish research performance from 1980 to the present in comparison with the corresponding developments in performance for Sweden and the Netherlands respectively. Based on six hypotheses formulated by DFiR, a cross country comparison between these three countries serves to examine a number of proposed explanations in different national settings and at different points in time. The hypotheses, which have been formulated on the basis of document analyses and interviews with key stakeholders, state that the strong Danish research performance may be related to six selected policy factors. These factors are illustrated in Figure 1.3 below and include selected funding issues, issues related to training and recruitment, and issues related to management and collaboration (international as well as cross-sectoral). The six hypotheses are outlined in more detail below the figure based on the 2014 Annual Report of the Danish Council for Research and Innovation Policy (DFiR 2015).

Figure 1.3: Key factors in the study



1) Hypothesis one concerns the funding system and in particular the balance between institutional funding and project funding. It states that the Danish system has benefitted from appropriate balances between these funding streams and it highlights in particular how increased competition over time may have led to increased research performance. It also states that the mix between different types of funding may have been more appropriate in Denmark than in other comparable countries.
2) Hypothesis two is also related to the funding system and has a specific focus on the use of Excellence initiatives. It states that the Danish system has benefitted from an early and well executed prioritization of a large scale excellence initiative (the Danish National Research Foundation established in 1993). It is argued that these types of excellence initiatives in addition to their direct effects may have indirect positive spill-over effects on the research system as a whole.
3) The third hypothesis deals with the volume and the organization of the PhD education (and in broader terms the recruitment and training of new researchers) and states that explicit and well timed prioritizations of the doctoral training have secured a strong and talented growth layer in the Danish research system. The mechanisms mentioned include: stronger competition for positions, improved and more formalized frame-conditions and more international recruitment.

4) The fourth hypothesis targets the governance of the universities and in particular the internal research management structures. It is argued that two Danish reforms of the management system carried out in 1993 and 2003 respectively have strengthened the local research management resulting in a strong quality culture and good recruitment practices. It is in particular highlighted that the Danish 1993 act may have led to a stronger attention from the central management towards attracting the best international researchers and that the act may have led to stronger internal prioritizations of research.
5) Hypothesis five concerns the internationalisation of Danish research and states that the Danish system has benefitted from a high degree of international research collaboration.
6) The sixth and final hypothesis deals with cross sectoral collaboration and in particular public/private research collaboration. It is stated that that a strong Danish tradition of collaboration may be a contributing factor in explaining the high general impact of Danish research.

Although this study seeks to examine these hypotheses, it does not attempt to strictly confirm or disconfirm each individual hypothesis. While factors such as funding, management, internationalization, collaboration, PhD training and recruitment are vital elements in any well-functioning research system and obviously play important roles for the public research carried out in all the three countries, they do so in indirect and interconnected ways and with considerable time-lags. Furthermore, as the literature review in chapter 2 illustrates, there are strong indications that multiple balance points between these factors can lead to high academic performance at both micro-, meso- and macro-levels. Rather than a set of isolated tests of the individual hypotheses the study shall be seen as an examination of the interconnectedness of these factors in different national settings and at different points in time and a discussion of the multiple balance-points which either can enhance or hinder national research performance.

The main argument for this approach takes its departure in the fact that factors influencing research performance must be seen as highly interconnected in multi-level systems. The paths from changes in input-factors at a macro-level to the changes in individual and group level research behavior which eventually constitutes the basis of the developments in national publication productivity and performance are thus seldom straightforward and linear. In addition, we will expect that there will be substantial lags between changes at the policy level and changes in performance.

The following section outlines how the study has been organized in order to examine the overall questions of the study.

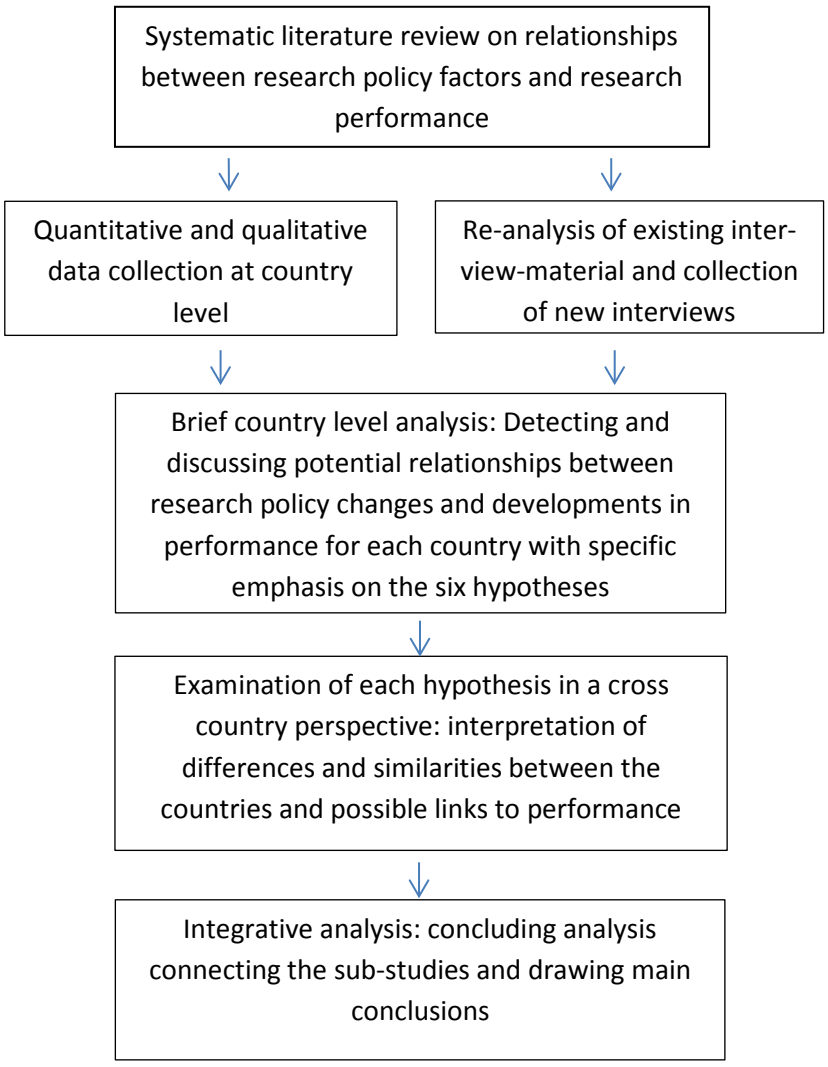
1.3. Methodology and data

The present study combines both quantitative and qualitative methods and data-sources. Figure 1.4 below shows the key elements in the study.

As the outset of the study a comprehensive literature review was carried out in order to establish a solid foundation for the subsequent analyses. Alongside this process the data-collection and interview-gathering was started in all three countries in order to gather as many comparable data-sets as possible. As part of this process, a collection of previously collected interview-material was re-analyzed.

In the next phase brief country descriptions were developed for the three countries in order to outline important system characteristics and to highlight major policy changes of relevance for the hypotheses. Policy timelines were constructed for each country and compared to the developments in performance. After this a large number of specific analyses were carried out at hypothesis level. The majority of these were carried in a cross-country perspective, but in a number of cases the comparative analyses have been supplemented with more detailed Danish analyses. Finally, all the analyses at hypothesis level were then examined in an integrative perspective in order to draw the overall conclusions of the study. The integrative analysis is presented in the main report of this study, while the analyses of the individual hypotheses can be found in chapter 4-9 in this report.

Figure 1.4: Methodology and work flow of the study



As the figure above illustrates, the analyses at hypothesis-level, country-level and the overall integrative level are all based on multiple data sources. Table 1.1 below outlines the types of data utilized for each element in the study and describes in more detail how the data has been collected and analysed.

Table 1.1: Data sources and data analysis

Data sources	Data analysis
Literature review	Secondary analysis of academic literature on relationships between research policy and research performance with a specific focus on the factors highlighted by DFiR
Document study/desk research	Analysis of relevant policy documents, reports and analyses for all three countries in relation to both country descriptions and the context of the different analyses
45 semi structured Interviews with key decision makers and stakeholders (15 per country)	Re-analysis of interviews conducted by Mats Benner as part of previous study (Öquist & Benner 2012). These interviews targeted vice-chancellors, heads of research councils and funding foundations, politicians, administrators and research leaders.
Semi structured Interviews with high performing researchers/central stakeholders (5-10 per country)	Analysis of the perceptions of high performing researchers and/or central stakeholders with long term experience functioning under different policy-regimes and with knowledge of different national contexts
Funding data	Analysis of national funding data primarily based on national statistics. Developments in funding coupled to developments in publication volume and impact. OECD and Eurostat data has been included where relevant to give a broader context
Bibliometric data	Bibliographic data from Thompson Reuters' citation database Web of Science (WoS). The in-house version of WoS of CWTS, Leiden University, Netherlands has been used. This database has among other features enhanced citation and address matching algorithms compared to the standard version.

The literature review examines state of the art of our knowledge of the relationships between research policy and research performance. Particular attention has been paid to the six factors brought forward by DFIR. The review has been carried out rigorously according to scholarly standards where thorough search strategies, both term- and citation-based, were developed based on the factors and hypotheses brought forward by DFIR, as well as supplementary knowledge from the various subject experts in the consortium. The literature searches were carried out in relevant databases and relevance judgements on the search results were made based on predetermined criteria, before the final set of documents was scrutinized for their relevance to the actual questions examined.

1.3.1. Interpretation of the data: Caveats and limitations

As outlined above the present study is based on several types of data. The following section discusses a number of limitations and caveats associated with the bibliometric data and the funding data in particular. As we will show, both the input and the output data have clear limitations. The interpretations of potential links between changes in input factors and developments in output factors should accordingly be conducted with caution. Throughout the report we highlight these limitations where relevant.

Bibliometric data: As emphasized in the introduction the point of departure for this analysis is academic performance measured by bibliometric indicators. The analyses are all based on bibliographic data from Thompson Reuters' citation database Web of Science (WoS). We use the in-house version of WoS constructed and maintained by CWTS, Leiden University, Netherlands. This database has, amongst other things, enhanced citation and address matching algorithms compared to the standard version provided by Thompson Reuters. The following is to a large extent based directly on Schneider and Aagaard (2015).

Only journal publications indexed in WoS from 1980 to 2013 are included in the analyses. The current low quality of the Conference Proceedings Citation Index basically excludes this index (and thus this publication type) from valid citation analyses. Currently, the WoS covers approximately 12,000 journals from the sciences, social sciences and arts and humanities. Each journal is assigned to one or more subject categories (up to six). There are approximately 250 subject categories in WoS.

In this report we use Mean Normalized Citation Score (MNCS) as the standard indicator for research performance. The indicator is item-normalized according to publication type, publication year, and field-specific citation rates. This means that citation rates per publication are compared to average citation rates for the same type of publications, in the same year, for the specific research field, before they are aggregated to provide totals. This enables the comparison of so-called relative citation indicators across research fields, publication types and publication years. Such relative indicators are needed here because the typical number of citations is highly dependent on research field, publication type and the time allowed before citations are counted. Self-citations are excluded from the calculation of citation rates and citation rates are calculated with four-year citation windows, i.e., the citations obtained during the publication year and the following years are counted. For the most recent publications, citations have only been accumulated during one or two years.

In general, citation indicators become more robust as the number of publications involved increases. At the country level, indicators are usually very robust. Also, differences in counting methods or citation windows do not seem to alter the performance rank among the selected countries in any substantial way.

The MNCS indicator is an average field normalized citation rate. When fractional counts of publications are used an index of 1 is the "database average" citation rate for the aggregated field(s). When full counting is used in combination with citation indicators, values do not sum up to unity and the "database average" of 1 does not hold. Generally, units have higher MNCS scores when full counting is applied. An important weakness of the MNCS indicator is its strong sensitivity to publications with a very large numbers of citations. Especially for smaller publication sets this can result in an overestimation of the actual impact of the publications assigned to the unit of analysis.

In the interpretation of the data presented in this report it should however be kept in mind that measuring the properties of science is a difficult exercise. Bibliometric data can contribute with important insights, but cannot stand alone. As an example, indicators measuring citation impact capture academic impact, rather than quality, and this capture is only partially. As a consequence of this partial and one-dimensional nature of the indicators, a single indicator is often not reliable. However, when various complementary indicators suggest similar insights more convincing evidence

about the property observed is offered. On the other hand, a lack of agreement between various indicators suggests that several contrasting perspectives may be relevant (Martin et al, 2014). In the present report as well as in the main report the bibliometric performance is in most cases shown as MNCS only. However, as written in the introduction these figures are based on a thorough bibliometric mapping where a number of other citation indicators have been examined as well. Overall, the patterns found for MNCS were also found for the other indicators.

Furthermore, the indicators have to be appropriate to the property under investigation and be applicable to the whole system under study. The limitations with regard to this are well-known within the Humanities and Arts and large parts of the Social Sciences, but also apply to certain areas of the hard sciences. As a consequence, the performance patterns shown in this report mainly reflect the performance of the medical and natural sciences. We cannot firmly establish to what extent the social sciences and the humanities show the same developments in performance. Thus, when we draw conclusions on the performance of the national science systems as a whole, it should be kept in mind that the coverage of the WoS restricts our possibilities of examining all individual areas in detail. Further discussions on this issue can be found in Schneider and Aagaard (2015).

Another important element is the fact that bibliometric indicators are unreliable below certain levels of aggregation and need careful mathematical normalization to be used across diverse research areas. However, these normalization procedures are by no means perfect. As a consequence comparisons across fields should be treated with caution. In addition, within-field differences may also be a factor of importance which the normalization procedures fail to capture.

Also language is a factor which should be taken into account. Although English by far is the most important language in written scientific communication today, and even can be considered 'the' international language of science, other languages are used as well. The language of publications has a marked effect on citation-based measurements of research performance. Publications in non-English language journals indexed in the WoS count as part of a country's output, but these publications generally have a low impact as fewer scientists can read them. This effect is particularly evident in application-oriented fields such as clinical medicine. As clinical medicine represents a considerable part of the scientific output of most nations, the language of publication directly affects their performance. However, language bias is also a factor in other fields. Consequently, papers from non-English language journals have considerably lower impact than those in English-language journals. Over the period examined in the present report there has been a steady decrease of non-English language publications in WoS; from approximately 15% in 1980 to 5% today. Apart from English, German was the second largest language in 1980 at approximately 5% of the publications. This figure has dropped to just below 1% today, but it is still the second most common language in the database. Countries such as Germany, Switzerland and Austria are affected by this, but to a diminishing degree as they have decreasing numbers of publications in languages other than English (see e.g., van Leeuwen et al., 2001). With regard to the three countries included in this the study the language issue should however be of minor importance in the comparative investigations.

Finally, it should be mentioned that interpreting time series based on the international citation databases can be somewhat challenging because the databases has undergone, and still undergoes, substantial changes both in structure, data format, at not least changes in scope and coverage. For

several decades the WoS (essentially the Science Citation Index[1]) were stable in its coverage, where inclusion of new journals often meant exclusion of others. This has changed considerably in later decades, where commercial interests seem to be an important factor when it comes to journal inclusion. In the 2000s the database saw a huge intake of so-called regional journals especially from Asia raising the total number of journals covered by WoS markedly (Testa, 2011). While many of these journals are English language, citation traffic between them and western journals is mostly one-way. They cite western journal papers, but the opposite is rarely the case. This has consequences for the global average impact in the database; countries with many publications in western journals, where citation traffic is denser, will generally experience a rise in average impact, albeit experiences may differ between countries. Furthermore, not only has the database grown when it comes to number of journals covered, journals themselves have also grown considerable in size especially in the last two decades. In general, the annual number of issues has risen and so has the number of papers per issue. Overall, these growth factors in the database need to be considered when examining the output of countries. Likewise, it has to be remembered that the annual output for a country is the number of journal papers with at least one author participating from the country covered by WoS in the year in question.

All these factors point in the direction of using relative indicators and towards comparisons between comparable units of analysis to minimize the effects of methodological choices and database effects. Emphasis is thus placed on relative differences rather than changes in absolute numbers throughout the report.

Despite the limitations, these types of bibliometric data do have a lot to offer in assessing aggregated, long term developments as done in this report. Large amounts of data gathered over long periods may reveal interesting trends, although potential biases still exist. While many types of statistical bias tend to level out with larger data sets, some do not. In particular as argued above, language bias and certain field biases should be taken into consideration (Moed, 2005). Similarly, the uneven growth of the Web of Science (WoS) database should also be taken into account.

Funding data: However, not only the bibliometric output data should be treated with caution. Also the data on the input side, in particular the funding data, has a number of limitations.

It is in general acknowledged that an important limitation with regard to cross country comparisons of funding patterns concerns the data quality of the time-series in the OECD MSTI (Main Science and Technology Indicators) databases which go back to 1981. The database suffers from breaks in the series and lack of unification across countries. There are in other words differences among countries in data collection methods and in the use of definitions from the Frascati Manual (Godin 2005, Lepori 2006, Crespi and Geuna 2008). The limitations of these data furthermore include problems in the measure of the share of research in higher education expenditure and a lack of categories needed for policy analysis. These lacks are not least prominent concerning funding agencies, instruments and scientific disciplines (Irvine et al. 1990, Godin 2005).

[1] The WoS is basically an umbrella of several citation indices with different origins. The oldest is Science Citation Index which covers journals from science, technology and medical fields. Other citation indices based on journals are Social Science Citation Index and Arts and Humanities Citation Index. Finally, in recent years, Thompson Reuters has introduced two Conference Proceedings Indices, one for science and technology and one for social science conference papers, as well as a Book Citation index.

For these reasons we have as our first priority attempted to rely on comparable national statistics where available. With regard to the balance between institutional funding and project funding as well as PhD volume these national statistics have provided us with fairly reliable and comparable long term time series. While not perfect, they do give a solid picture of differences and similarities between the three countries. However, with regard to overall volume of R&D investments at public research institutions as well as the distinction between HERD and GOVERD we were unable to find good comparable data based on national statistics for all three countries. Here we have instead used OECD MSTI data for the whole period. HERD (Higher Education Expenditure on R&D) covers all R&D performed in the higher education sector and includes both publicly and privately funded R&D. GOVERD (Government Expenditure on Intramural R&D) covers all R&D performed in the Government sector and includes both publicly and privately funded R&D. HERD + GOVERD is in this report used as proxy for the overall R&D expenditures performed in the public sector. We show all the measures as share of GDP in order to be able to make meaningful comparisons across the three countries. While these data have limitations as outlined above, the overall figures in this case fit well with the other sources available, and they have also been validated by our country correspondents. In particular with regard to the Dutch data there are however some discrepancies in relation to the available national data. Also this calls for cautious interpretations.

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2. Literature review

2.1. Introduction

Research policy and research funding have gone through substantial transformations in most OECD countries since the 1970s. The development has been covered with focus on the content of different periods, paradigms and policy agendas (e.g. Elzinga and Jamieson 1995; Guston 2000), and the consequences of the related changes in organisation, management and funding (e.g. Geuna 2001; Lepori et al 2007; Auranen and Nieminen 2010; Öquist and Benner 2012; 2015). In parallel we have witnessed an ever increasing interest in how nations "compete" in terms of publication volume and academic impact (e.g. May 1997; Adams 1998; King 2004; Leydesdorff and Wagner 2009). A number of studies have attempted to combine these two lines of inquiry to identify the policy factors (or clusters of factors) which explain why certain countries regularly outperform their comparators in terms of publications and citations. A central, but still largely unanswered, question is how different policy factors and/or different policy regimes affect academic research performance?

The first stream of literature is primarily based on the Science Citation Index (SCI) or other bibliometric databases and addresses the hierarchies among nations with regard to different aspects of their scientific production and impact (e.g. May 1997; Adams 1998; King 2004; Leydesdorff and Wagner 2009). In addition, there is a number of cross country comparative reports with similar objectives aimed at aiding policy-makers and administrators (e.g Öquist and Benner 2012; CPB 2014). In general, there are large differences in these rankings depending on whether we focus on publication volume, citation impact, publication measures per capita, publication measures relative to income, input-output efficiency or other measures. A number of determinants influencing variation in research output and impact have been put forward based on these studies, including country size, GDP, or GDP per capita (Inönü, 2003; King, 2004; May, 1997; Rousseau and Rousseau, 1998), public expenditure for R&D (King, 2004; May, 1997, Shelton 2006), incentive structures within research institutions (Almeida, Pais, Formosinho, 2009) and funding balances and governance (Öquist and Benner 2012). However, the data quality of the analyses has often been questionable and the literature is far from conclusive with regard to these types of relationships. While interesting, this stream of the literature is clearly challenged by data issues as soon as policy factors or input measures such as funding is included in the comparative studies (Aagaard and Schneider 2015; Wendt et al 2012). Some of these limitations are outlined in section 1.3 in this report.

If we, however, focus exclusively at studies emphasizing normalized citation impact indicators we see a more consistent picture with a select group of countries on top in most studies. We also observe that competitiveness in research tends to be a package: some nations perform well at both a specific and more general level, while others perform less well across the board (Adams 1998). Studies show that with very few exceptions, all leading scientific nations, both smaller ones such as Switzerland, Denmark and the Netherlands and larger ones such as the US and UK are world-leading not only overall, but also in many individual scientific disciplines. This indicates that excellence in individual disciplines or fields of research is hard to attain without a system that supports excellence at a more general level (Adams 1998). It also shows, however, that the group of high performing countries is very diverse in terms of how the science systems are organized and funded. There is clearly not one optimal science policy model according to this literature.

As indicated some of these contributions discuss possible reasons for differences in performance. For instance King (2004) points to the organization of the research systems as a potential explanation of cross country differences. However, to find a more thorough discussion of these relationships we need to turn to the other stream of literature mentioned above. In this stream, taking its departure in science policy studies rather than within the field of scientometrics, a number of factors such as funding, organisation, management, and career structures have been examined in more detail. Central findings from this literature are presented in the following sections. The sections are structured according to the factors associated with DFiRs hypotheses.

2.2. Funding

The funding system constitutes a central policy instrument for decision makers and works as the single most important element in defining the scope, content and direction of public research systems (Edquist 2003). Funding is thus one of the main channels by which authority is exercised over research, and funding changes can therefore be expected to have significant effects on the production of scientific knowledge (Whitley, Gläser and Engwall 2010). The variety of mechanisms for funding public research is however extremely diverse. On the one hand we have institutional funding (also frequently labelled as basic funding, block funding or core funding) which can be allocated as line item funding, historically based funding or as performance based funding (Aagaard 2011). On the other hand we have a very wide variety of grants ranging from personal grants and, faculty positions, to time-limited research center funding and strategic schemes at the program level. Furthermore, many countries also fund public research institutions outside of the university sector, where even greater varieties of funding modes and mechanisms can be found (Jansen, 2007; Laredo and Mustar, 2001; Crow and Bozeman, 1998; Heinze 2008). It is thus relevant to distinguish between a number of dimensions when we examine funding mechanisms: between grants for individuals and grants for centres; between project funding and institutional support (Bourke and Butler 1999); between initiatives targeting elite researchers and initiatives targeting 'normal scientists' (Laudel, 2006; Melin and Danell, 2006); between mechanisms targeting single-research field and schemes directed at multiple fields (Bourke and Butler, 1999; Laudel, 2006; Heinze, 2008); between short-term and long-term mechanisms (Bourke and Butler, 1999; Laudel, 2006), between schemes supporting curiosity driven research and schemes targeting strategic research; and between mechanisms applying selection criteria emphasizing originality and riskiness versus mechanisms mainly relying on track records (Melin and Danell, 2006; Heinze et al., 2007, Heinze 2008). These distinctions are however seldom clear cut in practice and can interact in multiple ways.

While we have evidence of some general lines of development in the evolution of national research funding systems and while a more detailed assessment has been made in a few countries (Lepori 2006, Braun et al. 2003, Larédo and Mustar 2001; Aagaard forthcoming), it is still uncertain how accurate these aggregated international trends are mirrored in most individual countries (Geuna and Martin 2003; Auranen and Nieminen 2010). An important limitation with regard to cross country comparisons of funding patterns concerns the data quality of the time-series in the OECD MSTI (Main Science and Technology Indicators) as outlined in section 1.3 in the introduction. As a consequence, evidence is often anecdotal: there are for example limited data on the share of project funding in different countries, since this category is non-existing in most R&D statistics. Likewise, there are few quantitative studies on shifts in the portfolio of instruments. Furthermore, great

uncertainty is linked to the questions of when, how and how fast these changes have occurred in different countries.

2.2.1. Funding mechanisms and their relation to performance

The most obvious and well examined factor influencing research performance is the level of public R&D funding. Overall, a rather clear positive correlation between national investments in R&D and publication volume has been found in several studies, although there appears to be evidence of decreasing returns when funding is increased (Shelton 2006; Crespi and Geuna 2008; Leydesdorff and Wagner 2009). Furthermore it is emphasized that a substantial time lag should be taken into consideration when effects are assessed. Crespi and Geuna (2008) for instance suggest that the total cumulated effects are spread over 6 years with regard to publications and even more with regard to citations (see also Auranen and Nieminen 2010). We do not, however find any consensus across studies on the most appropriate lags when funding and bibliometric performance is examined. The literature also shows that the relationship between the level of funding and impact is much more uncertain than the relationship to volume. Several studies do however appear to agree on the importance of relative funding stability over longer time periods for high research performance (Hollingsworth 2008; Heinze 2008; Öquist and Benner 2012).

In addition to funding volume a large number of studies have examined the effects of different types of funding mechanisms as outlined below. Some general tentative conclusions can be drawn from this literature, but it should at the same time be underlined that most of these effects appear to be highly context specific. In other words: funding mechanisms never operate in isolation and must be assessed in a broader context when we aim to understand aggregated impact scores.

2.2.2. Institutional funding vs. project funding

A number of the more specific studies discuss the effects of institutional funding (or other types of very long term, flexible funds). In general, it is emphasized in these studies that this type of funding may allow for the identification of research problems of wider and deeper content, closer to the research frontier. Likewise, it is argued that this type of funding tends to support the exploration mode, which yields higher outcomes and greater impacts than short-term sponsorship of research (Laudel 2006; Heinze 2008). There is however often a (political) concern that a high degree of institutional funding with no strings attached may lead to inertia, lack of dynamic and the absence of a healthy degree of competition in the science system.

Building on the latter argument we also find a substantial literature pointing in the direction of benefits associated with a highly competitive national funding landscape. These arguments appear to have had major influence on the shaping of research policy across most countries during the last three decades where a substantial increase in the share of external, peer-reviewed funding from research councils and other funding organisations has been observed as an almost universal trend (Geuna and Martin 2003; Laudel 2006; Langfeldt 2001; Bourke and Butler 1999, Heinze 2008). As a result scientists, groups and institutions are increasingly forced into a competitive environment driven by evaluation for the allocation of scarce funds. While benefits of competitive funding often are brought forward with the underlying rationale that increased competition for funds will draw out the best ideas and encourage research collaboration (Shapira and Kuhlmann 2003) there are certainly also great concerns. The consequences of the trend towards increasing competitive funding are in other words ambivalent and contested in the literature. It is for instance argued that project

funding allocated as relatively short term funding: 'may predispose researchers to choose lesser problems' (Bourke and Butler 1999) and encourage risk-averse research strategies which leads to proximate and often predictable outcomes. Likewise, this part of the literature underlines that project funding may lead to accept of externally predetermined themes and lead researchers to try to work in niche areas (Laudel 2006: 496–497). It is accordingly argued that a high reliance on project funding may 'promote low-risk, mainstream, "cheap", applied, inflexible research and therefore may restrain the quality and innovativeness of research' (Laudel, 2006: 502). Finally, some authors take somewhat of a middle stance and suggest that there might be an inversed U-curved relationship between competition and scientific performance meaning that both too little and too much competition for funding may decrease research performance (CPB 2014).

While there obviously are both advantages and drawbacks associated with both of these funding modes it is often argued that an appropriate balance between them may secure the best of both worlds. With regard to the composition of funding it is thus suggested that a balance of 60 percent institutional funding and 40 percent external funding provides an appropriate mix of stability and competition (Öquist and Benner 2012; 2015). Aghion et al (2010) on the other hand suggest a positive relationship between competition for research grants and research output (i.e. position on the Shanghai ranking), but they acknowledge with regard to their findings for Europe, that there is more than one single model for success in the university sector. When it comes to European countries the best performing systems thus display a large degree of diversity with regard to both funding and university autonomy. In line with this finding, Auranen and Nieminen (2010) show that there are significant differences in the competitiveness of different national policy- and funding systems, but no straightforward connection between financial incentives and the efficiency of university systems. There are in other words no clear conclusion with regard to finding the optimal balance between institutional funding and project funding. Factors such as major differences in overhead rules across countries further complicate the question.

A main message from the literature is thus that what counts is not only whether the funding is labelled as institutional or project based, but rather whether it is long term and flexible. Flexible and long term research funding is vital for the support of research groups conducting original, ground-breaking research it is argued (Hollingsworth 2008, Heinze 2008, Laudel 2006). Flexible funds may include: institutional funding, funds from agencies with a mission to fund non-mainstream research and large multi-year awards with few budget restrictions regarding the use of personnel, equipment, consumables or operating costs (Heinze et al 2007, Heinze 2008). It thus crosses the simple distinction between institutional funding and project funding. Heinze (2008) point out that this type of funding often is linked to other institutional factors including the freedom to define and pursue individual scientific interests which together make up an environment conducive to creative research. Another general and closely related conclusion from the same line of work is that a broad variety of funding mechanisms is better suited to enable original research than reliance on only one funding mechanism. Again the argument appears to be that funding diversity increases the flexibility at the research performing level. Diversification with regard to funding includes (at least) two key aspects: a multi-instrument approach in the public financing of research and a diversification of financial sources (European Commission 2009)

2.3. Excellence schemes

In accordance with the hypotheses formulated by DFiR one specific type of funding mechanism is given particular attention in this review: schemes specifically targeting research excellence.

Both national and European science systems have witnessed a rapid development and implementation of excellence policies during the last two decades. The result has been a multitude of funding instruments offering selective support for high-performing individuals, research groups or research organizations (OECD 2014, Bennetot and Estermann 2014, Sørensen, Bloch, and Young 2015; European commission 2009; Malkamaki et al. 2001). The common thread in these policies is the assumption that stimulating a small number of excellent performers will have positive effects on the vitality, attractiveness, and productivity of the whole science system

The term research excellence is however poorly defined and delineated in both practice and in the scholarly literature. The so-called excellence schemes across countries thus cover a large and diverse set of initiatives. Some instruments support individual researchers (e.g. European Research Council grant schemes, the Dutch Veni-Vidi-Vici program), others support research units such as departments (e.g. the Research Excellence Framework in UK) or entire universities (e.g. the Excellenz Initiative in Germany). Most excellence schemes do however support different types of 'centre of excellence' (CoE) constructions (e.g. schemes in Denmark, Norway, Sweden etc.). In addition to the differences with regard to the target groups of the schemes, there are further important differences both within and across the observed groups of initiatives with regard to factors such as size, duration, organization and orientation.

As this study has its main focus at Centres of Excellence (CoE) constructions in the three countries the following will mainly address this type of excellence scheme. The major objectives of CoE schemes are to promote high scientific quality, ground-breaking research and international competitiveness through long-term funding for the best research environments (Langfeldt et al 2015). But although CoEs are relatively new instruments in most countries, centres as a means to organize research are by no means a new feature in public research systems. These types of centres may emerge through a variety of channels: they can be the result of dedicated funding schemes; they can emerge gradually in their own right; or they can be created separately with contributions from actors such as public agencies, industry and universities (Borlaug 2015; Rip 2011). This study is mainly concerned with the first group. Typically this type of dedicated funding scheme has elements of both institutional core funding and project funding. On the one hand it provides general long-term funds which may be used for research and research infrastructures, as well as the recruitment of researchers and researcher training. As such this type of scheme shares some of the traits of institutional core funding. On the other hand, the funding is still time-limited and the selection is based on application and open competition, much like ordinary project funding (OECD 2014, Borlaug 2015).

But even this CoE-delineation covers many types of schemes. CoEs may vary in size (from small concentrated units to centres with large budgets), and they may display differences in organizational structures (Berman 2012; Aksnes et al. 2012). As such CoEs may cross diverse organizational boundaries such as departments, faculties, universities or even sectors. In terms of organizational structure, the CoEs are often formalized with a board of directors and an advisory board, a dedicated

centre leader, primary investigators and a small administration (Boardman and Gray 2010, Langfeldt et al. 2013). Finally, there are also differences in the orientation of the schemes: there are initiatives solely selected based on scientific excellence criteria, but also a large number of schemes aiming to combine scientific excellence and societal impact.

While CoE schemes often are highlighted as highly effective instruments, there may also be potential negative effects associated with this type of funding mechanism. It is particularly argued that: CoEs may have profound structural effects on the general systemic conditions for performing research and may skew the distribution of resources to an undesirable extent by rewarding already existing strongholds rather than fostering new ones. By amplifying the Matthew effect such excellence policies thus risk increasing the inequality in the system. Along the same lines it is also argued that CoEs may impede bottom-up renewal and hamper the establishment of younger scholars as they tend to reward recognizable success rather than early-stage researchers, novel ideas and young research areas. Likewise, it is argued that CoEs may have unintended effects for education, social relevance, public service, technology transfer and entrepreneurship as they risk driving a wedge between research on the one side and education and societal outreach on the other. Finally, it is also argued that CoEs may not fit all research areas equally well as the quality criteria used in the competition for funding and the size of the schemes often are based on collaboration and publication practices of the natural and medical sciences. It may accordingly be difficult for researchers within social sciences and humanities to attract this type of funding.

Whether and to what extent these potential negative effects may materialize will in most cases depend on a number of contextual factors. In particular differences across scientific fields and national science systems are likely to play important roles. Effects of excellence policies may vary strongly across scientific fields due to differences in social organization, communication and publication practices, and epistemic cultures (Hammarfelt and de Rijcke 2014, Hicks et al. 2015) and excellence policies may also have different functions in different science systems, even when the policy instruments have broadly similar designs. Crucial variables seem to be the existing distribution of resources in the system, the task division between universities and academic research institutes and typical career patterns (CWTS 2015). Empirical evidence is however limited when it comes to these effects in practice. One exception is a study examining CoEs in four Nordic countries. The data in this study indicate a modified Matthew effect with ceilings which limit excessive accumulation of resources. Important positive impacts of the CoEs are found, in particular in terms of enabling more interdisciplinary collaboration and risk-taking and enhancing international recruitment to the research areas involved. But, in contrast to what might be expected, the CoE grants seem to add less to the relative citation rate of those already performing at the highest level, than for those performing at a somewhat lower level prior to receiving the CoE grant (Langfeldt 2015). Similar results with regard to the relative citation rates are found in two Swedish studies (Sandström et al 2010; Vetenskapsrådet 2015).

2.4. PhD education

With regard to PhD education it is generally acknowledged that the socialization of students to research is an essential part of the reproduction of faculty and of the renewal of any scientific community (Gemme and Gingras 2008). The PhD education introduces research students to the norms and values which define the researcher community - and through the PhD education a

reservoir of qualified and competent researchers is established from where the research institutions can recruit future researchers (Mejlgaard et al 2012). PhD education therefore lies at the core of any nations' research capacity and is also seen as the primary source of research productivity and innovation. It is thus a question of vital importance to universities and nations how PhD-education is shaped (Nerad and Heggelund 2011; Hollingsworth 2008).

In spite of these notions PhD education was hardly articulated as an area of research policy until the early 1990s. But since then it has become an increasingly defined and highly discussed area of policy. The issue has thus become a site of ambitious reforms both at national levels and in the European Union (Thune et al 2012). In general it is argued that the most important changes in the development of PhD education over the last few decades have taken place in two steps. The first step was taken from a situation where individual professors held the direct influence and control over recruitment and training and where internal disciplinary values and standards held an almost hegemonic position, towards establishing the modern PhD in the late 1980s and 1990s. There were however some earlier attempts such as Sweden's attempt to start a modern, 3-4 year PhD in the 1960s and 1970s (SOU 1966:67 Forskarutbildning och forskarkarriär). According to Thune et al (2012) typical issues and challenges addressed in this first step were: how to retain broad academic/faculty competencies despite specialisation; how to increase enrolment; and how to bring completion times down. This step has now been completed by most countries resulting in a steep growth of enrolment and degrees. Similarly it has also been observed that there has been a significant reduction of completion times in many countries. The second step has taken place after 2000 in most western countries. Thune et al describes this step as "adapting PhD education to the knowledge society" and this step is seen as a process that is on-going and in some countries barely has started. As a result of these two steps the typical pattern in European countries has seen the annual number of new doctoral degrees double or treble since the 1980s.

Although PhD education is seen as vital to any science system and despite the fact that the development in the formal frameworks has been described to some degree across a number of countries, we have no real evidence of how PhD education affects research performance at a systemic level. Our knowledge of these relationships is accordingly very scarce.

2.5. University governance

Just like the question of funding mechanisms the governance issue is both complex and multidimensional. We need not only to distinguish between external and internal governance, but also to distinguish between the central leadership of the institutions and the local research management. Although the latter, understood as organising, managing and leading researchers at the research group level (Verbree et al 2012) is highlighted as a very important factor for research performance it is beyond the scope of this study and therefore it is not included in this review.

During the last few decades there have been shifts from traditional state-centered governing arrangements to alternative modes of governance in almost all western countries and within almost all sectors of the public sphere based on a number of popular New Public Management rationales. New Public Management is essentially a theory of generic management across all areas and sectors and it is implicit in the approach that all types of management are facing the same types of problems – and accordingly that the same types of solutions can be applied across different fields (Christensen

& Lægreid 2002). It is common for the reforms that they seek to challenge traditional steering and management methods in general and bureaucratic and hierarchical systems in particular. The approach has accordingly its main focus on efficiency, markets, contracts and institutional autonomy and has been described as a shopping basket of methods for reformists of public policy. Its main rationale is to raise the efficiency of public sector activities - above all in terms of performance and client satisfaction. The intellectual influences come from both public choice theory and management science.

Through this general reform movement the research and university sector increasingly has become subject to the same control mechanisms as most other sectors. In this respect the emerging reform policy path has represented a challenge to the traditional view of the universities as unique institutions, which should be managed according to traditional academic norms and values. In general the new demands have included strengthening of management structures and widespread introduction of market mechanisms. The main objectives have been to 'steer at a distance' and to hold institutions 'accountable'. With regard to the external governance of the universities, a framework for analysing autonomy developed by de Boer et al (2010) is useful to highlight the different dimensions of this concept. According to de Boer et al autonomy refers to the extent of which state regulation determines components of university governance. The approach includes six main indicators, namely (1) strategy, (2) quality assurance, (3) cooperation, (4) accountability, (5) human resource management and (6) finances.

With regard to the internal governance most western European university systems were dominated by a classical 'primus inter pares' collegial, self-governance model up until the late 1960s. From here variations of democratic governance models with inclusion of junior staff, students and administrative staff took over, before a series of NPM inspired reforms started to be introduced in the late 1980s and 1990s. Recently found designs are thus those that strengthen executive leadership at the central and middle level of universities. While these reforms have changed the traditional university governance structures rather fundamentally across countries, the timing and content of the changes have differed substantially. There are however some cross cutting observations: A comparative OECD study (Connell 2006) has found several common trends in the academic research management in different countries. Universities nowadays specify their research priorities and develop strategic plans; they regularly evaluate their research performance and develop principles for ethical conduct. Furthermore, research management has become 'professionalized', i.e. universities appoint high-level academic and administrative staff whose sole responsibility lies in overseeing research activities. Also Beerkens (2013) highlight a number of central management practices including: internal performance monitoring and performance funding, benchmarking and concentration of resources. Also the creation of individual incentives and upgrading of competencies are mentioned as central recent management practices.

While knowledge about general trends in research management practices is accumulating as outlined above, evidence about the effect of these practices on research performance is still scarce (Enders, De Boer and Weyer 2013; Beerkens 2013). There are however some interesting findings. Among others Aghion et al (2010) argue that the combination of widespread autonomy and a competitive environment creates good performance, but as already mentioned they acknowledge that several high performing models can be identified. At the level of internal university governance a correlation between the recruitment of esteemed academics as presidents or vice-chancellors, on

the one hand, and aggregated performance (as measured in ratings in UK Research Assessment Exercises) has been shown (Goodall 2006; 2009). The argument is that esteemed academics have credibility and legitimacy, and that they have an understanding which informs strategic decisions. This may raise the quality bar and sends a signal internally and externally that the institution values academic excellence. Also Schubert (2009) has studied the internal governance and demonstrates a positive effect of strong central leadership, operational flexibility, goal agreements, and an internal evaluation system in German universities. Finally, evidence is also provided by Hollingsworth and Gear (2012): Based on in-depth analysis of a large number of cases they highlight a number of characteristics of organizational contexts facilitating the making of major discoveries. With regard to organizational leadership they underline the following five factors as important: (a) capacity to understand the direction in which scientific research is moving, (b) strategic vision for integrating diverse areas and providing focused research, (c) ability to secure funding for these activities, (d) capacity to recruit individuals who can confront important scientific problems, and (e) capacity to provide rigorous criticism in a nurturing environment. Also Öquist and Benner (2012) highlight central management as an important factor for academic performance.

A number of potential negative consequences of strengthened central management are however also highlighted in a number of contributions. Among others Hollingsworth (2008) and Whitley (2012) emphasize that strengthened centralization may lead to hierarchies, standardization and bureaucratization which may limit 'protected spaces' and room to maneuver at lower levels. Whitley (2012) conceptualizes flexibility as: "[t]he openness of the scientific community, employers, funding agencies and other authoritative groups and organisations to novel and unusual ways of framing problems, developing new, especially cross disciplinary, ways of dealing with them and interpreting evidence" (Whitley 2012: 6). This is directly related to the university setting and may support the conception of universities as open systems where academic activities are carried out through multiple connections and dimensions within, across, and outside the academic organization. It is here argued that a high level of flexibility is directly proportional to a low level of centralization, formalization and standardization.

2.6. Internationalization

Concerning the fifth hypothesis related to "internationalization" two main streams of literature are examined: international research "collaboration" measured through co-authorships, and international mobility of researchers. The focus of both streams is their potential influence on citation impact; but most attention is given to the first: International collaboration measured through co-authorships.

The basic phenomena studied in the largest research fields (i.e. natural-, life- and medical sciences) transcends national borders.Since medieval times, scholarly communication has been international using common languages such as Latin and later English, and especially since the scientific revolutions in the 16th and 17th centuries, scientists have also been highly mobile. Marked changes in transportation and transportation costs in the last century has resulted in increased mobility. Here mobility encompasses researchers moving abroad to work for longer periods of time, sometimes for the rest of their career, to shorter research stays, but also travelling activities in relation to conferences, workshops etc. Mobility and travelling are thus essential activities in a research career.
Until the beginning of the 20th century, scholarly communication was mainly an individual business. While research collaboration took place and researchers were moving around, the formal business

of disseminating research was mainly the task of individuals. Also this has changed rapidly during the 20th century culminating now in what Adams (2013) calls the fourth age of research, driven by international collaborations and multiple authorships. As most scholarly activities are no longer the business of individual researchers, formal and informal communication with peers has become extremely important in order to establish a basis for collaboration and related activities (Crane, 1972). Obviously mobility in all its varieties plays an important role, but so does the revolutionary changes in communication technology.

An essential outcome of mobility is the placement of researchers into well-established networks. The social stratification in science is skewed and so is the "capital" which is bestowed upon researchers in the science systems (Cole and Cole, 1973). Belonging to an international network within one's field of research, other things equal, gives you cumulative advantages in relation to collaborations, publications, citations, funding etc. While still disputed in the literature, most appear to support the claim the Matthew Effect sets in once you get access the networks of the highest strata and that this can lead to a self-reinforcing process (Merton, 1968). There are indications that some of the strong and enduring international scientific networks were established more than a century ago.

When examining internationalization in relation to research performance at the level of countries it is important to emphasize that internationalization, while generally perceived as beneficial for research performance, not necessarily is an essential condition for high performance in all fields. However, internationalisation generally leads to network memberships and potentially greater visibility which are some of the main drivers when it comes to citation impact, i.e. the main performance indicator used in this and related studies. Citations signify use of the scientific literature and the reasons for citing or not citing scientific literature are many and complex (Nicolaisen, 2007; Bornmann & Daniel, 2008). Both cognitive and social factors play important roles and the epistemic value of citations scores are at best noisy. Nevertheless, citation impact of aggregated units of analysis do correlate moderately with corresponding peer assessments, but such associations are not solid evidence for neither citations or peer assessments ability to measure research "quality". The latter concept is complicated, multi-dimensional, theory-dependent, and not uniform across fields of research (Andersen, 2013).

A large number of studies indicate that there are many factors influencing the number of citations. For a recent review, see Tahamtan, Afshar and Ahamdzadeh (2016). The review identifies three general categories with twenty-eight "factors" which are associated with citation scores; factors related to the paper, the journal and the author(s). Among the strongest predictors of citations are visibility factors such as publication outlet (i.e. journal status), number of authors and not least number of international co-authors. Indeed, these three factors are internally connected. Internationally co-authored papers obviously include several authors, very often more authors than nationally co-authored papers, and they tend to be published in journals with higher international visibility. All other things being equal, higher visibility raises the probability of receiving citations and it is well-known that internationally co-authored papers on average are cited more than national papers (see Tahamtan, Afshar and Ahamdzadeh, 2016 for details). Two important aspects in this respect are: 1) when it comes to citations it matters a great deal whom you collaborate with (Pasterkamp et al. 2007; Sin, 2011) and a country's incidence for international collaboration are

mainly determined by its size (i.e. research system, country population and annual number of papers are proxies for that), language-orientation and geographical and historical proximities to other countries and research traditions.

Research collaboration and researcher mobility have been acknowledged as complementary processes. In the former, researchers may collaborate across great physical distances, using the latest developments in telecommunications to work together; in the latter, researchers may relocate to work alongside new or existing colleagues. Owing to the dynamic and mobile nature of modern research, these two processes are difficult to disentangle. The scholarly literature on mobility of researchers is however scarce due to lack of reliable data to trace scientists along their careers (Geuna, 2015). And linking international mobility to citation impact is even more difficult. The literature on this topic is accordingly very sparse. For the present analyses we rely on two reports produced by Science Europe/Elsevier (Kamalski and Plume, 2013) and OECD (2013). None of them are scholarly works, yet they are among the very few international comparative studies that bring together mobility and impact data.

Most scholarly mobility studies focus on labour market and more general economic issues (e.g., Agrawal et al., 2011; Cooper, 2001; Crespi et al., 2007; Azoulay et al., 2012). Recently, Franzoni, C., et al. (2012) have utilized the GlobSci survey to map mobility patterns within a number of natural science fields for 16 countries, but without relating such patterns to impact. The most up-to-date survey on researcher mobility is provided in the edited book by Geuna (2015); in here Franzoni and colleagues continue their examinations based on the GlobSci data set. In general, evidence suggests that mobility correlates with increases in researchers' individual visibility, as well as improving their performance, patterns of collaboration, and career development (Azoulay et al., 2012, Geuna, 2015). A general claim is therefore that mobility is beneficial for both the research system and the individual researcher (Geuna, 2015). But we should emphasize some important caveats and deficiencies of these mainly economically oriented studies. First, performance in these studies is conceptualized as "productivity" and as such solely related to publication activity. Further, the micro-economic perspective of individual publication activity fails to address the challenges of multi-authorships and credit distribution among co-authors. Second, while several of the studies try to relate individual behavior to supposed "impact" (Geuna, 2015), a prevalent fallacy is committed in these studies as Impact Factors of journals where the researchers have published their articles are taken as a "quality" measure of the individual articles. This is not only a general ecological fallacy, it is also high problematic due the well-known conceptual and statistical problems with Journal Impact Factors (Seglen, 1992).

2.7. Collaboration

The sixth hypothesis deals with cross sectoral collaboration and in particular with public/private research collaboration. In the literature the most prevalent label of this type of collaboration is university-industry collaboration (UIC). Like the previous internationalisation hypothesis, the sixth hypothesis is also mainly examined by linking UIC to citation impact, where UIC is measured by co-authorships.

Collaboration in scientific research is generally regarded as a positive asset which must be encouraged (Katz and Martin, 1997). Great efforts are thus made, generally in the form of governmental or institutional policies, to reinforce all kinds of collaborations. Several initiatives also

aim at fostering collaboration between various organizations active in research — particularly universities and industries — in order to integrate potential users of research as early as possible in the research process. Along the same lines, both Gibbons et al (1994) and Leydesdorff and Etzkowitz (1996) suggest that the organization of scientific research is changing and that, in contemporary societies, knowledge is more and more produced in collaboration between universities and industries.

Co-authorships can, however, only be considered a proxy for formal research collaboration (Katz and Martin, 1997). But this assumption is clearly strongest when researchers from two or more non-commercial research institutions co-author papers together because they essentially have similar epistemic aims and similar academic incentives and reward structures. This is not necessarily the case for co-authorships between non-profit research intuitions on the one hand and profit (research) institutions on the other. Nevertheless, co-authorships between "universities" and "industry" (UIC) have been used in several studies under the assumption that these joint scientific publications to some extent capture relevant U-I interactions (e.g. Calvert and Patel 2003; Sun et al. 2007; Abramo et al. 2009; Klitkou et al. 2009; Tijssen et al. 2009, Tijssen 2012; Giunta et al. 2014). However, despite this frequent use of UICs as a proxy of U-I interaction or collaboration, it still remains unclear what these joint publications exactly represent, which type of interactions led to these UICs as well as the level of accuracy in which these assumed interactions are captured. Indeed, only a few studies have tried to shed some light on this issue (e.g. Lundberg et al. 2006; Wong and Singh 2013).

Several studies have been published on UIC. Most come to the conclusion that university–industry collaborations are advantageous to both partners; the most tangible benefit for industry is a faster access to the new discoveries of universities whereas, in return, university researchers have access to equipment, research funds and an external viewpoint on their own work (Lee, 1996). At the individual level, Lee and Bozeman (2005) showed that US researchers who collaborate, with all types of collaboration included, are generally more productive in terms of publications than researchers working alone. Although they represent a small percentage of collaborative activities, UIC have a positive effect on productivity. Other researchers, such as Katz and Hicks (1997), obtained similar results for the UK science system. Indeed, UK articles published in collaboration with other institutions (be it universities, industries or government laboratories) received, on average, more citations than articles produced without such collaborations. This was also observed in the particular case of UIC. In the only large scale country analysis we are aware of, similar to the ones presented in this report, Lebeau et al. (2008) show for the Canadian case that the average citation impact of UIC is "significantly" above that of both university-only and industry-only papers.

2.8. Conclusion

Overall the literature review has revealed a very mixed and complex picture. On the one hand it broadly supports the selection of factors included in DFiRs hypotheses: Funding mechanisms (including excellence schemes), PhD education, governance structures, internationalization and collaboration are highlighted in the literature as important factors with regard to academic performance. On the other hand, however, the literature is far from conclusive when it comes to characterizing these relationships. There are in other words no clear crosscutting conclusions on the mix of factors which together create the conditions for high performance in national research systems; except that we are dealing with highly complex questions and multiple possible answers (Geuna and Martin 2003; Liefner 2003; Auranen and Nieminen 2010). For all the examined factors

positive aspects are highlighted, but it is at the same underlined that there also may be substantial negative side-effects. Similarly, most of the potential explaining factors are most likely only conducive to performance within a certain range and under certain contextual circumstances, meaning that both too much and too little of a certain factor may have negative effects. Most relationships are in other words most likely non-linear. In addition, multiple balance points may lead to well-functioning systems.

Furthermore, as Aagaard and Schneider (2015) argue, the factors influencing academic performance are highly interconnected in multi-level systems with complex paths from changes in input-factors at a macro-level to the changes in individual and group level behavior which eventually constitutes the basis of the developments in national publication productivity and performance. In addition, the question of lags between changes and their effects is far from straightforward. Different policy changes may have different lags and these changes most likely often have both immediate and long term effects. Finally, most of the high impact publications are the result of international collaborations. As have been argued elsewhere, internalization may soften the consequences of changes in the frame-conditions of one country due to cross country spill overs (Crespi and Geuna 2008; Leydesdorff and Wagner 2009; Adams 2013). Small countries benefit the most from this internationalization, but are also most vulnerable to changes within other collaborating countries. In addition, it is increasingly discussed whether nations are a meaningful units of analysis due to increasing international collaboration (Adams 2013). All these methodological factors challenge the attempts to uncover clear causal relationships between policy factors and performance at an aggregated level.

However, across all the factors a group of key concepts still stand out as important preconditions for continuous high academic performance: these factors include stability, flexibility, long term horizons and diversity. Together they create what is labelled as “Protected space” (Whitley) or “Room to maneuver” (Mintzberg 1983, 96-97). In addition, it is also important to notice, that consistent high national research performance only is found in advanced, fairly rich countries with well developed education and research systems. This is however only a necessary condition for attaining high performance, but by no means a sufficient condition.

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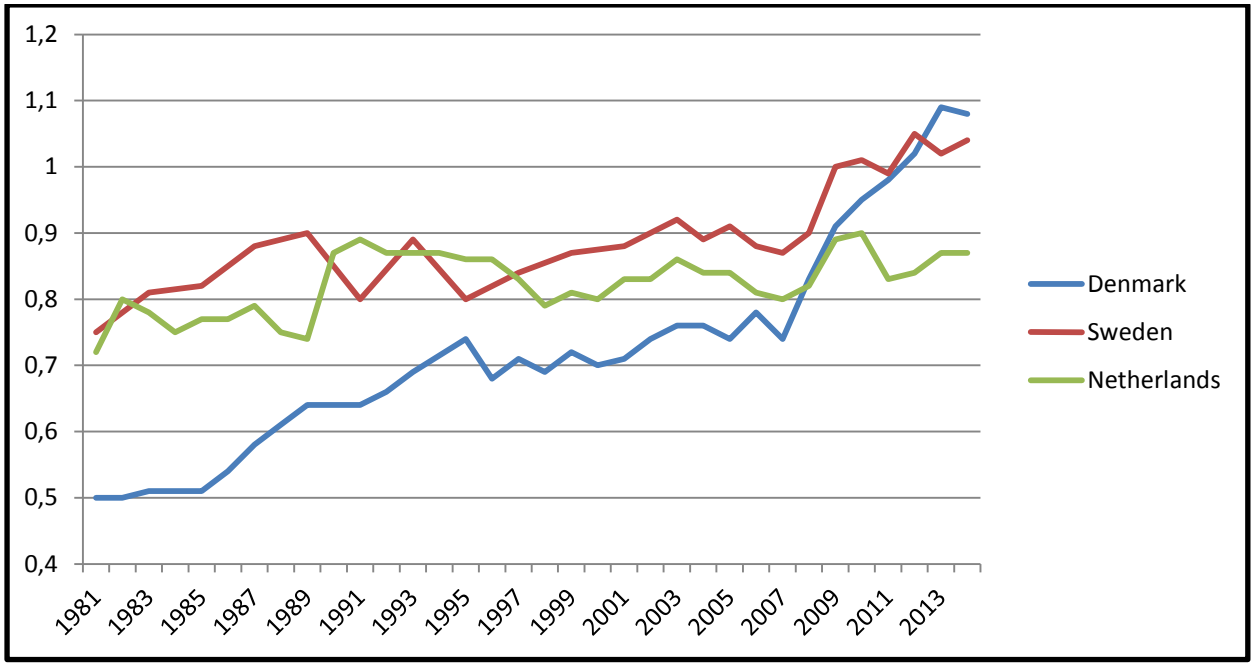
3. Country descriptions and policy timelines

This chapter presents three brief country descriptions outlining major research policy changes for the period 1980 to 2015. The country descriptions provide the overall policy context for the study and serve as starting points for the more detailed analyses at hypothesis level conducted in chapter 4-9 as well as for the integrative analysis presented in the main report of the study.

3.1. Introduction

The present study deals with three very similar countries. All three are relatively small, fairly wealthy and very open western countries with highly developed welfare systems including strong education and health care systems. All three countries have also been characterized by longstanding and very strong research traditions with internationally highly renowned research environments established long before research policy became a theme on the broader political agenda. Furthermore, they are all both EU and OECD members and have accordingly been subjects to the same international forces shaping the governance of the national research systems. Also with regard to basic structures of the public research systems there are clear similarities between the three countries. The university systems in all three countries share a Humboldtian legacy and a strong emphasis on the research-teaching nexus. Similarly, all the countries have research funding systems which have developed from traditional dual funding systems with a relatively high share of institutional funding towards more mixed funding configurations. In terms of funding volume all three countries today spend close to the Barcelona goal of investing 1 percent of GDP in public research. In 2013 Denmark held the highest share, but it is noticeable that Denmark started out from a significantly lower level than Sweden and the Netherlands during the 1980s as Figure 3.1 shows.

Figure 3.1: HERD + GOVERD for Denmark, Sweden and the Netherlands as share of GDP, 1981-2013

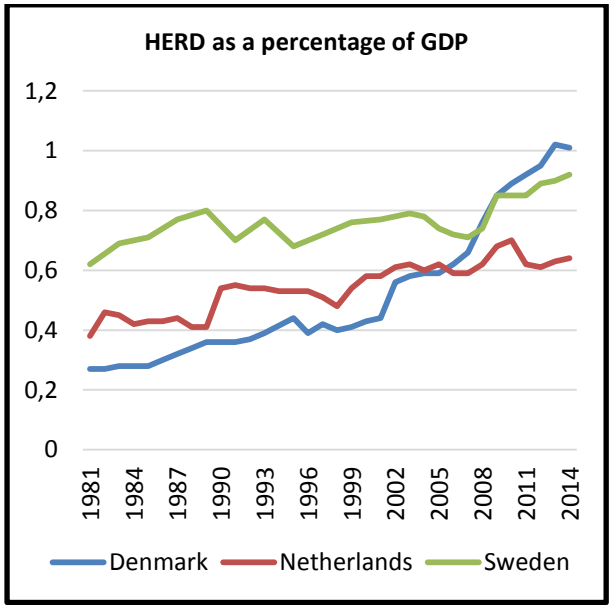


Source: OECD MSTI

Another interesting difference between the three countries can be observed when we look at the division between Higher Education Expenditure on R&D (HERD) and expenditures to R&D performed in the Government sector (GOVERD). As Figure 3.2 and 3.3 show: up until around 2000 both

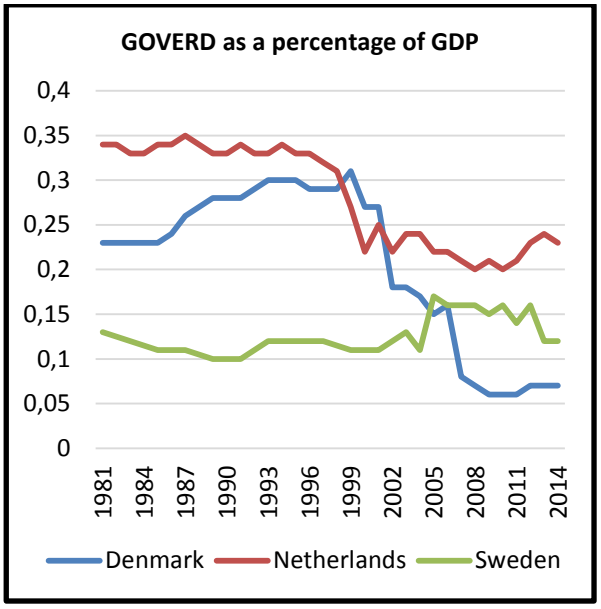
Denmark and the Netherlands had substantial government research sectors, while Sweden throughout the period has had a public research sector almost fully dominated by HE institutions. However since 2000 the three countries have become more similar in this respect.

Fig. 3.2: HERD as share of GDP



Source: OECD MSTI

Fig. 3.3: GOVERD as share of GDP

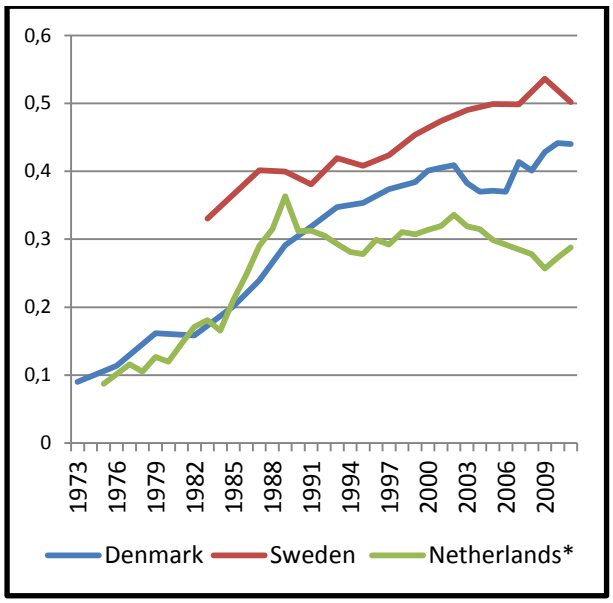


Source: OECD MSTI

Also in contrast to Denmark and the Netherlands, Sweden has had a unified HE sector throughout most of the period under examination, where the two other countries have had binary systems with a clear division between research universities on the side and other non-research HE institutions on the other. The result has been a concentration of research resources in a smaller number of HE institutions in Denmark and the Netherlands.

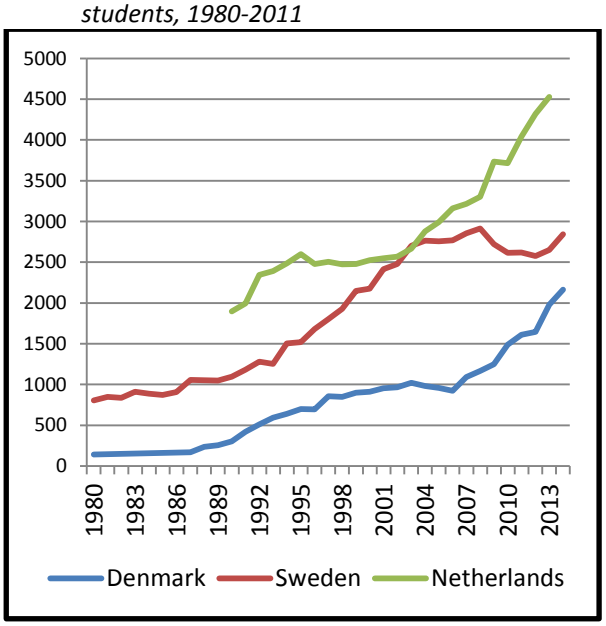
Finally Figure 3.4 and 3.5 also show the developments in the three countries with regard to their share of project funding and their PhD graduation volume. It is noticeable that the Swedish system has a larger share of project funding than Denmark and the Netherlands throughout the period, and also that the two latter countries have very similar developments up until 1990. Since then the Dutch system has operated with a lower share of project funding than the two other countries. However, a less developed overhead system in the Netherlands means that the differences between the countries may appear larger than they are in reality. With regard to the PhD graduation volume shown in Figure 3.5, it is in particular noticeable that the Danish system was characterized by a very low degree of PhD education throughout the 1980s.

Figure 3.4: Share of project funding, 1973-2009



Source: National statistics

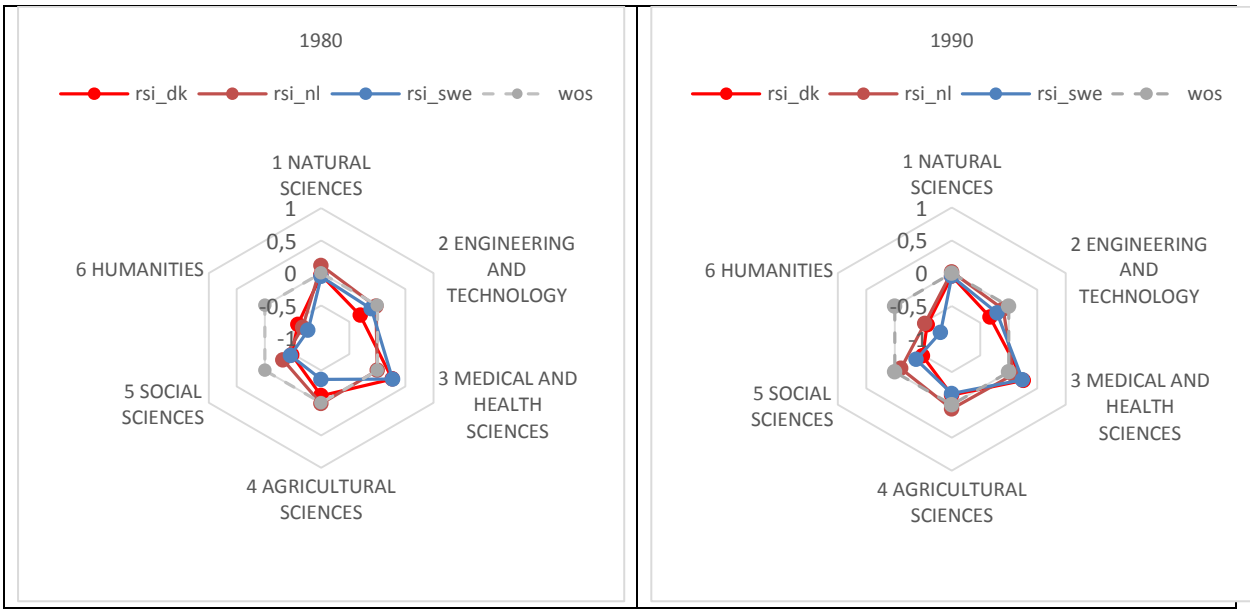
Figure 3.5: Number of Graduated PhD students, 1980-2011

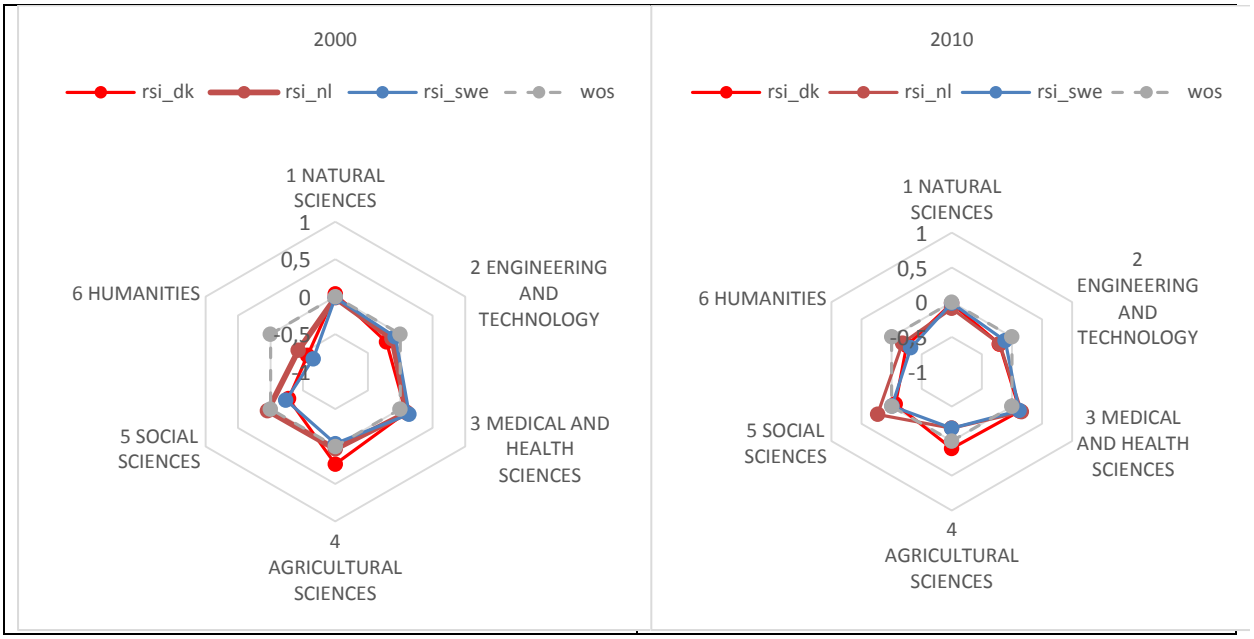


Source: National statistics

Another factor of importance with regard explaning differenes in research performance could be related to differences in national reseach specializations. However, the three countries also share clear similarities when we look at their degree of specialization within different scientific fields in four selected years (1980, 1990, 2000 and 2010). As Figure 3.6 –3.9 below shows we find small differences among the countries, but these differences are of marginal importance with regard to explaining differences in the development in performance across the three countries.

Figure 3.6-3.9: Research specialization in Denmark, the Netherlands and Sweden for the years: 1980, 1990, 2000 and 2001.

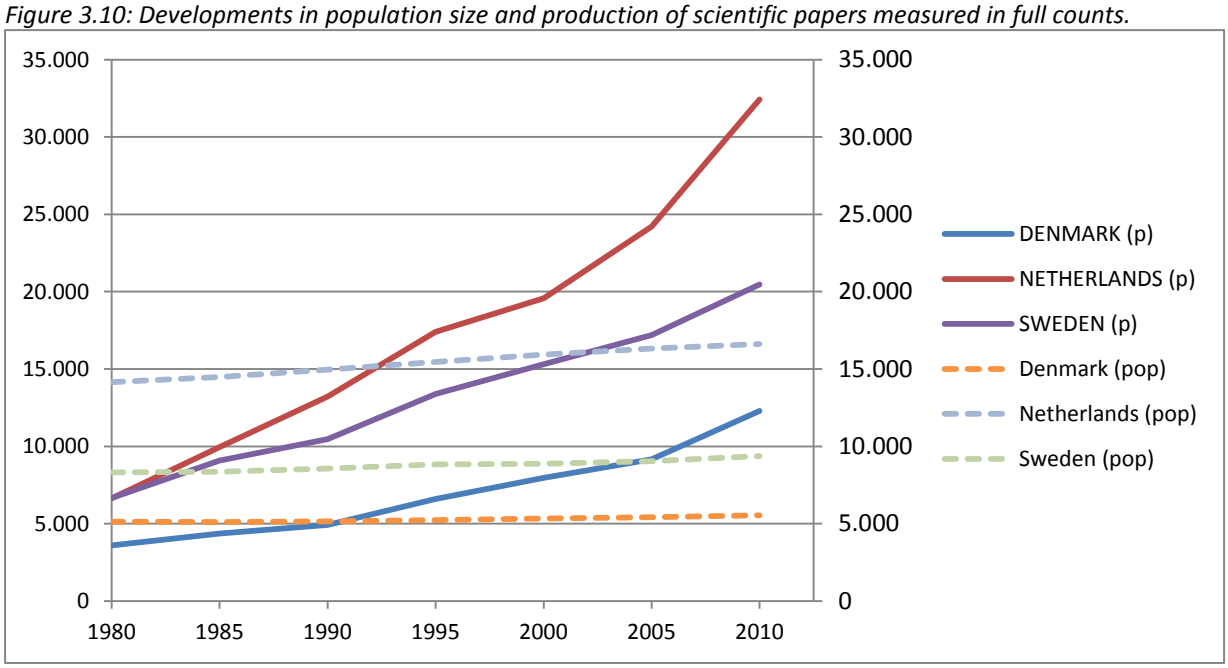




Source: CWTS Leiden

Finally, we highlight a few comparative time series concerning publication volume and academic performance which also were included in the bibliometric mapping carried out prior to this study (Schneider and Aagaard 2015): As shown in this report as well as in the introduction to this study the three selected countries, Denmark, Sweden and the Netherlands, can be labelled as high performing research nations in terms of mean normalized citation scores at an aggregated level, but they are also high performing with regard to publication volume relative to population size. Although the three countries can be labelled as similar in a global perspective, there are still significant differences in size and aggregated publication volume as Figure 3.10 below shows. In terms of population The Netherlands as the largest country is close to three times bigger than Denmark.

Figure 3.10: Developments in population size and production of scientific papers measured in full counts.



Source: Schneider and Aagaard 2015; The World Bank for population sizes.

As can be seen in Table 3.1 below the three countries also differ somewhat in terms of developments in publications per 1000 inhabitants. While all three countries have experienced a dramatic increase in numbers of publications relative to population throughout the period they have done it from different starting points and at different speeds. Denmark and Sweden have the highest ratios between population size and publication volume throughout the period, but with Denmark showing the strongest increase of the two. The Netherlands has the strongest increase of all but still ends up a bit below Denmark and Sweden due to a lower starting point. However, combining these figures with the results shown in figure 3.11 below we see that there is no straightforward relationship between the developments in research intensity relative to population size and the developments in research performance among this group of countries.

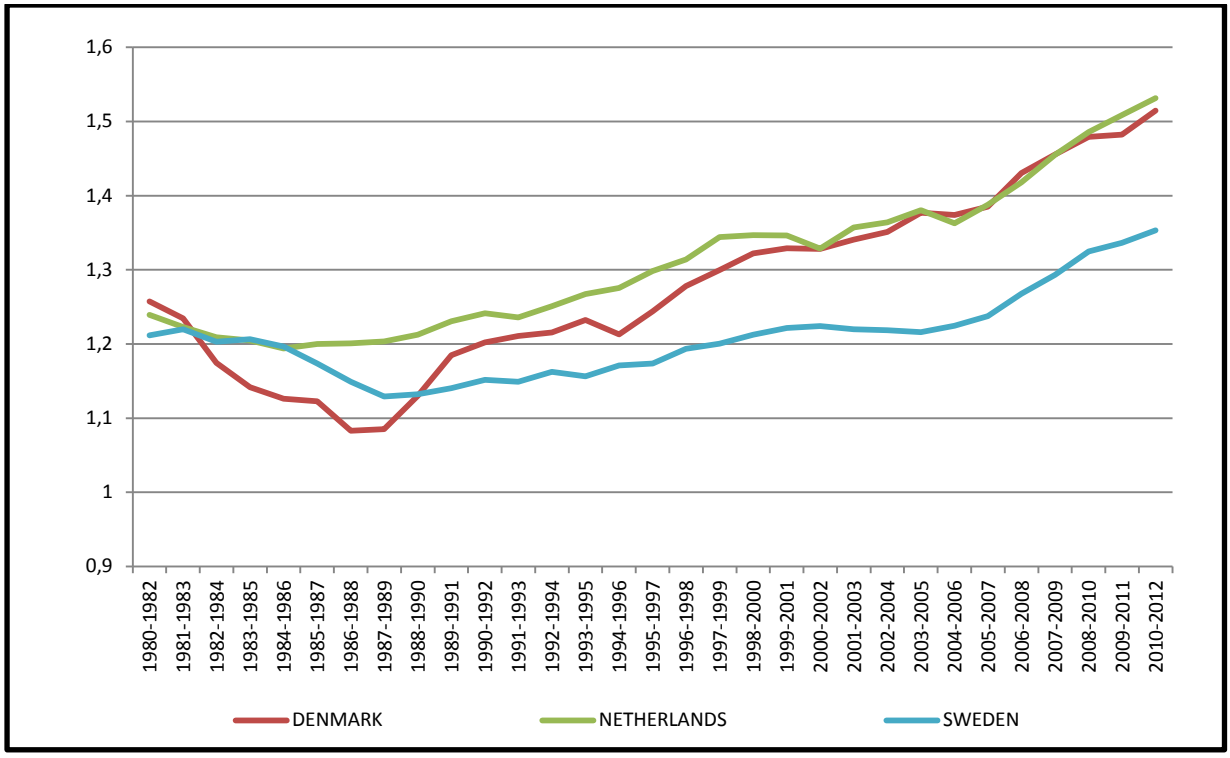
Table 3.1: Development in population size and the number of full and fractionalized publications; population size is in thousands and the calculated ratio is based on population numbers and full counts of publications. Notice, full counts can be seen as a country's participation and fractional counts is an expression of collaboration.

		1980	1985	1990	1995	2000	2005	2010
Denmark	Population	5120	5110	5140	5230	5340	5420	5550
	Publications $_{full}$	3603.25	4355.5	4914.75	6591	7962.75	9165.25	12289.25
	Publications $_{fractional}$	3229.4	3783.6	4087.3	5065.8	5713.0	6284.7	7863.9
	Ratio	**0.70**	**0.85**	**0.96**	**1.26**	**1.49**	**1.69**	**2.21**
Netherlands	Population	14150	14490	14950	15460	15930	16320	16620
	Publications $_{full}$	6646	9953.25	13213.75	17405.75	19575.25	24216.5	32416.75
	Publications $_{fractional}$	6110.4	8911.5	11439.2	14111.6	14713.2	17436.1	21631.2
	Ratio	**0.47**	**0.69**	**0.88**	**1.13**	**1.23**	**1.48**	**1.95**
Sweden	Population	8310	8350	8560	8830	8870	9030	9380
	Publications $_{full}$	6667.5	9082.5	10469.5	13379.75	15302.75	17187	20453.75
	Publications $_{fractional}$	6110.5	8040.0	8926.1	10677.3	11478.2	12259.2	13240.4
	Ratio	**0.80**	**1.09**	**1.22**	**1.52**	**1.73**	**1.90**	**2.18**

Source: Schneider and Aagaard 2015

There are, however, interesting differences in the trajectories of the three countries when we turn to the development in research performance measured by the MNCS indicator as can be seen from Figure 3.11 below. All three countries performed at a high international level in the early 1980s where the time-series start, but from there on the developments differ: The Netherlands has remained at a high and relatively stable level throughout the period. Denmark experienced a significant decline during the 1980s but showed a strong catch up during the 1990s bringing the performance back on par with the Netherlands for the remaining part of the period. Also Sweden experienced a drop during the 1980s, but unlike Denmark, Sweden has subsequently been unable to fully reverse this trend.

Figure 3.11: Developments in MNCS for Denmark and the two benchmark countries. Based on full counts and calculated for three year overlapping blocks.



Source: Schneider and Aagaard 2015

As outlined in chapter 1, the main question in this study is whether we can detect any relationships between policy changes (or non-changes) and developments in academic performance across the three countries. The first step in this analysis is taken in the following sections where three individual country descriptions are outlined in order to map the most important national research policy changes during the period under examination.

3.2. Denmark

The 1960s and 1970s: The Republic of Science model under pressure:

It is generally acknowledged that the institutionalization of a distinct Danish research policy was quite late compared to other western countries (Aagaard 2000; 2011). R&D investments were modest and there was almost no formal organization at a central level. Most policy decisions affecting Danish research were thus mere side-effects of decisions taken in policy areas such as education, industry and culture. For these reasons the Danish research system was increasingly criticized throughout the 1960s and 1970s for the lack of an explicit and coherent research policy and it was argued that major changes in both funding and management were needed (Aagaard 2000; Aagaard and Schneider 2015). Similarly, it was argued that national research policy objectives were missing. It was thus much of a surprise to most actors when the first bibliometric evaluations of the Danish national research performance - carried out almost a decade later - showed that the public research system had been performing quite well by the end of this period (as shown in Figure 3.11 and also documented in Nørretranders and Haaland (1990)) .

Up until the late 1970s the funding of public research at the Danish universities was almost fully dominated by floor funding with very few strings attached. These grants were in general allocated

based on input factors with student numbers as the main criteria. The research council system which was gradually institutionalized in this period was in general very academically oriented and closely linked to the universities. It was, however, of marginal economic importance. Also the funding of the Government Research Institute (GRI) sector was dominated by floor funding, but the research activities within the institutes were closely linked to the sector ministries (Aagaard 2011). The public research system as a whole was accordingly characterized by a fairly sharp functional division of labor between the almost purely academic oriented universities on the one side and the more mission oriented GRI sector on the other (Christiansen and Sidenius 1988). The two sectors constituted approximately 50 percent each and grew at largely the same pace. Concentration of research resources at the institutional level was not an issue; rather the opposite: the period as a whole was characterised by a steady growth in number of institutions with regard to both universities and GRIs. It was in particular argued that the non-university sector suffered from fragmentation (Aagaard 2011).

The internal governance of the universities changed significantly within this period as a new act in 1970/1973 changed the management structure from a classical meritocratic model to a highly democratic model with strong student and administrative representation (Aagaard and Mejlgaard 2012). Critics argued that an unintended consequence of the new act was a shift from quality to equality in the internal allocation of research funding (Olesen Larsen 1981, Aagaard 2011).

The period as a whole was accordingly characterized by universities with a very strong academic orientation and a high level of autonomy at all levels with regard to substantive matters. But in spite of the limited outside interference and a relative stability in frame conditions, the traditional model was increasingly challenged. The modest and stagnating volume of research funding was gradually undermined by increasing student numbers. At the same time the system suffered from lack of competition, increasing fragmentation of the institutional landscape, weak leadership at all levels, and an ageing workforce coupled with limited renewal and an unformalized recruitment and training system.

The 1980s: Difficult transition to a new policy regime:

Although it was later documented that Danish research by the early 1980s was performing well by scientometric standards, the general impression throughout the decade was that the public Danish research system was in a state of crisis and that major reforms were needed. The public research effort was increasingly perceived as lacking integration and cooperation with the outside world in general and the private sector in particular (Grønbæk 2001). In addition, the university research was seen to suffer from a lack of competition, environments of sub-critical mass and lack of mobility. This was perceived as a serious dysfunction of the system considering the emerging policy belief that renewed industrial growth should be based on key technologies such as information technology, biotechnology and materials science (Aagaard 2000; Grønbæk 2001). As a result of these beliefs among stakeholders and politicians, a painful transition to a new policy regime was started.

The first step towards a new policy regime was taken with the funding system as an instrument. The direct link between student numbers and institutional funding was abandoned in 1982. An activity-based funding system was introduced for education, but no alternative could be agreed upon with regard to the allocation of the research funding (Aagaard 2011). Instead a strong growth in

earmarked program funding of university research took off during the following years. A major part of the program funding was placed in special comities outside of the existing academically oriented research council structure which was distrusted by the political system. As shown in the introduction to this chapter, the share of external funding for the system as a whole thus increased from 11 percent in 1976 to 35 percent in 1993. No overhead system yet was established in this period meaning that the shift towards more external funding was binding large shares of the institutional funding as well. However, this growth of earmarked funding also led to a substantial increase in the total funding of university research. The total research funding for the universities thus grew from 3.5 billion DKK in 1985 to 6.5 billion DKK in 1995 in fixed 2011 prices.

Even though major changes were implemented with regard to the research funding, other reforms proved difficult to carry through. The research system as a whole was still perceived as too fragmented and it was in particular seen as a problem that almost half of the public research took place in the GRI-sector which according to critics were dominated by too small units, unclear quality criteria and non-standardized frame conditions (Aagaard 2011). Also inside the universities the highly democratic leadership model was continued in spite of heavy criticism from stakeholders. It was argued that the democratic system was a barrier to priority-setting and that the universities suffered from a general leadership vacuum. The 1973 university act had abandoned the leadership function that was previously in the hands of the professoriate, but without replacing it with another legitimate authority it was argued (Olesen Larsen 1981: 190). Also the OECD was critical towards the system and argued in an evaluation of the Danish research policy system in 1987/88 that it was seen as: "essential to give the universities an organisational structure which provides them with more authority and leadership. This means that the existing, highly participative system for research decision-making must be modified to enable the university management to act and function more efficiently" (OECD 1988; Petersen 1997). Finally, the recruitment to the system through new PhD's was in general both limited and unformalized (Nørretranders and Haaland 1990). The research system as a whole was in other words suffering from an ageing workforce and limited renewal.

The 1980s were thus a period of transition, crisis and distrust. The university system as a whole including the research councils still had a strong academic orientation. Nevertheless, it became increasingly clear that the system had become imbalanced and fragmented and by the end of the decade a number of influential internal and external actors started to jointly work on solving some of the most pressing problems (Aagaard 2011).

The 1990s: Striking a balance between classical and modern research policy ideas.

By the late 1980s the academic performance of the Danish system had reached a low point. As a result of the general crisis and distrust there was a strong pressure for change on a number of important dimensions: The funding system, the internal university governance, the organization of the system and the volume and organization of doctoral education were in particular mentioned.

With regard to the funding system three important changes were implemented during the early 1990s. First of all, it was agreed that the balance between institutional funding and project funding should be maintained at the level that was reached at this point (Aagaard 2011). Hereby the relative growth in program funding stopped and this led to more than a decade of relative stability in the balance between these two funding streams. In addition, an overhead system was established in

1995, further reducing the pressure on the institutional funding. As a third important change the so-called Danish National Research Foundation (DNRF) was created with effect from 1993 to supply long-term of support new "centers of excellence" (CoEs) solely based at academic quality criteria. Together these three reforms were important elements in a general academic reorientation of the system after a decade dominated by strategic research funding.

However, attempts were also made to reform the traditional academic research council system which all through the period in question was considered to be too closely connected to the universities, reflecting the academic organisation based on disciplines. The councils were expected by the political system to play more of a mediating role between politics, society, industry and research, but served in the eyes of many stakeholders primarily to maintain the autonomy of science (Grønbæk 2001). A number of changes proposed by the Government in the 1990s thus aimed at loosening the disciplinary and institutional linkages of the councils and, correspondingly, strengthening the relations between disciplinary, sectoral and industrial research. In reality, only limited changes were carried through and the strong academic orientation of this part of the system as a whole was thus maintained (Aagaard 2003).

1993 was also the year where a new Danish university act was passed strengthening the authority of the vice-chancellors both externally and internally. A result was a shift of power from the representative organs to the elected leaders. A main goal of the new act was also to increase the influence of society on the universities by including external representatives in the boards (Petersen 1997). While many stakeholders and politicians felt that the act was too limited in scope, most actors within the universities saw it as a good compromise providing opportunities for strategic priority-setting and recruitment of highly qualified staff on the one side and maintaining internal legitimacy on the other. However, large parts of the previous criticisms continued after the passing of the new act. Also the discussion of concentration of resources and division of labour continued, but there was still no reduction in the number of research units. However, the universities started to receive a larger share of the total public research funds at the expense of the GRI sector. In addition, the establishment of the first ministry of research in 1993 meant that the conditions for the GRI research became more standardized across sectors and that higher demands on management and quality assurance were placed on the institutes. Academic quality and international publishing was accordingly emphasized to a larger extent within most GRIs (Aagaard 2000).

Finally, the early 1990s also saw a significant strengthening of the PhD education. This development was initiated in the late 1980s when the so-called "Forskerakademi" (The Researcher Academy) was established and further strengthened when a reform of the PhD-system as a whole was carried through in 1992. Not only did this lead to a considerable growth in volume as shown in the introduction to this chapter, it also led to a strengthening and formalization of the content and frame conditions of the doctoral training (Aagaard 2000, Aagaard & Mejlgaard 2012).

As a whole the 1990s thus saw a strong academic reorientation after the growth of strategic research in the previous decade. This reorientation, however, came with new instruments, new funding channels, higher PhD volume and stronger internal management at the universities. Following these changes in the early part of the decade, the following 10-15 years were characterized by relative stability in both funding balances and frame-conditions. In terms of

academic performance the policy changes coincided with a remarkable increase situating Denmark among the strongest research nations of the world.

The 2000s: Major reforms, but uncertain consequences for research performance

By the early 2000s this period of stability in the general research policy frame conditions was brought to an end. In late 2001 a new Danish government took office and started a sweeping reform-process including a far reaching management reform of the universities, a transition to a more competitive and more strategic oriented research funding system, a large scale merger process and the introduction of a new performance-based floor funding model to mention just a few of the major initiatives (Aagaard and Mejlgaard 2012). However, most of the reforms did not take real effect before the latter half of the decade.

In 2001 a new Ministry of Science, Technology and Innovation assumed the overall responsibility for both research- and innovation policy. The increasing ministerial emphasis on innovation policy proved to be crucial for the coming reforms which rather than aiming at strengthening the traditional "Republic of Science" elements of Danish research policy aimed at transforming the institutions into key players in the global knowledge economy (Aagaard and Mejlgaard 2012). As a consequence demands for accountability, strategic capacity, responsiveness and social responsibility increased at a rapid pace. At the same time it was (again) argued, that there was too little competition for research funding and that the funding was spread too thinly. As a consequence the government aimed for a turn towards a 50/50 balance between institutional funding and project funding. In addition, a performance based institutional funding model was introduced. Finally, the 2000's also saw the establishment of a number of strategic or innovation-oriented research funding channels, including a council for technology and innovation, a strategic research council and an advanced technology foundation. In headlines, these changes in the funding system was dominated by three tendencies: a shift from institutional funding towards project funding, a shift from basic research towards strategic research, and finally a shift from the funding of many small projects towards fewer and larger projects (Aagaard 2011). In particular from 2006 and onwards these changes were followed by a significant increase in total public R&D investments.

Alongside the changes in the funding system a new University Act from 2003 introduced boards with a majority of external members as the superior authority of universities and prescribed employed leaders instead of elected at all levels. The objective was to sharpen up the profiles of individual institutions, to professionalize and empower the managerial structures, and to increase collaboration between the actors of the research and innovation system – the latter exemplified by new claims for universities to formulate goals and strategies for cooperation with trade and business. The Act emphasised that the universities' new management should make strategic selections of research areas and give high priority to these areas (Aagaard and Mejlgaard 2012). The new boards were in place in late 2005 and most universities had the appointed leaders installed by 2006.

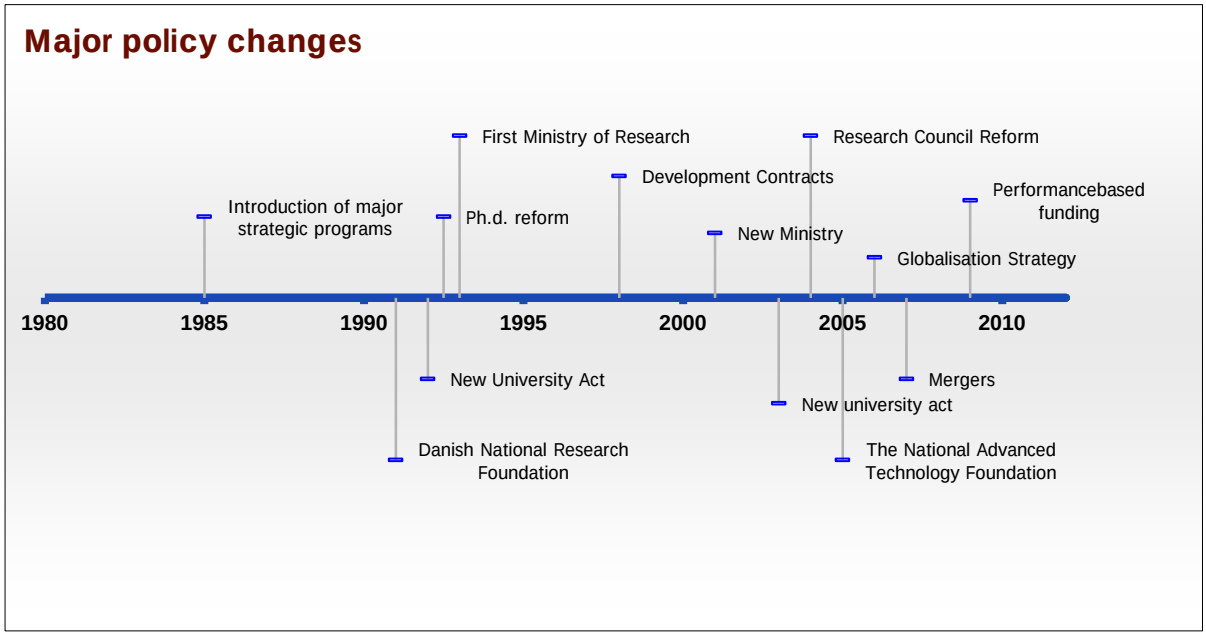
As it turned out, the new management system worked as a "window of opportunity" for the next major reform - presented in 2006 as well (Aagaard, Hansen and Rasmussen 2015). With this reform the Government implemented a far reaching merger process which reduced the number of universities from twelve to eight. In the process 12 out of 15 GRIs were transferred to one of the

eight remaining universities - in reality closing down the majority of the GRI sector. The result was a large concentration of resources within a few select institutions, and also a clear break with the former division of labour between academic research and the more applied GRI research (Aagaard 2011).

Finally, PhD education was once again highly prioritized with a 100 percent increase in uptake in the period 2004-2010. This increase was, however, highly selective as almost 90 percent of the increase took place within the natural, medical and technical sciences as these areas were perceived to contribute the most to innovation and growth.

The post 2003 period of Danish research policy has thus been dominated by an unprecedented reform pace transforming all major parts of the research system. In general, the reforms can be seen as an attempt to open up the universities to the outside world in general and to the needs of the corporate sector in particular (Aagaard and Mejlgaard 2012). How these developments will affect the long-term academic performance is, however, still an open question.

Figure3.12: Major policy changes – Denmark



3.3. Sweden

The 1960s and 1970s – the rise of the sectoral paradigm

In the 1960s, Sweden pioneered the customer-contractor model of research governance in Europe under the banner of "sectoral research" (Stevrin 1978). The state expanded research funding dramatically in areas with hitherto very limited research funding or activities: areas such as environment, housing, work environment, social affairs, etc. However, most of these mission-oriented activities took place in a university setting. Unlike many other countries, Sweden thus abstained from a full-blown institute sector (even though it did establish a number of institutes anyway), and primarily channeled the sectoral funding via the university system. Sweden also changed its university governance system in this period, with experimental reforms already in the late 1960s and a full-blown reorganization of university governance in 1977. The 1977 reform was

also accompanied by a massive reorganization of the entire university system: professional training and community colleges were integrated into the now comprehensive university system, enacting one of the very first non-binary academic systems in the world. Alongside this widening of both the public research system and the higher education system more generally, the traditional academic formats still existed in the form of the research councils and the faculty structure, which remained largely unaffected by the changes (Fridjonsdottir 1983).

The 1980s – consolidation and de-sectorization

The 1980s was primarily marked by a consolidation of Swedish research policy. The very strong expansion of funding via sectoral (mission-oriented) agencies during the 1960s and 1970s came to a halt and resources were partially redeployed to the research councils. Here two new research councils were set up on the basis of former mission-oriented agencies (for social policy research and for technical research), but major changes were also made in the constitution of funding in other areas, such as housing and agriculture (Premfors 1986).

In 1989, the funding of PhD training was reformed, with the introduction of fully funded PhD positions instead of the earlier systems of stipends. This reform culminated in 1997, when a new PhD model was introduced with a maximum of four years of funding and where alternative sources of funding were not allowed anymore. The PhD programme was therefore regulated and streamlined. Hence, the 1980s represented a modest retreat of research policy and of university governance into more "orderly forms".

The 1990s: A decade of intensive reform activities

The 1990s was a hectic period of reforms of the Swedish research funding and governance systems (for an overview, see Benner 2001). First came the aforementioned changes in the research council system, with the addition of two new councils. In 1991, a technical research council (outside that of the Technical Research Council, established in 1989) was merged with two other industrial policy agencies to form NUTEK (the National Swedish Board for Industrial and Technical Development).

A more wide-ranging change of the landscape for research funding was incepted in 1992 when the recently elected Bildt government set out to establish a string of research foundations, based on money from the so called wage earner funds (established in 1983, where corporate profits were reinvested in funds aimed to diversify ownership of Swedish companies). The main part of the resources were put into the Foundation for Strategic Research (60 per cent of 10 billion SEK), and the rest to one foundation for environmental research and a special donation to research on culture and society (administered by the Bank of Sweden Tercentenary Foundation). In 1994, a string of other foundations were established, some with research focus (such as the Knowledge Foundation, supporting Sweden's new universities, and the Vårdal Foundation, supporting research on care and allergies).

The allocation of resources for research to universities was however altered at the same time as the fine-grained allocation to individual faculties among Sweden's universities was replaced with a lump-sum allocation to universities. At the same time, universities were given the right to appoint professors on their own – a right which earlier had been shared by the universities and the government.

In 1995, the massive transformation of research policy (new organizations, resource increases, decentralization etc.) in the period 1991-1994 came to a halt, and was to some extent reversed, as a consequence of the deep economic crisis in Sweden. Institutional funding to universities and research council budgets were cut (with up to 10 per cent), while the social democratic government failed to dismantle the new research foundations (which it first attempted to do). In 1997, university colleges were given the right to establish professorships independently (this could be done earlier, but then only in collaboration with a university). The same year university colleges were given the right to be elevated to university status – including the right to confer PhD degrees without prior assessment and they started to receive higher levels of direct appropriations from the government. In 1998, three university colleges were elevated to university status. In addition, three new university colleges were established, two in urban settings (Malmö and southern Stockholm) and one in a rural setting (Gotland). Gender equality was also a policy objective of this period, addressed in two ways: by establishing six professorships in women's and gender studies, and by establishing 20 professorships based on the principle of affirmative action.

Another significant, if primarily rhetorical, reform came in 1998 when the university law was amended and the third task (collaboration) was elevated to equal importance of the other two tasks – education and research. In 1999, the model of appointing professorships (a chairs system, with only a limited number of fixed positions) was reformed, and each university lecturer (i.e. associate professor) was given right to apply for promotion.

By the end of the 1990s, many of the now dominant features of Swedish research governance were thus established: a shift from dominance of institutional funding to a growing reliance on external funding; a widening of the university landscape by the elevation of university colleges to research institutions with the right of applying for university status; and a streamlining of the PhD training system (30 years after the initial reforms were incepted). Many of these changes were not done in concordance with policy advice or policy anchoring via advisory bodies or similar, but were rather relatively quickly devised solutions to the evolving crisis of the Swedish economy and the concomitant waves of policy adjustment – first to propel Sweden out of the crisis (by means of an expansion of research and innovation policies via university deregulation), and later by shifting the university system and research policy more generally into a regionally responsive mode. Underlying this was a stop-go political philosophy: that reforms and changes could be introduced at will and with (expected) immediate results.

The 2000s and beyond – retreat and reforging

Foe Swedish research policy the 2000s were marked by continuity but also an element of reconciliation. The policy system of the 1990s had been highly turbulent and volatile: the emphasis was now on order and stability. The first element in this was the reform of the funding system in 2001, which was preceded by a remarkably protracted process of analysis and deliberation (in two phases). The outcome was that the formerly independent research councils in medicine, engineering, natural sciences and humanities-social sciences were merged into the Swedish Research Council (VR). Two other research councils were formed on the basis of a reshuffle of government agencies for environmental and planning research, and for social and labour market

issues, respectively. Similarly, innovation policy was reconfigured and a new agency for innovation system (Vinnova) was established alongside the reforged research councils.

The most significant policy issues in the 2000s was the issue of funding levels – the model that research should predominantly be supported via external funding had been galvanized with the organizational reform in 2001, and the issue that remained was how a hike in public investments (of which there was a broad political consensus) should be devised and crafted. The solution was to channel this primarily via the research council system, first via the support of specific prioritized areas (in 2001-2003), then in the form of a doubling of funding for medical research via VR and a similar rise for engineering and innovation (via Vinnova) in 2006-2008, in the inception of several programmes for excellent research centres (Linnaeus centres, Berzelius Centres, VinnExcellence centres, FAS centres) from 2004 until 2008.

The focus on externally channeled resource hikes was given a further push when the Reinfeldt government (conservative) took over in 2006. It launched a programme of so called Strategic Research Areas as the cornerstone of its 2008 research policy bill (admittedly, complemented by a hike in institutional funding). The Strategic Research Areas (SRA) were large (20-60 million SEK annually) programmes in 21 areas to be run for five years and - pending successful evaluation – be included as permanent parts of host universities' government appropriations. Altogether, more than one billion SEK were allocated through the SRA programme annually

In parallel, the government increased direct appropriations (institutional funding) to universities, but the proportion between institutional funding and project funding continued to slide in the favour of the latter: estimates put the relations to 40/60 today (2015). The hike in institutional funding was linked to the implementation of a new system for assessing research quality – based on a mixture of bibliometric indicators and funding success.

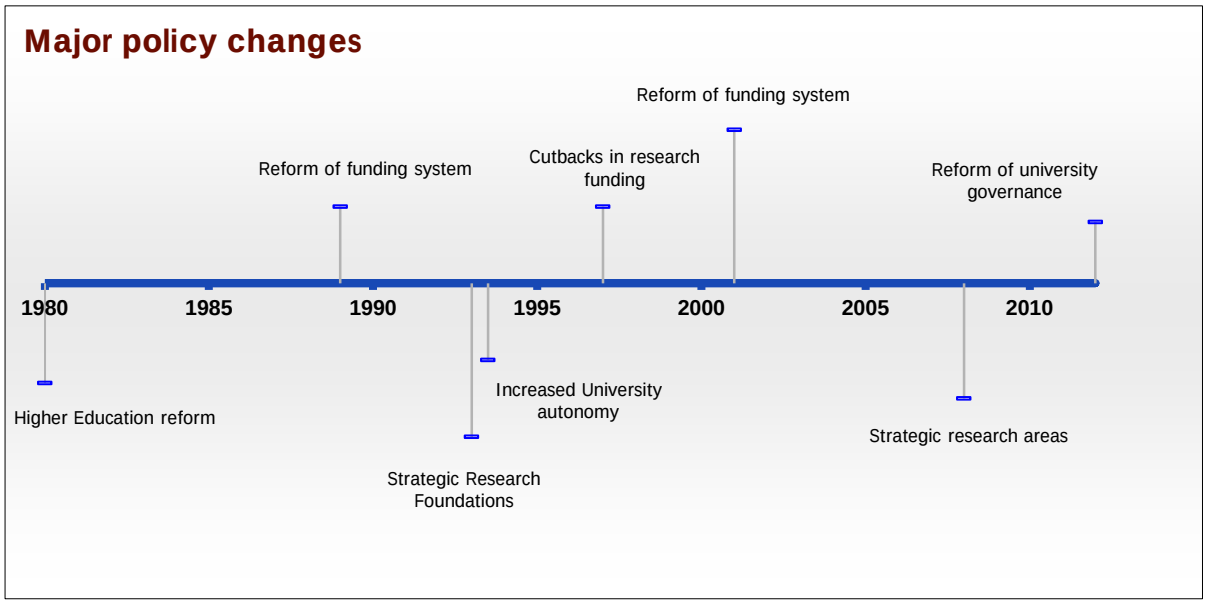
The focus on university organization and the efficiency of universities' operations continued in the coming years, particularly through the so-called autonomy reform in 2011. This was primarily a wide-ranging deregulation of university organization and appointments systems, where universities were allowed to choose organizational structure according to the own preferences and to organize their career structure independently of state regulation (only three types of positions were stipulated: professors, lecturers and post-docs).

Alongside these developments – and culminating in the research policy bill of 2012, Sweden made significant investments in two large infrastructural clusters: one for materials research in Lund (synchrotron source and spallation source, MAX IV and ESS), and for life science within Science For Life Centre (SciLifeLab) in Stockholm/Uppsala. The amount of investments here is a complex matter which involves many different, both private and public, sources, but they make up at least 10 billion SEK with annual running costs of 500+ million SEK.

In the light of mounting critique of the impact of large scale funding via centres and programmes, a programme for international recruitment of "top scientists" was established in 2013, and a similar programme for junior and senior scholars based in Sweden, as part of the 2012 research policy bill. Some 500 million SEK were allocated to these missions.

The currently most topical issue concerns the balance between different streams of funding – where the tipping of the balance in favour of external funding has been mentioned as one key element behind the falling scientific impact of Sweden's research. The exact form of a realignment of funding sources is yet to be decided but will form the cornerstone of the coming research policy bill (to be presented in 2016). Altogether, Sweden has now been in the process of reforming its system of research governance by learning from others – notably Denmark and the Netherlands, but also by incepting its own instruments, which are more path-dependent in nature: strategic areas target Sweden's strong research environments and areas, whereas strategic innovation areas and the like target Sweden's large industrial and (to some extent) social interests. The long-term impact on Sweden's research strengths are yet to be seen.

Figure3.13: Major policy changes – Sweden



3.4. The Netherlands

The 1960s and 1970s:

The Dutch research policy system was clearly centered around the universities until the 1980s. The universities received the absolute majority of their funding, almost 90 per cent well into the 1970s, as institutional funding. In addition, a string of research councils had been set up in the postwar period, but they were of marginal importance during this period. Finally, an extensive system of research institutes had existed even before the war, some more toward the applied spectrum (especially the TNO system), others with a basic research mission.

Within the framework of academic self-control, radical change took place in the university governance in the Netherlands, along the same lines as in Sweden and Denmark. The change was enacted in 1971 and reformed the system from a classical meritocratic model to a much more democratic model with strong student and administrative representation alongside the academic representatives (De Boer 1999).

The 1980s – a focus on excellence

The introduction of a research assessment system in 1986 was a key reform in Dutch research governance, when a model of evaluating research areas and research units was established. The system became a mechanism of regulating academic behavior, in particular publication patterns. The introduction of the system was part of a realignment of the relations between the state and the universities, where the state receded from its relatively fine-grained model of steering into a model of "steering at a distance". Increased university autonomy was therefore coupled to performance expectations and evaluations (De Boer et al 2006). The initial ambition of the system was to link the research assessment to resource allocation but this proved to be a conflictual issue. Instead, the universities committed themselves to adapting to the outcomes of the assessments, and demote areas that were not of international significance – and for instance transfer staff and activities to other universities where these fields were more prominent (which in turns entailed a coordination between universities, which had hitherto been unusual) - and instead gear resources to more promising and viable activities. Even 30 years on, the system still remains as a voluntary, but institutionalized, part of Dutch research governance, where universities self-select areas to be assessed and use the assessment for their own purposes without national interference. Various sources indicate that the assessment system has been a major boost to scientific impact of Dutch research, primarily by demoting research which resulted "only" in domestic publications, and generally research activities of limited international significance. Nationally, a protocol for these assessments is in place, and hence, the assessment system works in tandem between national coordination and institutional autonomy.

The 1990s – reforming university governance and PhD training

Around 1990, a series of reforms of the PhD training system produced a more orderly structure of graduate training, with a clearer division of labour and collaborative structure among Dutch universities and with a concentration of resources and facilities for PhD training to a delimited set of research schools (Vossensteyn 2011). The reforms have streamlined time frames and established stringent expectations on publishing (accounting for impact factors and similar). The main part of this has been the inception of national graduate schools. Typically for the Netherlands, the national graduate schools were first funded by the government but later taken over by the universities themselves (and ran with their own funds). In addition to the 80+ research schools, a select number (10+) of top research schools were established and funded by the NWO.

The 1990s also saw a new reform of university governance which seeked to further strengthen university governance. The reform was implemented in 1997. After a streamlining of internal decision-making following the autonomy reform in 1986, the leadership of various levels of Dutch universities was strengthened as part of the new reform. Department heads, deans (in particular), and vice chancellors control significant resources, have high influence on recruitment, and are generally responsible for the qualitative outcome of Dutch research. University leadership therefore exerts a strong influence it also also enforces a strong quality control with articulated expectations (De Boer 2006).

The 2000 – infusing new resources into the system

The expansion of Dutch research funding in the 1990s and 2000s has been operationalized in a series of loosely coordinated, but mutually reinforcing steps to propel funding, instigate clearer career

paths and create a more coherent, yet diverse, funding system – all under the auspices of a national model of policy coordination and policy advice.

Part of the reform of the research funding system was the consolidation of public research support via the reforged and widened remit for the NWO implemented in 1994 (van der Most 2008). This widened the remit of the research council NWO to also cover issues of the valorization of research – and integrated a string of previously independent funders under one organizational umbrella. Arguably, this made the research council into a more proactive part of research governance, shown for instance in the role that NWO played in establishing a coherent career path system (Veni, Vidi, Vici). Part of the changes in research funding in this period was also the establishment of funding outside NWO, in the form of large appropriations of support in expansive and expensive areas such as medicine and engineering. The funding of this was based on the windfall profits the Dutch state made on oil and gas extraction and refinement. Beginning in 1993 and then recurrent until 2010, a string of national programmes were incepted, typically in the range of 100 million Euros annually (van der Most 2008). This meant that certain areas and fields received windfall increases of resources. The expansion was taking place outside the NWO and at the behest of other ministries than the Ministry of Science and Culture, which may be seen as a sign of weak coordination. On the other hand, with the more stringent internal coordination of research and the various measures of assessment, quality does not seem to have suffered from the influx of resources via the big national centres and programmes.

In 2000, the so-called innovational research incentives scheme was established in collaboration between NWO, the universities and KNAW (the science academy) as a way to streamline recruitment and afford a clear-cut career path. It established a three pronged model of recruitment and promotion, with a first step (Veni, equivalent to assistant professorship), followed by funding for established post-docs (Vidi, similar to associate professor level) and then a more exceptional funding level, as Vici for internationally outstanding scholars. Similarly, and to avoid a parallel career path solely based on external funding, a five year limit for positions based on soft money is in operation. It is also the rule that permanent positions should not be based on external funding (with one technical university, Twente, as the exception – at least in 2012). Otherwise, career paths and permanent positions are to be founded on internal funding of the universities.

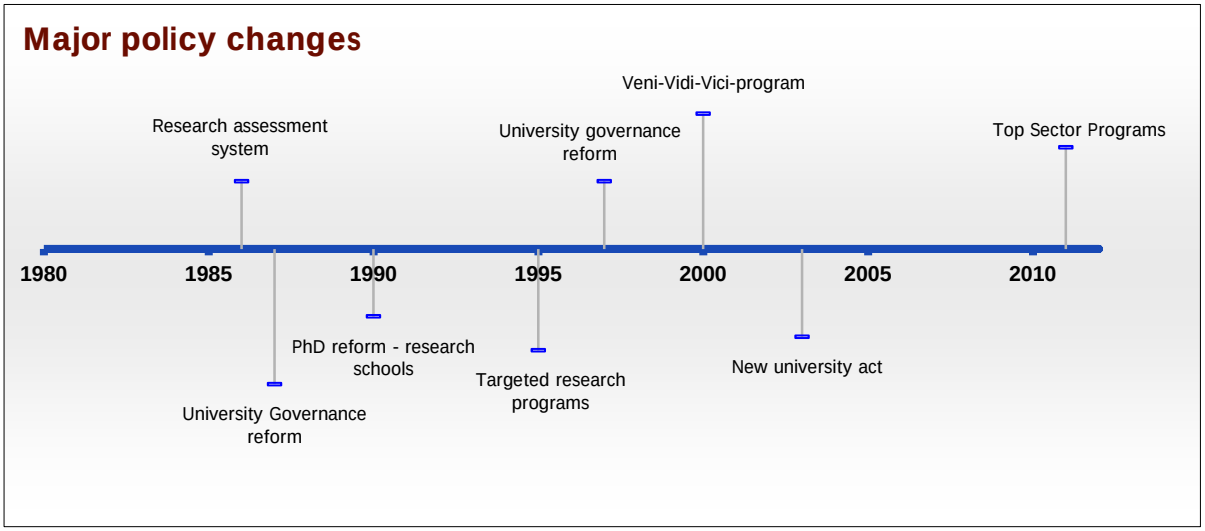
All in all, the period between 2003 and 2010 was generally quite favourable to Dutch research, with a stringer model of leadership and governance in place, with strong mechanisms for policy deliberation and analysis, with a productive, if largely uncoordinated, relationship between ministries in the formation of policy, and with a durable relationship between strong institutional funding to universities (around 70 per cent of total funding) and different layers of external support (project funding, career grants, centre and programme support). Other factors, such as the reform of PhD training, further propelled a culture of international production and aspiration.

The 2010s: crisis and realignment?

The real test for the Dutch governance system will follow as a result of the economic crisis around 2010 and onwards with falling growth rates and dwindling extra resources for research (with oil and gas revenues now used for other purposes). The recently launched Top Sectors initiative may however serve as an indication that the model still holds. In 2011, a deep economic crisis put the

expansion to a halt and instead came the so-called top sectors, where the aim was to restructure funding into different top sectors, the building blocs of the Dutch economy (and society). The inception of the top sectors primarily meant that NWO funding was realigned (relabeled) to match the sectors identified. The main significance for our purposes is that the top sectors are aligned with the priorities of NWO and that the process behind the top sectors – where the science academy KNAW played a core coordinating role – meant that resources were deployed without destroying the underlying commitment to scientific quality. Overall, the system of policy deliberation remains strong and influential, and showed, through the management of the top sector initiative, its capacity to integrate different ambitions for research and innovation.

Figure 3.14: Major policy changes – The Netherlands



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Section 2: Chapter 4-9: Examination of each hypothesis in a cross country perspective

In continuation of the brief country descriptions outlined in chapter 3, the following six chapters zooms in on the six selected hypotheses formulated by DFiR and conducts more detailed cross country analyses for each policy factor. In general strongest emphasis is given to the Danish case in relation to the analyses. More contextual material is provided to the Danish case and for some of the hypotheses additional Danish analyses are also carried out. The Swedish and Dutch cases are mainly included to situate and interpret the Danish development in a broader international perspective.

It should also be noticed that different weights have been given to each of the six hypotheses. The weight assigned to each hypothesis has been decided both according to considerations of importance and based on data-availability.

4. Balances in the funding system

4.1. Introduction

The public R&D funding system as a whole is seen as the main tool for the implementation of research policy. Both the overall volume of funds available and the mechanisms and criteria adopted for their allocation are closely linked to policy objectives (Braun 2003; Lepori 2006). Funding, in other words, reveals the ambitions that governments have with public research and is also expected to have a direct effect on academic performance (Sörlin 2007).

As outlined in the literature review in chapter 2 most national research funding systems are highly complex configurations with a wide variety of partly overlapping funding mechanisms. The complexity of the systems constitutes a major challenge for cross country studies where few elements can be compared directly. One important distinction applicable to most systems is however made between institutional funding on the one hand and project funding on the other. Project funding can be argued to influence performance by providing incentives for research units to improve performance and through the re-allocation of funds to the most productive researchers (Auranen and Nieminen 2010). On the other hand, an increased emphasis on project funding may lead to decreased risk taking, reduced flexibility and lack of stability and may thus have unintended negative consequences. The relation between competition for funding and performance is accordingly not likely to be straightforward (Auranen and Nieminen 2010). It is therefore highly relevant to investigate potential relationships between different types of funding and performance.

The distinction between the two main public funding streams is closely connected to DFiRs first hypothesis: It addresses the central balance between institutional funding and funding through competitive channels (project funding) and states that the Danish system in general has benefitted from appropriate balances between these funding streams. In particular it highlights how increased competition over time may have led to increased quality. It also states that the mix between different types of funding may have been more appropriate in Denmark than in other comparable countries.

In this chapter two main questions are analyzed for the three countries in relation to the developments in funding of public research: 1) First we investigate to what extent the development in the overall level of funds available for the public research institutions play a role for the development in impact. The question is here: can we detect any links between developments in overall funding volume and developments in publication volume and citation impact? 2) Secondly we move on to the question directly linked to the hypothesis: Can we detect any links between developments in the balance between institutional funding and project funding on the one hand and developments in publication volume and citation impact on the other for the three countries? Following up on this a number of additional analyses are carried out based solely on Danish data. These analyses address the same questions, but they include more contextual material and uses longer time series. The Danish analyses also briefly examine the relationships between funding and performance at the field level for the three largest scientific fields.

However, as mentioned above funding systems are highly complex systems with a multitude of mechanisms and mediating factors which hardly can be captured by simple distinctions. Thus, in order to support the interpretation of our findings we will include observations on the overhead

systems of the three countries, the division of labor between the higher education institutions and other governmental research institutions and some main trends in the composition of the project funding.

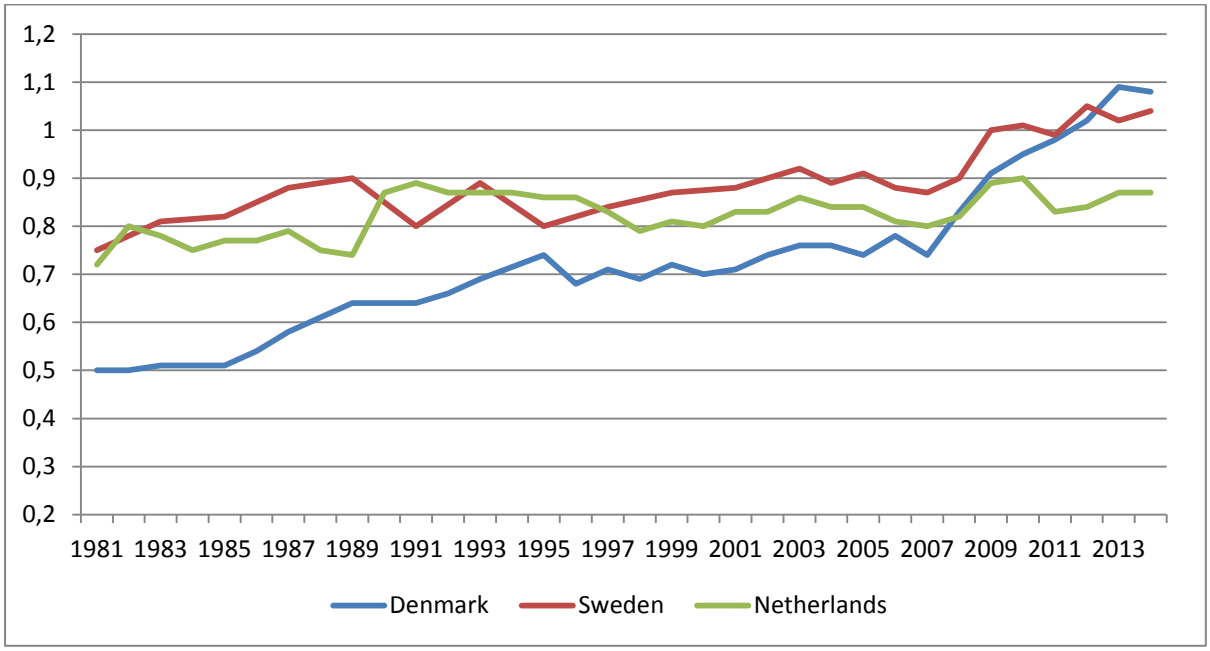
4.2. Funding trends in the three countries

Before we move on to the actual analysis, the main funding trends of the three countries are briefly presented in a comparative perspective. This part overlaps with the introduction to chapter 3, but it has been extended somewhat in this chapter.

First we take a closer look at the development in the overall volume of funding in the three countries. In this case we operate with the two OECD MSTI categories: HERD and GOVERD. HERD (Higher Education Expenditure on R&D) covers all R&D performed in the higher education sector and includes both publicly and privately funded R&D. GOVERD (Government Expenditure on Intramural R&D) covers all R&D performed in the Government sector and includes both publicly and privately funded R&D. HERD + GOVERD is used here as a proxy for the overall R&D expenditures performed in the public sector. We show all the measures as share of GDP in order to be able to make meaningful comparisons across the three countries.

If we first look at the overall expenditures in the three countries it is noticeable that the Danish expenditures were at a fairly low level in the early 1980s and remained well below the levels of Sweden and The Netherlands until the early 2000s. Since then, and in particular since 2006, the Danish growth has been significant and Denmark has now passed both Sweden and the Netherlands. The Netherlands shows a rather stable development throughout the period, while also Sweden has increased its funding volume during the last 10 years. Notice however, that the financial crisis in 2009 and the subsequent drops in GDP influence this figure. Increases in the volume of funding as share as GDP are not necessarily the results of increased overall investments in absolute numbers in times of recession. Decreasing GDP figures may thus hide stagnation or even cuts in the level of funding in real terms.

Figure 4.1: HERD + GOVERD as share of GDP for Denmark, Sweden and the Netherlands, 1981-2014.



Source: OECD MSTI

To gain a more detailed insight into these trends it is however necessary to take a closer look at the division of the expenditures between higher education institutions (HERD) on the one hand and other government research institutions (GOVERD) on the other. These two figures (Figure 4.2 and Figure 4.3) together show an interesting difference between the three countries.

Fig. 4.2: HERD as share of GDP, 1981-2014

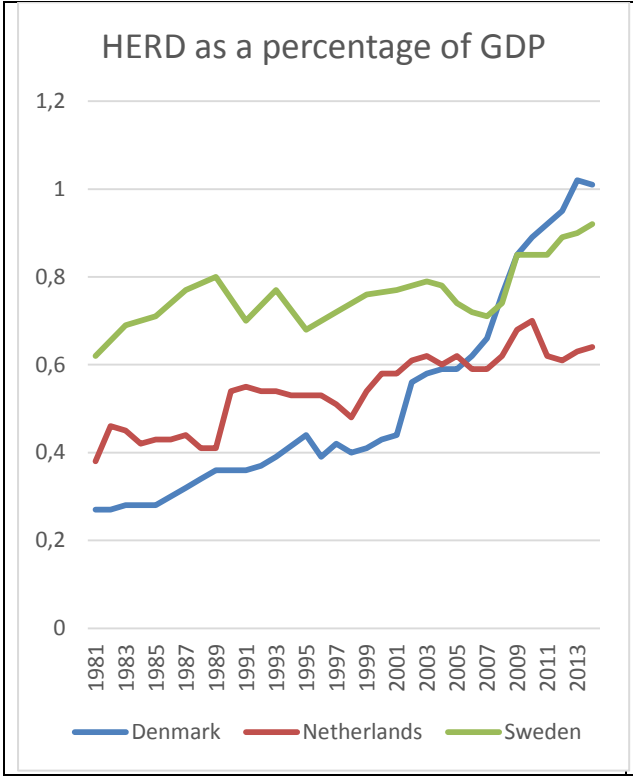
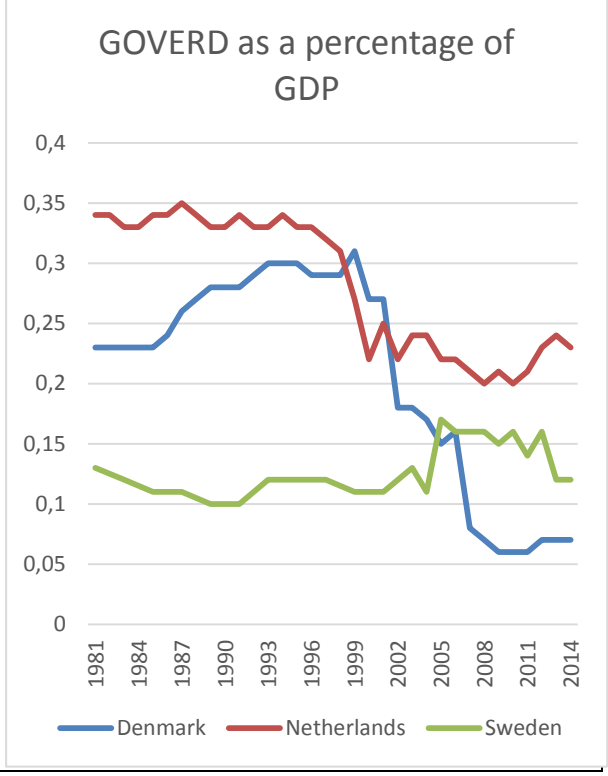


Fig. 4.3: GOVERD as share of GDP, 1981-2014

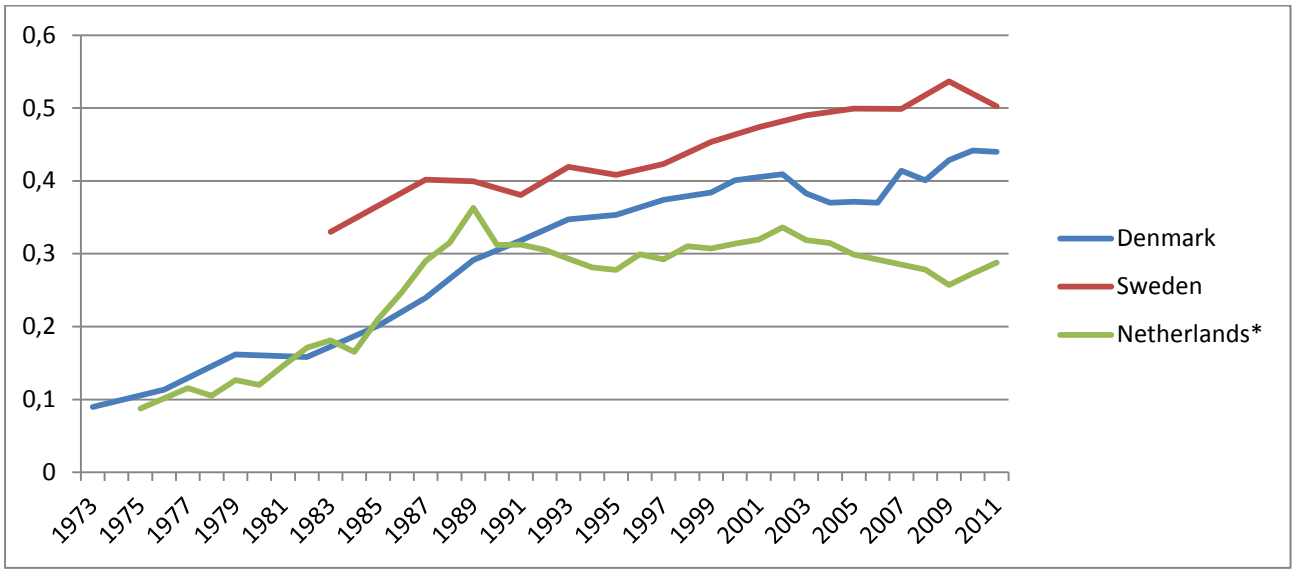


Source: OECD MSTI

As can be seen from the two figures – and as outlined in the country descriptions in chapter 3 – the universities have been very dominant in the Swedish system throughout the period. This is quite different from Denmark and the Netherlands which both have had a substantial degree of public research carried out by government research institutions. However, since around 2000 these sectors have decreased dramatically in both countries. This is most evident in the Danish case where the universities for the latest decade have had the responsibility of almost all public research – not least as a consequence of a large scale merger process implemented in 2007.

Next we move on to the funding trends in the balance between institutional funding and project funding. For Denmark and the Netherlands we have data on this balance dating back to the early 1970s while the Swedish time series starts in 1983. For all three countries we observe substantial increases in the share of project funding throughout the period as a whole. There are however also interesting differences with regard to this issue. The Netherlands and Denmark have very similar developments up until 1990 with a quite steep increase from very low levels. From the early 1990s the Dutch balance stabilizes and even drops towards the end of the period, while the share of project funding continues to grow for Denmark. Sweden, however, starts out at a higher level and remains above both Denmark and the Netherlands throughout the period.

Figure 4.4: Project funding as share of total public R&D funding for Denmark, Sweden and the Netherlands



*Source: National Statistics, *2008-2011 for the Netherlands based on: www.innovationpolicyplatform.org*

However, to be able to interpret this balance properly we need to take the overhead practices within the three countries into account as well. Overhead is the institutions mechanism for recovering administrative and facilities costs associated with conducting research and other sponsored activities. Overhead is thus meant to cover indirect costs exceeding the "pure" costs directly applicable to a given project. Overhead rules are often centrally decided for public foundations and institutions, while private funders are free to decide to what extent they are willing to cover indirect costs. We typically find an inverse relationship between institutional funding and degree of overhead: The lower the share of institutional funding, the higher the need for institutions to get indirect costs covered by the funders (or the state).

As shown in more detail in Appendix 4.1 there are important differences in the overhead systems of the three countries which to some degree lessen the differences in share of project funding. Most notably, the Netherlands do not have a formal overhead system. In reality this may mean that the amount of available institutional funding is more limited than the figures imply. It also means that we need to interpret the differences between the three countries with caution.

Furthermore, it should be taken into account that we find different balances between institutional funding and project funding between sectors (the HEI sector and the Government Research Institute sector) and different balances between different scientific fields. Similarly differences in the composition of the project funding obviously also play a role. We do not have sufficiently detailed data enabling us to make comparative analyses at these levels across all three countries, but in section 4.7 we analyze these issues in more detail from a Danish perspective.

With these caveats in mind we then turn to the comparative analysis. First we look for potential relationships between changes in overall funding levels and changes in publication volume and citation impact. Secondly, we analyze potential relationships between the balance between institutional funding and project funding on the one side and publication volume and citation impact on the other. Finally, we examine whether any links can be found between changes in the share of university research of total public research and the developments in academic impact.

4.3. Funding volume and its relation to academic performance

The two figures below show the development in funding volume as share of GDP and citation impact respectively. The main question is whether changes in overall funding levels – positive as well as negative – translate into changes in aggregated citation impact.

Figure 4.5: HERD + GOVERD as share of GDP

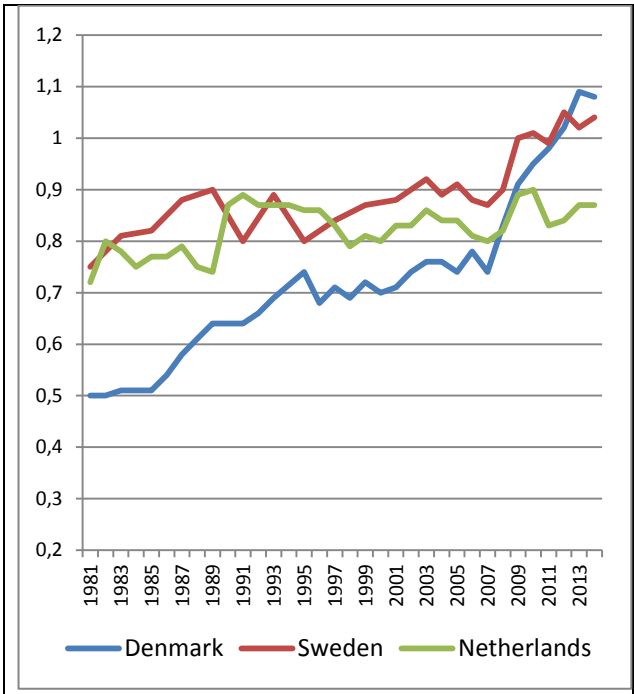
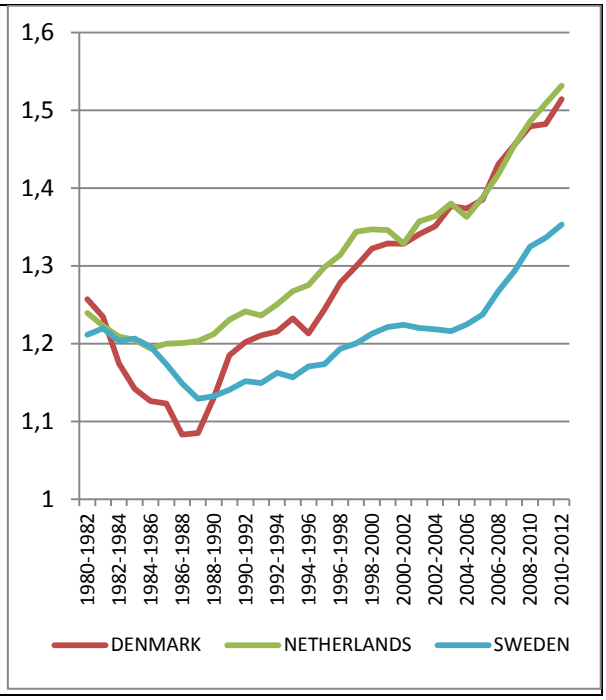


Fig. 4.6: Development in MNCS

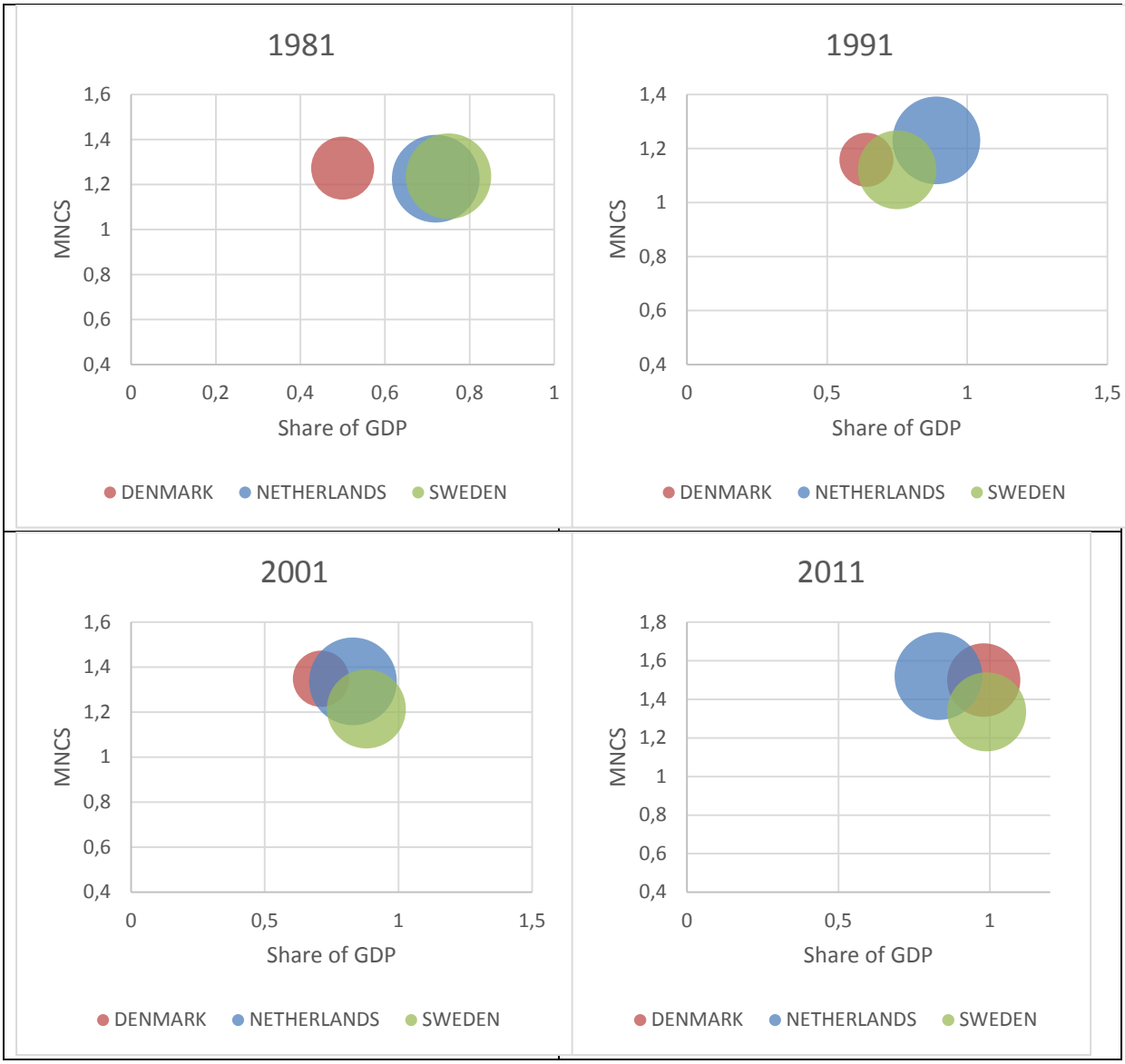


Source: OECD MSTI, Schneider and Aagaard 2015

As the figures show, there are no straightforward links between changes in funding levels and changes in impact across the countries. The negative development in impact that can be observed for Sweden during the 1980s is not directly linked to the level of funding based on these figures. On the contrary it coincides with a period of growing overall investments. The Danish case is different, however. As we show in section 4.7 where we look at the Danish development in more detail there are indications that a long period of stagnating resources during the 1970s and early 1980 could be a contributing factor in explaining the Danish drop in the 1980s. Similarly, the Swedish economic crisis in the 1990s which was translated into funding cuts and changes in the composition of the funding could be a contributing factor in explaining why the Swedish system – in contrast to the Danish - was unable to fully reverse the negative development. Notice here, that the cuts in the Swedish funding in real terms in this period are hidden in the figure as it coincided with a drop in GDP. The Netherlands has a fairly stable development in both funding and impact indicating that long term funding stability at a relatively high level creates good conditions for high performance at system level. Notice here that the sharp increase from 1989 to 1990 in the Netherlands mainly can be ascribed to a data-break as the result of a change in calculating methods.

In order to zoom in on these relationships across the three countries we have created four snapshots illustrating the relationship between funding levels as share of GDP, MNCS and publication volume for the years 1981, 1991, 2001 and 2011.

Figure 4.7: Relationship between funding levels as share of GDP, MNCS and publication volume for the years 1981, 1991, 2001 and 2011. The size of the circles shows the relative publication volume of each country.



Source: Schneider and Aagaard 2015; National statistics

While we may see some indications of relationships between changes in funding levels and impact within each country over time, the cross country comparisons in Fgure 4.7 show almost no correlations. Absolute funding levels and impact seem to be largely unrelated across countries when we look at a number of selected individual years.

4.4. Balance between institutional- and project funding and relation to performance

Secondly in this part of the chapter we examine to what extent we can detect relationships between changes in the balance between institutional funding and project funding on the one side and changes in impact on the other. Again we start out by looking at changes within each country over time, before we apply a cross country perspective.

As outlined in section 4.2, The Netherlands and Denmark have very similar trajectories up until the late 1980s with a rather sharp increase in the share of project funding. However, while this development in Denmark coincides with a significant drop in impact, the development in impact in

the Netherlands appears to be less affected – although we do observe a slight drop and then a period of stagnation. Also for Sweden it is hard to detect a direct correlation between changes in funding balances and impact, when we look at this relationship in isolation. Also here however, the drop in performance during the 1980s coincides with an increase in project funding, but the increase in Sweden is more stable and less steep – although at a general higher level.

Fig. 4.8: Share of project funding;

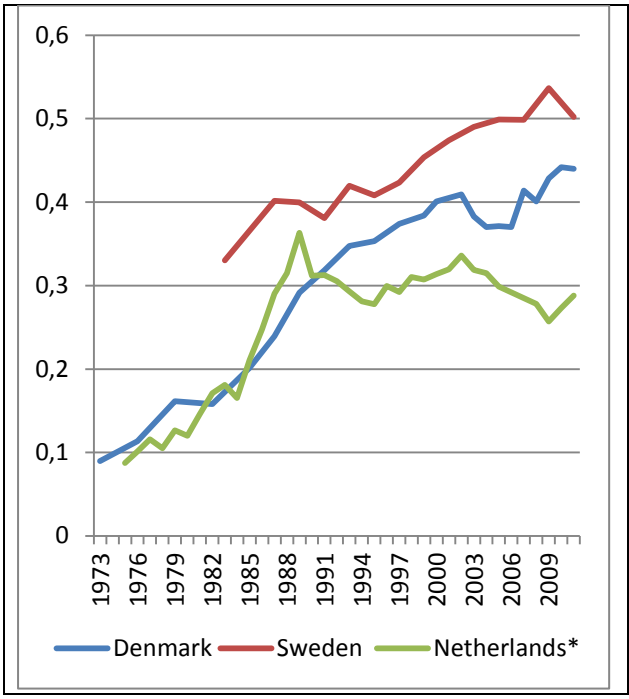
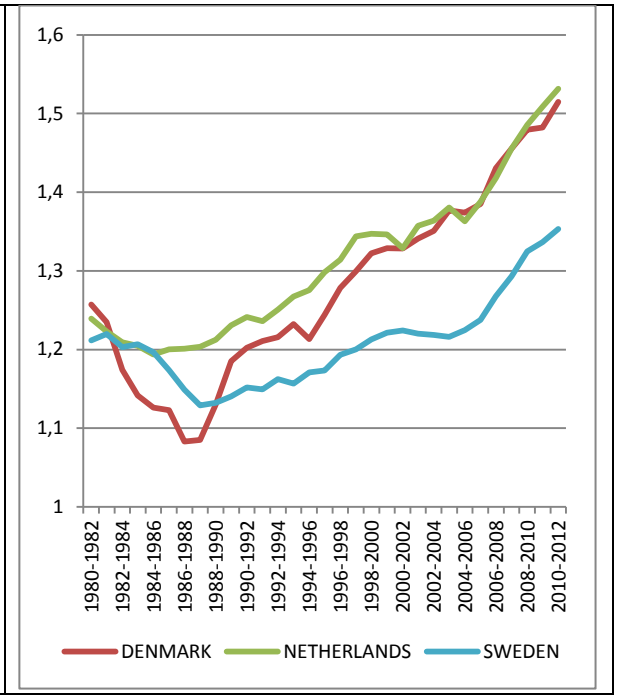


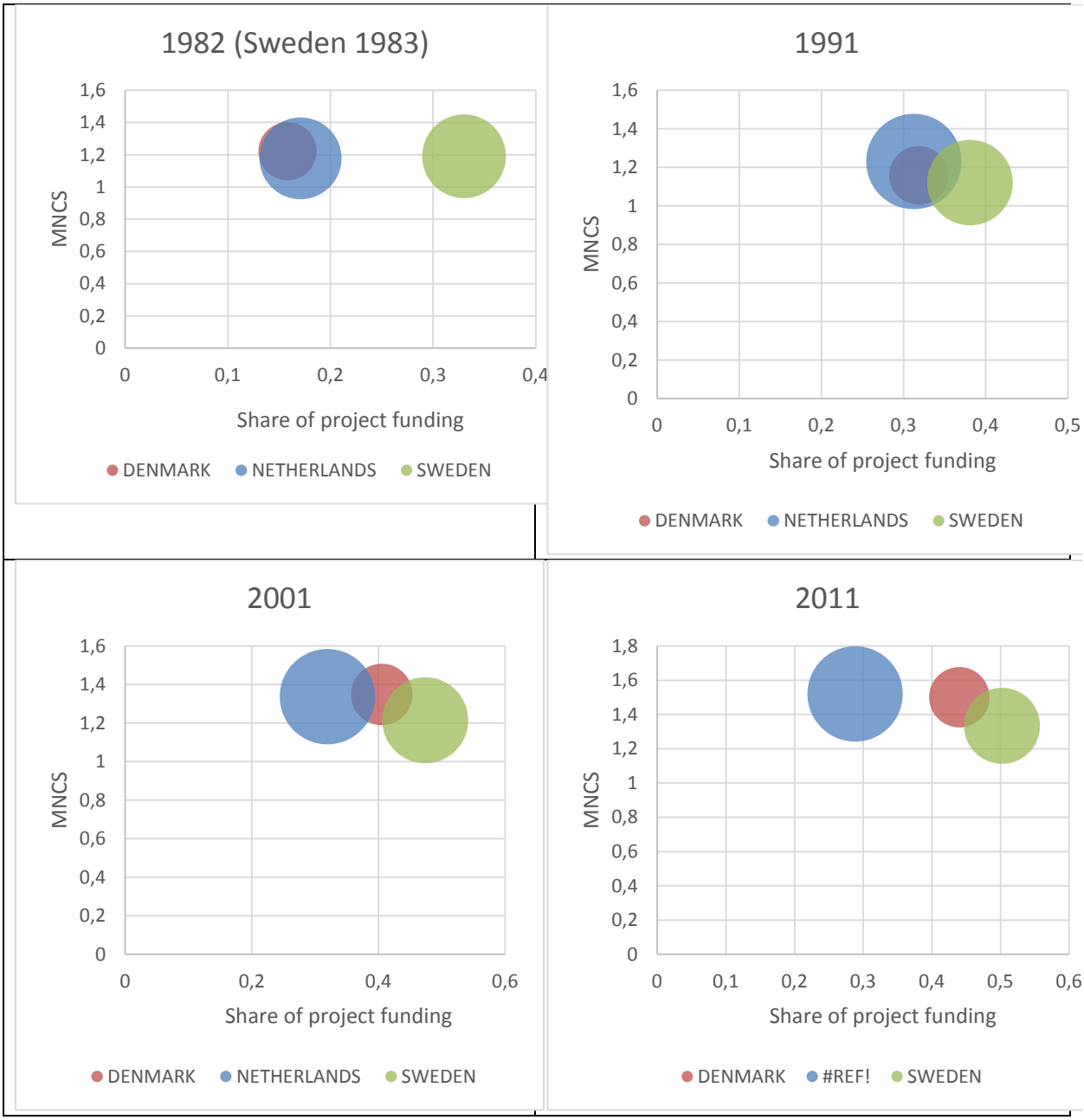
Fig. 4.9: Development in MNCS



*Source: National statistics (except *2008-2011 for the Netherlands based on https://www.innovationpolicyplatform.org/content/statistics-ipp?l=PBF_XTFNP;v1)*

To get a closer look at the cross country differences we have again created four snapshots – this time of the relationship between funding balances and impact. In this case the years 1982 (1983 for Sweden), 1991, 2001 and 2011 are selected. The exact years are selected based on data availability. As we see from Figure 4.10 the three countries score very equally on impact in 1982 although Sweden has a much higher share of project funding than Denmark and the Netherlands. In the following years Denmark and the Netherlands experience significant increases in the share of project funding, but again there do not appear to any systematic patterns in relation to the corresponding development in impact.

Fig. 4.10: Relationship between share of project funding, MNCS and publication volume for the years 1982, 1991, 2001 and 2011. The size of the circles shows the relative publication volume of each country.



Source: Schneider and Aagaard 2015; National statistics; project funding 2008-2011 for the Netherlands based on www.innovationpolicyplatform.org

4.5. Balance between university research and research performed by other public research institutions

As the final part of the comparative analysis, we take a brief look at potential relationships between the balance between higher education institutions and other public research institutions on the one hand and changes in impact on the other. Somewhat counter-intuitively we see that Denmark and the Netherlands which both have a fairly large non-university research sectors have a more positive development in impact up until 2000. After 2000 these sectors are reduced in both countries, most noticeable in Denmark, but without any significant correlation to the corresponding development in impact.

Fig. 4.11: HERD as share of GDP, 1981-2014

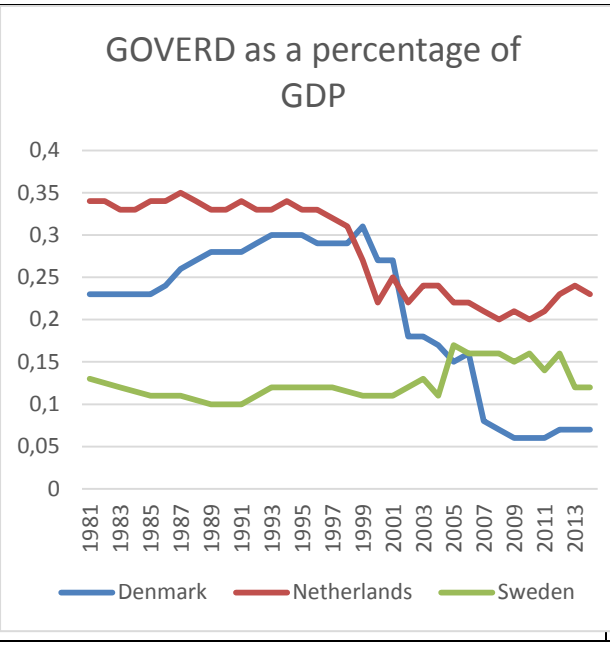
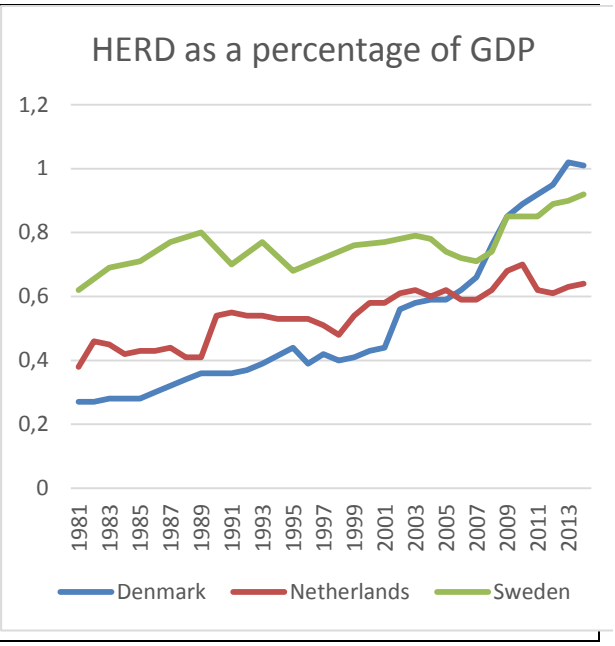
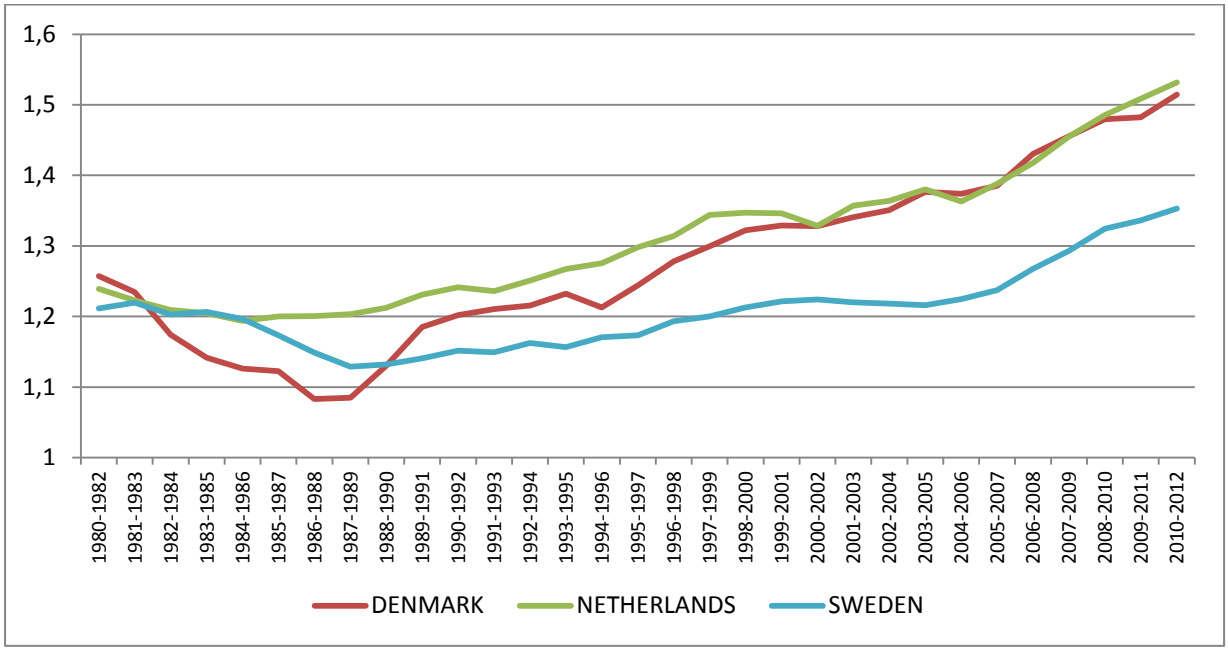


Fig. 4.12: GOVERD as share of GDP, 1981-2014



Source: OECD MSTI

Fig. 4.13: Development in MNCS



Source: Schneider and Aagaard 2015

4.6. Conclusions on the comparative analyses

In general we find no clear links between funding levels and funding balances on the one side and academic performance on the other when we apply a simple cross country perspective. We do however find indications of potential relationships when we analyze each country over time. This observation supports the view that funding changes and differences in absolute levels of funding seldom are sufficient factors to explain changes in impact. However, as we show in the following section, when the funding system is analyzed within one country over time with the inclusion of rich

contextual material we gain a better understanding of how changes in funding configurations may affect system performance.

However, one interesting cross country conclusion appears to emerge – which at first may seem counter-intuitive: Denmark and the Netherlands, which historically have had a substantial non-university research sectors have clearly outperformed Sweden with a very dominant university sector. One potential explanation could be that the university systems in Denmark and the Netherlands have had a more 'pure' academic orientation than the university system in Sweden with a broader span of missions.

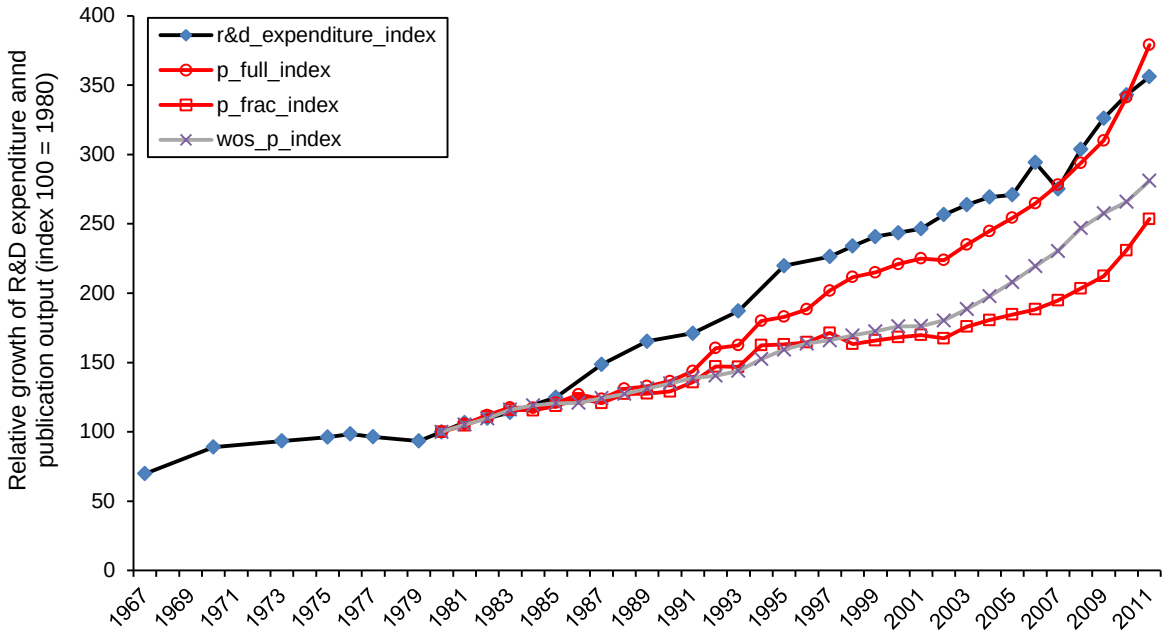
4.7. Additional Danish analyses

In order to examine the relationship in more detail we now zoom in on the Danish case. We repeat the steps carried out in the comparative analysis above, but now with a longer funding time series and the inclusion of more contextual material. This part draws extensively on Aagaard and Schneider (2015) from which substantial parts are integrated directly in this text.

Funding volume and publication volume

As the first step in the more detailed Danish case-study we examine the relationship between funding volume and publication volume: The time-series presented in Figure 4.14 below shows the development in total Danish R&D expenditures throughout the period from 1967 to 2011 and the corresponding development in publication volume from 1980 to 2011.

Figure 4.14: Development in total public R&D funding 1967-2011 and publication volume (1980-2011). Developments are depicted in index numbers where the numbers are calibrated to index 100 in the year 1980 (the first year with publication data). Besides R&D expenditure, the graph depicts the relative development in Danish publication volume in the WoS database; we show the development for both full and fractional counting schemes. As the database itself has been considerably expanded during the period examined, we also depict its relative development hereby contextualizing the Danish development.



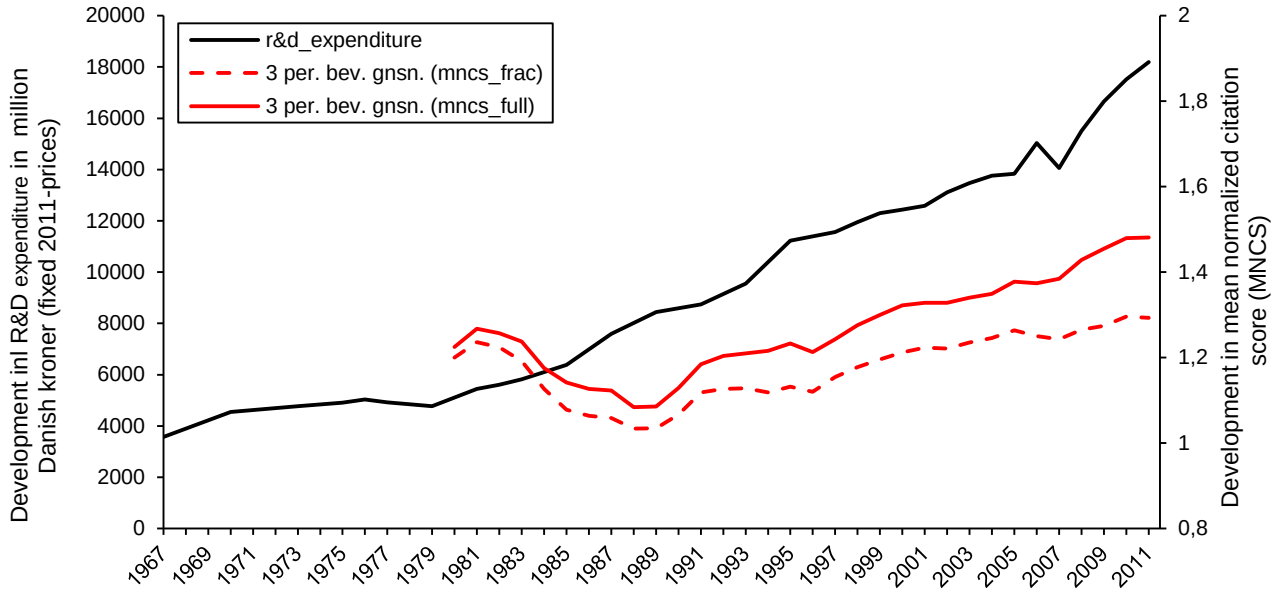
Sources: Lauridsen & Graversen (2013) and CI-WoS, CWTS, Leiden University, Netherlands.

In line with previous findings in the literature there appears to be a rather clear correlation between the development in funding and the development in publication volume (e.g., Leydesdorff and Wagner 2009). It is also observed that while the developments in funding and publication volume are positively correlated and increasing, the development also correlates with the trend in the WoS database. However, much of the recent growth in the WoS database results from the inclusion of a large number of regional journals of limited interest for Danish researchers. The observed development thus most likely reflects a real increase in output and not only an effect of database extensions. The link to funding is especially visible in the last period where the funding associated with the Danish Globalization Strategy was distributed. As can be seen the growth rates for both full and fractional counts steepens whereas the database remains linear.

Funding volume and impact

Figure 4.15 below shows the same development in total public funding, but now related to the development in impact. Previous findings, for example King (2004), show positive relationships between national wealth intensity and impact intensity. But as Figure 4.15 shows, long term correlations between the developments of funding levels and citation impact appear to be a lot less obvious. In particular the drop in the 1980s and the steep increase in the 1990s appear to be largely unrelated to the overall funding pattern. While the stagnating or even dropping level of funding may be a contributing factor to the drop in impact during the 1980s, it is unlikely to be a major explanation. Similarly, the steady growth in funding from the 1980s and onwards has most likely been a necessary condition for some of the subsequent increase in impact, but again this is at best only a part of the explanation for the sharp increase in MNCS. Funding can help secure advantageous conditions under which good quality research can be produced. The reception of such research as measured by citations is however influenced by other factors (e.g., Bornmann and Daniel 2008).

Figure 4.15: Development in total Danish R&D expenditure in million DKK compared to the development in national mean normalized citation impact (MNCS) for journal articles in WOS (secondary y-axis).



Sources: Lauridsen & Graversen (2013) and CI-WoS, CWTS, Leiden University, Netherlands.

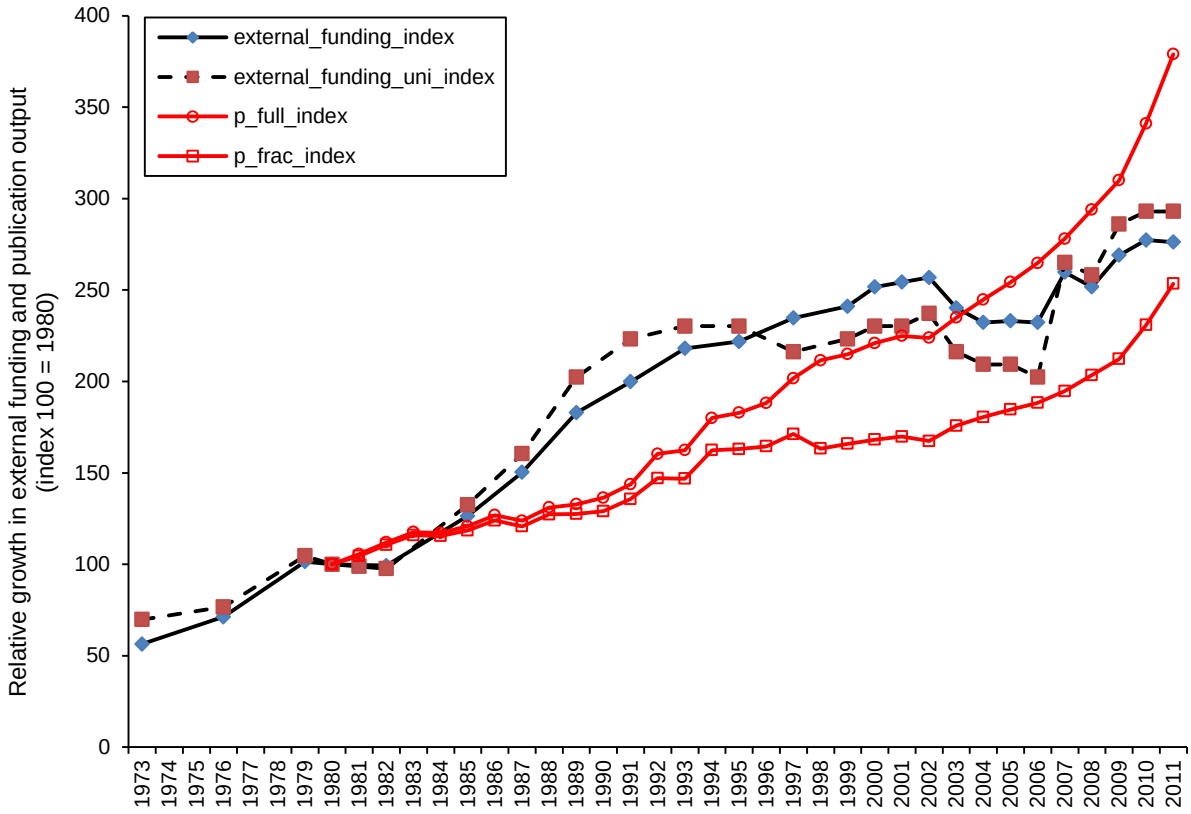
Share of external funding

Next we turn to the development in the share of external research funding where a quite different picture can be seen.

Up until the late 1970s the funding of public research at the Danish universities was almost fully dominated by core funding with very few strings attached. These grants were in general allocated based on input factors with student numbers as the main criteria. Also the funding of the GRI sector was dominated by core funding, but the research within the institutes was closely linked to the needs of the sector ministries (Aagaard 2011). The research council system, which was gradually institutionalized in this period, was in general very academically oriented and closely linked to the universities. It was, however, of marginal economic importance. From the 1980s a strong growth in earmarked strategic program funding of the public research took off as a result of an emerging policy belief that renewed industrial growth should be based on key technologies such as information technology, biotechnology and materials science (Aagaard 2000; Grønbæk 2001). A major part of the new program funding was placed in special comities outside of the existing academically oriented research council structure which was distrusted by the political system. The share of external funding for the system as a whole thus increased from 11 percent in 1976 to 35 percent in 1993.

However, during the early 1990s this trend was reversed somewhat. First of all, it was agreed that the balance between core funding and external funding should be maintained at the level that was reached at this point (Aagaard 2011). Hereby the relative growth in program funding stopped and this led to more than a decade of relative stability in the balance between core funding and external funding. In addition, a larger share of the program funding was gradually returned to the academically oriented research councils and along the same lines a new Centres of Excellence Scheme was established in 1993. This so-called Danish National Research Foundation (DNRF) was created to supply long-term of support new “centres of excellence” solely based at academic quality criteria. The annual level of distribution aims at an average of approximately 54 million Euro corresponding to about two percent of total public research expenditure. Since its establishment, the DNRF has supported Danish research with approximately 830 million Euro (Evaluation of the Danish National Research Foundation 2013). The importance of DNRF for the development in Danish research performance is analysed in chapter 5 of this report. In addition, an overhead system was established in 1995, further reducing the pressure on the core funding. As a whole this period has been described as an academic reorientation in the funding and management of the public Danish research (Aagaard 2011).

Figure 4.16: Development in share of external funding for the Danish public sector research institutions and the universities alone, compared to the development in publication output, full and fractional counting schemes (index 100 is set to 1980, the first year of publication output).



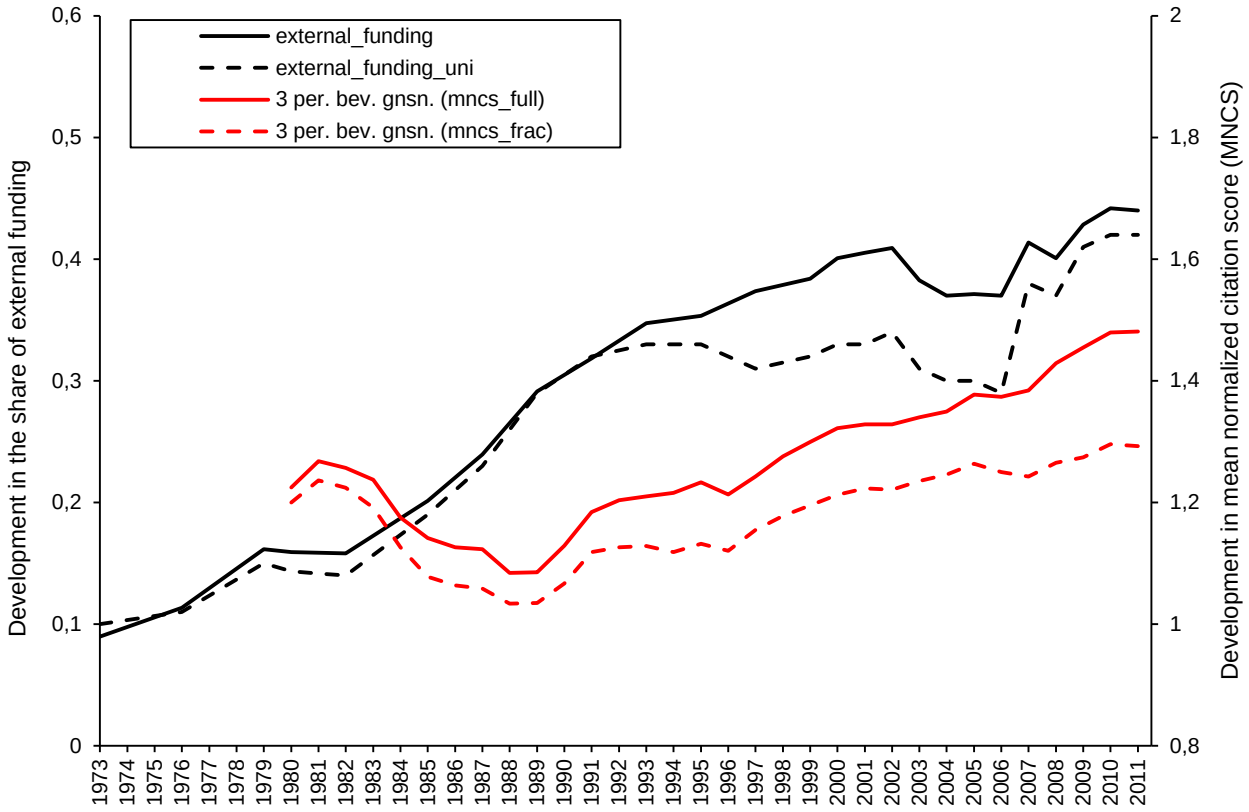
Sources: Lauridsen & Graversen (2013) and CI-WoS, CWTS, Leiden University, Netherlands.

Up until this point in the early 1990s the university sector and the GRI sector followed the same pattern concerning the degree of competition in the funding system, but while the growth in the share of external funding continued for the GRIs, it started to stabilize and even drop for the university sector. However, since 2006 a renewed growth in the share of external funding has been experienced within the university sector as well. A large part of this increase has taken place in newly established foundations placed outside the academic oriented research council system and has been directed towards strategic research and large scale innovation oriented projects (Aagaard & Mejlgaard 2012).

As Figure 4.16 shows we find no obvious correlation between the share of external funding and publication. Considering the development in total funding shown above it seems most likely that the major part of the explanation in the development in the publication volume should be found here, and that the degree of competition in the funding system only plays a marginal role in explaining the publication productivity.

If we however turn to the relationship between the share of external funding and impact, an interesting pattern emerges.

Figure 4.17: Development in share of external funding for the Danish public sector research institutions and the universities alone (primary y-axis), compared to the development in national mean normalized citation impact (MNCS) for journal articles in WOS (secondary y-axis).



Sources: Lauridsen & Graversen (2013) and CI-WoS, CWTS, Leiden University, Netherlands.

As can be seen in Figure 4.17 the substantial drop in impact during the 1980s corresponds to a very sharp increase in the share of external funding in the same period. However, the interpretation of this relationship depends very much upon what kind of lag we expect between the funding changes and the impact. Contrary to many other studies, we will argue that this type of change may have had an immediate impact on the "quality" of the research production. The swift transition period during the 1980s from an almost pure core funding based system to a much more competitive funding environment with strong external demands was a shock to the universities and affected the daily work conditions as well as the academic orientation of the system as a whole (Aagaard 2011). However, it is also worth noticing that once the system stabilizes (at a new and much higher level of competitive funding) the impact starts to increase again, implying that multiple balance points in the funding system may lead to high performance. What appears to be of importance in explaining the drop is thus most likely rather the hard transition than the actual level of competitive funding.

Overall, we thus see a pattern almost opposite to the pattern observed with regard to the overall level of funding: the share of external funding shows no or very limited relation to publication volume, but we see a possibly correlation to impact, although this relationship rather appears to reflect the transition period than the actual level of external funding.

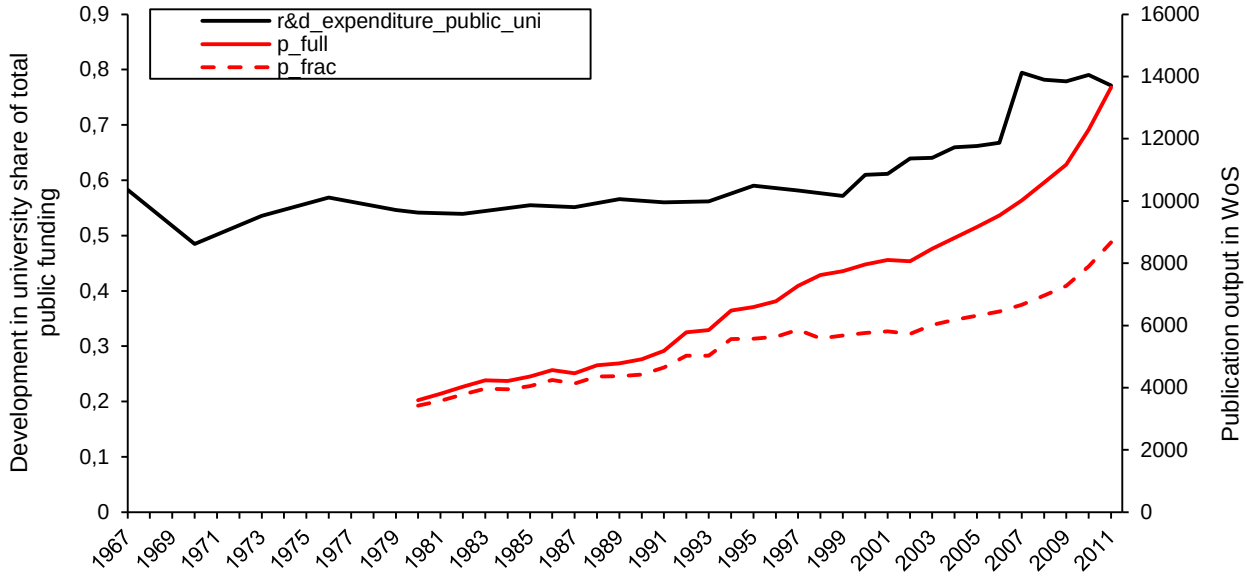
Share of university funding

When we then finally turn to the share of total public R&D funding allocated to the universities another interesting pattern emerges on the input side. The public Danish research system as a whole has traditionally been characterized by a fairly sharp functional division of labor between the academic oriented universities on the one side and the more mission oriented GRI sector on the other (Christiansen and Sidenius 1988). The two sectors were almost equally sized and followed a very similar growth pattern up until the early 1990s. As a result of this division of labor, and the proliferation of small institutes, the public research system as a whole was perceived as too fragmented and it was in particular seen as a problem that almost half of the public research took place in the GRI-sector which according to critics were dominated by too small units, unclear quality criteria and non-standardized frame conditions (Aagaard 2011).

However, from 1993 and onwards a significant shift in funding towards the university sector can be observed. In addition, the establishment of the first Ministry of Research in 1993 meant that the conditions for the GRI research became more standardized across sectors and that higher demands on management and quality assurance were placed on the institutes. Academic quality and international publishing was accordingly increasingly emphasized within most GRIs. This development was further strengthened with the comprehensive mergers taking place in 2007, where the Government reduced the number of universities from twelve to eight and transferred 12 out of 15 GRIs to one of the eight remaining universities - in reality closing down the majority of the GRI sector (Aagaard 2011). The result was a large concentration of resources within a few select institutions, and also a clear break with the former division of labor between academic research and the more applied GRI research (Aagaard 2011).

From Figure 4.18 one could get the impression that the continuous rise in the university share of the public research funding from 2000 and onwards, and especially the marked rise around the mergers in 2007, influences the publication output in this period. This is indeed possible, but it would most likely only be a small and derived contribution. Notice, that this is also the period where the Danish R&D expenditures increase considerably as a result of the Globalization Strategy, and also as analysed in chapter 6 in this report at the same time as a PhD-reform is implemented effectively doubling the number of doctoral students in the natural and medical sciences. These factors all lead to more researchers and eventually more publications.

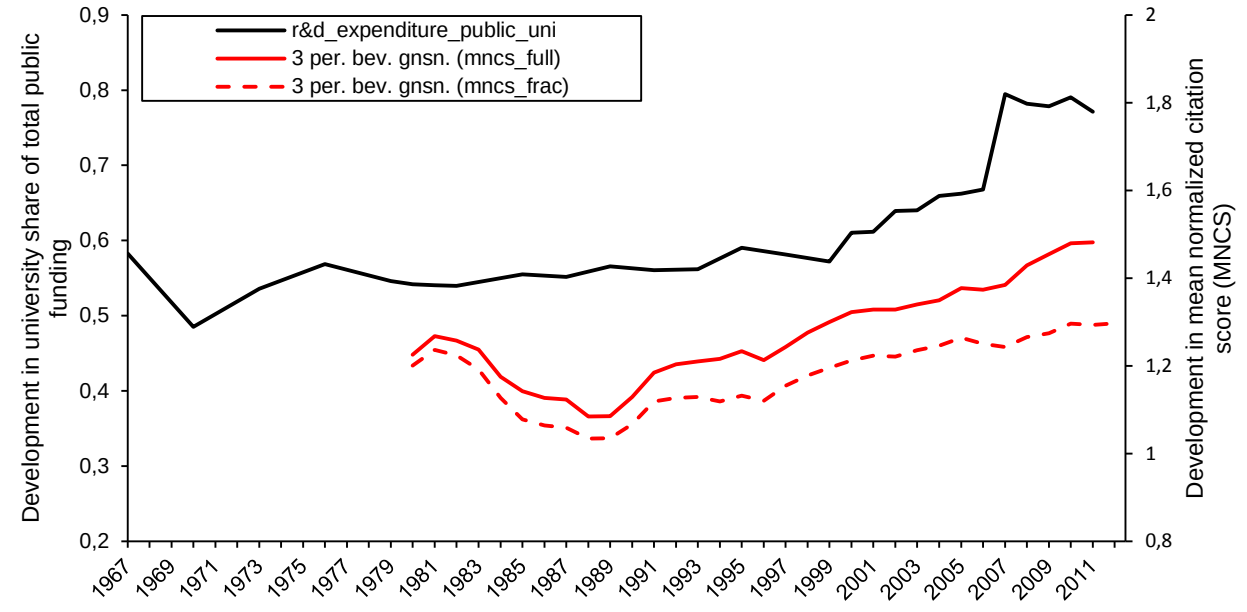
Figure 4.18: Development in the university share of total public funding (primary y-axis), compared to the development in absolute publication output, full and fractional counting schemes (secondary y-axis).



Sources: Lauridsen & Graversen (2013) and CI-WoS, CWTS, Leiden University, Netherlands.

Also when we look at the relationship between the share of university funding and impact, correlations are hard to identify as Figure 4.19 shows. It is evident that both the drastic drop in impact and the first part of the subsequent increase takes place in a period with no major changes in the balance between the two sectors. However, the strong prioritization of university research at the expense of GRI sector may be a contributing factor to the increase in impact towards the end of the period.

Figure 4.19: Development in university share of total public funding, (primary y-axis), compared to the development in MNCS for journal articles in WOS (secondary y-axis).



Sources: Lauridsen & Graversen (2013) and CI-WoS, CWTS, Leiden University, Netherlands.

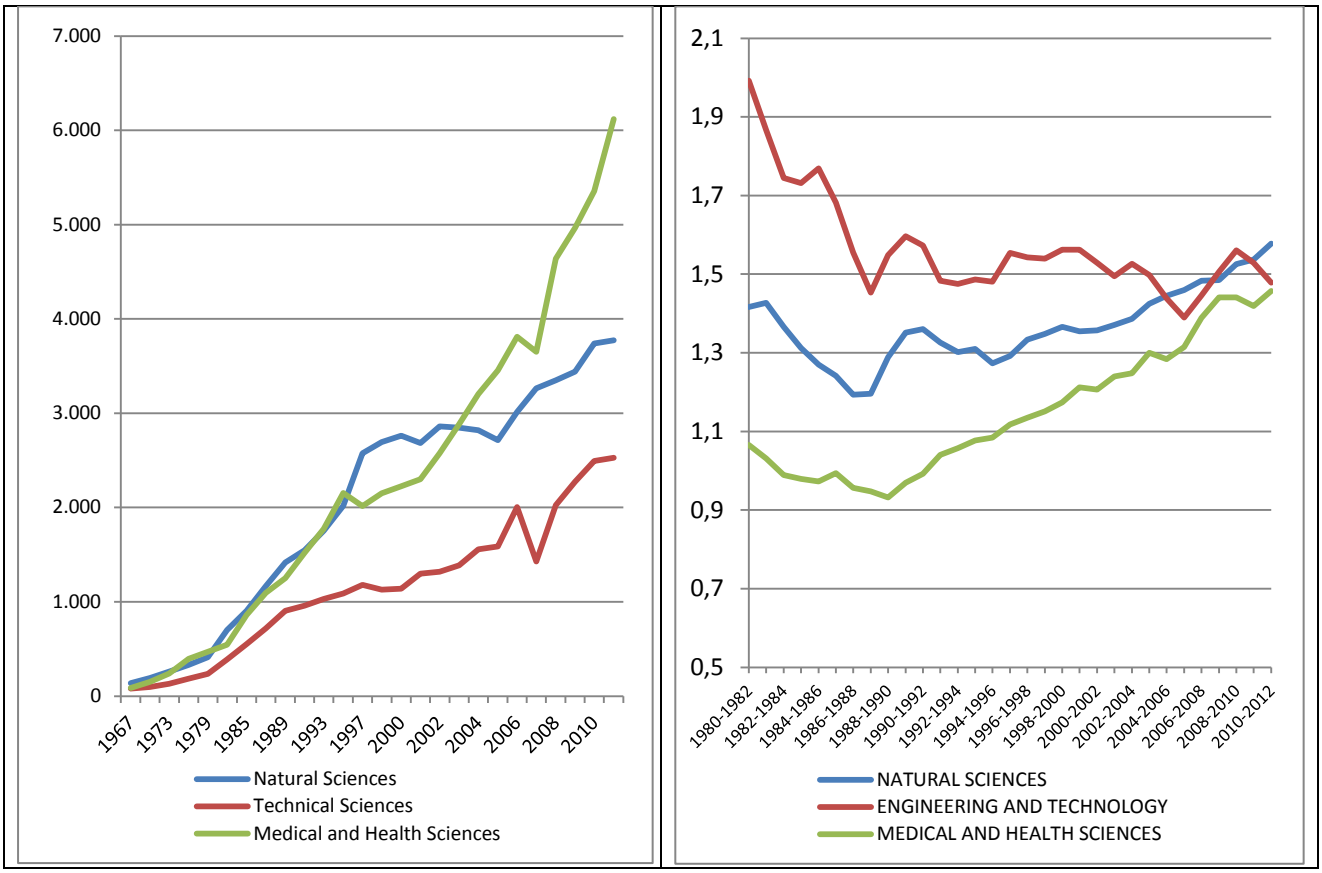
Relationships at fields levels

However, as mentioned above important differences (and potentially clearer relationships) may be hidden beneath the aggregated national level. In this final part of the national Danish analysis we therefore take a brief look at the developments at fields-level. Again we mainly look for two types of relationships: 1) between funding volume and impact; 2) relationships between the share of project funding and impact.

Figure 4.20 below shows the development in overall funding levels for the three main scientific fields which constitute the vast majority of Denmark's contribution to the Web of Science database that forms the foundation for the bibliometric measures used in this report. Next to this, in figure 4.21, we show the corresponding development in impact for the same three fields. Notice however that comparisons between fields should be made with caution with regard to aggregated citation scores (see Schneider and Aagaard 2015 and chapter 1 in this report for further details).

Fig 4.20: Funding volume at fields-level: Current prices, in 1000 DKK

Fig. 4.21: Development in MNCS at fields-level



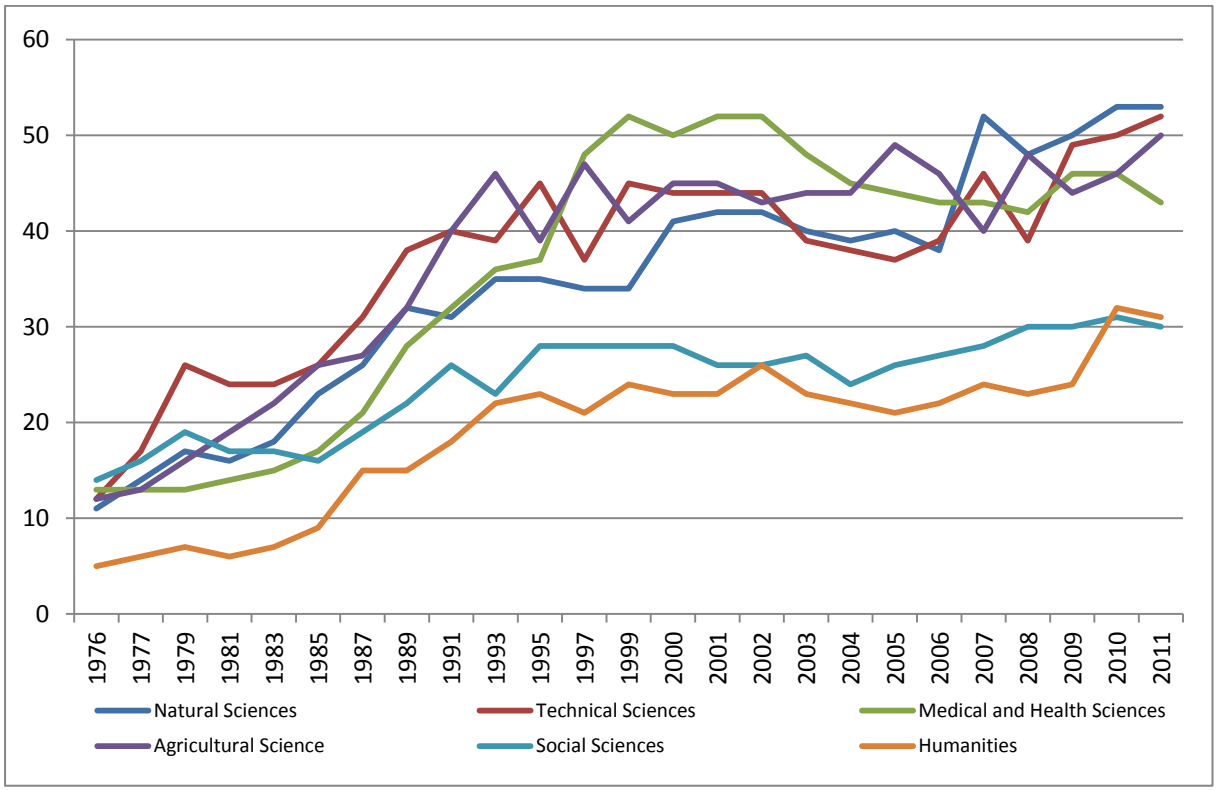
Sources: Lauridsen & Graversen (2013) and CI-WoS, CWTS, Leiden University, Netherlands.

At this level we find some indications of a relationship between developments in funding levels and impact. The medical and health sciences has by far experienced the most positive development in both funding and impact, while the technical sciences have experienced the most modest funding growth and also displays a negative and then stagnating trend in performance (all figures are shown in running prices and the increase in funding therefore appear steeper than it actually is). Two things are however important to notice before we jump to conclusions on this relationship. First, the starting point is of high importance: The technical sciences performed extremely well by the early

1980s while the Medical and Health Sciences started out at a more mediocre level. So even though the field of Technical Sciences has experienced a substantial drop it has stabilized at a very high level. Similarly, improvements were easier to attain for the Medical and Health Sciences due to the relatively low starting point. Secondly, the Danish research system was fairly small at the early 1980s meaning that the rise or fall of a few very strong research groups could influence the development in impact at fields-level to a substantial degree.

If we then turn to the development in the share of project funding at fields level we can observe quite large differences between the different fields as Figure 4.22 shows. The differences are however most noticeable between the Social Sciences and the Humanities on the one hand and the other fields on the other.

Figure 4.22: Share of project funding at fields level



Sources: Lauridsen & Graversen (2013)

As the fields with a relatively low share of project funding are of very limited importance for the overall development in impact we have left them out of the following analysis. Again we therefore concentrate on the three largest fields only.

Figure 4.23: Share of project funding at fields level

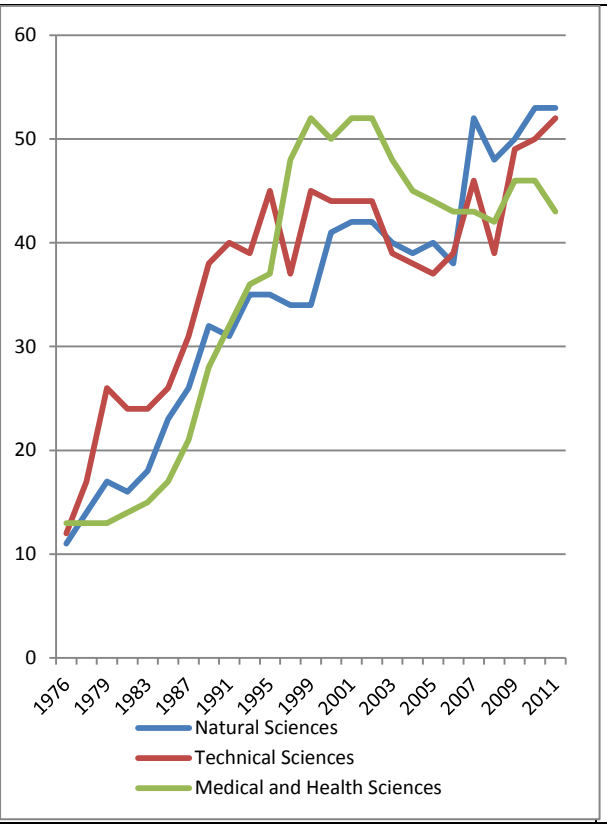
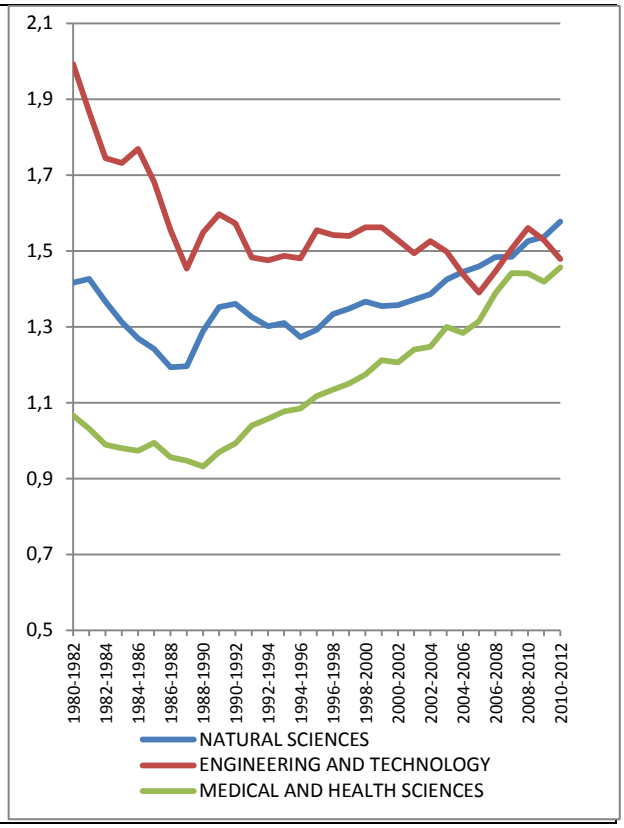


Figure 4.24: Developments in MNCS at field level



Sources: Lauridsen & Graversen (2013) and CI-WoS, CWTS, Leiden University, Netherlands.

As Figure 4.23 shows these three fields have experienced very similar developments in the share of project funding. When we look at these three fields only we observe that the shift towards a larger share of project funding has been more dramatic here than for Danish system as a whole. In particular the period from the late 1970s to the early 1990s saw an increase in project funding from a very low level to between 40 and 50 percent. Again we see that the period of the most dramatic increase in project funding corresponds to a substantial drop in impact for all three fields. It is however, important to notice that all other differences in the development of impact for the three files appear to be difficult to relate directly to the share of project funding. It is also important to notice that the reverse of the negative trend related to impact occurs before the shift towards project funding peaks for the first time in the mid-1990s. We also observe that a second peak in the share of project funding can be seen in the late 2000s. But overall, we cannot find support for the claim that changes in share of project funding translate directly into changes in impact – not even at this more detailed field level. We do however find support to the more general claim, that dramatic transition periods with great instability in funding may have consequences for developments in citation impact at an aggregated level. Again, to have a strong argument for this relationship we need to include additional factors.

Conclusions based on the detailed Danish analysis

Overall, our analysis highlights the difficulties in explaining performance, i.e. publication productivity and citation impact, as a linear function of input-factors. When the factors are analyzed in isolation only the relationship between the development in funding and the publication volume appear to be relatively straightforward, while all other interpretations are more tentative and elusive.

However, it is also obvious that the funding changes interact with other policy changes and that the effects of single factors seldom can be isolated in complex, multi-level research systems. We return to this point in the integrative analysis presented in the main report.

4.8. Summary of findings

When we look at the relationship between funding and academic performance in a cross country comparative perspective very few clear patterns emerge. This is hardly surprising giving our knowledge of previous studies – as outlined in the literature review in chapter 2.

Even among comparable countries such as Denmark, Sweden, and the Netherlands we find noticeable funding-differences, but no clear links to the developments in performance. But if we include other high performing countries such as the U.S. and Switzerland it becomes even more evident that very different types of funding systems all may produce high impact research. Switzerland (which for decades has been even stronger performing than Denmark and the Netherlands) has a very high share of institutional funding. The U.S. on the other hand (which since WW2 has been the world's scientific superpower) has hardly any institutional funding. We must accordingly conclude that the balance between institutional funding and project funding is too crude a measure to really capture the important dimensions.

Also here it is however interesting to notice that several models may lead to high impact within countries over time. Denmark, for instance, showed high performance both in 1980 and again from around 2000 onwards, but the underlying funding configurations and research governance systems of these two periods differed fundamentally. Even within one country multiple balance points with regard to both competition and share of funding allocated to the university sector can thus be found over time. In continuation of this, it is also interesting to notice, that while several models may lead to high impact, drastic shifts from one system type to another may have negative consequences – at least in the short run until a new equilibrium has been found. This finding thus supports the claim that stable funding appears to be important. But stable funding is most likely not a sufficient condition to achieve high performance. To understand impact trajectories we also need to look elsewhere.

However there are other factors which limit the possibilities of drawing clear causal conclusions between funding and performance. Drawing on Aagaard and Schneider (2015) we interpret the unclear relationships as the result of several interrelated factors:

First, the factors influencing performance are highly interconnected in multi-level systems with complex paths from changes in input-factors at a macro-level to the changes in individual and group level behavior which eventually constitutes the basis of the developments in national publication productivity and performance. In addition, the question of lags between changes and their effects is far from straightforward. Different policy changes may have different lags as we have argued and these changes most likely often have both immediate and long term effects. Second, some of the potential explaining factors are most likely only conducive to performance within a certain range and under certain contextual circumstances, meaning that both too much and too little of a certain factor may have negative effects. Most relationships are in other words most likely non-linear. In addition, as we have shown multiple balance points may lead to well-functioning systems. Third, some factors are difficult to quantify, but may be equally important. Fourth, the allocation of citations to publications is highly skewed. Our data shows that in a Danish context over the period a

stable 60% of the total number of citations within a given field are given to the highest scoring top 10 percent of all publications within this field. Thus, only a limited part of the overall system makes a big difference for the overall national ranking, and this high performing part of the system is most likely more independent of changes in frame-conditions due to better access to external funding, a higher degree of autonomy, focus on beneficial publication behaviors, benefits from existing cumulative advantages etc. Fifth, most of the high impact publications are the result of international collaborations. As have been argued elsewhere, internalization may soften the consequences of changes in the frame-conditions of one country due to cross country spill overs (Crespi & Geuna 2008; Leydesdorff & Wagner 2009). Small countries such as Denmark benefit the most from this internationalization, but are also most vulnerable to changes within other countries. Less internationalization in the 1980s may explain why potential relationships between input and output factors are more visible in the first part of the period. And finally, sixth, clinical medicine constitutes a very large part of the research covered by WoS, but at least in a Danish context this part of the research system is partly detached from overall science policy framework due to its location at the hospitals and due to rich private funding opportunities.

All these factors challenge the attempts to uncover clear causal relationships between input and output factors at an aggregated level. As we have argued, it is indeed possible to gain a better understanding of trajectories and turning-points in specific political and historical contexts. We can for instance learn how a certain mix of factors in a given situation created the foundations for high impact. While these lessons not are directly transferrable from one context to another, they do improve our general understanding of the mechanisms at work in complex science systems. However, to identify universal relationships of this kind irrespective of time and place based on model-approaches is in our view not achievable.

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Appendix 4.1: Overhead mechanisms in Denmark, Sweden and the Netherlands

Overhead: Mechanisms for covering indirect costs

Overhead is the research institution's mechanism for recovering administrative and facilities costs associated with conducting research and other sponsored activities. Overhead is thus meant to cover indirect costs exceeding the "pure" costs directly applicable to a given project. Overhead rules are often centrally decided for public foundations and institutions, while private funders are free to decide to what extent they are willing to cover indirect costs. We typically find an inverse relationship between institutional funding and degree of overhead: The lower the share of institutional funding, the higher the need for institutions to get indirect costs covered by the funders (or the state).

Overhead rules: Denmark:

Since the early 1980s the Danish universities have operated with a so-called administration-cost of 3.1 percent applied to all externally funded projects – except funding from the research councils. However, with the increasing share of project-funding in the system as a whole during the 1980s, the discussion of how to cover indirect cost became more and more pressing. In spite of the increasing pressure no formal rules were formulated until 1995 where the Ministry of Finance decided that all public funders were obliged to pay a 20 percent overhead on all grants given to university research. The research councils were however compensated for this extra cost, meaning that neither the number nor the size of their grants were affected. Other public funders such as the Danish National Research Foundation were however not compensated. This system was in place from 1995 to 2008.

As a consequence of a further increase in the share of project funding following the so-called Globalization Strategy from 2006 it was in 2008 decided that a new and more transparent overhead system was needed. From 2009 and onwards it was thus decided that all public funders were obliged to pay 44 percent overhead to universities and GRIs and that The Independent Research Council as well as The Strategic Research Council were restricted from demanding more than 10 percent co-funding from the institutions. This time the councils were not compensated with extra funding. It is however important to note that for instance the hospitals not are included in this systems. As in the 1980s the hospitals are still only receiving a 3.1 percent overhead from public funders. It is also important to note that most private funders still refrain from paying indirect costs – and if they do it is mostly in the 5 to 10 percent range.

Overhead rules: Sweden

The overhead issue has also been debated in Sweden throughout the entire period of investigation. Traditionally, external funding had been regarded as 'icing on the cake': it was taken for granted that the institutional funding, which in the beginning of the 1980s was around 70 per cent, would cover all costs for e.g. central administration, premises, libraries and equipment. During the 1980s external funders admitted approximately 1–3 per cent of their funding for covering additional costs at the HEIs, but not costs for premises. In 1990 a parliament decision established that 'full cost coverage' would be uniformly applied across the Swedish HEI system, and the overhead was changed to 12 per cent. Costs for premises were still not included. The external funders and many influential researchers protested against the increase, arguing that the state should, as a principle, fully carry all fundamental costs. In 2001 the parliament adjusted the overhead fee to "at least 18 per cent for

direct project costs plus direct costs for premises". After negotiations between SUHF and external funders, an agreement was reached with most funders to apply 35 per cent overhead from 1 January 2003 to cover all direct and indirect costs. SUHF however calculated that 'full cost coverage' would implicate 52 per cent overhead. In 2005 the Swedish National Audit Office criticised a number of large universities for inadequate book-keeping with regard to overhead costs, and a number of external funders voiced similar opinions. This led SUHF to develop, in collaboration with three large external funders, a common model for all HEIs on how to attribute direct and indirect costs to specific uses (premises, central administration etc.). The model, called the SUHF-model, was introduced from 2009, and since 2010 it has used by practically all Swedish HEIs. The model enables HEIs to attribute direct and indirect costs to specific projects, and thereby to be more transparent towards the external funders. Since the introduction of the SUHF model, the government has ordered all public funders to compensate HEIs fully. The indirect costs for research vary between different HEIs but have oscillated around 20 percent on average. The total 'full cost coverage' is typically around 50 per cent. When funders do not compensate fully, HEIs typically decide from case to case whether or not they accept the project.

Overhead rules: The Netherlands

A large share of the available Dutch project funding is allocated by the Netherlands Organisation for Scientific Research (NWO). Whilst this is an important source for research, NWO only covers part of the total costs of research. The rules have been agreed between NWO, related research councils and the Royal Academy of science and arts and the Association of Universities in the Netherlands (VSNU). They have agreed that funding provided by the research councils encompasses:

1. Personnel costs (wages + additional funding (23%) for costs social welfare, taxes, etc.)
2. Material costs direct related to the research.
3. A basic fee for PhD students (5000 euro for travel arrangements, publications, etc.)

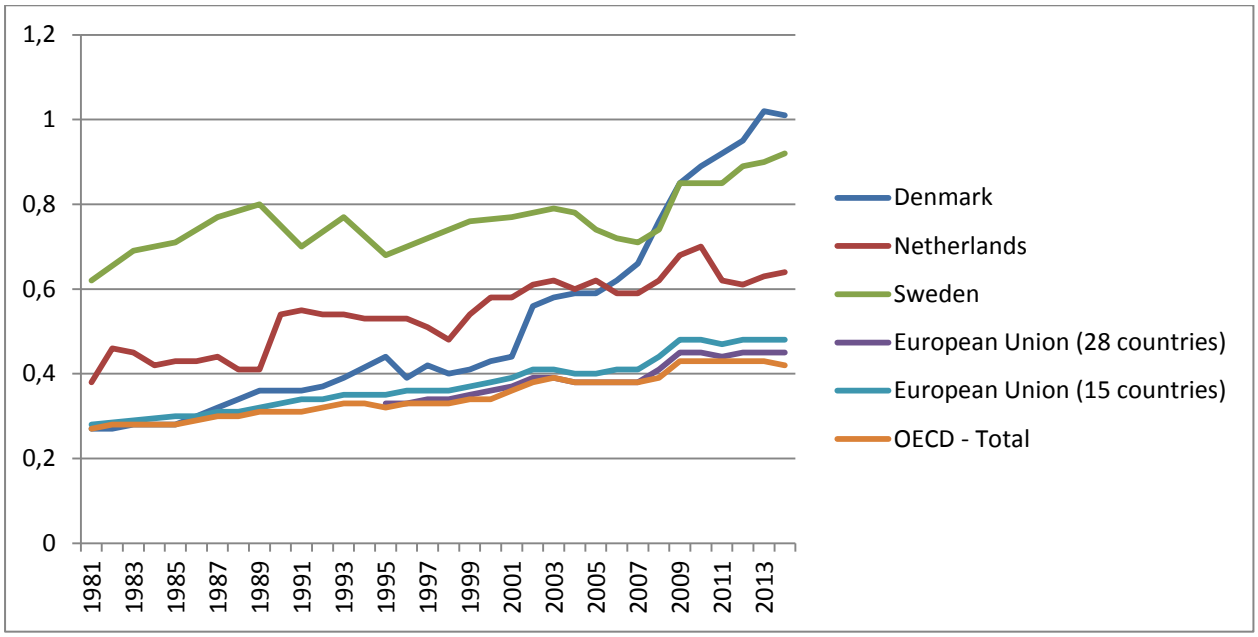
The research institutions are expected to cover the remaining costs (housing, ICT, mentoring, training, etc.) from their institutional funding. This is the so-called matching obligation. According to an analysis of accountants (Ernst & Young), the research councils' funding covers on average around 48% of the full costs while the universities and the research institutes have to pay the remaining 52%. For EU schemes the matching obligation is on average 43%. This matching does not include the costs for preparing and assessing research proposals. In 2014 the amount of institutional funding for research for universities was 1,8 billion euro and the total matching obligation amounted to more than 1,1 billion. That left about 650 million euro 'free money'. This system has been in place for decades and has not changed (substantially) over time.

The situation has led to a long lasting debate in the Netherlands. The Council for Science and Technology (AWTI) and the universities argue that this form of matching is undermining the strength and quality of the Dutch knowledge infrastructure. They argue that especially strong groups will suffer and become victims of their own success (as success will limit the availability of 'free' money and internal strategic funds). NWO is in principle in favour of paying real project costs, with the condition that their total budget will be doubled. If not, the outcome will be a dramatic decrease of the success rate in their funding schemes, they argue. The government however, is not prepared to increase NWO's budget. The Minister of Education, Culture and Science argues that funding of research councils is aligned with the research activities of universities and research institutes and

matching therefore does not hinder the financial autonomy of the universities and institutes (they are free to apply for research funding). In 2014 the Ministry of Education, Culture and Science created an annual matching fund of 50 million euro. This matching fund will only cover matching and co-funding for EU funding schemes.

Appendix 4.2: Developments in HERD for a broader range of countries

HERD for the three benchmark countries in comparison with EU15, EU28 and OECD



Source: OECD MSTI

5. Excellence initiatives

Chapter 5 deals with the impact of so-called excellence schemes. The hypothesis formulated by DFiR first and foremost takes its departure from the observation that the Danish National Research Foundation (DNRF) has been a longstanding and highly regarded element in the Danish research funding system. Previous studies as well as many central stakeholders have pointed at this feature of the Danish system as one of the important factors contributing to the highly positive overall development in national research performance since the early 1990s. The second DFiR hypothesis thus states that supporting "excellent" research groups through Centres of Excellence (CoE) schemes not only benefits "top research" in the funded centres, but also creates a 'spill over' effect to the general benefit of public research. According to the hypothesis the CoEs become "lighthouses" to which other researchers align and they attract the "best" national and international talents. The argument is accordingly that both the CoE schemes in isolation and the indirect effects of these initiatives contribute to a positive development in research performance at an aggregated level.

To investigate this hypothesis this sub-study provides a brief overview of relevant schemes in the three countries. It outlinines the main characteristics of these with regard to size, duration, organization and role in the overall funding system. For all three countries available information on the effects of these schemes will also be discussed and linked to the overall question of the study: to what extent do these schemes play a role in explaining the development in overall research performance in the three countries? As a part of this analysis we also make a comparison of the development in the share of top 1% highly cited papers for the three countries and link these findings to a recently developed approach for detecting potential "breakthrough" articles (Schneider & Costas, 2016). This approach is specifically developed and tested on the basis of validated publications "belonging" to Danish CoEs and peer identified breakthrough research from some of these centers. For Sweden and the Netherlands this part is purely indicative as performance information associated with CoE schemes are scarce, and as we cannot establish a direct link between individual schemes and performance. Hence the analysis examines the countries' ability to produce potential breakthrough research in the time period from 1993 to 2011, and discuss to what extent the share of top 1% highly cited papers give indications of the ability to produce such potential breakthrough research. For the Danish case we do however take a few additional steps in the analysis by linking the CoEs directly to bibliometric data. We thus have an additional section with a number of analyses on Danish data only. In the final section we sum up the overall conclusions with the inclusion of data from the interviews.

5.1. Excellence schemes: Definitions and delineation

Both national and European science systems have witnessed a rapid development and implementation of excellence policies during the last two decades. The result has been a multitude of funding instruments offering selective support for high-performing individuals, research groups or research organizations (OECD 2014, Bennetot and Estermann 2014, Sørensen, Bloch, and Young 2015; Orr et al. 2011; European commission 2009; Malkamaki et al. 2001). The common thread in these policies is the assumption that stimulating a small number of "excellent" performers will have positive effects on the vitality, attractiveness, or productivity of the whole science system (CWTS 2016). These types of initiatives have become popular, with over two-thirds of OECD countries operating such schemes, of which a large proportion was established within the past decade (OECD 2014).

The term research excellence is however poorly defined and delineated in both the scholarly literature and in practice. The so-called excellence schemes across countries thus cover a large and extremely diverse set of initiatives (European Commission 2009). Some instruments support individual researchers (e.g. European Research Council grant schemes, the Dutch Veni-Vidi-Vici program), others support research units such as departments (e.g. the Research Excellence Framework in UK) or entire universities (e.g. the Excellenz Initiative in Germany). Finally, many excellence schemes support different types of centre of excellence constructions (e.g. CoE schemes in Denmark, Norway, Sweden etc.). In addition to the differences with regard to the target groups of the schemes, there are further important differences both within and across the observed groups of initiatives with regard to factors such as size, duration, organization and orientation.

In this study the centre of attention will be at CoE constructions in the three countries. Although CoEs are relatively new policy instruments in most countries, centres as a means to organise research are by no means a new feature in public research systems. These types of centres may emerge through a variety of channels: They may be pushed through dedicated funding schemes; they may be emerging in their own right; or they may be created separately with contributions from actors such as public agencies, industry and universities (Borlaug 2015; Rip 2011). This study is only concerned with the first group. Typically this type of dedicated funding scheme has elements of both institutional core funding and project funding. On the one hand it provides general long-term funds which may be used for research and research infrastructures, as well as the recruitment of researchers and researcher training, and as such it resembles institutional core funding. On the other hand, the funding is still time-limited and the selection is based on application and open competition, much like project funding (OECD 2014, Borlaug 2015).

But even this CoE-delineation covers many types of schemes. CoEs vary in size (from small concentrated units to centres with large budgets), and display differences in organisational structure, and they can be either a virtual centre or an institutionalised research unit (Berman 2012; Aksnes et al. 2012). In terms of organisational structure, these are often more formalised than regular research groups and may have a board of directors and an advisory board, a dedicated centre leader, primary (or principal) investigators and a small administration (Boardman and Gray 2010, Langfeldt et al. 2013). Furthermore, CoEs may cross diverse organisational boundaries such as the department, faculty, university or even sector. Finally, there are also differences in the orientation of the schemes: there are initiatives solely concerned with scientific excellence, but also a large number of schemes aiming to combine scientific excellence and societal impact. While CoE schemes often are highlighted as highly effective instruments, there are however also potential negative effects (CWTS 2016). It is particularly argued that:

- CoEs may have unintended structural effects on the general conditions for performing research and may skew the distribution of resources too much by rewarding already existing strongholds rather than fostering new ones. By amplifying the Matthew effect such excellence policies thus risk increasing inequality. Along the same lines it is also argued that CoEs may impede bottom-up renewal and hamper the establishment of younger scholars as they tend to reward recognizable success rather than early-stage researchers, novel ideas and young research areas.
- CoEs may not fit all research areas equally well. It is argued that the quality criteria used in the competition for funding most often are based on publication practices of the natural

sciences, and that their expected moda operandi are less suitable for social sciences and humanities. The same is also often argued with regard to the size of the CoEs.

- Likewise, it is argued that CoEs may have unintended effects for education, social relevance, public service, technology transfer and entrepreneurship as they risk driving a wedge between research on the one side and education and societal outreach on the other.

Whether and to what extent these potential negative effects may materialize will in most cases depend on a number of contextual factors. Effects of excellence policies may vary strongly across scientific fields due to differences in social organization, communication and publication practices, and epistemic cultures (Hammarfelt and de Rijcke 2014, Hicks et al. 2015) and excellence policies may have different functions in different science systems, even when the policy instruments have broadly similar designs. Crucial variables seem to be the existing distribution of resources in the system, the task division between universities and academic research institutes and typical career patterns (CWTS 2016).

With regard to the present study it can be argued that all types of excellence schemes (whether directed at individuals, groups or larger units) may be of relevance for the aggregated development in performance and that both purely scientific excellence oriented schemes and more societal impact oriented initiatives may play important roles. However, due to the formulation of the hypothesis by DFiR, the given time- and resource constraints, and the wide variety of schemes making direct cross country comparisons difficult, it was chosen mainly to focus at schemes comparable to the Danish National Research Foundation Scheme. We thus have a primary emphasis in this chapter on long standing CoE schemes with an explicit aim of promoting scientific excellence/ breakthrough research/research in the international forefront and which have selection criteria focused on this. Schemes more oriented towards societal significance will only be described briefly.

5.2. Overview of Schemes

CoE schemes aiming for scientific excellence have become a core feature in a number of research funding systems during the latest decade – not least in the Nordic countries including Denmark and Sweden, albeit this has happened with significant differences in design and timing. The trend has only to a lesser extent been observed in the Netherlands where other types of excellence schemes have played more important roles. The following sections outline the main characteristics of the relevant schemes in the three countries.

5.2.1. Denmark:

In Denmark politically induced research centre constructions started to emerge during the 1980s as a result of a number of large scale strategic research programs. The centres were established in a variety of forms, but they were all to some extent related to politically selected areas of strategic importance. But even before that the Danish research system had important research centres of excellence which rather than being established as the result of political programs emerged in their own right (often with substantial support from private foundations). Niels Bohr's and August Krogh's research centres are prime examples here and as such this type of organization has been an integrated part of Danish science for at least a century.

However, the first large scale Danish CoE Scheme solely concerned with promoting scientific "excellence" was established in 1991 and implemented from 1993. The DNRF was created as an independent organization by the Danish Parliament with the objective to promote and stimulate

basic research at the highest international level at the frontiers of all scientific fields. While the foundation has other smaller schemes, the CoE program was from the beginning the primary funding mechanism and the flagship of the foundation. A CoE grant from DNRF is large and flexible, and a center may have a lifetime of up to 10 years. The objective of the CoE scheme is to strengthen Danish research by providing the best possible working conditions and organizational set-up for selected top researchers. The scheme does however also target internationalization, research management, research training and recruitment. Researchers are awarded a CoE through a two-stage application process. At its establishment, the DNRF received a start-up capital of approximately 268 million Euro. The annual level of distribution aims at an average of approximately 54 million Euro corresponding to about two percent of total public Danish research expenditure. Since its establishment, the DNRF has supported Danish research with approximately 830 million Euro – mainly allocated between a total of 100 CoEs. 47 of these centres are currently active. (Evaluation of the Danish National Research Foundation 2013).

While the scheme today stands out as a fully integrated part of the Danish research funding system it was a significant break with the past when it was implemented in the early 1990s. In 1993 and the following years this initiative thus played an important role in a general academic reorientation of the Danish system after a decade dominated by strategic research. It is, however, noticeable that the DNRF was placed as an independent foundation outside of the traditional research council system which was distrusted by the political system.The DNRF has recently been evaluated by an international panel and received a very positive overall assessment. We will return to this scheme and its effects on Danish national research performance in the final part of this chapter.

Although the DNRF by far has been the most significant foundation supporting research excellence in the Danish system, other schemes have been implemented as well. Most of them are however quite recent and have only played important roles in the system as a whole during the last 5-10 years. The tables below are modified from Aksnes et al 2012.

Table 5.1: Other publicly funded CoE-like initiatives

Instrument	**Actor**	**Since**
UNIK (Investment capital for University Research): Funding allocated through competition between universities. Aims to develop elite research.	Danish Agency for Science, Technology and Innovation	Announced in 2007. Funding amounting to DKK 480 million, allocated to four projects at three universities. 5 years of duration from 2009.
Strategic research centres: Funding from DKK 30 million, for 5-7 years.	Danish Council for Strategic Research	First grants approved 2006.
SPIR (Strategic Platforms for Innovation and Research): Funding from DKK 60 million, for 5-7 years.	Joint initiative between the Danish Council for Strategic Research and the Danish Council for Technology and Innovation	First grants approved 2010.
Sapere Aude: Researcher career program for the elite. Three purposes: 1) strengthening young research talents, 2) more female researchers at the top, 3) launching point for research elite.	The Danish Council for Independent Research	Announced first time 2010.

However, in addition to the public Danish initiatives a number of large private Danish foundations have also to an increasing degree started to support large scale centres with clear CoE traits. Also this trend is quite recent and has only played an important role during the latest decade.

Table 5.2: Most important privately funded CoE-like initiatives

Instruments	Actor	Since
Centres of Excellence	The Lundbeck Foundation	15 grants decided 2005-2009 within medical and natural science. Grants are between 25 and 100 million DKK for a five year period.
VKR Centres of Excellence	The Villum Foundation	11 grants since 2004 to natural and technical science. Grant sums between 25 and 33 millon DKK typical for a 5 year period.
Research centres	Novo Nordic Foundation	Since 2007, the Foundation has awarded DKK 3.5 billion (€469 million) for establishing four large research centres and the Danish National Biobank

5.2.2. Sweden

CoEs in the form of research centres for strategic or needs-motivated research have a fairly long tradition in Sweden, and combine aims to promote excellence with the intention to be relevant for industry or society. CoEs focusing entirely on scientific excellence (and basic research) are however a more recent phenomenon.

The first Swedish strategic research centres were established in 1990, when the Swedish Board for Technical Development (STU) in collaboration with the Swedish Research Council for Natural Sciences (NFR) launched eleven Materials Consortia. Through supporting scientifically excellent and industrially relevant centres for ten years, the aim was to break new paths within Swedish materials science. The Materials Consortia were generally viewed as successful, which paved the way for the Competence Centre (CC) programme in 1995. Funded for ten years, 28 CCs were established across the technical, natural and medical sciences, each having one third of the funding from public agencies, one third from host universities (in kind) and one third from industry (both cash and in kind). Participants and external reviewers regarded the CC programme as a success, which led its main funder, VINNOVA, to launch a very similar programme, VINN Excellence, when the CC programme ended. Its other funder, the Swedish Energy Agency, continued funding six CCs. Virtually all other large funders of strategic and needs-motivated research have funded research centres as well. In 2003 the Strategic Research Foundation (SSF) initiated CoEs in microelectronics and the life sciences focusing more or less on basic research, an initiative which after a few years was expanded to include all kinds of technical and medical research. The Knowledge Foundation (KKS) has since around 2005 funded collaborative research centres at university colleges in order to build research excellence in specific research areas, while the Knut and Alice Wallenberg Foundation (KAW) and the Swedish Foundation for Strategic Environmental Research (MISTRA) have funded large, single CoEs in areas of strategic importance such as neuroscience, forestry science and environmental resilience.

In 2005 the first CoEs with a pure focus on basic research were established, as the Swedish Research Council (VR) and the research council Formas launched a number of small-scale CoEs. The next year the only Swedish programme funding large CoEs in basic research was launched, the Linneaus Centres. Two rounds in 2006 in 2008 funded in total 40 CoEs for ten years each with 12 MSEK per year and CoE. Also the research council Forte launched a programme for CoEs in basic research around the same time. Unlike CoEs in strategic and needs-motivated research, CoE programmes in basic research have by and large been the outcomes of the political will expressed in the research

bill 2004/2005, rather than initiatives driven by the funders.[2] This in particular concerns the Linneaus Centres.

Table 5.3: Key Swedish CoE schemes

Programme	**Funder**	**Focus**	**Time period**	**CoE-duration**	**Total budget (MSEK)**	**Budget per year (MSEK)**	**Number of CoEs**	
Material Consortia	STU/Nutek and NFR; SSF (1998-)	Excellence and user relevance	1990-2001	10	400	50	11	Industry co-funding required from 1995
Competence Centres	Nutek; VINNOVA and STEM (2001-)	Excellence and user relevance	1996-2006	10	1447	168	28	Industry co-funding required
Strategic Research Centres, Life science	SSF	Excellence and user relevance	2003-2008	6	348	58	6	
Strategic Research Centres, Microelectronics	SSF	Excellence and user relevance	2003-2008	6	282	47	6	
Strong research environments	VR	Excellence	2005-2010	5	220	44	10	
Strong research environments-1	Formas	Excellence	2005-2010	5	125	25	5	
KK-profiles-1	KKS	Excellence and user relevance	2005-2011	6	252	42	7	Industry co-funding required
Strategic Research Centres	SSF	Excellence and user relevance	2006-2010	5	800	160	17	
VINN Excellence Centres-1	VINNOVA	Excellence and user relevance	2006-2015	10	280	28	4	Industry co-funding required
Linnaeus Grants-1	VR and Formas	Excellence	2006-2016	10	1500	150	20	
Competence Centres	STEM	Excellence and user relevance	2006-ongoing	ongoing	n/a	45	6	Industry co-funding required
VINN Excellence Centres-2	VINNOVA	Excellence and user relevance	2007-2016	10	1050	105	15	Industry co-funding required
Berzelii Centres	VR and VINNOVA	Excellence and user relevance	2007-2016	10	400	40	4	Industry co-funding required
Forte Centres-1	Forte	Excellence	2007-2017	10	570	57	10	
Linnaeus Grants-2	VR and Formas	Excellence	2008-2018	10	1390	139	20	
Forte Centres-2	Forte	Excellence	2008-2018	10	150	15	3	
Strong research environments-2	Formas	Excellence	2009-2014	5	175	35	7	

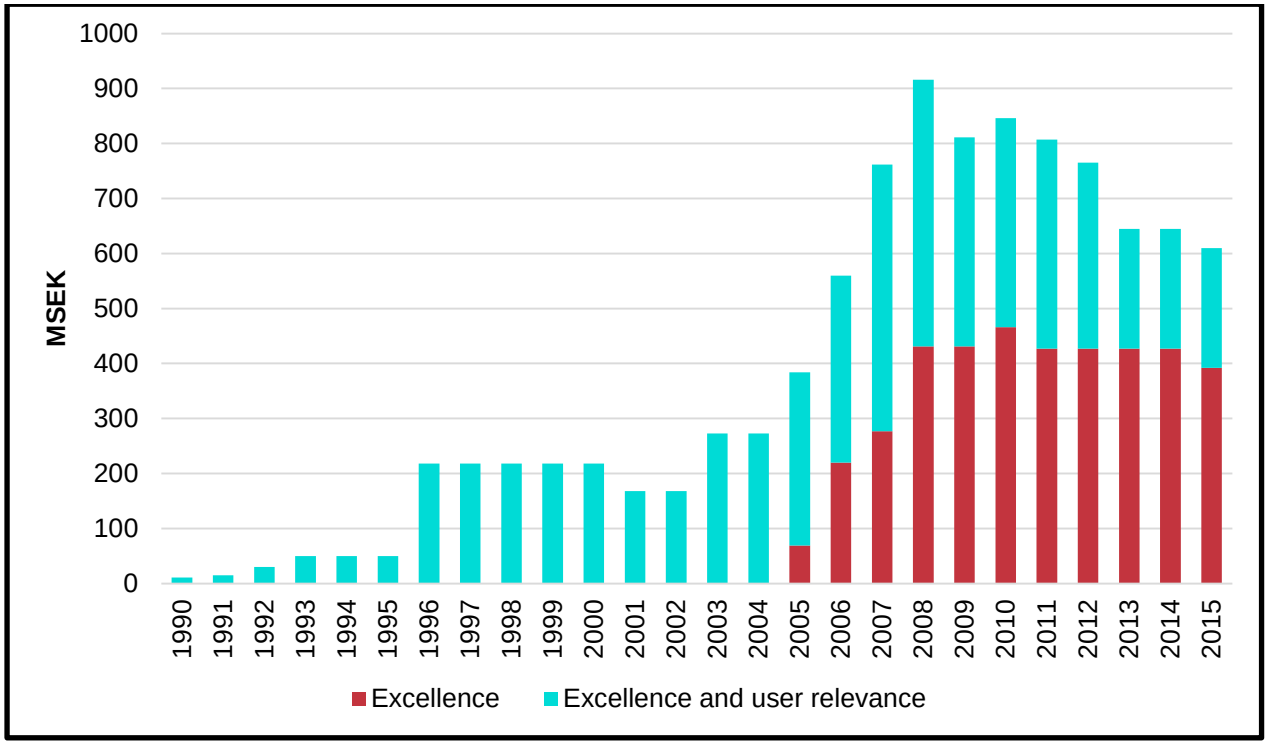
[2] Prop. 2004/05: 80. "Forskning för ett bättre liv". Swedish government.

Strong research environments-3	Formas	Excellence	2011-2016	5	150	30	6	
Total					9539		185	

Note: Not included are: KK-profiles funded after 2005, STEM's competence centres established/re-classified after 2007, large single centres such as Stockholm Resilience Centre (MISTRA), Swedish Brain Power (KAW, VINNOVA and others), a centre for molecular biology at UmU (VR), SAFER at Chalmers (VINNOVA and others), and KAW's centres in Human Proteomics, Wood science etc.

At the time of writing, the CoE concept again appears to be marginalised in the Swedish policy debate. After a peak around 2005–2008 when a number of (basic research) CoE schemes were introduced, current excellence initiatives mainly focus on funding single researchers or smaller groups. The fading interest in CoEs is shown in Figure 5.1. It may however be argued that CoE schemes to some extent have been replaced by 20 so-called strategic research areas, introduced in 2008 by the Swedish government. The initiative implicates funding to research areas of strategic importance for Sweden, in particular areas where Swedish research is held to be strong. Most of these areas are shared between several universities, which receive funding directly from the government. An evaluation after four years of activities concluded that only a third of the research areas fulfilled the aim of internationally leading research, although some of them were leading already at the outset. Half of the environments were judged as promising, while the remaining 20 percent struggled with both research quality and strategies.[3]

Figure 5.1: Funding to CoEs in Sweden, yearly estimates (current prices).



Sources: Stenberg, Lennart (2008). Starka Forsknings- och innovationsmiljöer i Sverige: Utmaningar för Sverige i en globaliserad värld. Kungl. Ingenjörsvetenskapsakademin. Stockholm. Sandström, Ulf, Agnes Wold, Birgitta Jordansson, Björn Ohlsson and Åsa Smedberg (2010). Hans Excellens: om miljardsatsningarna på starka forskningsmiljöer. Delegationen för jämställdhet i högskolan. Stockholm. Lundequist, Per and Anders Waxell (2010). Regionalizing "Mode 2"? The adoption of Centres of Excellence in Swedish research policy. Geografiska Annaler: Series B, Human Geography 92 (3): 263–279. Websites and annual reports of funding agencies.

[3] Swedish Research Council (2015). Evaluation of the Strategic research area initiative 2010–2014. Stockholm: Vetenskapsrådet

The CoE programmes for strategic or needs-motivated research have generally been positively evaluated. The research quality has in most cases been regarded as high, and the programmes have been very important in deepening and broadening relations between universities and industry. Their impact is particularly visible in the gradually improved management of collaborative research projects, also of more basic character, and in providing industry with PhDs who understand both academic and industrial research processes.

Also the half-time evaluations of the Linneaus Centres have been positive about in particular the research quality, which has been high and in some cases world-leading, and the PhD education, but many centres have been criticised for weak leadership and insufficient international recruitment. An investigation into a number of CoE programmes in basic and strategic research even concluded that the CoEs appeared to have a negative impact on the publication performance of their leading researchers (Linneaus Centres were not studied though) and that the schemes allocated a disproportionate share of funding to men (Sandström, 2010). Another report which studied a selection of Nordic CoEs including a number of Linneaus centres on the other hand reported increased impact as a result of the schemes (NIFU, 2013). Both studies were however based at a very selective sample of centres. A mid-way evaluation of the Linnaeus centres funded in 2008 was published in 2014 by Vetenskapsrådet. 20 centres were included and the bibliomtric analyses do not at this point show any indications of increased citation impact. While the centres perform very well they do not appear to have improved their performance after the funding was received. The end-evaluation may show another picture, however (Vetenskapsrådet 2015).

5.2.3. The Netherlands

As was the case with Sweden the development of excellence initiatives in the Netherlands has differed somewhat from the case of Denmark. Also here the large-scale CoE schemes have had strategic and innovation-oriented research areas as their main target rather than pure scientific excellence. However, unlike Sweden, the Netherlands have had a prominent long lasting scheme with a very strong emphasis on scientific excellence at the individual level: The Innovational Research Incentives Scheme administered by NWO.

The Dutch advisory council for Science, technology and Innovation (AWTI) produced a report in 2007 on strategic investments in so-called focal points. The council distinguished between three different focal points

- The first focal point for scientific excellence encompasses policies that stimulate specific scientific areas in which the Netherlands can excel. The rationale behind this is that the Netherlands, a relative small country, has to pick and choose scientific areas in order to create excellence. Choosing specific areas will lead to more (international) visibility, attract the best scientists and stimulate economies in scale (e.g. in terms of use of infrastructure). Currently the NWO (Netherlands Organisation for Scientific Research) has an important role in defining and funding scientific excellence.
- The second focal point is concerned with promising economic areas and encompasses policies stimulating innovation and competitiveness. Currently the Ministry of Economic Affairs coordinates and funds most of the initiatives in this area, mostly concerning R&D-project and PPPs.

- The third and final focal point is concerned with social challenges and includes research & development activities targeted to finding solution to social challenges (e.g. health, safety, environment, education).

However, the intiatives concerning these three focal points seldom exist in isolation. They often strengthen each other. For example, research & development activities in water management are meant to stimulate scientific excellence, improve the competiveness of the Dutch water sector and address environmental issues.

Although the Dutch policy for excellence initiatives is fragmented, the total amount of additional funding generated by these initiatives together is substantial. The table below summarizes the main initiatives from 1998. Some notes on the table:

- Some of the initiatives overlap in terms of funding.
- Although the top sectors has a seemingly large budget, large part of the funding is reallocated from other research/innovation funding to these specific nine sectors.
- The sectors with most funding are Life Sciences & Health + High tech systems & materials
- Most initiatives target specific sectors & PPP. The main exceptions are: The Bonus Incentive Initiatives, The Innovational Research Incentives Scheme & the NWO funding. Of these the Bonus Incentive Initiatives really targets unbound fundamental research.

Table 5.4: Key Dutch CoE (or CoE-like) schemes

Name + period	**Funder(s)**	**Grant size**	**Criteria to get funded**	**Type/aim**
Bonus Incentive Scheme (BIS) From 1998- Currently continued as "gravitation"	Ministry of Education, Culture and Science	50 milion per year. 6 research school have been funded	Selection on quality and excellence. Not bound to themes or applied research.	To identify and encourage national concentrations of outstanding scientific research in top research schools. It's one of the few instruments that allows for unbound fundamental research.
Innovation-oriented research programme (IOP) 1979 – current.	Ministry of Economic Affairs	Average subsidy of 2 x EUR 8 million for a period of 2 x 4 years 24 IOP's have been funded	- Through Calls for Proposals, selection in two rounds.	To enhance fundamental strategic research in the public infrastructure in a direction that is in line with industry's innovation requirements.
Top Technology Institutes (TTIs) 1997 - 2005	Ministry of Economic Affairs, the private sector, universities and research centres.	Four TTIs were established in 1997 and funded for a period of 2 x 4 years, with a two-year extension. The TTIs received an average of around EUR 5 million per year. In 2005 another 4 institutes.	Selection TTI's: - Bottom-up selection by a commission - Two criteria: scientific quality (excellence) and technological/ economical relevance.	To enhance the innovative capacity and competitive position of Dutch industry by focusing excellent scientific research on areas which are relevant to industry and by increasing industry's influence on determining the research agenda.
Top Social Institutes From 2005	Ministry of Education, Culture and Science	4 institutes have been funded with an initial grant of +/- 5 million		The aim of the MTIs is to improve alignment between excellent scientific research projects concerned with social issues and challenges.
BSIK incentive (ICES/KIS-3) 2004	FES (Economic Structure Enhancing Fund).	EUR 800 million has been invested through BSIK in 37 projects with terms varying from 4 to 6 years.	Project proposals submitted in relation to five strategic themes:	The main aim of the scheme is to create high-quality networks in the knowledge infrastructure and to identify and encourage promising areas of research
FES	FES (Economic	2005: 500 million for 21	As with BSIK, the ICES/KIS	Aim was to encourage innovation

incentives 2005 & 2006	Structure Enhancing Fund). A fund investing in project of national economic importance.	projects (1 project was 130 million) 2006: 300 million for 8 projects (1 project was 150 million)	Expert Committee played an advisory role in the selection procedure, in partnership with the Netherlands Bureau for Economic Policy Analysis. No prior investment framework with thematic priorities was established and no invitations to submit proposals are published.	programmes and top-level research, with the aim of enhancing the knowledge infrastructure in the Netherlands.
Smart Mix 2006-2007	Ministry of Economic Affairs & Ministry of Education, Culture and Science (50/50)	100 million for 7 programmes with a duration of 4 to 8 years.	No themes or priorities were defined in advance.	The Smart Mix instrument was terminated after a single round in 2006-2007. Smart Mix had two objectives: *to create social and economic value* and *to enhance 'focus and mass' in excellent scientific research*
Innovation programmes in key areas Since 2005	Ministry of Economic Affairs	Six innovation programmes with an average subsidy of around EUR 50 million. These key areas often also receive money from other funds (e.g. the FES fund)	Innovation programmes in key areas are developed bottom up and the parties concerned take the lead themselves. After the minister of Economic Affairs agrees with the agenda, the consortium is asked to set up an innovation programme.	The key feature of the programmed approach to innovation is that *innovation programmes are initiated in fields that are strategically important to the Netherlands and in which the Netherlands already has a relatively strong position*.
Innovational Research Incentives Scheme From 2000 – modified in 2008	Ministry of Education, Culture and Science & NWO	100 million of basic funding was transferred structurally to this scheme implemented by NWO, who added another 50 million. Researchers can apply for a maximum of 250,000 euros for Veni, 800,000 euros for Vidi, and 1.5 million euros for Vici.	Veni, for researchers who have recently obtained their PhD Vidi, for researchers who have gained several years of research experience after their PhD Vici, for senior researchers who have demonstrated an ability to develop their own line of research	The Innovational Research Incentives Scheme offers personal grants to talented researchers. The funding enables applicants to do their own line of research. The Innovational Research Incentives Scheme comprises three grants geared to different stages in a researcher's scientific career:
National Roadmap Large-Scale Research facilities Since 2008	Ministry of Education, Culture and Science & NWO	2012 – 2014: 80 million 2014: 75 million	The proposals are assessed for scientific quality, importance for innovation, importance for the Netherlands, and quality of the setup. Financial and technical criteria are also assessed.	The National Roadmap Large-Scale Research facilities aims to strengthen the scientific position of the Netherlands by encouraging the development and construction of large-scale research facilities.
Top sector policy Since 2012	Funding stems from different sources.	1.5 billion euros of research funding from different sources is earmarked for the topsectors.		The top sector approach is geared towards providing a solid exchange between businesses, knowledge institutes and the government. The government has chosen nine top sectors: Water, agri-food, horticulture, high-tech, life sciences, chemicals, energy, logistics and creative industries.

As shown in the table above, the Dutch excellence and center policy must be characterized as diverse and very much oriented towards strategic or societal goals. Long lasting schemes targeting pure scientific excellence in CoE constructions are rare. The Bonus Incentives Scheme (which we describe in the chapter on PhD education) and in particular the Innovational Research Incentives Scheme are however exceptions. In contrast to the Danish CoEs the Innovational Research Incentives scheme is directed towards individual researchers rather than towards large scale centres. The scheme which later inspired the Danish Sapere Aude scheme has three steps: Veni, for researchers who have recently obtained their PhD, Vidi, for researchers who have gained several years of research experience after their PhD, and Vici, for senior researchers who have demonstrated an ability to develop their own line of research. The scheme which was implemented in 2000 received a

very positive evaluation in 2007. Therefore the minister made funds available to continue the programme and to expand it. Thanks to an increase in the annual budget to 150 million euro, NWO is now able to make more awards and increase the individual awards. The Veni subsidy was increased to 250,000 euro (from 208,000 euro); Vidi applicants now receive 800,000 euro instead of 600,000 euro, and the Vici subsidy has rised to 1,500,000 euro from 1,250,000 euro. Up until 2008, an institution was required to pay 33 percent of the subsidy and NWO 67 percent. From 2008 onwards, NWO will pay the entire subsidy. The scrapping of this institutional contribution coincides with the transfer of 100 million euro from the universities to NWO. A number of the abovementioned schemes have been evaluated since 2010:

- Rathenau (2010) addressed the Focus & Mass policy: It was thus an evaluation of the Dutch policy targeting research to specific sectors/theme's it excels in: The conclusion was that the policy does not seem to be working. The size and performance of the selected areas are not larger/higher than other areas. Some are even losing compared to other. The only field in the Netherlands that is growing more than the others is the bio-medical research.
- NWO (2009-2010): Another evaluation targeted the Leading Research Schools / the Bonus Incentive Scheme (BIS): The conclusion was that the BIS-funding has been put to excellent use with benefits such as: improved collaboration and focus on the national scale, establishment of cutting-edge infrastructure, as well as considerable enhance international visibility and impact in the fields selected.
- Finally, the BSIK incentive initiative was evaluated by Commissie Wijzen (2011). Overall the scheme was assessed as successful.

5.3. Comparison of the ability to produce highly cited/breakthrough articles in the three countries

A key question related to the impact of excellence schemes is whether such schemes lead to a higher occurrence of highly cited articles. While we are able to examine publications linked to Danish CoEs in the period from 1993 to 2011 (see below), we are not able to do the same for the Swedish and Dutch excellence initiatives. However, we are able to compare the three countries directly when it comes to their developments in the share of the most highly cited papers in the WoS database (top 1%), and we can further compare this development to the countries' ability to produce so-called "potential breakthrough research" papers.

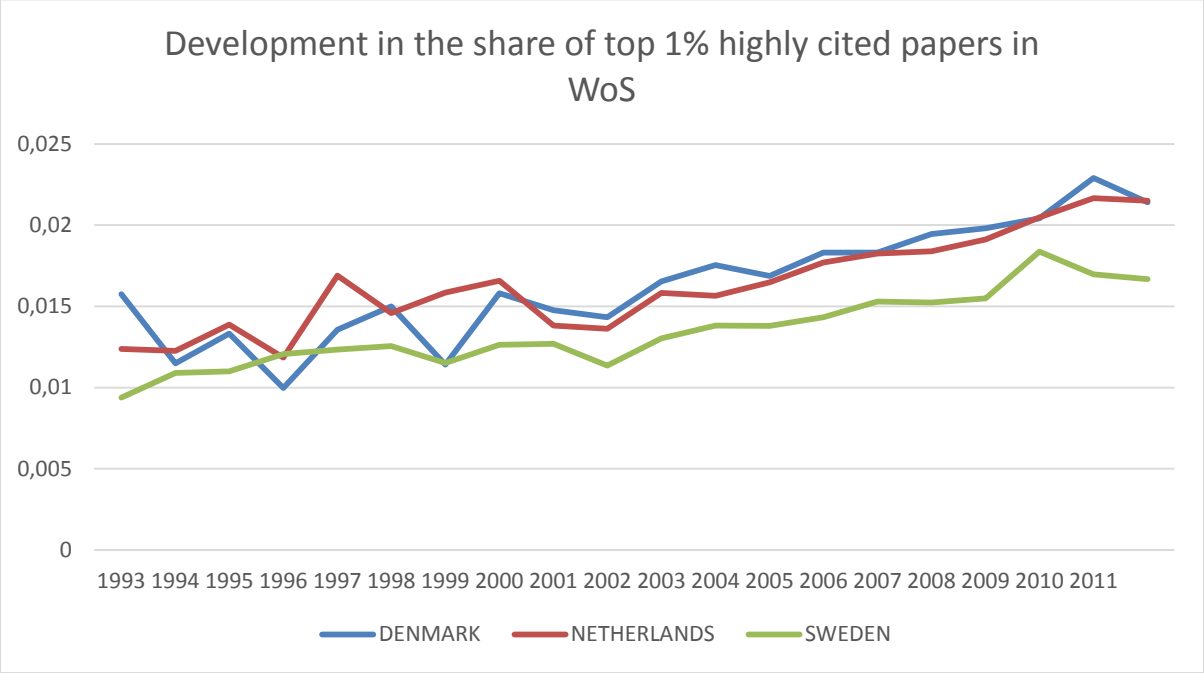
In a recent study, Schneider and Costas (2016) developed and validated three advanced citation-based methods used to detect potential breakthrough papers among very highly cited papers (i.e. papers reporting or partially reporting what has later been designated as "breakthrough" research). The advanced citation-based methods were explored and evaluated using specifically validated publication sets linked to different Danish funding instruments including CoE from the Danish National Research Foundation. The findings confirmed that long-term funded excellence initiatives such as CoEs were very efficient in producing potential breakthrough papers compared to funding instruments with other modes, purposes and a shorter duration. The results were not surprising given the special nature of CoEs – one could say that this is what they are created for.

Not surprisingly, the study also found good evidence for a solid correlation between shares of top1% highly cited papers and a unit of analysis' production of potential breakthrough papers. It is however

important to emphasize that not all highly cited papers are highly cited because they present potential breakthrough research. Noise is present. While certainly not perfect, the citation approaches presented in Schneider and Costas (2016) are able to filter out some of the noise among the extremely highly cited papers, and when this is done correlations with top 1% papers in general is still found to be good. The approaches can accordingly been seen as a rudimentary indicator for "breakthrough" research or "excellence". It is therefore interesting to compare countries' capability to produce extremely highly cited papers as well as potential breakthrough papers as they may reflect some underlying excellence initiatives or lack of these in the individual countries. Obviously we cannot directly infer to what extent, if at all, such initiatives influence the results.

Consequently, as the final part of the comparative section on excellence schemes we take a closer look at the ability of the three national science systems to produce highly cited (top 1%) articles as well as so called breakthrough articles. First Figure 5.2 shows the development in the share of top1% highly cited papers for the three countries.

Figure 5.2: Development in the share of top1% highly cited papers for the three countries.



Source: CWTS Leiden

Several interesting patterns emerge from Figure 5.2. All three countries have relative higher shares of extremely highly cited papers than statistically expected (1% of the total annual output). But the share of top 1% highly cited papers for Sweden has almost consistently been below those of Denmark and the Netherlands. While there are fluctuations in the 1990s in the Danish and Dutch shares, the annual trajectory stabilizes with a remarkable growth rate in the rest of the period. The stability seems to set in around 2002.For Denmark it is tempting to conclude that this aligns with the first batches of CoEs now publishing the fruits of the research efforts, but the similar patterns for all three countries undermines such a claim. It is also interesting that the Netherlands perform at least as good as Denmark throughout the period is spite of the lack a CoE scheme comparable to the DNRF scheme.

Next we turn to analyses of breakthrough papers based on the approaches presented by Schneider and Costas (2016). The study finds that especially two methods, Method 2a and Method 2b, roughly correlate with very high citation impact. The models for Method2a/2b were based upon 1) different ways of calculating extremely highly cited papers, 2) a filtering approach where so-called "followers" were removed ("followers" are papers which capitalize on original breakthrough papers), and for 2b, 3) also a knowledge diffusion rule where citations from other main fields of research is considered a positive weight.

To demonstrate the approach Table 5.5 gives some impressions of the results for two Danish funding instruments: The Independent Research Council (DFF) which mainly allocates smaller individual grants and DNRF. Briefly we present their share of potential breakthrough papers in the total set of potential breakthrough papers for Denmark in the period from 2005 to 2011.

Table 5.5: Proportion of Danish, DFF and DNRF breakthrough articles from 2005 to 2011

Breakthrough methods	**Method 1**	**Method 2a**	**Method 2b**
% DFF publications among Danish breakthroughs	3.7%	8.2%	9.4%
% DNRF publications among Danish breakthroughs	18.5%	16.4%	18.9%

As shown above, based on methods 2a and 2b, the DNRF funding instrument produces roughly twice as many breakthrough papers as the DFF funding instrument which generally is oriented towards individual careers and has considerable shorter funding periods. Method 1, on the other hand, is even more special, as this is a very restrictive method where it is required that the potential breakthrough papers must have been defining in establishing a cluster of papers constituting a research field. In that sense, the DNRF instrument appears to be even more efficient.

As can be seen the number of potential breakthrough papers is generally low. This is intentional since "breakthroughs" is a rare happening in science. In order to compare the production of breakthrough papers at the country level, we need to normalize for publication volume resulting in very low numbers. So in order to be able to interpret the data more straightforwardly, we have used Denmark as a reference and compared the relative production of potential breakthrough papers from the Netherlands and Sweden to this reference value of 1 (i.e. countries output of breakthrough papers are weighted according to an expected value based on the Danish output). Denmark is chosen as a reference because: 1) it is the smallest of the three countries, and 2) we have thorough knowledge about excellence initiatives for Denmark in this period. The results are presented for the whole period 1993 to 2011 in Table 5.6 below.

Table 5.6: Relative differences in the production of breakthrough papers

	DENMARK	NETHERLANDS	SWEDEN		NETHERLANDS	SWEDEN
	(reference)				(difference)	
Method 1	1	1.05	0.93		0.05	-0.07
Method 2a	1	0.95	0.89		-0.05	-0.11
Method 2b	1	0.88	0.82		-0.12	-0.18

Overall, the results support the findings in Figure 5.2 concerning the developments in the share of top 1% highly cited papers, but the breakthrough data provide some nuances. The Netherlands produce relatively more potential breakthrough papers compared to Denmark measured with the most restrictive method 1. These are the defining papers around on which research specialties are built. In the two other approaches Denmark produces relatively more potential breakthrough papers given it size compared to the Netherlands and Sweden. These are also the two methods that correlate most with the top 1% indicator. Sweden consistently produces relatively fewer breakthrough papers with all three approaches. Noticeably, the gap between Denmark on the one hand and the Netherland and Sweden on the other when it comes to the more restrictive method 2b is larger than the less restrictive 2a. Method 2a is the least restrictive with only one filtering rule. Consequently, the method will probably contain more noise than 2b where more filtering rules are enforced. It therefore also means that 2a is more susceptible to cumulative effects, larger countries benefitting from denser citation networks.

Overall, Denmark and the Netherlands thus clearly outperform Sweden when it comes to production of extremely highly cited papers and potential breakthrough papers. Denmark seems to be marginally ahead of the Netherlands especially after 2002 and when it comes to breakthrough papers detected by methods 2a and 2b.

Conclusions of comparative analysis:

As the comparative analysis has shown, the CoE scheme of DNRF is a quite unique feature in this comparative perspective. We do not find comparable schemes in neither Sweden nor Netherlands with similar long term duration and the same type of organization. In Sweden comparable schemes have only been implemented during the last 10 years and there are no comparable instruments in the Netherlands.

The lack of this type of CoE scheme does not, however, appear to influence the ability of the Dutch science system to produce highly cited or breakthrough papers. There are clearly other equally efficient ways of supporting excellence than large scale, long term CoE schemes. Similarly, the introduction of CoE schemes do not (yet) appear to have increased the overall Swedish performance with regard to producing highly cited papers.

Although other measures may be effective, we cannot, however, conclude that the Danish CoE scheme hasn't been an important part of the positive Danish development since the early 1990s. In the following section we examine the effects of the DNRF more closely for the whole period.

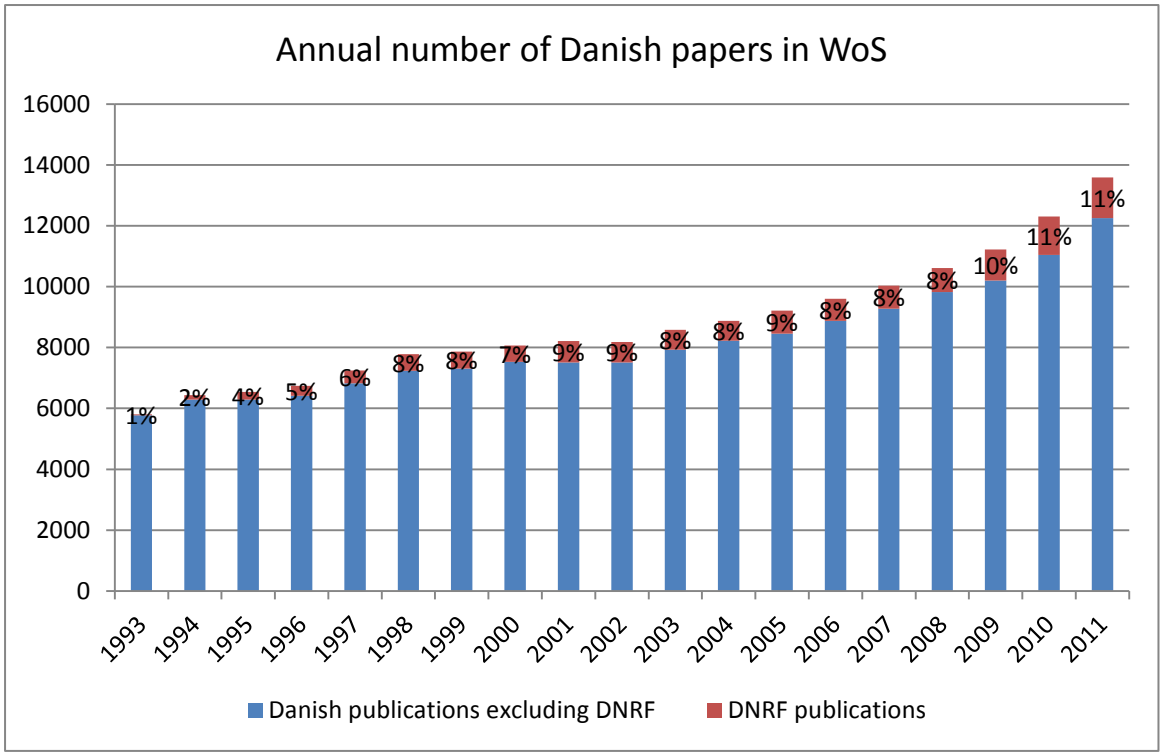
5.4. Detailed analysis of DNFR

The following analyses investigate the importance of the DNRFs CoE scheme with regard to both volume and impact. We look at the development in overall impact of DNRF in relation to Danish research indexed in the WoS as a whole; the development in overall volume of DNRF in relation to Danish research indexed in the WoS as a whole; the developments at aggregated OECD levels compared to Danish research indexed in the WoS as a whole; analysis of PI performance until their CoE was funded; analysis of developments in impact over time at centre level; relation between funding size and impact; and finally the ability to accrue extra funding

Development in overall volume DNRF in relation to Denmark

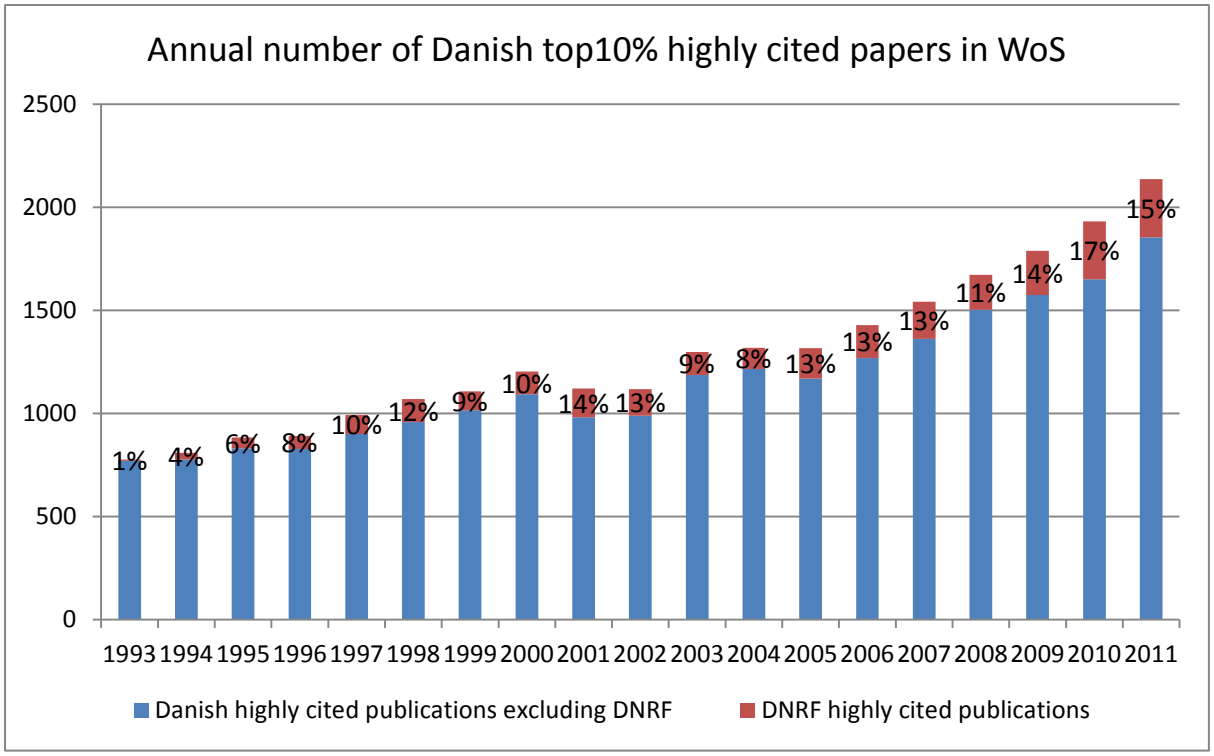
First we examine the proportion of papers from the total Danish production indexed in the WoS which can be linked to the DNRF. Secondly we look at PPtop10 articles only and again relate this to the overall Danish production. As can be seen from the figures below the shares have been increasing throughout the period and more than 10 percent of all Danish papers can be linked to DNRF in the latest period examined (2007-2011). If we look at PPtop10 papers only, the proportions are even higher. In the most recent years they fluctuate around 15 percent. So, the DNRF (seen as a unit) clearly performs well above the statistically expected when it comes to producing highly cited papers (i.e. 10%). This can be seen in Figure 5.4 below. Notice however that all CoEs attract large amounts of both internal and external funding in addition to the DNRF funding.

Figure 5.3: Annual output of DNRF papers as a proportion of the total Danish output



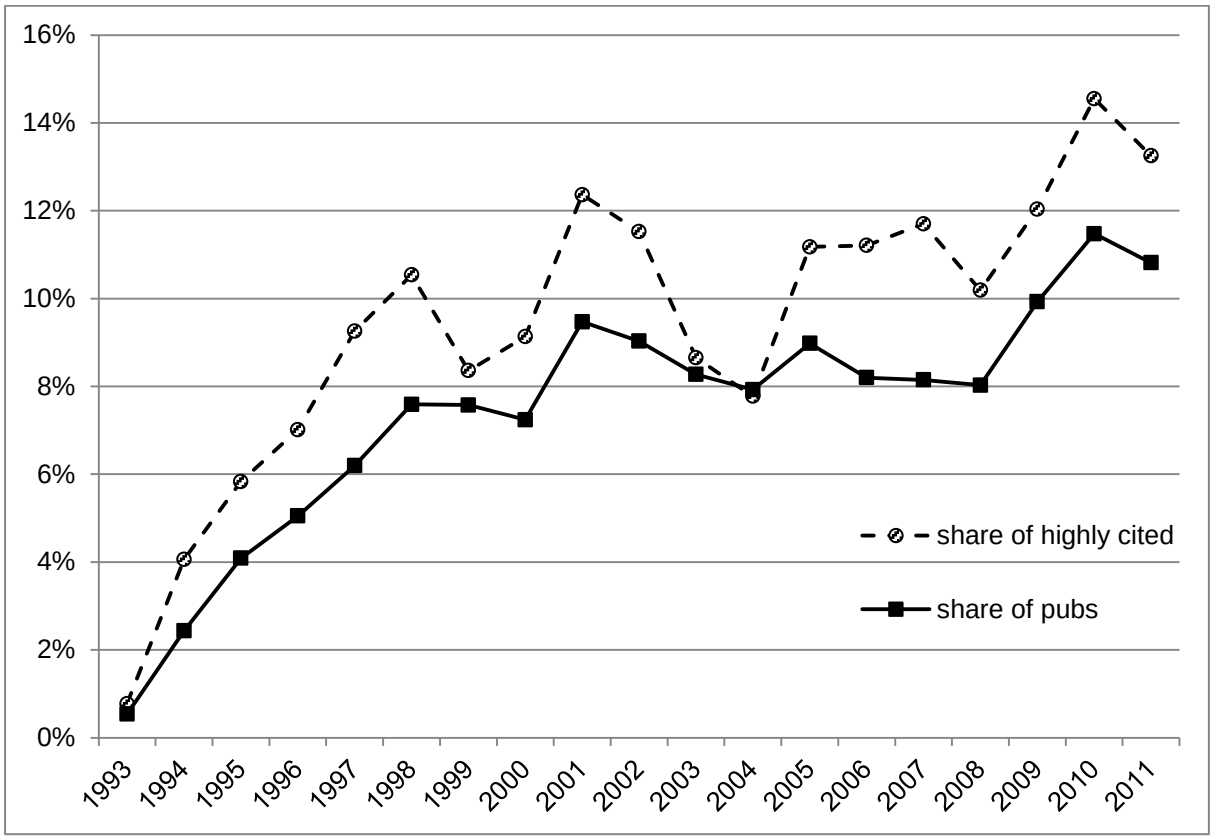
Source: CWTS Leiden

Figure 5.4: Annual output of top 10 % highly cited DNRF papers as a proportion of the total set of Danish top 10% papers



Source: CWTS Leiden

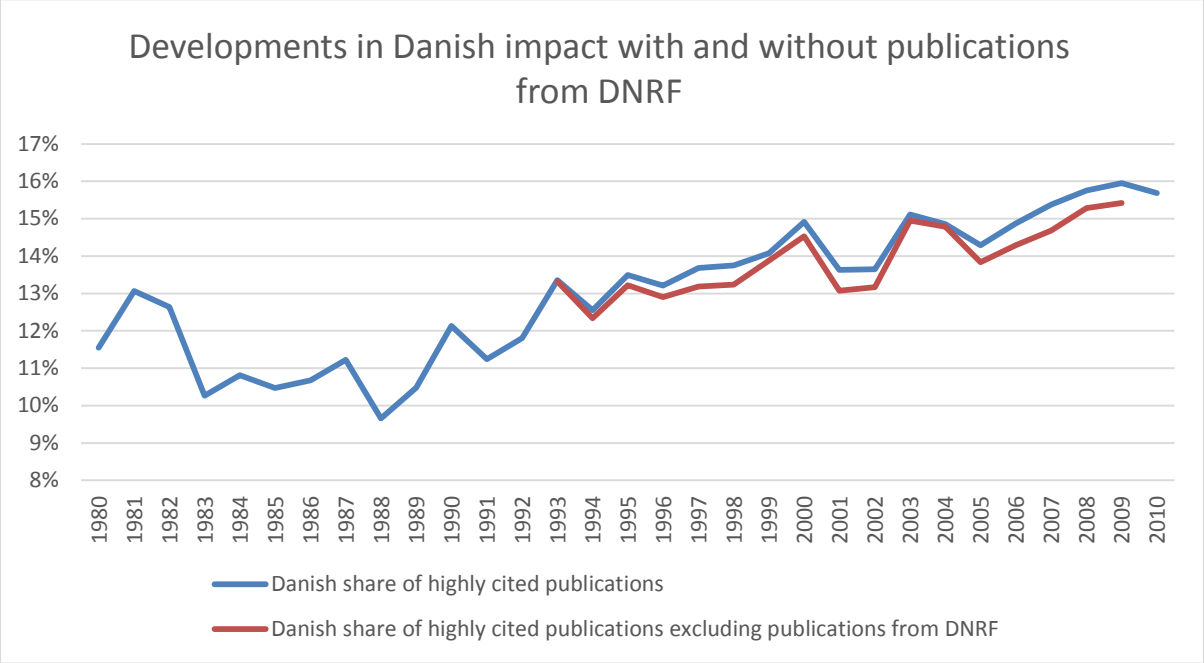
Figure 5.5: Development in DNRF shares of Danish publication output and top 10% highly cited output.



Source: CWTS Leiden

Notice also that DNRF papers were few in absolute numbers in the period in the 1990s when Danish research as a whole experienced a strong increase in impact – but they did have an "overrepresentation" of highly cited papers almost from the start as the figure above shows.

Figure 5.6: Developments in Danish impact (PPtop10%) with and without publications from the DNRF

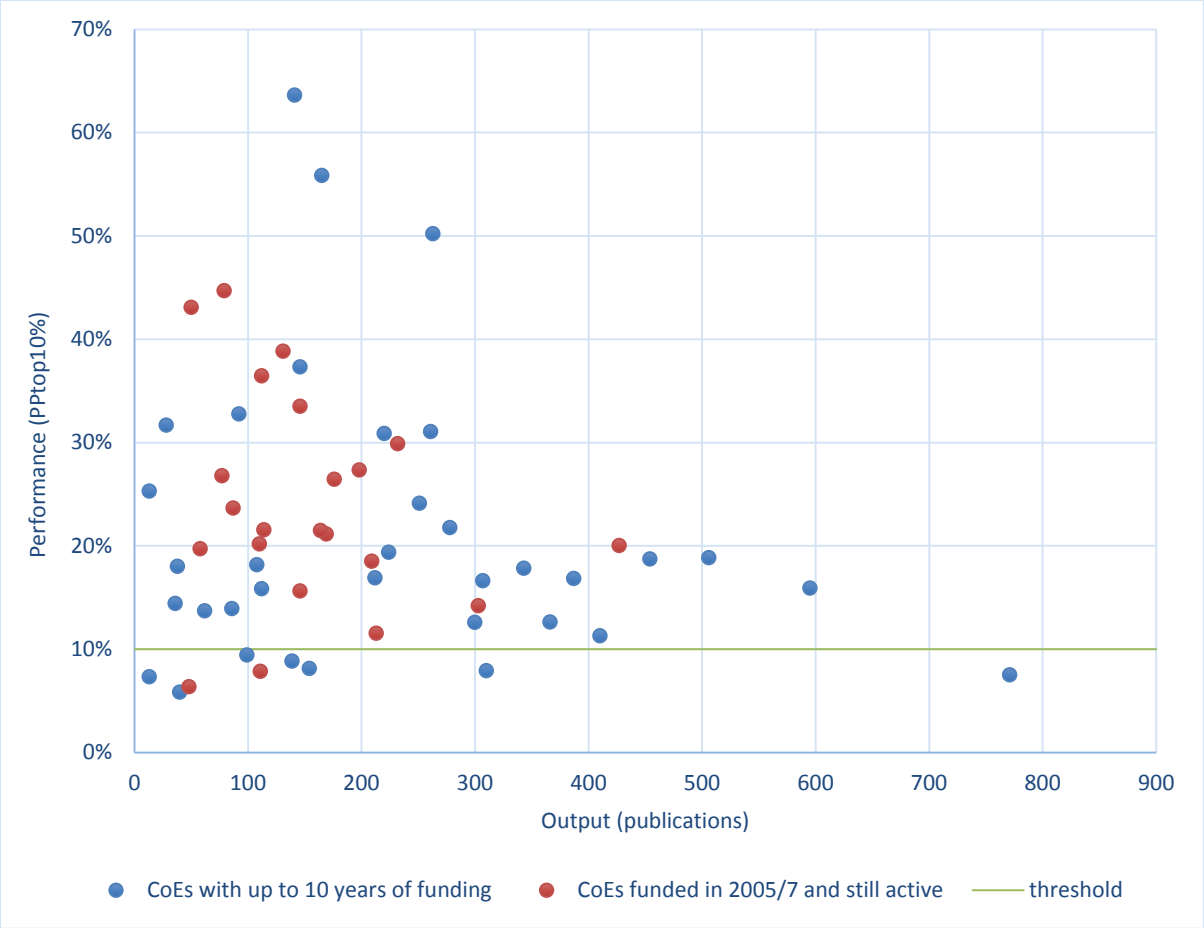


Source: CWTS Leiden

To get a proper visualization of the proportions involved, Figure 5.6 above shows the development in Danish impact and the corresponding development when the DNRF set of papers are removed. As can be seen the DNRF papers start to play a role from around 1996 and onwards. It is however noticeable that even without the papers associated with the CoEs, Danish research is still performing very well. It is also important to notice that the positive overall Danish development started before the CoEs began to play a role. Rather than initiating the positive Danish development these papers have mainly strengthened it.

Next we move on to a number of analyses examining the performance of the CoEs in isolation. Here we examine developments in impact over time for the centers, the relation between funding size and impact, and the ability of CoEs to accrue extra funding. This part is based on Bloch, Schneider & Sinkjær (2016). But first, Figure 5.7 below show the citation impact for each of the 57 COEs included in the study.

Figure 5.7: Performance of 57 CoE funded by the DNRF, impact is measured as the proportion of the 10% highly cited papers in the database (PPtop10%).

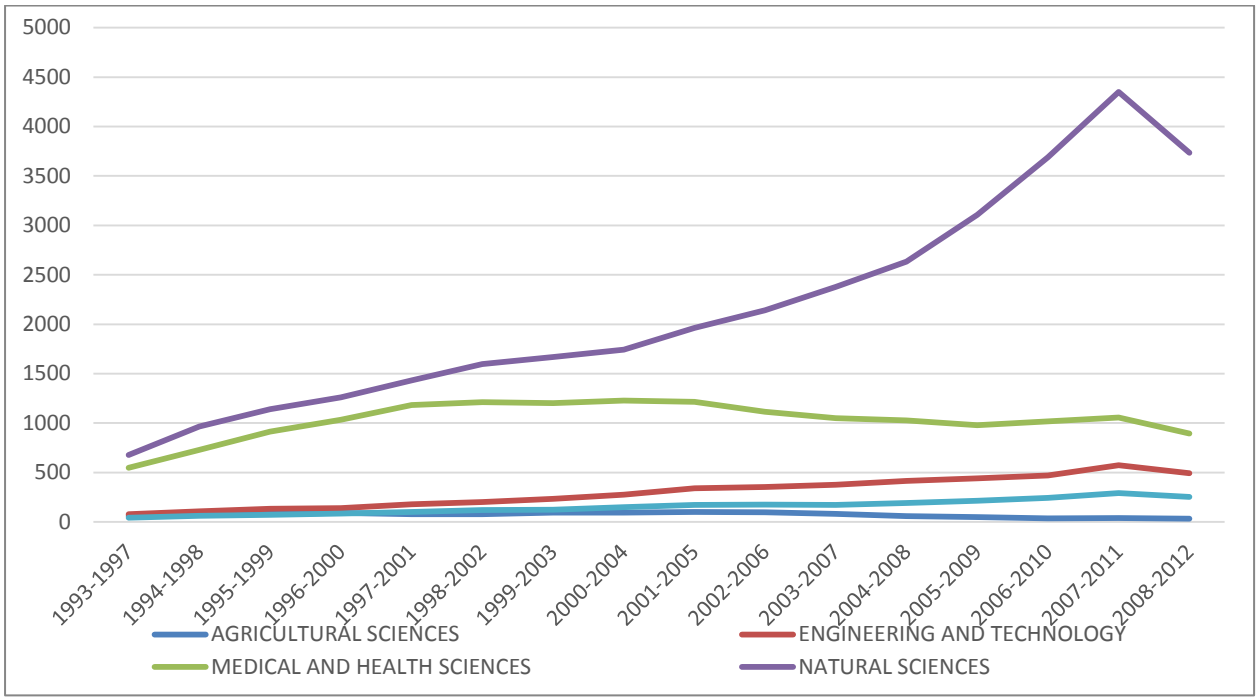


Source: CWTS Leiden

In general, performance for these CoEs has been very high. The average MNCS for the 57 CoEs covered in the analysis is 2.07, which implies a field normalized citation impact that is more than double of the world (WoS database) averages. The share of highly cited (top 10%) articles is also very high, with an overall share of 26% of articles among the top 10% most cited within their respective field. However, it is also evident that there is considerable variation in the performance among the CoEs, some perform at extremely high levels, others are very good, but around 9-11 CoEs perform at the average level or even below.

Figures 5.8 and 5.9 below illustrate which main OECD areas the DNRF papers are linked to. This gives an impression of the research intensity of CoEs in various areas.

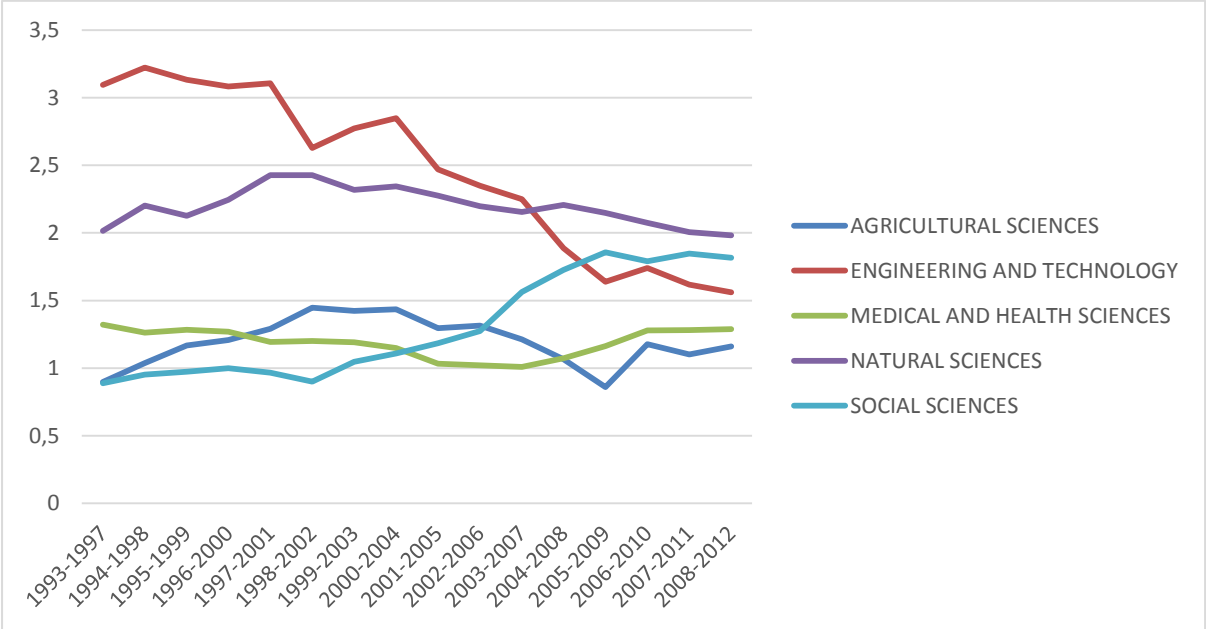
Figure 5.8: Development in publication output for the DNRF set of papers according to OECD main areas



Source: CWTS Leiden

Initially the medical and natural sciences had the same upward trajectory. However, around 2000 they separate: the absolute output for the medical science stagnates and eventually drops, whereas the output in natural sciences rises considerably. Thus, the CoE instrument in Denmark has mainly been focused on the natural sciences. Consequently, an important critique in the recent evaluation of the CoE funding instrument was that the instrument is indeed oriented towards supporting natural science research practice. Other practices, especially those dominant in the social sciences and humanities, fit poorly in the centre-construction envisaged by the DNRF.

Figure 5.9: Development in impact (MNCS) of the DNRF publication set according to OECD main research areas.



Source: CWTS Leiden

What we see in Figure 5.9 is seemingly a huge drop in impact for DNRF papers in Engineering and Technology as well as the natural science. However, a large part of this "drop" is due to the fact that in the first period publication numbers were low causing fluctuations. As publication numbers increase more stable indicator values arise. Nevertheless, impact has generally dropped although performance levels for the natural sciences (and social science) are high.

The CoEs have in general been very successful in securing additional funding, which can be viewed as a "cumulative effect" of center grants. Over the course of funding periods, the CoEs have obtained additional funding amounts that nearly match the size of centre grants themselves, which in turn leads to increases in the number of researchers (Bloch, Schneider & Sinkjær, 2016). In terms of new personnel, the vast majority of additional funding is spent on early career researchers, both postdocs and PhD students. Hence, this accumulation would appear to have a "generational" dimension, allowing for scientific expertise to be passed on to an increasing number of younger researchers. The fact that the levels of research performance are maintained over the course of this accumulation suggests that this generational transfer is successful.

Table 5.6: Relation between impact and grant size.

	MNCS		PPtop10%	
Grant size	**Mean**	**Median**	**Mean**	**Median**
Q1 (<0.864 MN €)	2.024	1.281	0.23	0.20
Q2 (0.864–1.102 MN€)	1.595	1.392	0.21	0.20
Q3 (1.102–1.456 MN€)	2.654	1.758	0.32	0.25
Q4 (> 1.456 MN€)	1.957	1.724	0.30	0.27
Total	2.069	1.517	0.26	0.23

doi:10.1371/journal.pone.0147726.t002

When examining overall performance over the course of the funding periods, larger CoEs have higher performance both measured in citation impact (MNCS) and shares of highly cited articles (PPtop10%), though there appears to be some indication that performance peaks and begins to fall for the largest CoEs, see Table 5.6 median values. However, the picture is somewhat different when we examine performance over time, see Table 5.7 below. In general, it appears that both MNCS and PPtop10% are falling over the course of grant periods for the largest CoE grants, while it is increasing for those among the smallest half. Hence, while performance is quite high for the largest CoE grants, particularly in the initial years, performance appears to increase most for the smaller CoEs. In fact, for the final year of grant periods, the median value for MNCS is highest for the smallest grants. A possible explanation for this pattern is that there may be greater coordination costs connected with the largest CoEs, which slows their growth in performance.

Table 5.7: CoE performance distributed according to year after funding

		MNCS		Number publications		Number highly cited (top10%) publications		Number highly cited (top10%) publications per MN€		PPtop10%	
Grant year	Number CoEs	Mean	Median	Mean	Median	Mean	Median	Mean	Median	Mean	Median
1	41	2.47	1.65	12.66	10	3.902	3	3.16	2.42	31.0%	30.0%
2	57	1.94	1.61	16.35	15	4.436	3	3.79	3.09	28.4%	26.7%
3	57	2.00	1.51	20.39	20	5.053	4	4.45	3.67	25.9%	21.9%
4	57	1.72	1.47	22.62	20	5.436	4	4.60	3.89	23.9%	20.8%
5	56	1.88	1.44	25.04	23	6.107	5	4.90	3.98	24.4%	23.3%
6	47	2.64	1.43	27.11	24	6.426	5	5.42	4.64	26.8%	22.2%
7	40	1.93	1.51	29.15	22	6.7	5.5	5.57	4.78	24.9%	21.1%
8	27	2.11	1.70	29.00	29	6.963	6	6.33	5.11	27.1%	22.6%
9	27	2.21	1.57	34.37	31	8.259	6	7.34	6.15	24.8%	20.0%
10	24	1.97	1.43	30.08	26	7.458	6.5	6.91	4.77	28.1%	21.7%
Total	57	2.07	1.52	23.54	20	5.811	5	4.97	3.96	26.4%	22.7%

doi:10.1371/journal.pone.0147726.t001

At the same time, these general findings may be unable to capture the dynamics in the accumulation of funding and research performance for individual CoEs. In order to examine these relations in more detail, we conducted a multivariate regression analysis of the role of size and time for research performance, also taking into account past performance of the CoEs. These dynamic panel data analyses find evidence that performance, as measured by average citation impact, is increasing with grant size and over time. In both cases, the relation appears to be non-linear, suggesting that there is a point at which performance peaks. Concerning grant size, grant amounts are positive while its square is negative. This indicates that citation impact is increasing with grant size, but at a decreasing rate. We use these coefficients to calculate an estimate of the optimal annual grant size, which gives 1.45 MN euros. Though, it should be noted that these are general trends that do not take into account any potential differences across fields. For example, the need for expensive equipment or materials would clearly influence these size considerations. A similar estimate for grant years suggests that research performance in terms of MNCS peaks at 6.7 years.

These findings contradict those of Fortin and Currie (2013), although it is very important to recognize that they examined relatively smaller NSERC grants to individuals, whereas we examine large-scale CoEs with long-term generous funding. As Fortin and Currie (2013) point out themselves, the answer to the "question does greater funding of high performers lead to greater scientific impact, versus funding more researchers" depends upon the goals of the funding program. In the case of Danish CoEs the goal to "maximize discoveries" by focusing on "excellence" seems to work. And one thing to notice, numerous younger researchers are involved with a CoE over time

For CoEs with significant growth in researcher staff over time, the PPtop10% remains fairly constant. Results from the regressions show a high degree of autocorrelation with a coefficient of 0.65 for the

lagged value of PPtop10% and no effect of grant size or length. One potential interpretation of this is that CoEs or perhaps the smaller research groups within CoEs are able to transfer or maintain their research capabilities to new and typically less experienced researchers, with the result that production of highly cited articles increases parallel to increases in publications overall.

In the literature review in chapter 2 we discussed the 'cumulative effects' within science and the potential adverse effects of this accumulation. While we are unable to discern from our analysis what is driving accumulation, eg. whether it is reputation of individual researchers or of the CoE, or if it is grounded in the research results themselves, it seems clear from the data that these CoE grants lead to a further accumulation and concentration of resources. It thus also seems reasonable to assume that this accumulation contributes to existing inequalities among senior researchers, though the scope of this depends to a great degree on how large the centre grant funding is relative to other forms of funding. At the same time, it is important to again note that this accumulation of funding often goes towards an increase in the funding of younger researchers.

An important consideration in studies where impact effects of funding are examined is the pre-performance level of the funded unit. As shown above, CoEs generally seem to be high performing from day one and the development is mostly stable perhaps somewhat declining over the years as the publication volume increases. In effect this tell us that the funded units are already high performing and to further substantiate this we have also examined the performance level of the PIs at the time when they received funding for a CoE. Obviously this is only a crude indicator as more researchers are often involved in CoE applications, nevertheless the findings substantiates the indicative results presented above.

Figure 5.10: Analysis of PI performance prior to getting funded by DNRF

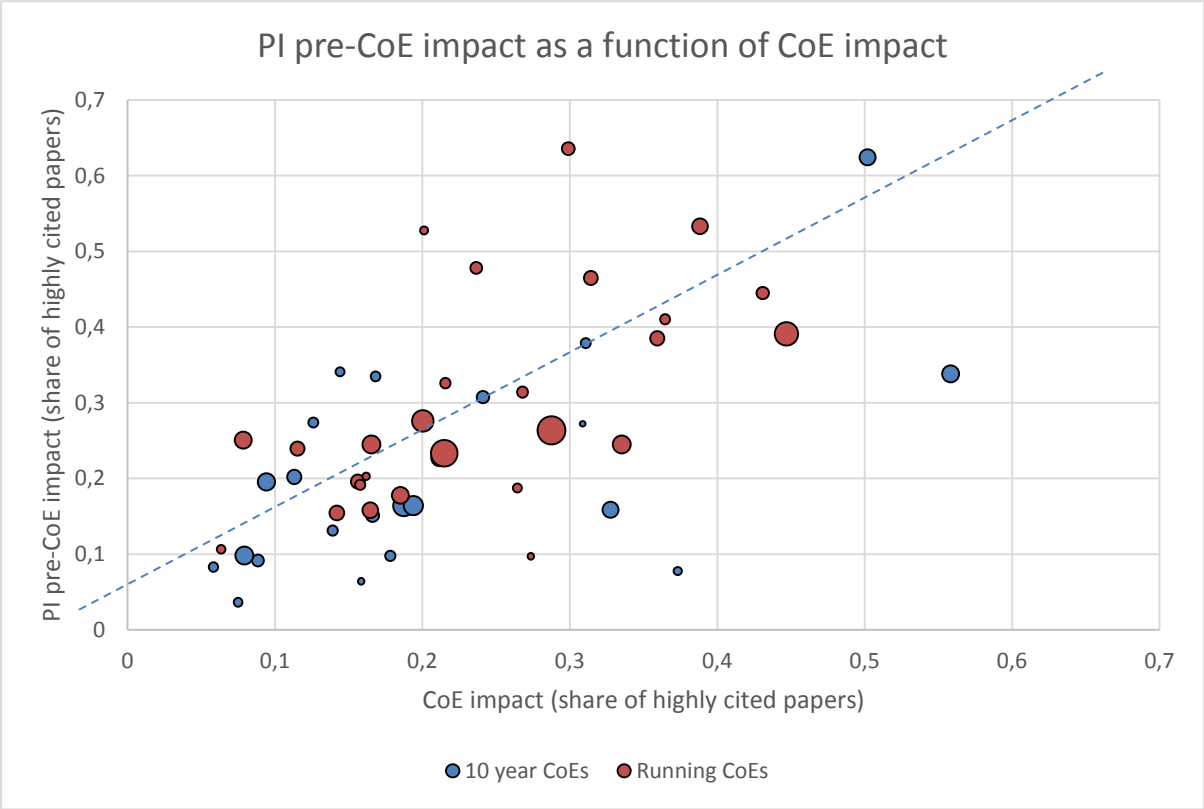


Figure 5.10 plots PI pre-CoE performance against CoE performance (PPtop10%) and the size of circles indicates the cumulative publication volume of the PI up to year when the CoE is funded. Notice, the colors indicate whether CoEs funding had expired or were still running at the time of the analysis.

Two main observations from Figure 5.10 are, 1) many PIs are (very) high performing before getting funded, and 2) PIs for CoEs funded in the later periods seem to generally have considerable larger publication portfolios than earlier ones. Overall, the findings confirm that PI's, and most probably the groups they lead, are already high performers when they receive their CoE funding and many CoEs do not improve this high level performance during their funding period. What we should emphasize in this context is that while PIs and the centers as such may not improve their impact or only slightly, being a member of such a center especially for junior researcher is most likely extremely beneficial. Such young researchers will not only be working and studying in high performing research environments, most likely acquiring profound academic skills, they will also benefit from introduction to international networks, gain important experience in relation to publishing where senior researchers will open doors to prestigious journals, and finally they will benefit from cumulative advantages which will be extremely valuable for their future career, especially in matters such as future funding and performance.

5.5. Summary of findings

The excellence initiative (CoE) funded by the DNRF is unique for Denmark when we compare it to the Netherlands and Sweden. It was introduced earlier and has a distinctively different character than corresponding, longstanding initiatives in the other two countries. At the country level the CoEs in Denmark have contributed to a positive development, but it is by no means the sole explanation of the Danish trajectory. It is also noticeable that the Netherlands perform at least at the same level as Denmark without such CoE schemes and the presumed benefits they bring.

However, if we look at Denmark in isolation: DNRF must be seen as an important instrument in the Danish funding system – and in particular the organization of the scheme is highlighted as very positive. The conception and implementation of the CoE most likely made a strong contribution to the academic reorientation in Denmark in the 1990s with focus on quality and excellence. It was thus a well-conceived tool implemented at the appropriate time with the right back up from previous reforms - especially the PhD-reform which basically created parts of the basis upon which the CoEs could be built. With regard to DFiRs hypotheses it should also be mentioned that schemes such as DNRFs CoEs in addition to directly improving the overall impact serve to strengthen management, internationalization, and contribute to PhD education, talent development and recruitment.

Excellence schemes should however be carefully calibrated to the remaining science system as argued in the introduction. Appropriate balances need to be found between concentration of resources to high performing individuals and groups on the one hand and a broad and diverse growth layer on the other. In the 1980s and the early 1990s there were limited mechanisms leading to concentration of resources. During the latest decade this situation has however changed drastically. In addition to DNRF a large number of other schemes and mechanisms contribute to this development: ERC, Private foundations, large strategic centres, performance-based funding, etc. This calls for careful attention to the overall balances of the systems.

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6. PhD-education

The third DFiR hypothesis states that two strong Danish prioritizations of PhD education, the first initiated in the late 1980s and the second in the mid-2000s, may be part of the explanation of the positive Danish development in academic performance. It is argued that the increased number of PhD students have intensified the competition in the system and hereby enhanced the quality. It also states that PhD positions became an instrument to attract talented international research talents. In addition, it is mentioned that the increased formalization of the PhD education further served to increase research quality, for instance through the establishment of formal PhD schools. Finally, it is stated that there is a strong Danish tradition of collaboration associated with the doctoral training.

6.1. PhD education and academic performance

With regard to PhD education it is generally acknowledged that the socialization of students to research is an essential part of the reproduction of faculty and of the renewal of any scientific community (Gemme and Gingras 2008). The PhD education produces a reservoir of qualified and competent researchers from where the research institutions can recruit future researchers (Mejlgaard et al 2012). Similarly, the PhD education introduces research students to the norms and values which define the researcher community. PhD education therefore lies at the core of any nations' research capacity and is seen as the primary source of research productivity and innovation. It is thus a question of vital importance to universities and nations how PhD education is shaped (Nerad and Heggelund 2011; Hollingsworth 2008).

In spite of this PhD education was hardly articulated as an area of research policy until the 1990s in most countries. But since then it has become an increasingly discussed area of policy. The issue has thus become a site of ambitious reforms both at national levels and in the European Union (Thune et al 2012). In general it is argued that the most important changes in the development of PhD education over the last few decades have taken place in two steps. The first step was taken from a situation where individual professors held the direct influence and control over recruitment and training and where internal disciplinary values and standards were dominating. The step led towards the establishment of the modern PhD in the 1980s and 1990s. According to Thune et al (2012) typical issues and challenges addressed in this first step were: how to retain broad academic competencies despite specialisation; how to increase enrolment; and, how to bring completion times down. This step has now been implemented by most countries resulting in a steep growth of enrolment and degrees. Similarly it has also been observed that there has been a significant reduction of completion times in many countries.

The second step has taken place after 2000 in most western countries. Thune et al describes this step as "adapting PhD education to the knowledge society" and this step is seen as a process that is on-going in most countries (if started at all). As a result of these two steps the typical pattern in European countries has seen the annual number of graduated PhDs double or treble since the 1980s.

But although PhD education is seen as a vital component in any science system, and although the development in the formal frameworks has been described to some degree across a number of countries, we have no real evidence of how PhD education affects research performance at a systemic level. One obvious reason is that the link to performance far from can be seen as

straightforward. Our knowledge of these relationships is accordingly very scarce. Different hypotheses can however be formulated: The first potential relationship is fairly obvious: An insufficient quantity and quality of PhD graduates will harm the growth layer and limit the renewal of the researcher community and eventually lead to decreasing performance. However, also a large PhD volume could lead to negative effects. All else being equal, PhD students are expected to produce academic work with a lower aggregated impact than more experienced researchers. In systems with a very high permanent volume of PhD education this will be expected to decrease aggregated impact. Furthermore, a strong prioritization of PhD education will require resources (funding as well as supervisory capacity) which otherwise could have been used for other research activities. Finally, a very high volume of PhD education may also have negative effects on the career systems of the research institutions. In other words, the relationship between PhD education and performance is most likely not linear. Both too low and too high a volume of PHD education may have negative effects at the system level.

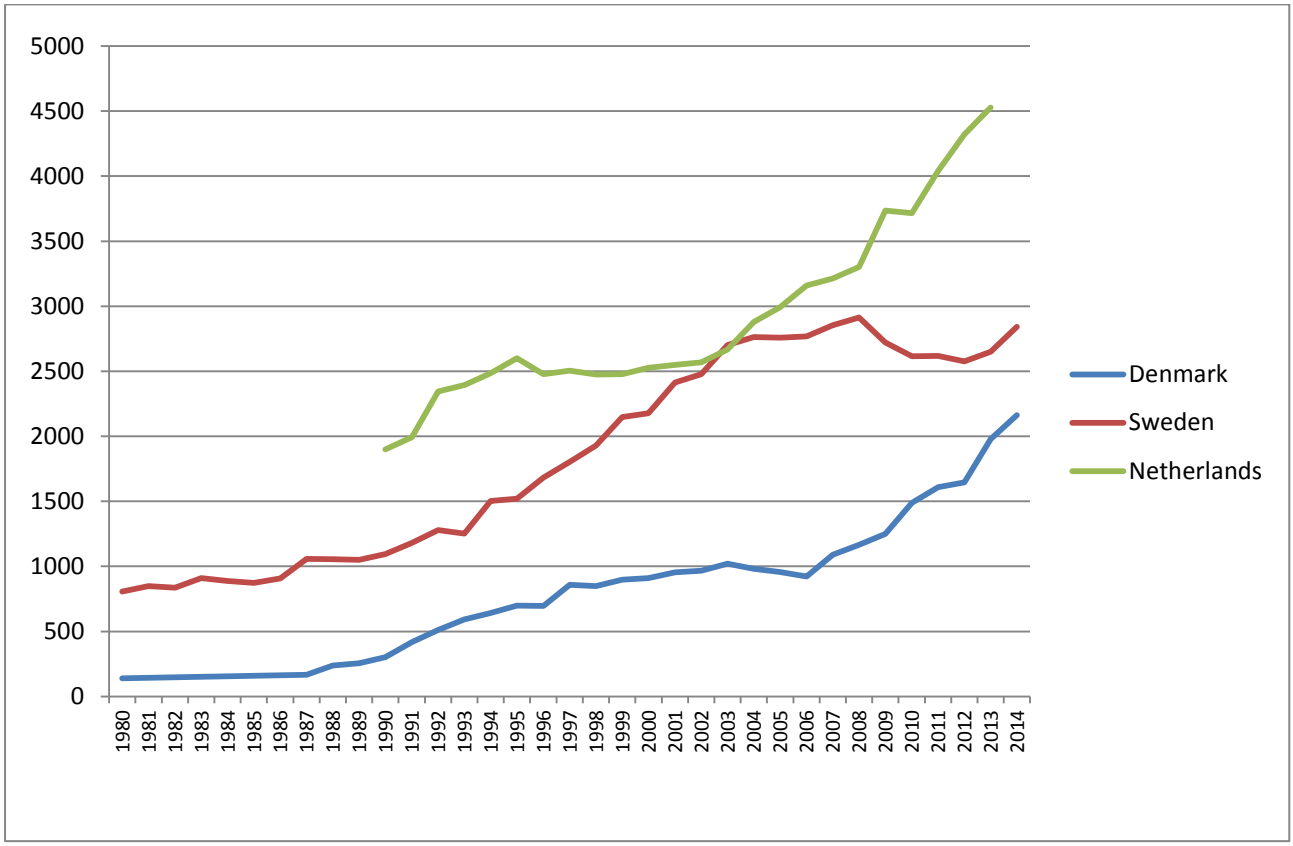
From this outset the present chapter seeks to examine the development of PhD education in the three countries with regard to both volume and regulatory frameworks. We examine to what extent the Danish case differs from the developments in Sweden and the Netherlands and if these developments in the scope and content of the doctoral training quantitatively or qualitatively can be linked to the aggregated development in research performance within the three countries.

First we provide a broad quantitative overview of the development in the volume of PhD education in the three countries. Secondly we give a more qualitative account of the development in the organization and formal regulatory framework of PhD education in the three countries. Thirdly we show an indicative bibliometric analysis examining the relationship between the growth in number of PhDs and the growth in the number of "visible" researchers in WoS. Finally, we sum up in the concluding discussion.

6.2. PhD education in a comparative perspective

As shown in figure 6.1 below both Denmark, Sweden and the Netherlands have experienced strong growth in the number of graduated PhD students during the last three decades. All three countries have almost tripled the number of PhD graduates since the late 1980s and the national developments are thus fully in line with the more general international development outlined in the introduction to this chapter.

Figure 6.1: Number of graduated PhDs in Denmark, Sweden and the Netherlands 1980-2014 (The Netherlands only from 1990-2014 due to lack of historical data; 1981-1985 estimated for Denmark based on Forskningsstyrelsen 2003)



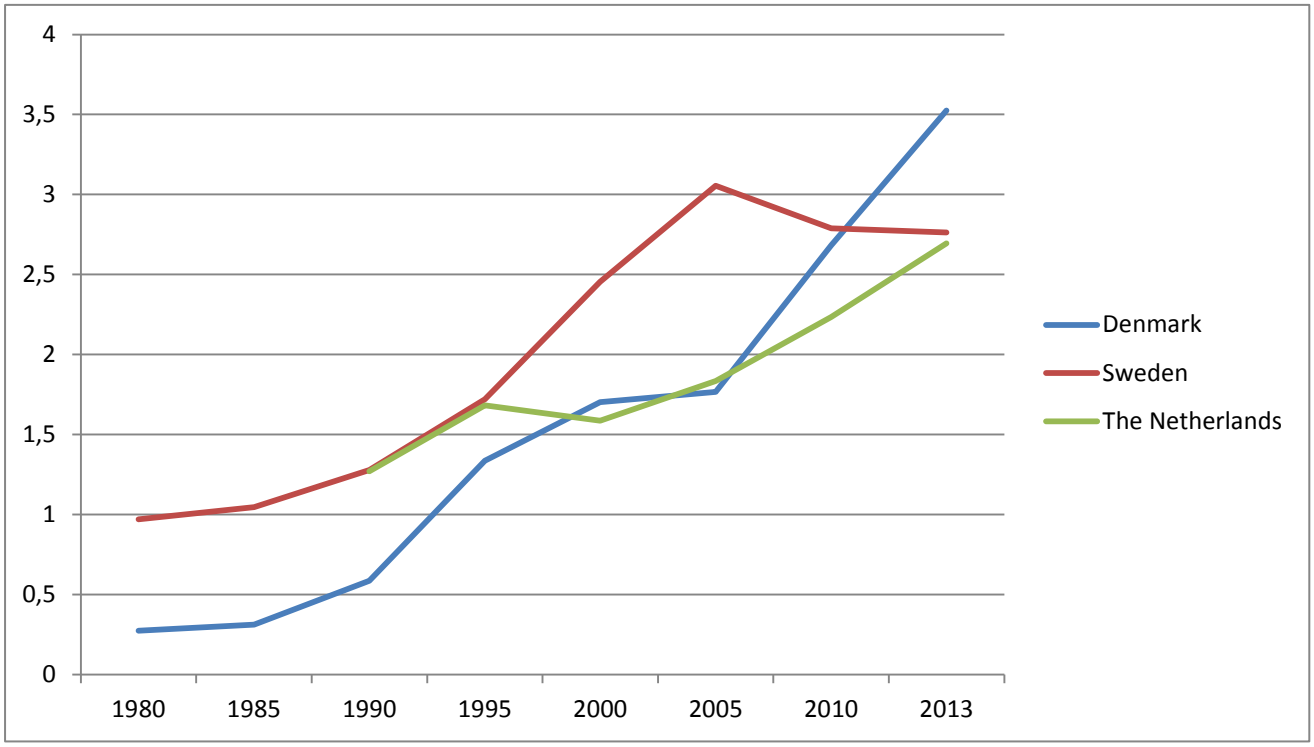
Souces: National Statistics

There are however important differences in the timing of the growth across the three countries. In particular, it is noticeable that Denmark started out at a very low level during the 1980s compared to the two other countries. From the late 1980s and onwards we see three distinct periods in the PhD education area for Denmark. First, we observe a strong growth from the late 1980s to the mid-1990s from less than 200 graduated PhDs per year to more than 800. This period is followed by a little more than a decade of relative stability, before we see a new period of strong growth from 2005 and onwards. This pattern is thus similar to the pattern of total funding for Denmark shown above in chapter 3. Sweden has a somewhat different development. Already in the early 1980s the number of graduated Swedish PhDs was relatively high. Up until the early 2000s this figure has increased steadily to above 2500 per year. The latest decade has however seen a stagnating and at times even decreasing development in the growth in the number of graduated PhD students – but still at a very high level. For the Netherlands our first figures are from 1990, but from the available period we see a pattern comparable to the Danish: Growth up until the mid-1990s, stability from the mid-1990s to the early 2000s, and then relatively strong growth for the remaining period.

However, to really be able to interpret the development we need to make the figures comparable across the countries. The very low level of Danish PhDs during the 1980s is thus clearly shown in figure 6.2 below where we have related the number of graduated PhDs to the population sizes in the three countries. While Sweden and the Netherlands more or less follow the exact same path from 1990 and onwards it is obvious that the Danish system shows an extreme quick catch up from 1985

to 1995 from a very low level. In 1980 Sweden had more than three times more graduated PhDs per year per 10.000 people compared to Denmark. From 2005 and onwards Denmark enters another period of steep growth and by 2013 Denmark are clearly ahead of both the Netherlands and Sweden.

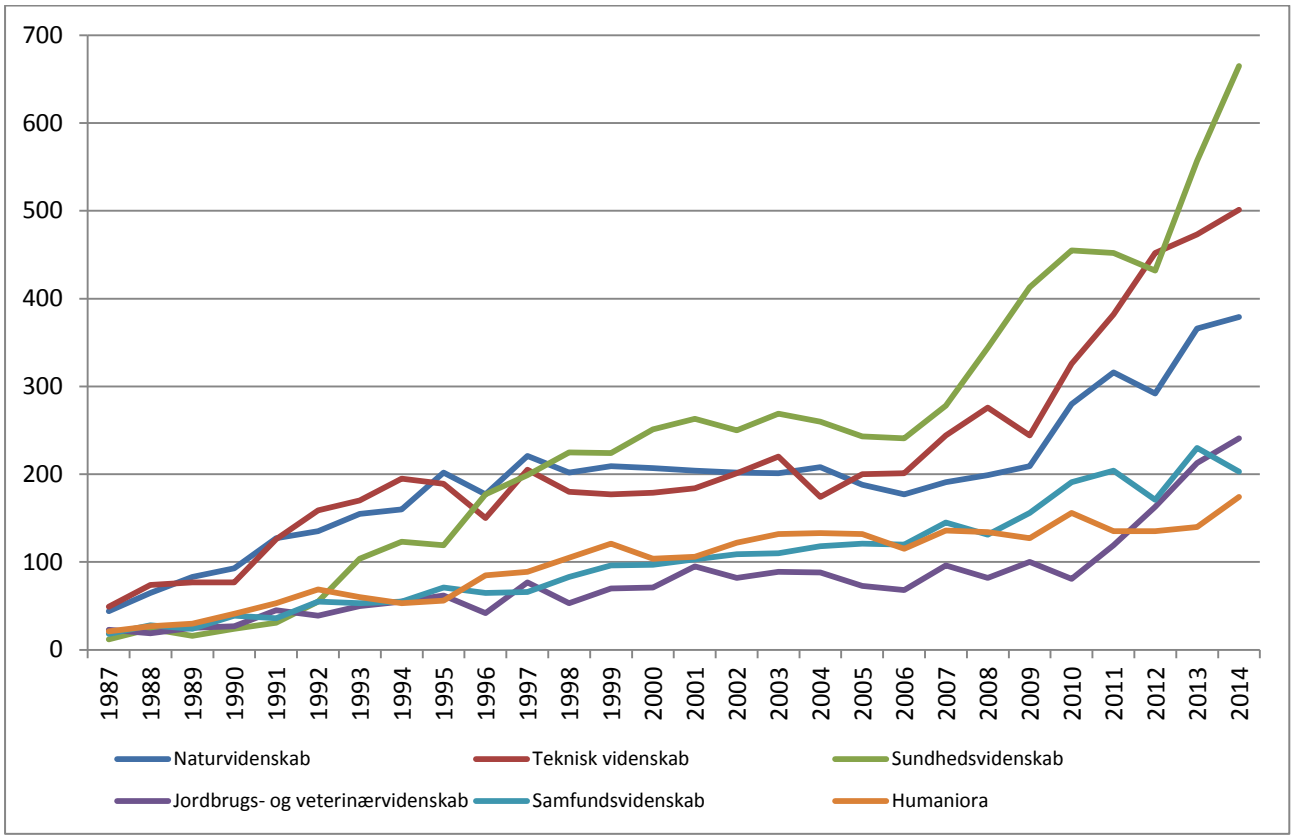
Figure 6.2: Number of graduated PHDs per 10.000 people in population: 1980, 1985, 1990, 1995, 2000, 2005, 2010 and 2013 (latest available). No data for the Netherlands for 1980 and 1985; 1985 is estimated for Denmark.



Source: National Statistics (Denmark: Estimated data from 1981 to 1986 based on Forskningsstyrelsen 2003).

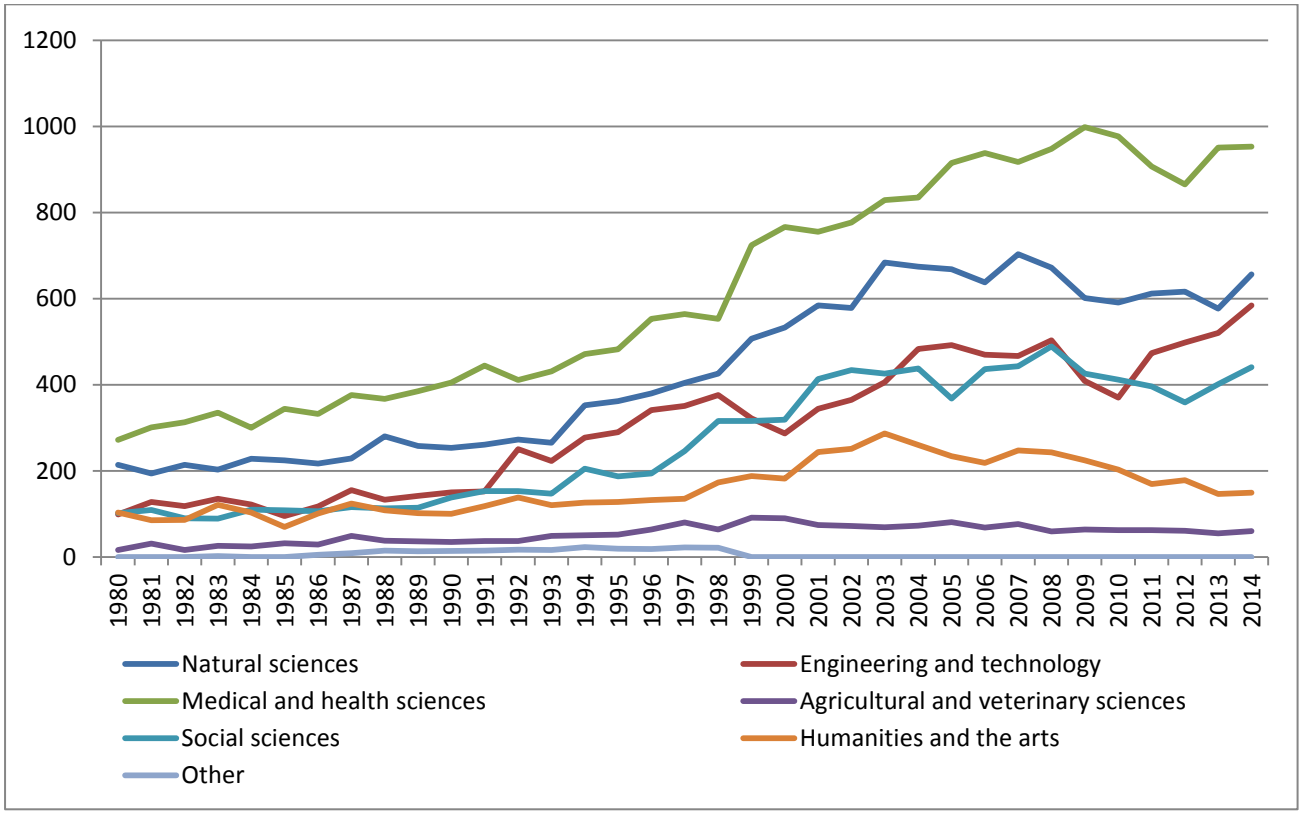
However, not all scientific fields have benefitted equally from the increase in the number of graduated PhDs as Figure 6.3, 6.4 and 6.5 show. In all three countries the medical sciences have experienced the strongest growth throughout the period, and this field also by far has the highest volume across the countries. It is however noticeable that the medical field in Denmark starts out with a fairly low volume. It has a steep growth during the 1990s and becomes the largest Danish field by the end of the 1990s. Again from 2005 and onwards it shows a very steep growth. In Sweden and the Netherlands the medical fields have the highest volume throughout the period.

Figure 6.3: Denmark: Number of graduated PhDs per year per field, 1987-2014



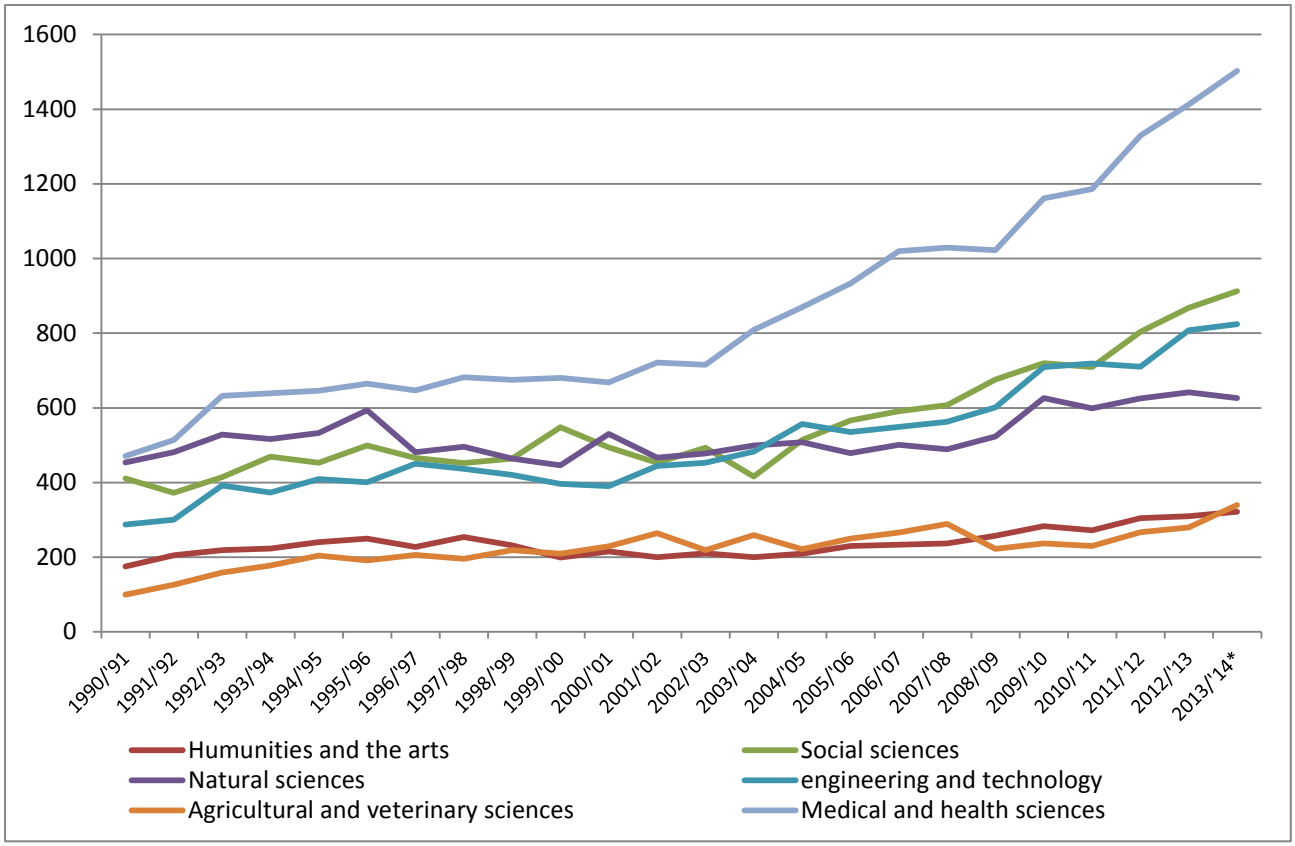
Source: http://www.statistikbanken.dk/statbank5a/selectvarval/saveselections.asp and the PhD register.

Figure 6.4: Sweden: Number of graduated PhDs per year per field, 1980-2014



Source: Statistics Sweden. Note: Time series break in 1998 due to changes in subject classification.

Figure 6.5: The Netherlands: Number of graduated PhDs per year per field, 1990-2014



Source: National Statistics

6.3. PhD education in a national perspective: Organization and framework conditions

After this comparative overview of the development in the volume of PhD education in a cross country perspective we now turn to a more qualitative description of the development of PhD education within the three countries.

6.3.1. Denmark

Doctoral training in Denmark was characterized by large differences between fields during the 1970s and 1980s and there were no overall political targets or ambitions with regard education and recruitment of researchers. In some areas a so-called licentiate degree was used, but other formats could be found as well. In general there were no external quality assessment mechanisms. How to educate future researchers was thus a local issue only (Danmarks Forskningsråd 2000; Christiansen 1991; Kim 2000). There were accordingly hardly any political attempts to influence doctoral training in this period and no demands of any mandatory elements in the education. In general, the system was almost solely targeting the internal reproduction of the public science system.

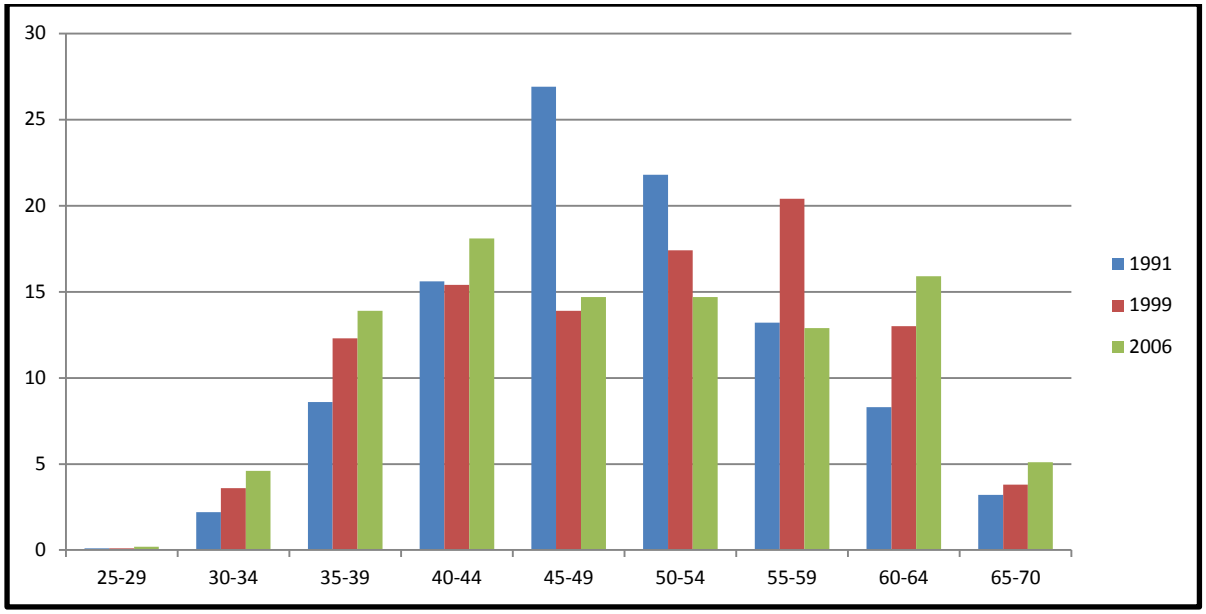
However, a growing recognition of the need for a quantitative and qualitative lift of the PhD education started to emerge among key stakeholders from the beginning of the 1980s. The background was both a comparison with other similar countries which spent significantly more resources on this task (as shown in the figures above) and a widespread notion that the Danish research system was in a state of crisis. In 1984 this led to a researcher recruitment strategy as a first

step and in 1987 the so-called "Forsker-akademi" (The Researcher Academy) was established as a follow up. It is noticeable that the Researcher Academy was established as an independent institution with an independent budget rather than placing the responsibility for the education of researchers within the universities. Most of all this reflected a political distrust to the universities. The Researcher Academy aimed for at least a doubling of the number of graduated PhDs within a few years. In 1988 the existing licentiate system was revised and the licentiate degree replaced by the PhD degree (Forskerakademiet 1990: 13). Finally, this development was further strengthened when a formal reform of the PhD-system as a whole was passed in 1992 and implemented from 1993. Not only did all this lead to a considerable growth in the volume of graduated PhDs as Figure 6.1 showed, it also led to a strengthening and formalization of the content and frame conditions of the PhD education (Aagaard & Mejlgaard 2012). The PhD reform explicitly aimed to create an internationally recognized education and to establish international networks. In addition, the aim was to give the education a clearer and more formalized structure and to reduce completion times as well as the age of the candidates completing the education (Mejlgaard et al 2012).

It is noticeable, that these changes took place in a period where the Danish system was suffering from a very low degree of renewal. As a result of the rapid expansion of the university system during the 1960s and early 1970s a large number of researchers of roughly the same age were hired at the Danish universities. As the growth stopped during 1970s and 1980s almost no new positions became available. The result was a system with a weak growth layer, very little renewal, and a lack of competition for positions.

The increased volume of PhD graduates in turn led to a much more even age distribution among the public researchers as the system started to grow during the 1990s as figure 6.6 below shows. The result was both a higher degree of competition for positions and a more dynamic research culture.

Figure 6.6: Age distribution of associate professors in 1991, 1999 and 2006, Percentage by age group



Source: Ståhle 2007

The frame-conditions established in this period has been the cornerstone of Danish PhD education ever since. In 1998 the PhD education was evaluated and it was concluded that the reform overall

had been successful (Danmarks Forskningsråd 2000). In particular it was emphasized that the aim of increasing the volume had been reached and that the internationalization of the education had been improved considerably. There were however still room for improvement according to the evaluation panel - in particular with regard to even further strengthen the internationalization and with regard to securing more critical mass in the PhD educating environments. The evaluation led to a number of revisions of the framework conditions in 2002 of which the most important was an increased emphasis on Research schools as a means to secure quality and critical mass. In 2005 there were 140 Danish Research Schools, but this number was later reduced. After 2007 where the so called PhD schools replaced the Researcher Schools the number dropped to 53 by the end of 2010 (Mejlgaard et al 2012).

Throughout the period from the mid-1990 until the middle of the 2000s the number of graduated PhD's per year had been fairly stable. However, this situation has been drastically changed during the last 10 years where the number of graduated PhDs per year once more has more than doubled. The increase in the volume was the result of two steps. First, the Ministry of Finance in collaboration with Ministry of Science, Technology and Innovation recommended to increase the volume of graduated PhDs by 500 per year. Secondly, the so-called Danish Globalization Strategy from 2006 further increased this target and stated that the number of graduated PhDs by 2010 should be doubled from the 2004 level. Rather than mainly aiming for the reproduction of the public science system these increases were targeting the wider labor market based on the notion that a larger share of highly skilled PhDs (in the private sector in particular) would be an asset in an increasingly competitive globalized knowledge economy. As a consequence of this notion the increase in volume was highly selective as 90 percent of the increase was to take place within the natural, medical and technical sciences as these areas were perceived to contribute the most to innovation and growth.

6.3.2. Sweden

Sweden already introduced a four year PhD training system late in the 1960s and had a PhD training model in place in the 1980s which essentially is the same as the model used today. One difference however is the funding structure, and as a consequence of that, the average duration for completing the PhD. Until the 1990s it was essentially up to the university faculties to admit applicants to doctoral training, in such numbers that sufficient study conditions were guaranteed, especially regarding supervision. During the 1990s however, rationalisation in terms of resource-efficiency was increasingly requested. The idea to shorten the duration of doctoral training to three years was discussed in 1996 and 1997, but in the budget bill of 1997, the government kept the four year duration and in fact put up a barrier towards admission, through a regulation stating that the whole training period should be fully funded for the individual. The funding model used included financial support to the doctoral students, primarily in the format of stipends and/or salary, the latter following formal employment. This change also more or less terminated the funding of PhD scholarships and positions from the research foundations, which in turn redirected their flow of funds towards excellence initiatives, strong research environments and support to academia-industry cooperation. Altogether, the Swedish PhD system became less dependent on competitive external funding. This in turn resulted in fewer available PhD positions, and falling numbers of examined PhDs.

With time, the norm has become to supply four years of full time salary, but often paying the doctoral students for 20 percent teaching in addition, which in practice means that the duration of

the doctoral training is five years. The time from admission to graduation has decreased significantly over time. In 2014 the average PhD graduate needed 5.5 years (4.2 years of full studies) to compete his or her exam, down from 6.0 years in 2003 (4.4 years of full studies), 6.5 years in 1996/1997 (4.7 years of full studies) and around 7.5 years in 1986/1987 (around five years of full studies).[4]

The level of the salary is negotiated between the employing institution and the trade unions, as for other employees in Sweden. There are no governmentally regulated salaries. There is however still no ruling that states that the individual support must come in the format of an employed position and salary. Stipends or scholarships are still used to support some doctoral students, who in such cases miss out on social security rights and pension rights. For a small minority of doctoral students, the studies are in reality not financially covered by the institution at all, but left to the individual him- or herself to cover. This is essentially a violation of the legislation, but difficult to put an end to as the student at hand may be happy to be admitted despite lacking financial support.

In the early 2000s, so called research schools became a hot topic. The government decided to launch and fund a set of national research schools in selected thematic areas. The purpose was to strengthen multidisciplinarity and create platforms for cross-fertilisation from different research fields in the training programmes. For a few years already, the Foundation for Strategic Research had given funding to research schools as part of their support to various research programmes. The format was appreciated and perceived modern and promising.

In the 2010s, doctoral training in the format of research schools has become an established alternative to traditional disciplinary doctoral training, and is provided by many HEIs in many research areas as part of their everyday activities. The design of a research school and its curriculum is up to the institution at hand to decide. The doctoral students are more and more seen as part of the staff and are included in research groups or other collegial networks. They conduct research, teach, or assist the department in other ways. Internationalisation activities are typically part of the setup and training, for instance in terms of support to conference attendance, but in some cases also cooperation and periods of stay at a partner institution. International publishing in journals is nowadays the norm except in the humanities and parts of the social sciences, but this is not regulated in any way. The institutions also decide on the amount of required course attendance and requirements of the dissertation. The doctoral student is graduated by defending the PhD dissertation in public. A field expert from another HEI is appointed as opponent. A board of three members from the department, the faculty and one other HEI is present and may also ask questions, and the board will afterwards decide if the student will pass and have the dissertation approved. There is no grade system, only “pass” and “not pass”, and no motive or other written or oral report from the board’s discussions is permitted. An approved dissertation together with approval of the stipulated coursework result in a PhD degree.

Other alternative formats of doctoral training have also emerged. One such alternative format is the ‘industrial PhD’. Since 1995, the Knowledge Foundation has funded more than 30 industrial PhD schools. The purpose is to meet the business sector’s needs for research expertise in relevant areas via co-produced doctoral training programmes, thereby strengthening the long-term

[4] Swedish National Agency for Higher Education (1997). Årsrapport för universitet och högskolor. Stockholm: HSV. Swedish National Agency for Higher Education (2004). Högskoleverkets årsrapport 2004. Stockholm: HSV. Swedish Higher Education Authority (2015). Årsrapport 2015 för universitet och högskolor. Stockholm: UKÄ.

competitiveness of the business sector. Industrial PhD schools should also improve the conditions for long-term relationships and collaboration between universities and companies by increasing the mobility of personnel. The scope varies between 6–15 doctoral students (each school funded by SEK10–30m). The Knowledge Foundation covers part of the costs of each doctoral student who is awarded a degree from the school. Also the Foundation for Strategic Research runs a programme for industrial PhDs, with the purpose to contribute to excellent research within the Foundation's areas of activity and to foster cross-fertilisation between academia and industry. The Foundation initiated the programme after the Swedish Research Council had terminated its equivalent programme. Prioritised areas during 2012–2017 are Life Sciences, Life Science Technology, Materials Science and Technology, Information, Communication and Systems Technology and Data-X and Computational Sciences and Applied Mathematics.

For Sweden it is also worth noticing, that the number of HEI institutions accredited to award PhD degrees has increased throughout the investigated period. Until 1999 granting PhDs was an exclusive right for twelve institutions: the seven universities, three universities of technology, the Karolinska Institute (medicine) and Stockholm School of Economics. In 1999 three university colleges were granted university status and thereby the right to award PhDs. From 1999 and onwards also a number of university colleges have been granted rights to award PhDs, restricted to specific fields of science and technology. In 2005 Mid Sweden University College was granted university status, making the number of universities to the present 16, including the universities of technology, Karolinska Institute and Stockholm School of Economics. An additional five university colleges have the right to award PhDs in specific fields of science and technology (e.g. natural sciences) and a handful other university colleges have from 2010 and later been granted the rights to award PhDs in very specific subjects (e.g. textile and fashion at Borås University College).[5]Still in 2014 however, 90 percent of all PhDs graduated from the original twelve PhD-granting HEIs. The four oldest and broadest universities (Lund, Uppsala, Gothenburg and Stockholm) have however seen their combined share drop from 67 percent of all PhDs in 1980 and 60 percent in 1990, to 45 percent in 2014, while the three large specialised universities (Chalmers University of Technology, Royal Institute of Technology and Karolinska Institute) have increased their share of PhD graduates from 20 percent in 1980 to 28 percent in 2014.[6]

6.3.3. The Netherlands:

As part of a wider reform of the provision of higher education, the Netherlands introduced the employee function of 'assistant in training' (assistant in opleiding, or 'aio') within the research system as part of the collaborative labour agreements in 1986. Salaries for this function were to be paid from basic financing for the university, or if appropriate by additional third stream income.

The 'assistant in training' at the time was considered a transitional position between being a student and researcher and – despite being an employment function - remained an important part of the 'education system'. The function was designed with advancing scientific research as an equally important objective, by establishing stricter agreements on guidance with the research, freedom within research and also to facilitate sufficient time spent on research (vs teaching for example). Prior

[5] Swedish Research Council (2008). Reformer inom forskning och forskarutbildning 1990-2007. Stockholm: Swedish Research Council

[6] Statistics Sweden (2015). Number of PhD graduates per institution, subject area and calender year.

to this function, research activities conducted by the assistant in training were often done by university staff with higher salaries than that of an assistant in training.

In order to become an assistant in training, the researcher had to have completed one year of preparatory research education (propodeuse) and three years of doctoral level education (doctoraalfase). In comparison, the system is currently aligned conversely in that a bachelor degree is to generally take three years and a master degree generally one year, before being able to embark upon a PhD. The assistant in training function was designed as a stepping-stone into the pathway of a scientific researcher and intended to support both the individual researcher's career as well as the scientific system as a whole. Notably the concept that the assistant in training counted as an employee rather than a student - despite the continued education component of the position – was considered an important way to boost selection and facilitate growth of researchers in the university system.
The assistant in training position did not evolve without criticism, notably as a 'half student function'; with relative low wages and insufficient clarity in task leading steadily to an increase in vacancies that became hard to fill in several research areas. Particularly the latter became an important indication that students interested in pursuing research were not necessarily interested in preparing for a scientific career within academia. In the battle for talent in the mid to late 1990s, the private sector began playing into this development by marketing the future of a research student as much more exciting in businesses than a 'dull' academic career path. For those areas of research where a shortage of talent was indeed an issue (especially in the technical programmes), these forms of criticism did eventually lead to a series of talent stipends from universities and eventually the Ministry of Education for the assistant in training positions. More importantly, by the start of the millennium (between 2001-2004) these developments led to an evaluation of the function by the Union for Universities (VSNU) and eventually to significant changes including more rights as an employee, increase in salary and the change in title to 'promovendus'.

Around the same time as the evolution of the function of the assistant in training began, another change in the system took place that has left its legacy on the current PhD system. In the mid to late 1980s, faculties of different universities began collaborating and organizing themselves along the concept of a graduate schools. In 1991 this process led to the formalization of 'research schools'. Important in this process was that the research schools would be organized in such a way that they would offer sufficient variety in their specializations. The choice to set up a research school was left to the universities themselves, but under the conditions that they needed to fulfill specific criteria in order to receive official recognition (by the Dutch Royal Academy of Sciences – KNAW). These research schools still exist and are characterized by their inter-university collaborations and their role in programming research. For PhD candidates these research schools do not only form a way to increase research quality, but also widens the network of fellow candidates and links their research closer to societal needs.

Both the financing of PhD candidates and their employment future remain highly debated issues in the Dutch university system, and are closely linked. Regarding the careers of those completing a PhD the discussion revolves around numbers; should universities only prepare PhD candidates for the academic pathway or also the private pathway? And if for both, what do universities need to do differently to facilitate that transition? Also, if for both, what should be the balance between basic funding and other forms of funding for a large group of PhD students? Several universities have experimented with

providing fellowships over employment positions, but not without legal barriers (and a court case) and push back from representatives. In 2015 the Minister of Education proposed a pilot project to facilitate a fellowship approach but was met with hesitance by several universities who were worried about the impact on the legal employment status.

6.4. Bibliometric analysis

The question is, however, to what extent we can link the developments in PhD volume and formal framework conditions to the development in performance within the three countries. In this study no direct, quantitative links can be established, but a more indicative analysis is carried out in the following section.

A main argument in Nørretranders and Haaland (1990) is that the decline in Danish impact in the 1980s partly was due to skewness in the age profile of the Danish researcher cohort. In the late 1960s and 1970s the universities experienced radical changes where especially the number of students and academic staff grew strongly as outlined above. Sudden critical increases in the academic staff obviously put strains on the established research system as many of the new staff members were recruited without formal research training. Nørretranders and Haaland (1990) argue that the sudden enlargement of the academic cohort also meant that the continuous inflow of younger researchers in the Danish system stalled and as a consequence the cohort simply became older. According to Nørretranders and Haaland (1990), this growing skewness in the age profile had detrimental effects on the Danish impact, talented young researchers were kept out of the system and the system's general dynamic and self-organising character was fundamentally challenged.

The analysis presented by Nørretranders and Haaland (1990) looks back at the 1970s and 1980s and they argue that if nothing was done this would also negatively influence Danish impact in the future. However, something was done in Demark with establishment of first the Researcher Acdemy and soon thereafter also the PhD reform as outlined previously in this chapter. Likewise the establishment of the Danish National Research Foundation also meant that younger talented researchers gained new career opportunities as argued in chapter 5.

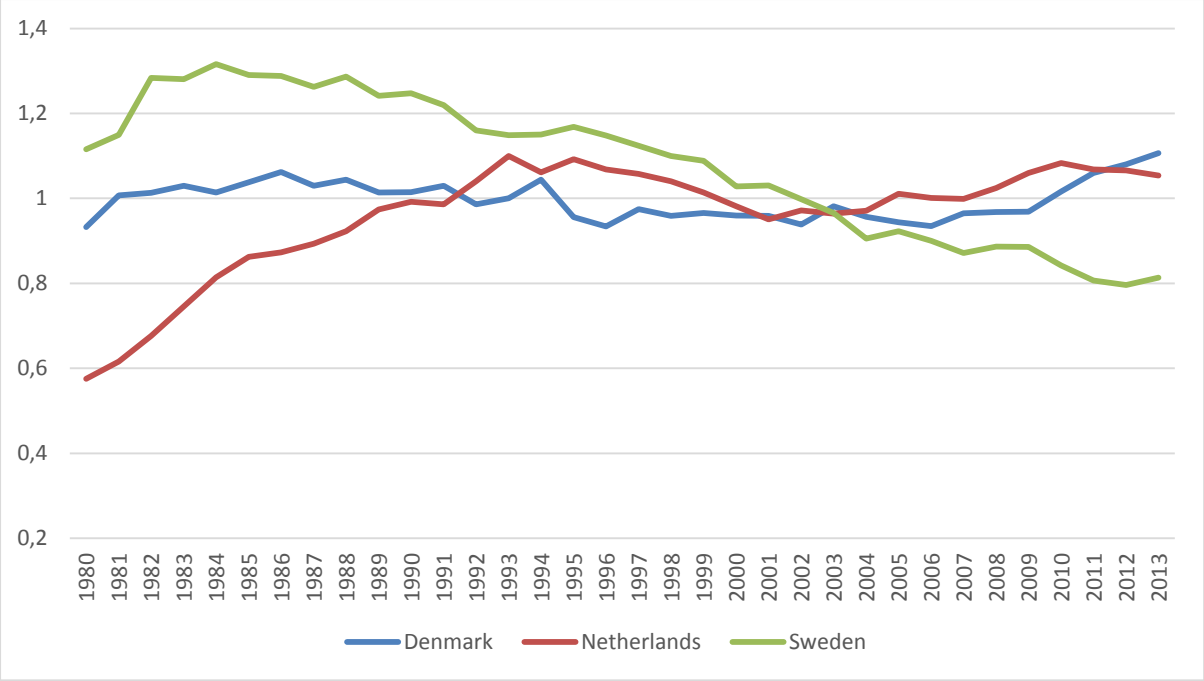
In order to examine empirically the potential changes in the age cohort and its potential influences on research performance, we have estimated the annual rate of new publishing researchers for Denmark, Netherlands and Sweden, relative to the annual established number of publishing researcher (i.e. researchers who have published papers in the database before the particular year in question). We have normalized the rates to the development in the database where 1 means the same development of new publishing researchers as in the database. Further, we have examined the ability of new publishing researchers to produce highly cited publications within three years of becoming active. This analysis is based on former studies made in relation to the evaluation of the Danish National Research Foundation is somewhat different in its time perspective; this so-called recruitment rate analysis is comparable to the results presented in Karlsson and Persson (2012).

Productivity of new researchers

Figures 6.7 and 6.8 below show the relative development in the rate of new publishing researchers for each of the three countries for "medical and life sciences" and "natural sciences" respectively. Notice, the curves do not show the actual size of the annual output, only the rate of new publishing researchers relative to 1) the total number of national publishing researchers in the area in that year

and 2) the development in the database. A value of 1 would mean that the relative "recruitment" rate in a given years is equal to the rate for the database for that year.

Figure 6.7: Relative recruitment rates of new publishing researchers in given year in the medical and life sciences for Denmark, the Netherlands and Sweden.

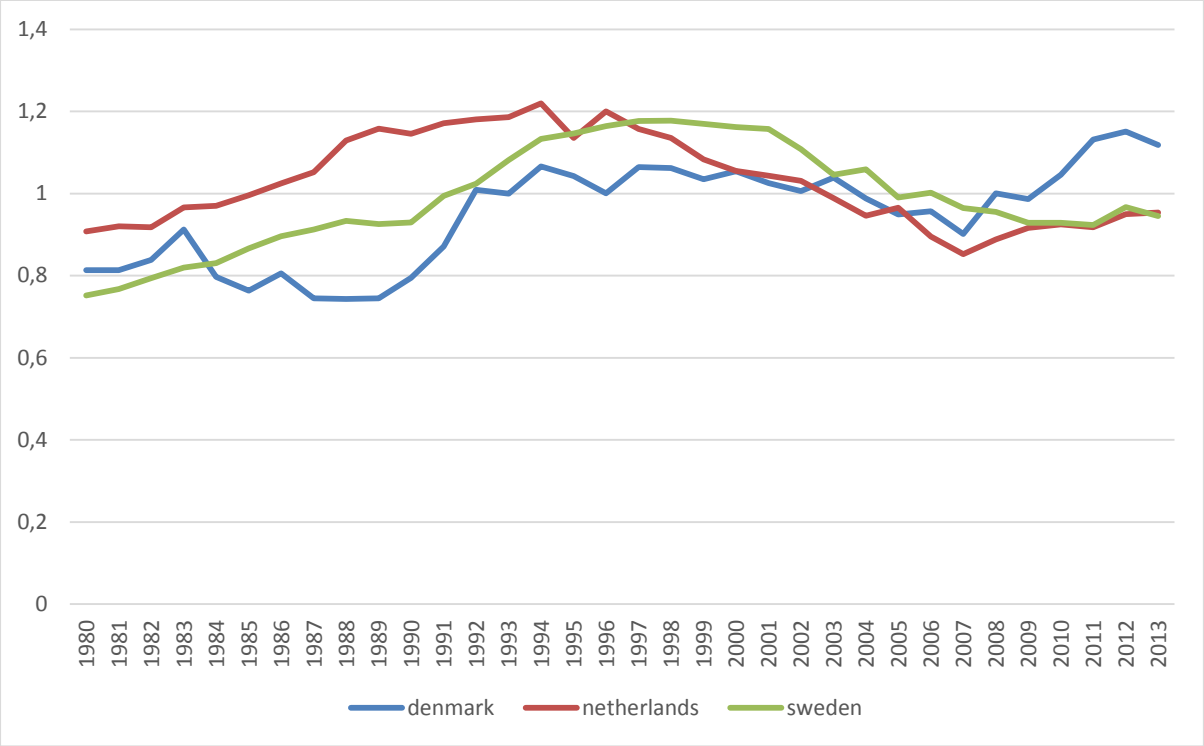


Source: CWTS Leiden

The figures should be examined for the trajectories or long term developments in "recruitment rates" and we would expect to see sudden upward changes in the rates at critical junctures such as after the two PhD reforms in Denmark which in principle should lead to an increase in new publishing researchers.

The Danish "recruitment rate" in the "medical and life sciences" have been relatively stable over the period very close to the general development in the database. Interestingly around 2009 coinciding with the latest PhD reform in Denmark the rate of new publishing researchers rises markedly. The developments for the Netherlands and Sweden are rather different. The rate for the Netherlands is markedly rising from a low level during the 1980s going beyond 1, and then drops somewhat with a new increase in the 2000s. The case for Sweden is generally a continuous drop for most of the period albeit from a very high level in the 1980s. Only around 2003 does Sweden drop below 1 and then below the two other countries, but noticeable, the drop seems to continue. One important fact to remember when examining the "medical and life sciences" is that this group is by far the largest main research area in the database measured by publication output. Further, as this analysis does not distinguish between universities and hospitals it is somewhat biased when it comes to linking "new publishing researchers" to actual reforms in as much as the hospital sector may have different hiring practices over the years.

Figure 6.8: Relative recruitment rates of new publishing researchers in given year in the natural sciences for Denmark, the Netherlands and Sweden.



Source: CWTS Leiden

Figure 6.8 shows the same developments for the natural sciences and in this case we are predominantly examining researchers affiliated to universities or related public research institutions which are most likely directly influenced by national political steering in this area.
The developments for the Netherlands and Sweden resemble each other with a general increasing trajectory from 1980 culminating around 1995 and then a period of decline and finally, stabilization from 2005 onwards. What is characteristic for these developments is that sudden "critical junctures" are not particularly visible. However, this is the case for Denmark. The development in new publishing researchers for Denmark basically show the sudden fluctuations as expected close to the "critical junctures" conceived as reforms related to formalising the education of young researchers and increasing their numbers. We see generally low rates in 1980s and then a sudden marked increase in the late 1980s and early 1990s corresponding with the first PhD-reform. Hereafter we experience a period of stability where the "recruitment rate" in Denmark is on par with the development in the database for the natural sciences. In the early 2000s a minor drop is seen but then again around 2008-2009 we see a marked increase again coinciding with the second PhD-reform.

These figures give us an indication that the reforms actually leads to an increase in new publishing researchers. Whether the numbers are slightly above or below the database average is not as important as the continuity in the trajectories. Sudden and too many fluctuations indicate instability in the research systems whereas stable long term trajectories may point to a more balanced system where the influx of new researchers is well-adjusted. What we cannot see from the figures is the fate of these new researchers, how many of them continue to publish (i.e. stay in the system) and how does sudden increases in the research population affect impact? We know that for Denmark

especially the natural sciences contributed (and contribute) extensively to the total Danish impact so increasing the number of new publishing researchers can actually have negative influences on impact unless such new researchers after a short duration of time generally perform at least on par with the national level of impact. This is examined below.

The 'recruitment' rate of new scientists publishing highly cited publications

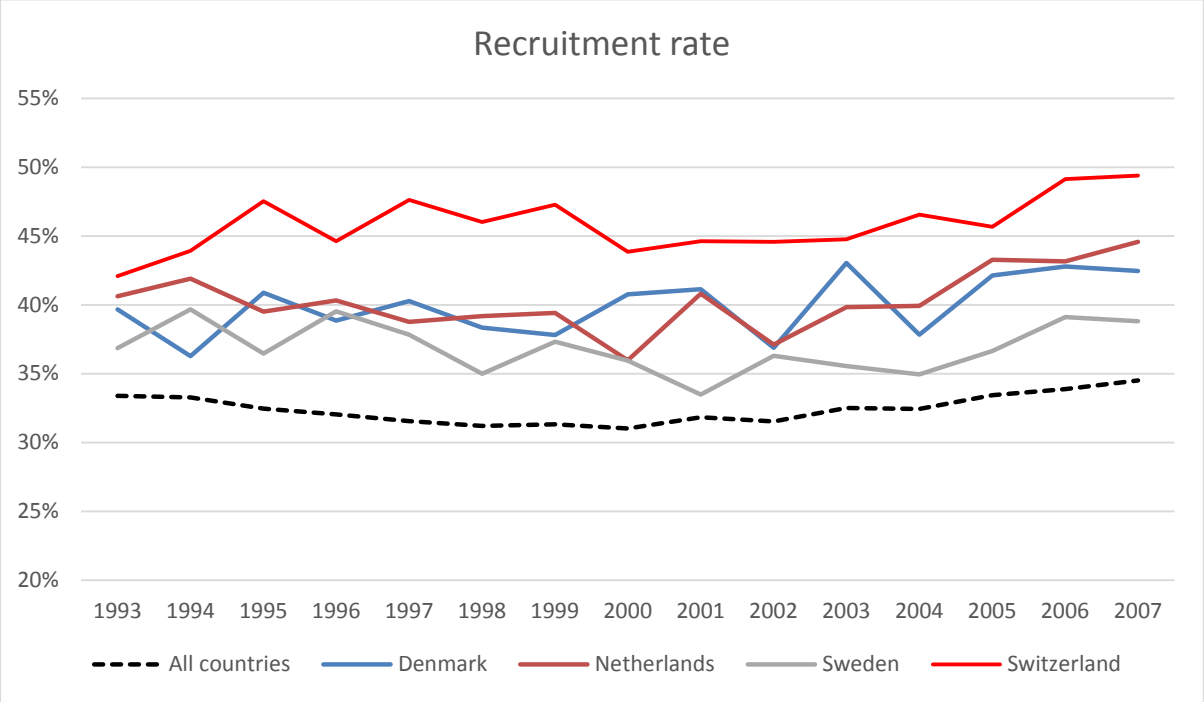
In a recent Swedish report (Karlsson & Persson, 2012), the ability of certain countries to recruit new top scientist is estimated by use of a bibliometric approach. Investigating several time periods, the idea in the Swedish report was to estimate a 'recruitment' rate for each country, which is supposed to indicate how many new scientists would produce highly cited publications from period to period. The Swedish approach had some clear limitations in relation to identifying national researchers. We have therefore developed an alternative approach where we utilize the CWTS-WoS database' superiority when it comes to address and name matching in order to examine basically the same question (see Schneider and Costas, 2013 for a description of the methodology).

Figure 6.9 below presents the "recruitment" rates for "successful" new researchers over time for Denmark, the Netherlands and Sweden. Contrary to the relative "recruitment rates" of new publishing researchers presented above, Figure 6.9 shows the annual rate of proportion of new researchers in that year who within three years from the first publishing year has produced a highly cited publication (i.e. a publication among the 10% most cited). For example, if the proportion is 50% then half of the new publishing researchers detected in a particular year have produced at least one highly cited publication within three years from the starting year. Notice "producing a highly cited publication" means being an author or a co-author of such a publication; the actual contribution to such a publication is not considered. We therefore emphasize that the actual "recruitment rates" should be interpreted carefully, in as much as they to a large extent reflect collaboration practices. Young researchers starting their publication career in a high performing environment where teamwork and co-authorships are the norm will obviously benefit from this; their socialization into the stratification of science will, all other things being equal, be advantageous compared to young researchers from lower performing environments.

However, what is more important to notice, are the actual patterns and differences between the countries. We have included Switzerland in this analysis for benchmarking purposes and the overall developments and recruitment rates are basically as expected. Switzerland has higher rates which conform to their general high impact compared to Denmark, the Netherland and Sweden. In bibliometric evaluations, Switzerland is usually always among the top three ranked nations in the world, the others usually being USA, UK and the Netherlands. Denmark is usually on par with the Netherlands, and ranked above the other Nordic countries, such as Sweden, Norway and Finland. In that respect, the differences between the countries in this analysis verify the expected pattern. For example, Switzerland is *per se* the best performing country of the five in the analysis and Switzerland is also able to produce or 'recruit' a higher rate of new top scientists compared to the other countries. Hence, it seems that 'recruitment rates' are correlated to impact rank order. Further, if we compare our results to the results in the aforementioned Swedish report (Karlsson & Persson, 2012), which are based on a different approach, the results are actually similar. We see the same rank order between the countries based on the ability to 'recruit' new top scientists. Hence, we therefore consider the results in this analysis to be reliable and also more robust than the Swedish analysis. In general the Danish proportion of new researchers with highly cited publications fluctuates around

40% and perhaps most notably we see that as the national impact for Sweden drops in the 1990s so does the "recruitment rate" and while it begins to increase again, it does not close the gap to Denmark and the Netherlands.

Figure 6.9: Development in the rate of 'successful' new scientists, where 'successful, means publication of at least one highly cited publication (top 10%) within three years from the scientist's first publication in WoS.



Source: CWTS Leiden

We can therefore conclude the "success" of young new researchers, measured as impact, on the aggregate level of national research systems is to large extent a function of the performance of the system they "feed into". National performance and recruitment rates correlate. The results also confirm that the increases of new young researchers into the Danish system due to the early reforms in the late 1980s and early 1990s seemingly have not influenced the national impact negatively, on the contrary the recruitment rate has been stable when it comes to producing highly cited publications within a short period after becoming active.

6.5. Summary of findings

In the Danish case the hypothesis concerning PhD education stands out as one of the most important explanations for the reversal of the negative trend during the early 1990s. The power of the explanation has however more to do with the character of the imbalances in the Danish system during the 1980s and thus with the timing of the initiatives, than with the actual content of the changes. As shown in the analysis the Danish system suffered from a very low volume of graduated PhDs and limited renewal in the composition of the staff at the universities throughout the 1980s. The Researcher Academy and the subsequent PhD reform addressed this imbalance and in turn created a solid foundation for the growth that characterized the Danish system throughout the following decades. Neither the Netherlands nor Sweden were suffering from the same problem during the 1980s as they already had a fairly large PhD-production during the 1980s.

While the PhD education hypothesis thus stands out as an important factor in explaining both the Danish drop in performance and the subsequent reversal of the trend, we find no indications that the Danish PhD education system today should be seen as fundamentally different from the systems in Sweden and the Netherlands. Seen in a comparative perspective the Danish PhD reform of the early 1990s and the following changes throughout the period have shared a great deal of similarities with the PhD reforms carried out in other countries during the same period. PhD education do however lie at the core of the research capacity of all nations, and as such form a central part of the foundation for high academic performance. The volume must however be calibrated carefully as it can displace investments at the expense of other parts of the science system and as it may skew the balance between continuity and renewal in the staff composition.

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7. Governance and management of the universities

The sub-analysis presented in this chapter deals with the governance of the public research system and in particular the governance of universities. The external governance of universities (Aghion et al 2010) and in particular the internal leadership of the institutions (Hollingsworth 2008; Goodall 2009; Öquist and Benner 2012) are often highlighted as important factors for research performance.

The fourth hypothesis of DFiR revolves around these issues and targets the internal governance of the universities in particular. The hypothesis states that a new university act in 1993 may have contributed to strengthen Danish research performance by placing the responsibility of hiring and recruitment decisions by the university management rather than in the collegial committees. In addition, the central university management was given better opportunities to affect the internal allocation of the institutional funding. These developments were further strengthened in 2003 when a new university act was passed. The main question of this sub-study is to what extent the developments in university governance differ for the three countries. Are there differences in their characteristics or in the timing of changes and can we see any relation between these differences and developments in performance?

However, just like the question of funding mechanisms examined in chapter 4 and 5 the governance issue is both complex and multidimensional. We need not only to distinguish between external and internal governance, but also to distinguish between central leadership of the institutions and local research management. Although the latter, understood as organising, managing and leading researchers at the research group level (Verbree et al, 2012), is highlighted as a very important factor for research performance it is not included in this analysis.

The chapter is structured as follows: Section 7.1 gives a brief introduction to the issues under examination based on the literature review presented in chapter 2. Following up on this section 7.2 gives a qualitative account of the main trends in the governance of the universities for the three countries for the whole period investigated in the present study. In continuation of this section 7.3 presents a direct comparative analysis between the three countries on a number of selected governance dimensions. Finally, section 7.4 highlights a few general conclusions.

7.1. Main trends

During the last few decades there have been shifts from traditional state-centered governing arrangements to alternative modes of governance in almost all western countries and within almost all sectors of the public sphere based on a number of so called New Public Management rationales. New Public Management is essentially a theory of generic management across all areas and sectors and it is implicit in the approach that all types of management are facing the same types of problems – and accordingly that the same solutions can be applied across different fields (Christensen & Lægreid 2002: 269-270). It is common for the reforms that they seek to challenge traditional steering and management methods in general and bureaucratic and hierarchical systems in particular. The approach has its main focus on efficiency, markets, contracts and institutional autonomy and has been described as a shopping basket of methods for reformists of public policy. Its main rationale is to raise the efficiency of public sector activities - above all in terms of performance and client satisfaction. The intellectual influences come from both public choice theory and management science.

Through this general reform movement the research and university sector increasingly has become subject to the same control and demands as most other sectors. In this respect the emerging reform policy path has represented a challenge to the traditional view of the universities as unique institutions, which ought to be managed according to traditional academic norms and values. In general the changes have included strengthening of management structures and widespread introduction of market mechanisms. The main objectives have been to 'steer at a distance' and to hold institutions 'accountable'. These developments are in line with the European Commission's Modernisation Agenda for Higher Education (2007). This agenda highlights that education, research, innovation and the modernisation of higher education institutions are main pillars of the Lisbon Strategy. To create effective governance and funding mechanisms in support of excellence is one of the pillars of this agenda.[7]

With regard to the internal governance of the universities most western European countries have developed from a classical 'primus inter pares' collegial, self-governance model dominating up until the late 1960s. From here variations of democratic governance models with inclusion of junior staff, students and administrative staff took over, before a series of NPM inspired reforms started to be introduced in the late 1980s and 1990s. Recently found designs are those that strengthen executive leadership at the central and middle level of universities. In sum these reforms have changed the traditional university governance structure rather fundamentally. The timing and content of the changes have differed substantially across countries, but there are however some cross cutting observations:

A comparative OECD study (Connell, 2006) has found several common trends in the academic research management in different countries. Universities nowadays specify their research priorities and develop strategic plans; they evaluate their research performance regularly and develop principles for ethical conduct. Furthermore, research management has become 'professionalized', i.e. universities appoint high-level academic and administrative staff whose sole responsibility lies in overseeing research activities. Also Beerkens (2013) highlight a number of central management practices including: internal performance monitoring and performance funding, benchmarking and concentration of resources. Also the creation of individual incentives and upgrading of competencies are mentioned as central recent management practices.

While knowledge about general trends in research management practices is accumulating as outlined above, evidence about the effect of these practices on research performance is still scarce (Enders, De Boer and Weyer 2013; Beerkens 2013). There are however some interesting findings. Among others Aghion et al (2010) argue that the combination of widespread autonomy and a competitive environment creates good performance, but they acknowledge that several high performing models can be identified. At the level of internal university governance a correlation between the recruitment of esteemed academics as presidents or vice-chancellors, on the one hand, and aggregated performance (as measured in ratings in UK Research Assessment Exercises) has been shown (Goodall 2009). The argument is that esteemed academics have credibility and legitimacy, that they have an understanding which informs strategic decisions. This can raise the quality bar and sends a signal internally and externally that the institution values academic excellence (Goodall Research Policy 38 (2009) 1079–1092). Also Schubert (2009) has studied the internal governance and

[7] http://ec.europa.eu/education/higher-education/agenda_en.htm

demonstrates a positive effect of strong central leadership, operational flexibility, goal agreements, and an internal evaluation system in German universities. Evidence is also provided by Hollingsworth and Gear (2012): Based on in-depth analysis of a large number of cases they highlight a number of characteristics of organizational contexts facilitating the making of major discoveries. With regard to organizational leadership they underline the following five factors as important: (a) capacity to understand the direction in which scientific research is moving, (b) strategic vision for integrating diverse areas and providing focused research, (c) ability to secure funding for these activities, (d) capacity to recruit individuals who can confront important scientific problems, and (e) capacity to provide rigorous criticism in a nurturing environment. Finally, also Öquist and Benner (2012) highlight central management as an important factor for academic performance.

A number of potential negative consequences of strengthened central management are however also highlighted in several contributions. Among others Hollingsworth and Gear (2012) and Whitley (2012) emphasize that strengthened centralization may lead to excessive hierarchies, standardization and bureaucratization which may limit 'protected spaces' and the room to maneuver at lower levels. Whitley (2012) has conceptualized flexibility as: [t]he openness of the scientific community, employers, funding agencies and other authoritative groups and organisations to novel and unusual ways of framing problems, developing new, especially cross disciplinary, ways of dealing with them and interpreting evidence. (Whitley 2012: 6). This is directly related to the university setting and may support the conception of universities as open systems where academic activities are carried out through multiple connections and dimensions within, across, and outside the academic organization. It is here argued that a high level of flexibility is directly proportional to a low level of centralization, formalization and standardization.

7.2. Developments at country level

In continuation of the broad conceptual introduction presented above the following section outlines three brief qualitative accounts of the developments in university governance for the whole period under examination.

Danish university governance

The governance of the Danish higher education system has been significantly reformed over the past decades, from the initial radical democratization reforms of the 1970s to the NPM-inspired reforms of the new millennium.

Until 1970 the internal governing authority of Danish universities was placed with all the full professors (and some of the associated professors), and they were given the right to choose their leaders, i.e. rectors and deans, from among their peers. This 'professorial rule' was, however, put to an end by the new Administration Act ('Styrelsesloven') in 1970 which changed the management structure from a classical meritocratic model to a highly democratic model with strong student and administrative representation (Aagaard and Mejlgaard 2012). This act allowed the remaining full-time academic staff members as well as the students to take part in the election of the university leaders. The students were given seats in all the governing bodies of the university and their representatives in faculty councils and course committees were given the right to vote in rector and pro-rector elections (1970 Act, § 4, 6, 9 & 10). Furthermore, the Act gave associated professors and other full-time academic staff members the right to run for office and it was now merely the positions as rector and prorector that remained the full professors' privilege. The technical and

administrative staff gained influence too by the right to be represented in the new department councils [1970 Act, § 9 (2)]. With regard to the external governance the universities were formally governed by the Minister of Education, but the internal management and governance of the university's affairs were guided by internally agreed rules and procedures and thus without external interference. The boundaries towards the external environment were thus continually safeguarded—also by the political system.

This governance system was, however, under heavy attack almost from the beginning. Critics argued that an unintended consequence of the new act was a shift from quality to equality in the internal allocation of research funding (Olesen Larsen 1981, Aagaard 2011). It was also argued that the democratic system was a barrier to priority-setting and that the universities suffered from a general leadership vacuum. The 1970/1973 university act had abandoned the leadership function that was previously in the hands of the professoriate it was argued, but without replacing it with another legitimate authority (Olesen Larsen 1981: 190). Also the OECD was critical towards the system and argued in an evaluation of the Danish research policy system in 1987/88 that it was seen as: "..*essential to give the universities an organisational structure which provides them with more authority and leadership. This means that the existing, highly participative system for research decision-making must be modified to enable the university management to act and function more efficiently*" (OECD 1988; Petersen 1997).

In spite of the criticism the act survived for more than two decades. First in 1993 a new Danish university act was passed which strengthened the authority of the vice-chancellors, deans and department heads both externally and internally. While the principle of self-organization survived, there was a clear shift of power from the representative organs to the elected leaders. A main goal of the new act was also to increase the influence of society on the universities by including external representatives in the boards (Petersen 1997). Department heads were given the authority to instruct academic faculty members to undertake particular tasks [the 1993 Act, § 7 (3)]—the so-called 'instruction authority'. But even though the heads of department in 1993 were given more power, they were still elected by their colleagues and had to answer to them for their dispositions.

While many stakeholders and politicians still felt that the act was too limited in scope, most actors within the universities saw it as a reasonable compromise providing opportunities for strategic priority-setting and recruitment of highly qualified staff on the one side and maintaining legitimacy on the other. However, large parts of the previous criticisms continued after the passing of the new act.

As the last step in this development, a new University Act from 2003 introduced boards with a majority of external members as the superior authority of the universities and prescribed employed leaders instead of elected at all levels. The appointed leaders were required to have a significant academic background but should no longer necessarily be recruited from among the university's own academic staff. The objective was to sharpen up the profiles of individual institutions, to professionalize and empower managerial structures, and to increase collaboration between the actors of the research and innovation system – the latter exemplified by new claims for universities to formulate goals and strategies for cooperation with trade and business. The Act emphasised that the universities' new management should make strategic selections of research areas and give high

priority to these areas (Aagaard and Mejlgaard 2012). The new boards were in place in late 2005 and most universities had the appointed leaders installed by 2006.

Swedish university governance

The links between Swedish universities and the state have always been strong, fundamentally because the state has taken on the role to fund the university system and to protect it from other interests in society. From the 1940s and onwards, accelerating in the 1960s, the policy-discussion has been largely focused on the contributions that universities make to society through its research and its education of students and PhDs. This has also shaped the university governance. Until the 1960s universities were essentially a protected area for professors and the faculty staff, but the late 1960s and 1970s saw the introduction of democratic steering institutions in which also students and representatives from external actors were represented (Andrén 2013). In 1977 the system for higher education was reformed. All state institutions for higher education were placed under a common category – högskola – which included both universities and a long row of university colleges which were established across the country. Research and the right to award PhD was however still an exclusive right for universities. At the same time the government decided to allocate funding to higher education institutions in two block grants: one for undergraduate education and one for research and PhD education (Fritzell 1998).

In 1993 there was a major reform of the system for higher education and research. The most striking change included the introduction of a system for 'management by objectives' and a new Higher Education Act and Higher Education Ordinance. Whilst formally recognising the role of public higher education institutions as government agencies with specific roles and responsibilities under the jurisdiction of the government and parliament, the Act and Ordinance recognised their special position within the government system and thereby provided substantial autonomy in comparison to other government bodies. Since then there have been changes towards strengthened governmental regulation again. From the mid-2000s, deregulation has characterised the governmental policy towards higher education institutions, prominently exemplified with the the so-called 'Autonomy Reform', which caused a new wave of governing changes in 2011. This reform ensured that universities have more freedom in deciding on their internal organisation, including legal requirements for collegial steering of faculty boards. As an effect of the reform, practically all university colleges and all universities established in the 1990s have reformed their organisations by considerably decreasing the power of collegial organs. However, this is not the case for the four largest, broad universities in Lund, Uppsala, Gothenburg and Stockholm. Furthermore, until 2010 the government appointed the external members of the governing board who make up the majority of representatives. This circumstance was also changed with the Autonomy Reform.

Dutch university governance

The Netherlands has been one of the frontrunners with regard to implementing new governance arrangements towards the university sector. Already in the mid-1980's the Dutch government introduced 'steering at a distance' mechanisms as a replacement of the former more direct steering. However, public universities in the Netherlands still had restricted leeway to determine their own internal governance structure prior to 1997. In 1997 the national Law on Higher Education was adapted and the ministerial regulations with respect to the internal governance structure were significantly changed. Although universities still have to apply the ministerial guidelines, they now have more discretion to make their own choices. As a result of the reform the executive leadership

positions were strengthened and powers became more concentrated. Notably, a new body, a 'supervisory board' was introduced at the top-level of the institution, consisting of five external lay members, appointed by the minister. Furthermore, the representative bodies where staff and students held seats became advisory bodies instead of decision-making bodies and the academic departments lost many of their formal decision-making powers. With further changes to the Law on Higher Education in 2010 and 2013, a charter for Good Governance was developed and stricter rules were put in place for the composition of the boards to ensure that they could function as a real countervailing power. Members of University Boards are no longer allowed to also be member of the Board of Colleges.

Since the changes to the law in 1997 made it mandatory for universities to increase transparency to the government, there have been no changes to the system of accountability. The law makes it obligatory to make strategic plans, an annual report, an audited financial statement and a peer evaluation taking place every six years. All this should be made available to the government. Universities are also legally obliged to produce a strategy document setting out the university's policies and objectives every six year. Whilst this also is a mandatory exercise, its content is neither restricted nor adapted by the government.

Dutch universities have substantial autonomy on staffing matters. Negotiations with trade unions were formerly conducted by the Ministry in the Netherlands, but this changed in 1998 when the universities themselves became responsible for these negotiations. Universities also experience large autonomy when it comes to other staffing considerations, including deciding on how many and which types of senior academic posts they wish to create as well as the selection process for filling these vacancies.

Universities in the Netherlands have a self-regulatory approach to quality evaluation. As of 2003 universities are legally obliged to have their research assessed but they can do this independently from each other. The universities jointly agreed to a standard evaluation protocol, which ensures uniformity in assessment criteria but leaves room for-tailor made adaptations. Peer-driven external assessments are required to take place every six years and made publicly accessible. These are formative evaluation as there the outcomes have no budgetary implications. As of 2002, universities can select their own peers for this external review. Furthermore, since then an additional mid-term review is also obliged to take place after three years, but does not need to be made public. In 2008 the standard evaluation protocol (SEP) for the external review changed slightly to decrease administrative burden for evaluators and evaluated bodies and to increase focus on societal relevance, positioning and on benchmarking. The emphasis on output has decreased over the years while the emphasis on relevance and integrity has increased. The evaluation of the SEP prior to 2008 showed positive results and users emphasized the importance of continuity in the guidelines for research assessments.

Recent development encompasses the introduction of steering arrangements. In 2010 the Ministry emphasised in their 'Strategic Agenda for Higher Education' the need for differentiation and announced the introduction of 'performance agreements' with all Dutch universities and colleges. The parameters for these agreements were defined in a broad agreement with the Association of Cooperating Dutch Universities (VSNU). Consequently all higher education institutions were invited

to submit proposals. These proposals were however not so much about research profiles but focus mainly on the quality of education and the plans regarding valorisation. If institutions do not meet performance targets cut back on their funding will be made. Five percent of state funding depends on meeting these performance agreements. In addition, two percent of funding will be selectively distributed by the state based on plans to realise performance agreements.

7.3. Comparative analysis of governance changes

In continuation of the qualitative accounts outlined above a more structured comparison of selected dimensions of governance in Denmark, Sweden and the Netherlands between 1980 and 2015 has been carried out. By comparing qualitative information on the differences in the characteristics and the timing of changes between the three countries, we have analysed the relationship between university governance and performance. This section presents these findings.

For the analysis of governance we have developed a framework for analysing autonomy inspired by de Boer et al (2010). With this approach autonomy refers to the extent of which state regulation determines different components of university governance. The 2010 study of de Boer et al. on *Governance and funding reform in European Higher Education*, captured the change in university autonomy regarding a wide number of areas and demonstrated its evolution between 1995 and 2008. By updating these indicators with the state of play in 2015, we have analysed them based on a framework for the internal and external governance of higher education, consisting of six main indicators, namely (1) strategy, (2) quality assurance, (3) cooperation, (4) accountability, (5) human resource management and (6) finances.

Strategy

To analyse the level of autonomy for universities to develop their own strategies, we compare the developments of government regulations on (mandatory) strategic plans, internal governance structures and research programmes captured by de Boer et al (2010) in 1995 and 2008. By updating these indicators with the state of play in 2015, it can be determined that the overall strategy setting of universities in the three countries has by and large been rather autonomous. Adjustments to the regulatory framework did take place over the past decades, but they have only slightly increased autonomy in the area of strategy setting since the 1990s.

In Denmark, public universities are not legally obliged to produce a strategic plan outlining their strategic objectives for the university, but many do so on their own account. In the Netherlands universities are legally obliged to produce a strategic plan setting out the university's policies and objectives every six years. The University Board must approve this plan. Whilst this is a mandatory exercise, its content is neither restricted nor adapted by the government. Strategic plans were also mandatory in Sweden between 1995 and 2008, but by 2015 this is no longer the case. Nevertheless, it has become a common practice so that, similar to Denmark, most institutions produce and maintain a strategic document setting out the vision and objectives of the organisation. The differences between the three countries with regards to strategic plans are thus rather limited and the changes over time appear insignificant.

In all three countries more autonomy to influence the strategy and direction of research has been enhanced by reducing ministerial involvement in determining the internal governance structure of universities, including the nature of the governing bodies, their composition and their main powers.

Universities have thereby become less dependent on the government and are more able to organise their decision-making process. These changes did not occur in the exact same year for all three countries, though shortly after each other. These changes are in line with the overall policy trends whereby universities moved from being subject to ministerial regulations to becoming subject to ministerial guidelines.

The foundation for institutional autonomy in Sweden was by and large laid with the Higher Education Act and the Higher Education Ordinance of 1993, which overhauled the governance and funding system. Whilst formally recognising the role of public higher education institutions as government agencies with specific roles and responsibilities under the jurisdiction of the government and parliament, the Act and Ordinance recognised their special position within the government system and thereby provided substantial autonomy in comparison to other government bodies. Since then there have been changes in the legislative framework that strengthen governmental regulation again. For example, in 2000 it became mandatory that universities include students in all governing bodies. From the mid-2000s, deregulation has characterised governmental policy towards higher education institutions, prominently exemplified with the so-called 'Autonomy Reform' in 2010. This reform ensured that universities have more freedom in deciding on their internal organisation, including legal requirements for collegial steering of faculty boards. As an effect of the reform, practically all university colleges and all universities established in the 1990s have reformed their organisations by considerably decreasing the power of collegial organs. However, this is not the case for universities existing prior to the 1990s. Furthermore, until 2010 the government appointed the external members of the governing board who make up the majority of representatives. This was also changed with the Autonomy Reform.

In Denmark similar changes arrived with the University Act of 2003. The Act grants universities more self-governance by creating a partial independent legal status to universities by recognising them as special administrative entities. The Act furthermore established that university boards should be composed of a majority of external stakeholders rather than elected leaders and by doing so, allowed for more long-term objectives to be set for universities. The university board sets the guidelines and defines the long-term strategy of the university (but not the strategic plans), manages the university funds, approves its budget, employs and dismisses its rector and other university executive management and enters into contract with the Ministry of Science. The Act was altered in 2011 to increase the power of the board and the rector of the university to decide on the structure of the university, making it no longer mandatory to operate with faculties and departments. Another substantial change for Denmark is that the 'Development Contracts' have been simplified; leading to a substantial reduction in the goals universities were expected to achieve. Although fewer in total, these goals are now binding rather than negotiated.

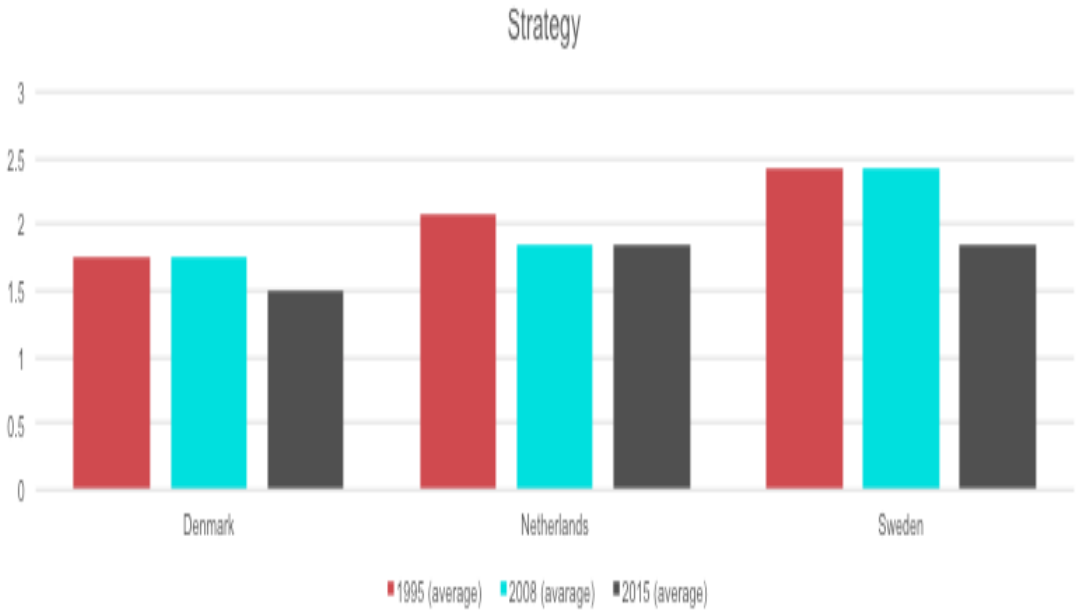
Similar changes occurred in the Netherlands in 1997 when a new law on higher education removed universities from being subject to ministerial regulations and instead to ministerial guidelines. Although the broadness of these guidelines offers the universities significantly more discretion on the internal organisation structure, it is still mandatory to oblige to the guidelines. A shift also took place in that executive leadership positions were strengthened and powers became more concentrated. A new body, a 'supervisory board' was introduced at the top-level of the institution, consisting of five external members, appointed by the minister. Furthermore, the representative

bodies where staff and students held seats became advisory bodies instead of decision-making bodies and the academic departments lost many of their formal decision-making powers. With changes to the Law on Higher Education in 2010 and 2013, a charter for Good Governance was developed and stricter rules were put in place for the composition of the boards to ensure that they could function as a real countervailing power. Members of university boards are no longer allowed to also be member of boards of colleges.

The autonomy of strategy making is however not only reliant on strategic plans and internal structures, but also influenced by the level of freedom to determine research programmes and research themes. In this regard, all three countries have a highly autonomous approach although the rise of national research agendas have or are becoming more influential in recent years. In the Netherlands agreements were made in 2011 on the development of 'performance contracts' of universities. The goal of these contracts was to improve the profiling – a clear research profile – of the universities and thereby the differentiation in research orientation available in the country. As of 2012 these agreements were made for every individual university. A small share of the base budget (5%) of the respective university is dependent on following these agreements.

Figure 7.1 demonstrates the changes to autonomy in strategy over time by showing the average 'scores' of the three areas discussed in this section (strategic plans, institutional governance and research agenda setting). A higher score implies lower autonomy. To this extent the graph depicts that on average there are similar levels of strategic autonomy in the three countries and that this level has increased in all three countries.

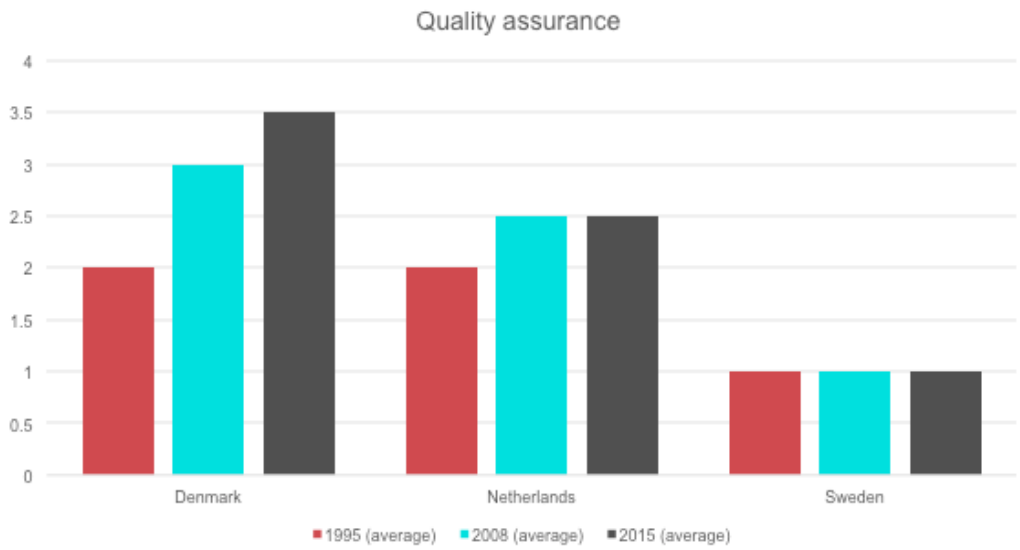
Figure 7.1: Level of regulatory influence on strategy making



Quality assurance in research

Whilst the level of autonomy in strategy making has evolved largely similar in the three countries, a different picture emerges when we look at the rules imposed on quality assurance in research. Few restrictions were in place for the three countries in 1995, but by 2015, this has only remained the case for Sweden. In Denmark and the Netherlands the rules have become stricter, as depicted in Figure 7.2.

Figure 7.2: Level of regulations on internal and external quality assurance systems



Although the methods to perform quality assurance in Denmark remain in the hands of universities – and specifically is placed with heads of departments, an Act from 2002 on transparency and openness obliges universities to publish the outcome of their evaluations. The methods used by the universities are evaluated by the ministry. Furthermore, all universities have to partake in an external quality evaluation system that informs national funding decisions. As of 2009 these evaluations are also used to determine the allocation of funding.

By 2015, the Danish system was more heavily regulated than the system in the Netherlands in terms of its consequences, but it is not necessarily more comprehensive. Whilst the Dutch system also obliges universities to hold internal and external quality evaluations and make them publicly available, neither is subject to government review or informs financial decisions. Universities in the Netherlands have instead cleared the path for a self-regulatory approach to quality evaluation. As of 2003 universities are legally obliged to have their research assessed but they can do this independently from each other. The universities jointly agreed to a standard evaluation protocol, which ensures uniformity in assessment criteria but leaves room for-tailor made adaptations. Peer-driven external assessments are required to take place every six years and made publicly accessible. These reviews are formative and not linked to budgetary decisions. As of 2002, universities can select their own peers for this external review. Furthermore, since then an additional mid-term review is also obliged to take place after three years, but does not need to be made public. In 2008 the standard evaluation protocol (SEP) for the external review changed slightly to decrease the administrative burden for evaluators and evaluated bodies and to increase focus on societal relevance, positioning and on benchmarking. The emphasis on output has decreased over the years

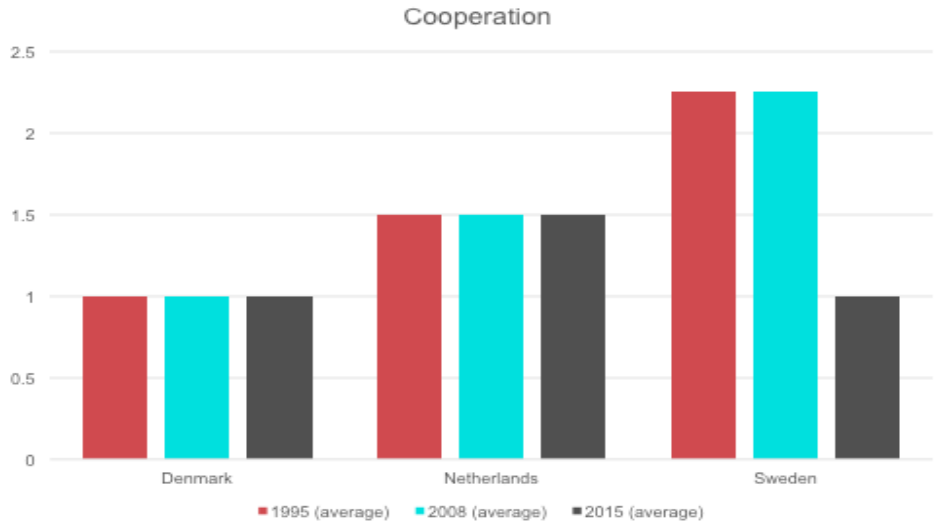
while the emphasis on relevance and integrity has increased. The evaluation of the SEP prior to 2008 showed positive results and users emphasised the importance of continuity in the guidelines for research assessments.

In Sweden institutions are required to conduct internal quality assurance, but are free to choose their methods to do so. Since 2008 the universities have organised external evaluations with peer experts on their own account. The use of an external peer review system has directed the internal organisation of universities towards quality assurance of research, but this has not led to regulatory changes in this area.

Cooperation

Increasing attention for the promotion of public private partnerships across Europe has translated into more financial incentives for universities to seek out such forms of cooperation in several countries. The regulatory framework for partnerships has however remained largely unchanged over the past few decades for the three countries subject to this study. Figure 7.3 depicts the level of autonomy in cooperation with higher education institutions and other organisations by the three countries over the three years measured and demonstrates that this has only changed in Sweden by 2015 and that Denmark has less regulation than the Netherlands.

Figure 7.3: Level of regulatory restrictions for cooperation with higher education and other organisations



In Denmark and the Netherlands universities have been free to decide upon their partnerships with non-higher education institutions throughout the past three decades. Partnerships with higher education institutions in Denmark can also be formed without any approval, but different to partnerships with the private sector, they are generally not incentivised financially. In the past these partnerships were often informal, but they have become more formalised in recent times.

In the Netherlands there were and still are some restrictions on university partnerships with other higher education institutions and thereby these require ministerial approval. Although the regulatory framework has not changed, partnerships with private sector organisations has been supported more intensely to stimulate innovation in the Netherlands.

Sweden is the only country where the rules have changed and since 2008 this has resulted in more formalised partnerships with the private sector. Although partnerships did exist prior to this point in Sweden, they were often *ad hoc* at department and staff level and less of formalised institutional agreements.

Accountability

Accountability refers to the obligation to report on an institution's activities and performances. In these three countries this includes accountability with regard to the internal and external evaluation reports as discussed in previous sections, but it also concerns annual financial reports, strategy documents, compliance with national policies, data on programmes, staff, etc. Within this definition of accountability, similar forms of mandatory reporting exist in all three countries and its content has remained largely the same over the past decades.

Swedish universities have been obliged to publish their annual reports, financial statements, supply information demonstrating compliance with other national policies, the outcomes of evaluations of teaching and research and to provide data and information to update national database over the past few decades. Since the 2009 there have been some changes towards documented accountability, notably in the use of performance indicators related to external funding, publications and citations.

Since the Dutch national law on higher education of 1997 made it mandatory for several forms of information to be made available to the government, there have been no changes to the system of accountability. The law makes it obligatory to make available to the government an institution's annual report, its audited financial statement, the strategic plan and the peer evaluation taking place every six years.

Also in Denmark these documents have been mandatory over the decades. Notably an annual report, an annual audited financial statement and data for databases. The most significant change amongst the three countries has been the Act on transparency and openness of 2002 in Denmark. The publication of evaluation results was made mandatory by this Act and also led to the development of a national database for research publications.

On the whole the three countries thereby have experienced similar changes to increase the level of accountability slightly.

Human resource management

One of the more dynamic areas of change in terms of university governance has been the development of autonomy regarding human resource management, notably in determining the size and functioning of the staff as well as staff salaries.

In both Denmark and Sweden the regulatory reforms have increased the autonomy of the universities when it comes to hiring research staff. Changes in this area arrived earlier for Sweden than Denmark when in 1999 new rules for employment, recruitment and promotion were introduced based on merit and performance indicators, removing security of employment for university professorship. Prior to this, ministerial permission was required for the creation of a new

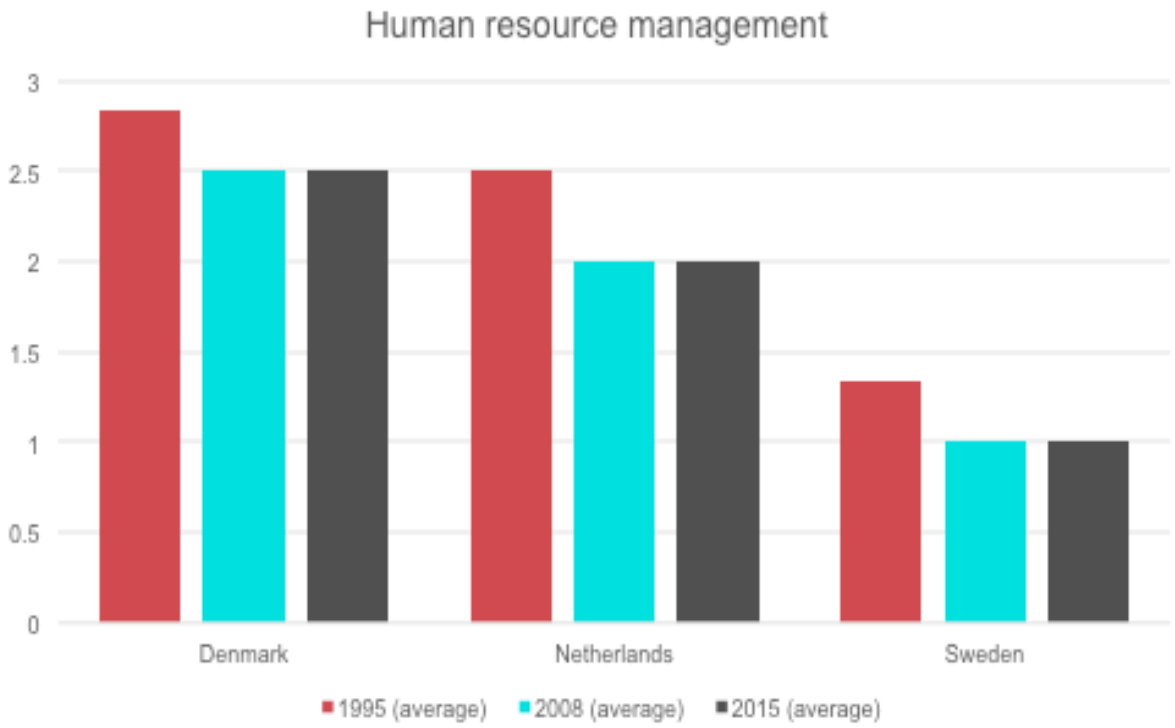
senior research position. The autonomy of universities in appointing research staff was further strengthened in 2010. Universities are completely autonomous on salary arrangements.

With the Act of 2003, high-level positions in Denmark such as rector, dean and head of department became appointed positions subject to decision by the university board, rather than elected positions. In 2011 more autonomy was created for these positions, with the board and rector able to define the functions and competences for these positions, in line with the greater freedom of the board and rector to determine the organisation's departments and faculties. The Act of 2003 created space similar to the 1999 changes in Sweden, allowing universities to decide how many and which types of senior academic positions to create. Prior to 2003 these positions required ministerial level permission for both creation of the function as well as the selection process. In Denmark there is less autonomy when it comes to determining the salaries of staff as research positions are unionised and, as a government organisation, negotiated between the trade unions and the Ministry of Finance.

Negotiations with trade unions were formerly also conducted by the ministry in the Netherlands, but this changed in 1998 when the universities themselves became responsible for these negotiations. Universities also have large autonomy when it comes to other staffing considerations, including deciding on how many and which types of senior academic positions they wish to create as well as the selection process for filling these positions.

Based on the autonomy to appoint full-time senior research staff and the decisions on salary levels, it can be determined that all countries became less regulation based and that Sweden has the most autonomy in this area amongst the three countries. Figure 7.4 visualises these trends.

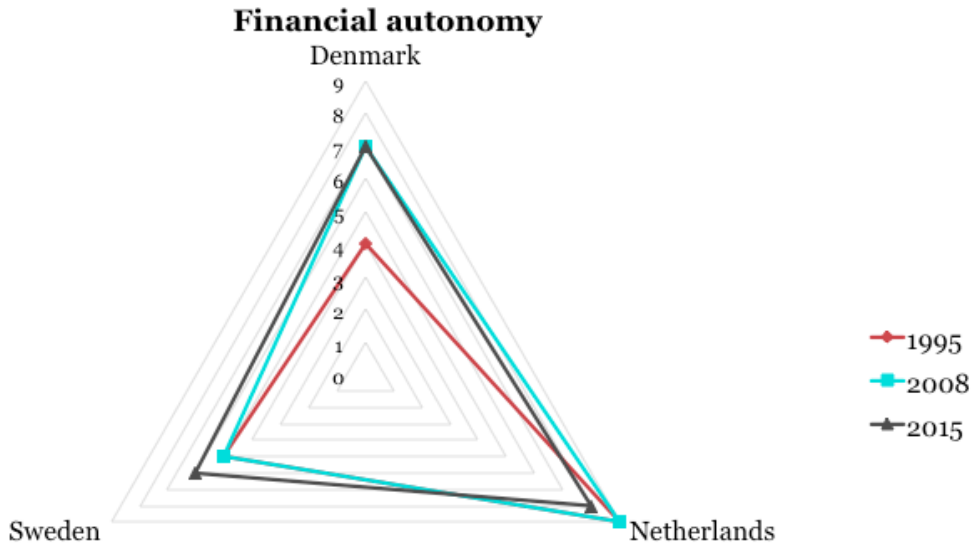
Figure 7.4: Level of university autonomy in human resource management



Financial autonomy

In addition to government funding for research, universities can generate income through private sources. Amongst the three countries, the system in the Netherlands has allowed for most freedom to access additional funding, as depicted by Figure 7.5.

Figure 7.5: Number of financial sources universities are allowed to access for research in 1998, 2008 and 2015



In general, there is substantial financial discretion for Dutch universities, also in relation to the internal allocation of public and private funds, borrowing money on the capital market and building up reserves and carry over unspent money to the next fiscal year as well as use their public grants freely. Up until 2015, Dutch universities were allowed to supplement their income with a large number of sources ranging from contract research, consultancy and/or services, teaching and training programmes directly funded by students and/or employers and not from public sources, patenting and licensing of intellectual property sales of assets (land, buildings, equipment, etc.), commercial activities linked to the university's operations (student housing, hotels, catering, sport facilities, printing, etc.), donations, gifts and endowments, holding and/or selling shares in spin-offs or other companies, interest and financial investments and universities establishing their own private companies. By 2013, with the changes in the law on higher education and the establishing of the Good Governance Charter, the financial freedom became more regulated to limit the possibilities for financial engineering. The previous absence of rules regarding finances were changed to ensure that loans and investments could only be used if they related to the core mission of the universities.

Although Swedish universities were also able to allocate funding internally to their own discretion, they are not entirely unregulated in attracting money. Firstly, they are not allowed to generate income through commercial activities linked to the university's operations and up until 2015 also not from donations, gifts and endowments. Most of the activities that generate income require this to belong to a holding company owned by the university.

Similarly in Denmark the regulatory framework did not allow universities to collect all types of income, such as from patents spin-offs or interest and financial investments. As of 1999 these rules have changed.

7.4. Summary of findings

On the basis of a qualitative assessment of the developments of the governance models in Denmark, Sweden and the Netherlands between 1980 and 2015, we cannot draw a direct correlation between this hypothesis and the developments in research performance. It is evident that all three countries have underwent rather similar changes towards more autonomy, notably in the 1990s, albeit at slightly different moments in time. There are some notable differences between the three models, whereby Sweden has chosen a slightly different path than the Netherlands and Denmark, with slightly less autonomy in terms of strategy, finances and cooperation (until 2008) and notably more autonomy when it comes to human resource management and quality assurance. However, these distinguishing factors alone do not appear to contribute directly to the over or under performance of the three countries. As these countries are rather similar in their approach to governance, it would be of interest to further test this hypothesis with models that contain substantially less autonomy.

This interpretation of the overall governance hypothesis was also dominant in the interviews conducted in relation to the Danish case. The management reforms were in general not seen as highly important factors in explaining the Danish development. One, more indirect, effect should however be mentioned. The two major governance reforms in Denmark in 1993 and 2003 may not have had a direct effect in improving the conditions for high impact research within the institutions, but they both played an important role in restoring the confidence and trust in the university sector from the political system. This in turn led to increased resources – and in particular in relation to the 1993 reform to more protected space for the academic system as a whole.

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8. Internationalisation

8.1. Introduction

The basic phenomena studied in many research fields (i.e. natural and life and medical sciences) are not confined by national borders. But scientists and scholars have national origins. They are trained and work at national research institutions and they are therefore constrained by local economic settings and national policies. For centuries elite scientists have been mobile and have communicated in common languages such as Latin and English. It is well documented how scholars and researchers in Europe have traversed the continent to work at different universities. With the industrialization and the marked improvements in transportation in the 19th century this became more pronounced culminating in the first three decades of the 20th century, where we saw a number of research intuitions around Europe and in the US attracting eminent scholars and scientists from many different (mainly European) countries. Scientists would typically visit such institutions for longer periods in order to work with the fields' most prominent researchers. This was the era of "Little Science" where the population of scientists was relatively small; where research collaboration mainly was informal; where publications mainly were single authored and where there were relatively few of them. Nevertheless, mobility was a very important activity. National research communities were small, so to be part of the international research front, to get access to knowledge and equipment, mobility was paramount. An important potential outcome of mobility is the placement of researchers into well-established networks. This was important in the era of 'Little Science' and this is perhaps even more important today in the era of 'Big Science'. The social stratification in science is skewed and so is the capital that is bestowed upon researchers in the science system. Belonging to an international network within one's field of research gives cumulative advantages in relation to collaborations, publications, citations, funding etc.

During the decades after World War 2 the era of 'Big Science' was established and the scale and scope of research, research facilities, research economics, internationalisation, mobility, and collaboration, as well as publication behaviour changed radically. But the essence of the need to be mobile and collaborate across borders was intact. The scale of the science system has grown rapidly in the last 60 years and the drastic changes in transportation and communication have been prime catalysts for the ever-expanding internationalisation of research. While mobility was a luxury for the elite few not so many decades ago, mobility and collaboration is today an integrated part of work for most researchers. But the social structure of mobility and collaboration is still highly stratified. Not all researchers can go to the highest performing environments around the world. In that sense, mobility and international collaboration probably have other connotations and implications than in the era of 'Little Science'.

Internationalisation is an important priority for many countries in order to foster new developments and to bring prominence to research. Internationalisation typically includes: formal and informal collaboration between researchers from institutions in different countries, and mobility of researchers (the inflow of researchers from abroad, the outflow of native researchers abroad, and native researchers returning home). Internationalisation is generally conceived of as something to strive for both epistemically and economically. However, internationalisation needs to be contextualized especially when it is linked to performance as conceptual and operational issues are challenging. Internationalisation cannot be seen as an end in itself and is certainly not a necessary

condition in all fields. Yet, internationalisation may lead to network memberships and visibility, which are main drivers when it comes to citation performance. These issues will be clarified and outlined before analysing the presented DFiR hypothesis on internationalisation.

First we need to establish some correlates of citations. There are many (see Tahamtan, Afshar & Ahamdzadeh, 2016 for a recent review), but among the strongest predictors of citations is visibility: factors such as publication outlet (i.e. journal status), number of authors and not least number of international co-authors affect visibility. Indeed, these three factors are internally connected. Internationally co-authored papers obviously include several authors, most often more authors than nationally co-authored papers, and they tend to be published in journals with higher international visibility. Other things being equal, higher visibility raises the probability of receiving citations and it is well-known that internationally co-authored papers on average are cited more than national papers; this is for instance documented in Schneider and Aagaard (2015). We should therefore expect that a country's degree of internationally co-authored papers would influence their performance level. Two related aspects are important in this respect: it matters a great deal whom you collaborate with and a country's incidence for international collaboration is mainly determined by its size, language-orientation and geographical and historical proximities to other countries and research traditions.

In this analysis we mostly rely on the bibliometric measure of co-authorships to measure internationalisation. It is important to point out that co-authorships are used as a proxy for "research collaboration" and international co-authorships are accordingly seen as a proxy for "international research collaboration" and it is thus one of several dimensions of "internationalisation". Some cautionary remarks are however needed. Empirically, "collaboration" has been examined with different designs but the most predominant one has for decades been to use journal publications in bibliographic databases and then measure collaborative activity by counting multiple author contributions (e.g., Luukkonen, Persson & Sivertsen 1992; Georghiou 1998; Wagner & Leydesdorff 2005). Such bibliometric analyses of co-authorships are valuable in the sense that they are invariant, verifiable, relatively inexpensive, and not least practical to do, but they are by no means perfect and have clear limitations. Katz and Martin (1997) have suggested that measures of co-authorship are best seen as partial indicators of collaboration. Likewise, international co-authorships can only be a partial indicator of internationalization. As we will discuss below, a country like the US has considerably lower shares of internationally co-authored papers compared to Denmark, Sweden and the Netherlands, yet in other respects large parts of the US research system can be considered foreign in the sense that many international researchers move to work in the US.

Obviously, co-authorships can only be used to count author contributions to publications assuming that such mutual authorships imply some form of "collaboration". But at the level of individual articles, co-authorship in itself does not necessarily mean that "collaboration" has actually occurred. Yet Narin (1976) has asserted the submission of a manuscript containing new knowledge claims is a crucial outcome of science, representing findings that the authors collectively are willing to claim as notable. So claiming authorship serves as a socio-cognitive filter on the multitude of relations in the social context of discovery (Melin & Persson 1996), and does indicate that mutual activities of importance has taken place, be it "collaboration", "cooperation", "contribution" or the like.

Examining co-authorships at the country level changes the meaning of collaboration from that of the individual level of publications. One could argue that while the concept perhaps becomes more abstract, as an indicator it becomes simpler, i.e. a proxy for a country's "internationalisation" through participation in formal knowledge production processes. The fact that we can measure this through co-authorships for all countries for the same time period strengthens the interpretative value for such a proxy.

Besides the conceptual challenges linking co-authorships to collaboration, a further important challenge is the actual distribution of credit among the authors of a publication. In practice, two counting methods exist, full counting, where all participating units (i.e. authors, institutions or countries) receive one full credit each, or fractional counting, where all participating units divide one credit among them (i.e. 1/n) so that more units mean less credit per unit (e.g., Gauffriau & Larsen 2005). It has been suggested that the counting approaches measure different constructs, where full counting measures a unit's participation and fractional counting a unit's contribution (Waltman & van Eck 2015). Yet both approaches are essentially flawed because they both disregard the fact that credit, be it participation or contribution, usually is unevenly distributed among units represented in the byline. This leads to what is known as inflationary bias when it comes to full counting, or equalizing bias when it comes to fractional counting (e.g. Hagen 2015). While the latter has been demonstrated in small scale studies, the challenge seems currently unsolvable as it requires statements of actual shares of contributions among units, something very rarely visible in publications and indeed difficult to quantify precisely. This bias should be taken into consideration when we discuss national performance because what we end up measuring with co-authorships is not the precise aggregated research effort.

We are therefore cautious when interpreting co-authorship trends as "collaboration". While co-authorships certainly capture "collaborative" activities, we agree that it is best seen as a partial indicator of such activity. Hence, we use it here to document the growing international character of research. We focus on full counting at the country level: Our analyses therefore examine the countries' international participation and not necessarily their contribution to the research efforts (see Waltman & van Eck, 2015). In Schneider and Aagaard (2015) we document developments for both full and fractional counting.

8.2. Comparative analyses of the internationalisation hypothesis

The fifth hypothesis of DFiR states that Danish research may have been particularly internationalised in the period under examination compared to other countries and that there is a relation between the degree of internationalisation and citation impact. The bibliometric background study commissioned by DFiR (Schneider and Aagaard 2015) is used as an indication for this hypothesis.

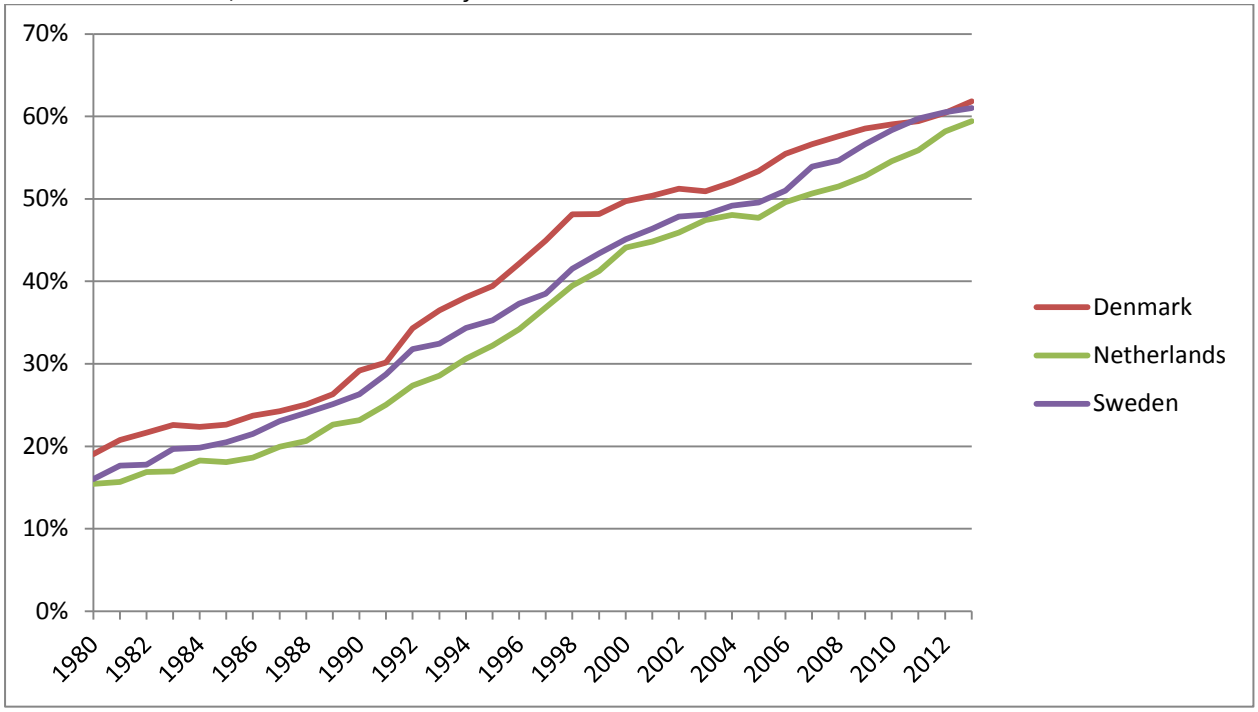
The following section examines to what extent different types of data support the hypothesis that countries with a high degree of internationalisation also have high impact and to what extent developments in degrees of internationalisation and international citation impact correlates. As mentioned above, internationalisation is not an end in itself when it comes to influences on performance. It matters whom you collaborate with and most likely where you go. We therefore find it important to qualify this hypothesis by expanding the bibliometric study and examining not

only the developments in internationally co-authored publications, but also examining collaboration patterns and how this influences impact. It is more straightforward to examine relations between co-authorships and citation impact than links between researcher mobility rates and impact. The latter is difficult for several reasons; prime among these are incomplete data and selection biases. Nevertheless, in the final section of the chapter we document some indicative associations indicating that higher mobility rates and impact levels correlate albeit a causal direction is impossible to discern.

Internationalisation measured through co-authorships

Figure 8.1 shows the development in the three countries shares of international publications based on full counts. The overall trends are similar for all countries: the degree of "internationalisation" has increased markedly from around one in five papers being the result of international participation in the early 1980s, to roughly two out of three papers today, more than thirty years later. The trend is not surprising, as it is well-known that research in general has become more international in the period under examination (Adams, 2013). There are, however, some interesting nuances in these trends, especially for Denmark and the Netherlands. The Netherlands are by far the largest of the two countries measured by annual publication output. However, their share of international collaborative papers is consistently below the other two countries. This is not surprising as larger countries in general have lower shares of internationally co-authored publications. As amentioned in the introduction, arger countries may show other signs of "internationalisation", most notably in their proportion of foreign-born researchers working in these countries. The Danish trajectory is also very interesting. In the early 1980s, when Danish citation impact ranked very high, the share of international papers was the highest among the three countries starting around 20 percent in 1980.

Figure 8.1: Development in the share of papers with international collaboration for Denmark and the two benchmark countries, shares are based on full counts.



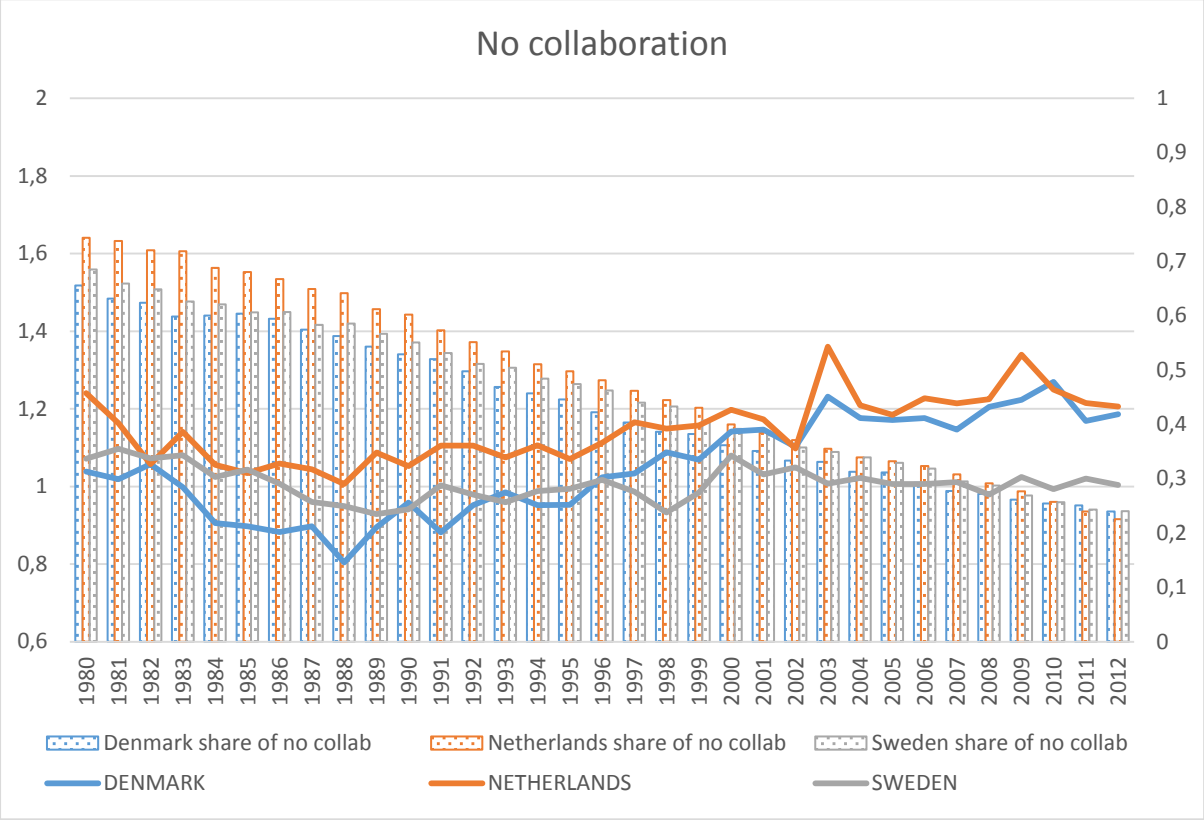
Source: Schneider and Aagaard 2015

As documented in the bibliometric report (DFiR, 2015) Denmark experienced a marked drop in citation scores during the 1980s, culminating around 1990; interestingly in during this period the growth in internationalisation flattens. Shortly hereafter Denmark experienced a marked increase in impact that corresponds well with the distinct rise in shares of international papers during the 1990s. Hereafter the Danish increase flattens again and at the end of the period all countries have similar shares of international collaborative papers.

The question is to what extent the international (and national) papers have influenced the trends in Danish impact and to what extent journal publication behaviour plays a role in this? From the bibliometric report we know that papers in the highest journal impact class accumulates on average a bit more than 40 percent of the annual Danish citations and that there is a larger share of papers with international collaboration in this class.

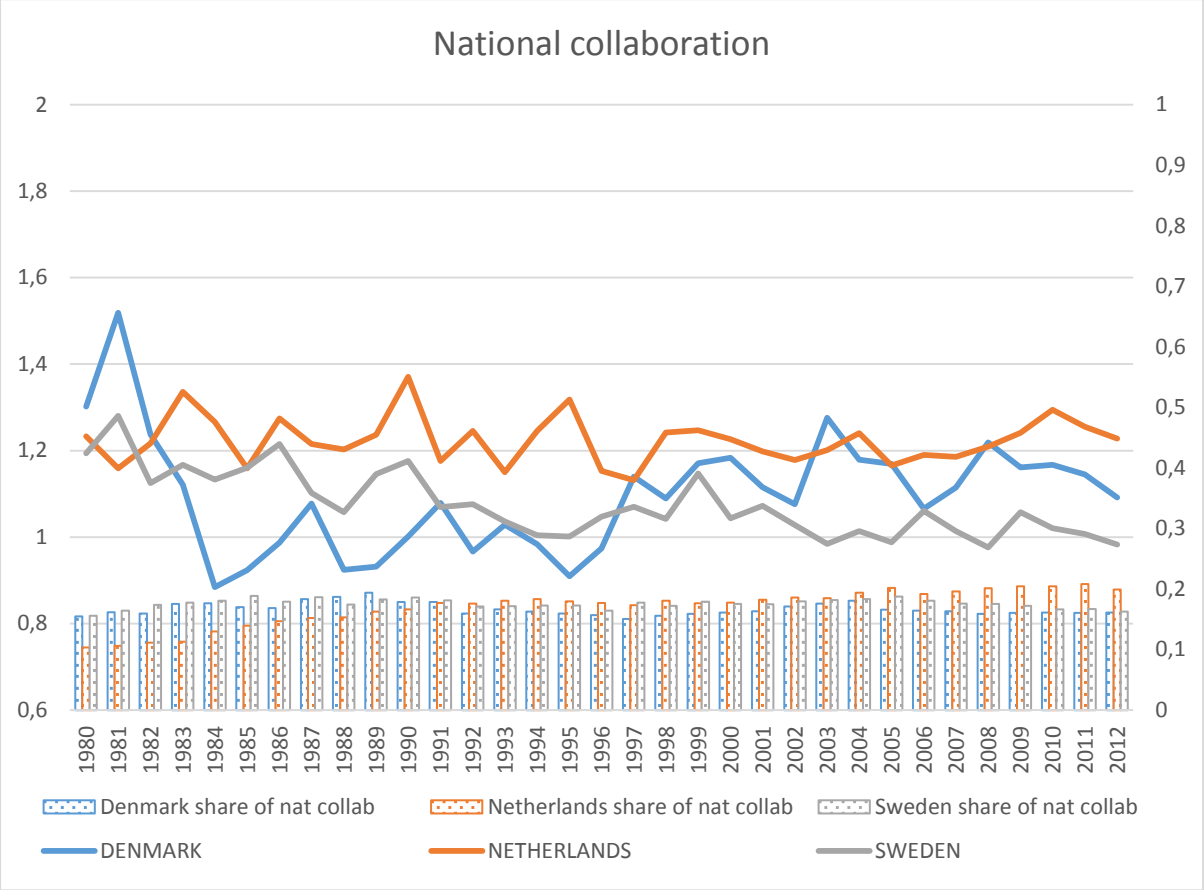
When studying the impact of international papers, it is also important to examine the impact of national publications and assess their common contribution to the overall national impact. In the early period, national publications constituted the majority of publications, so their impact obviously played a relatively larger role for the overall national impact. Figures 8.2 and 8.3 show the development in Mean Normalized Citation Scores (MNCS) for national publications, as well as the proportion of the annual output these publications constitute. The overall impact of national publications is lower compared to international publications.

Figure 8.2: Development in the mean normalized citation scores (MNCS) for papers with no national collaboration for Denmark, Sweden and the Netherlands



Source: CWTS Leiden

Figure 8.3: Development in the mean normalized citation scores (MNCS) for papers <u>with</u> national collaboration for Denmark, Sweden and the Netherlands

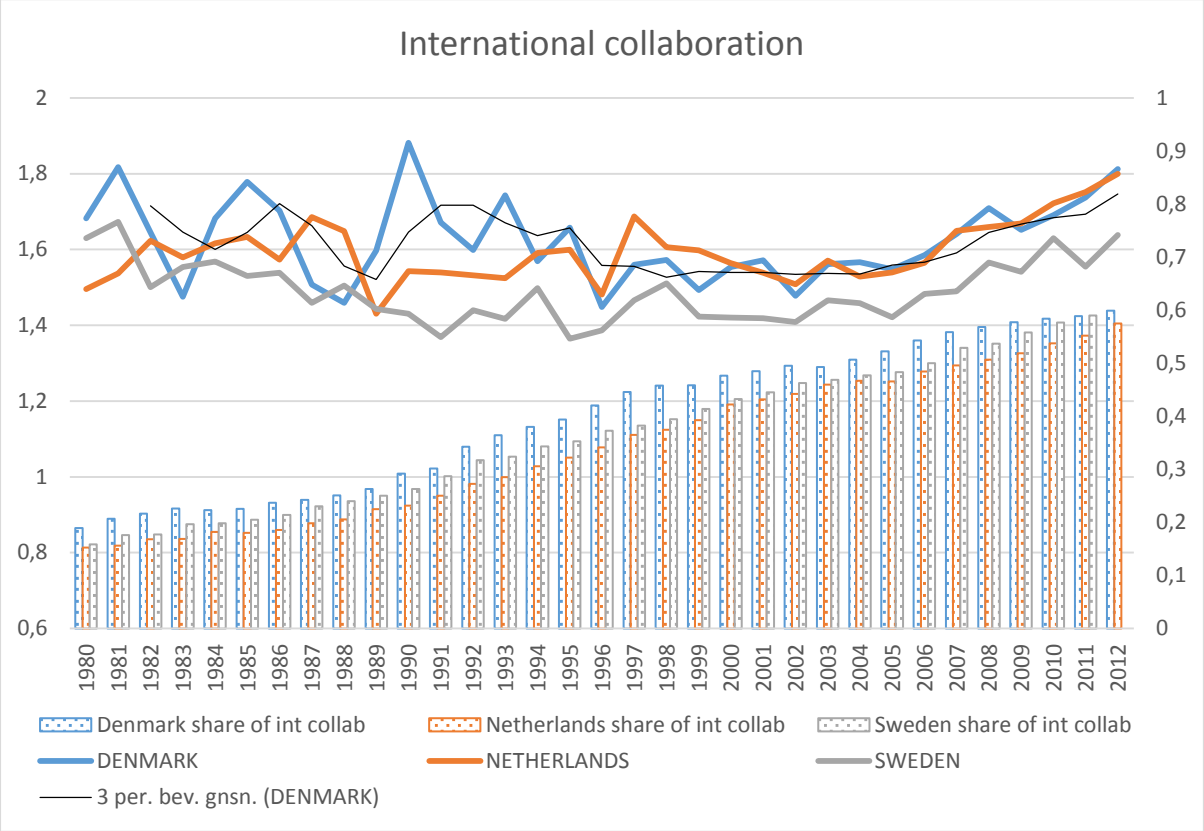


Source: CWTS Leiden

Notice, the three countries show markedly different trajectories. They have roughly the same point of departure in 1980, but whereas the Netherlands only experience a small drop to begin with and thereafter have a very stable slightly increasing trajectory, Denmark experiences a marked drop during the 1980s. The Danish drop is more marked than the Swedish, but whereas Denmark experiences a turn-around and then a continuous rise during the 1990s, the impact of national Swedish papers stagnates at a consistently lower level than both Denmark and the Netherlands.

The marked Danish drop thus came at a time when national publications constituted approximately 75-80 percent of the annual output. Further, the impact for the national Danish publications begins to rise again when their relative shares of the total Danish output continuously drops. Thus, it would probably be safe to conclude that the impact of national Danish publications has played an important role both in the drop during the 1980s, but also in the subsequent increase in the 1990s and to the present day high performance level. In fact, while the total share today is around 40 percent of the output, the performance level of these national publications is relatively higher compared to many other countries; it is comparable to the Netherlands, and distinctively above the performance level of Sweden.

Figure 8.4: Development in the mean normalized citation score (MNCS) for papers with international collaboration for Denmark and the two benchmark countries. The indicator is based on full counts.



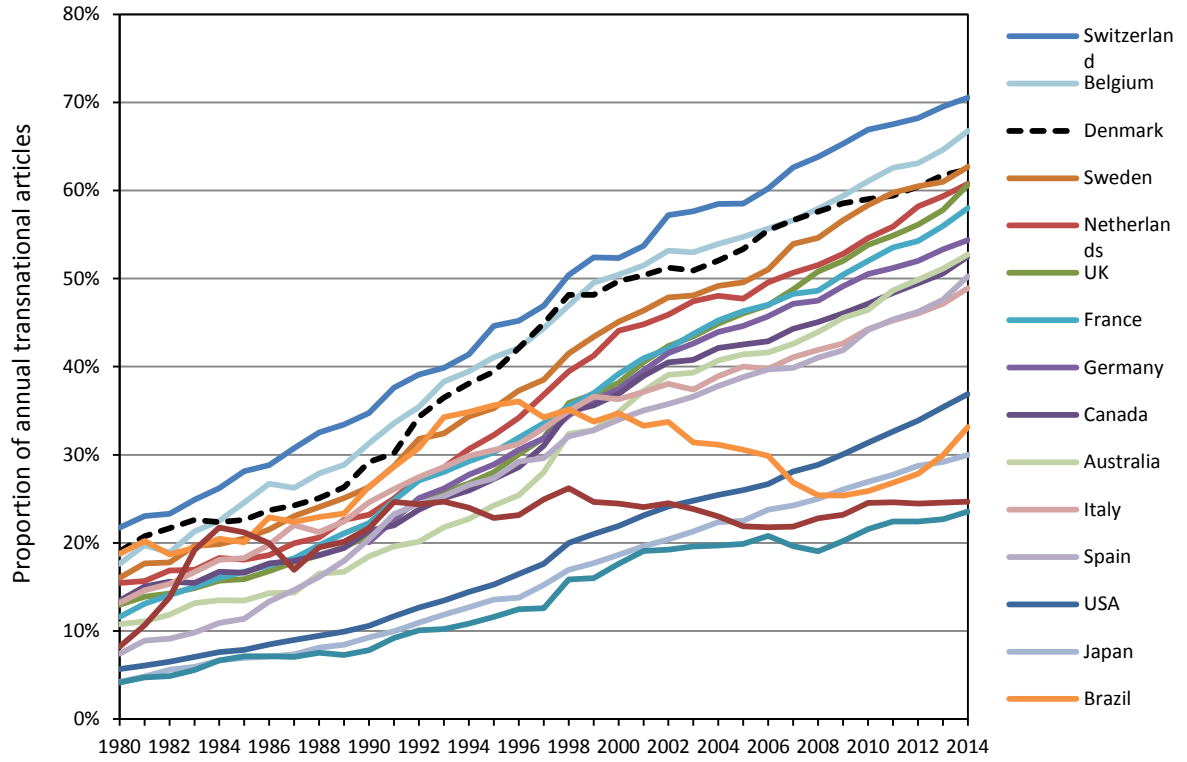
Source: CWTS Leiden

Figure 8.4 depicts the overall MNCS scores for the international papers. It is evident that international papers overall have higher citation rates compared to national papers. It is also noticeable that the MNCS scores fluctuate considerably, especially in the first half of the time series. To a large extent this is a function of smaller annual outputs. Nevertheless, the Danish case is interesting. Being a smaller country, the fluctuations are more drastic than those of larger countries such as Sweden and the Netherlands. Yet Denmark experiences some drastic peaks and valleys in the first decade. Denmark experiences the highest impact value and rank of all countries in 1985 and then immediately drops to rank #3 in 1988, below Sweden and the Netherlands, and then rises to a new high point in 1990. Hereafter the international papers from Denmark more or less continuously show the highest impact, in the later period almost identical with the development of the Netherlands. There is no doubt that some very highly cited papers influence the fluctuations in the early period for Denmark. It is also noticeable that the sudden drop from 1986 to 1988 corresponds with the overall drop in MNCS values for Denmark, amplifying the corresponding drop in impact for the national papers. But despite these fluctuations, it is notable that Danish international papers overall have very high impact. This is true in the early 1980s and it is also the case today. We have to remember that between the three countries, in 1980 Denmark was already the most "internationally" research-oriented of them (on the premise that the share of papers with international collaboration can be seen as a proxy of this).

International collaboration patterns – country size and collaboration partners

If we expand the analysis of internationalization to 17 countries, see Figure 8.5, we see that for most of the period the degree of internationalisation is distinct for Denmark, Switzerland and Belgium. However, at the end of period the degree of internationalisation converges with a group of 10 smaller to medium sized countries.

Figure 8.5: Annual developments in 17 countries' proportion of journal articles with transnational collaboration. The country legends to the right are ordered according to their rank in the graph in 2014, so that Switzerland is first and India last. Source: Web of Science, CWTS, Leiden University.



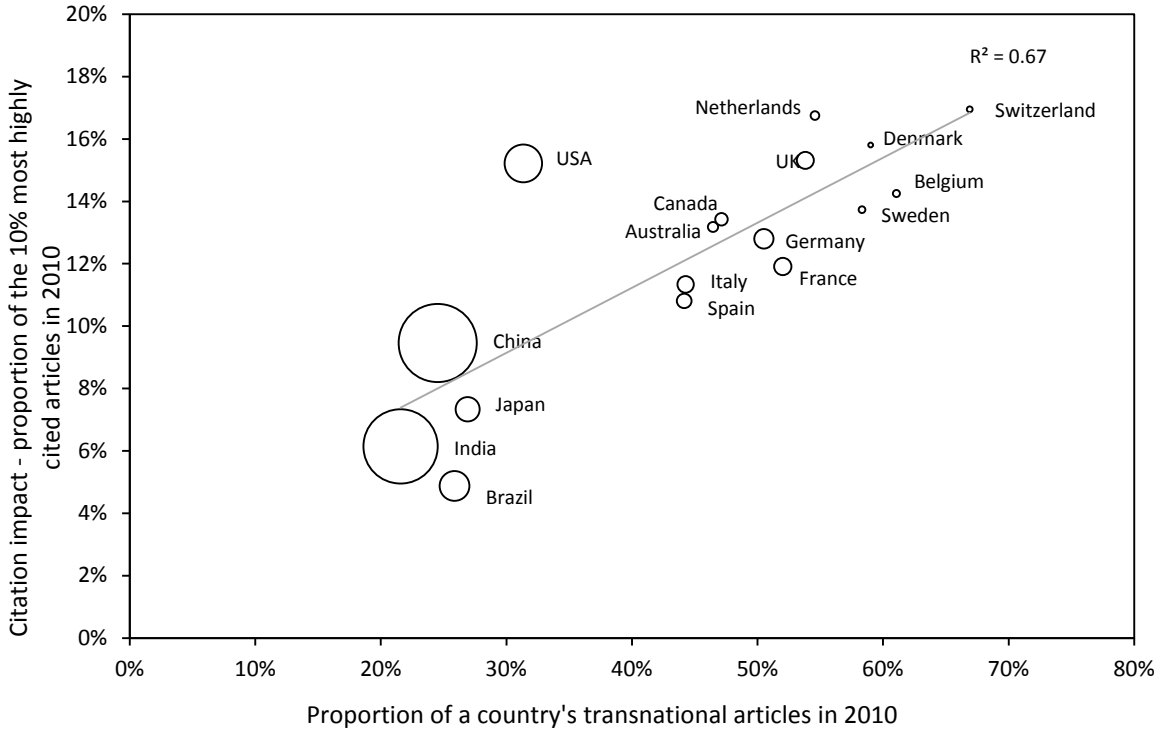
Source: CWTS Leiden

The fact that only a little more than 1 in 3 papers with a US institutional address also has an international address do not in itself indicate that the US science system generally is less international. The US science system is so large that it in many ways it does not need to turn its attention to formal collaborative efforts abroad. Some US universities, for example Harvard, have a larger research output per year in the Web of Science than some of the smaller western European countries: For instance in 2010 the Danish output (i.e. publications with at least one Danish institutional address) was roughly 12,000, whereas Harvard University alone had an output of more than 25,000 publications. Furthermore, geographically the US system sees a lot of collaborative activity, albeit across federal state borders and not so much across national borders. But perhaps most interesting, the US science system can indeed be considered to be international when one studies the composition of faculty at US universities. Talented junior and senior researchers from around the globe go to the US to work, most likely because the US science system is still considered to be the centre of gravity in the world science system.

In Figure 8.6 below we correlate a country's degree of internationalisation with its citation impact in 2010. We also indicate the size of the country because smaller countries have larger incidences of international collaboration. We expect a good correlation between impact and degree of international collaboration, which is also the case as shown in Figure 8.6. The caption explains the axes and circle sizes. Estimating a simple linear function, where impact is a function of the degree of international co-authored articles, "explains" 67% of the variance and can be considered a reasonable fit, but there are notable outliers: in particular USA, UK and the Netherlands.

As discussed in the introduction, an article's status as "international" is only a proxy for a number of underlying characteristics of such articles which on average give them a higher citation rate. Multiple authors increase the likelihood for spreading the knowledge presented in the article. If then these authors are dispersed across countries this tendency is amplified. International research efforts are also often characterized by investigating topics of considerably interest or hype. The latter often results in publication in journals where citation activities are generally higher. And then there is the more controversial presumption that international research efforts in general should be of better quality (see Adams 2013); the latter claim is to a large extent questionable especially when quality claims are based on citation impact alone.

Figure 8.7: The relation between "national" citation impact and a country's degree of transnational journal publication activity in 2010. The y-axis shows the total citation impact for a country's articles in Web of Science published in 2010. Citation impact is here measured as the proportion of articles among the 10% most cited in database for that particular year. It is expected that a unit will have around 10% of its articles among the most cited; more means that the impact levels are higher than expected. The x-axis shows the proportion of the 2010 articles which can be considered transnational. The size of the circles indicates the size of the country depicted with 2010 population statistics from the World Fact Book.



Source: CWTS Leiden

Returning to Figure 8.7, USA is clearly an outlier in as much as the impact is high, while the proportion of internationally co-authored articles is modest compared to the other countries with high impact. Since the end of World War 2 the United States has been considered to be the world leader in science (Hollingsworth & Gear 2012). Scientific hegemony means that a country such as the US dominates and establishes the standards of excellence in most scientific fields. The US scientific elite, scholars and institutions, are considered the most prominent in the world and consequently the US attracts more foreign young people for training than any other country. Finally, and important for the present analysis, today the language of the dominating scientific communication systems is English and the databases used for scientometric analyses is dominated by Anglo-American journals. These characteristics obviously increase the likelihood for receiving citations.

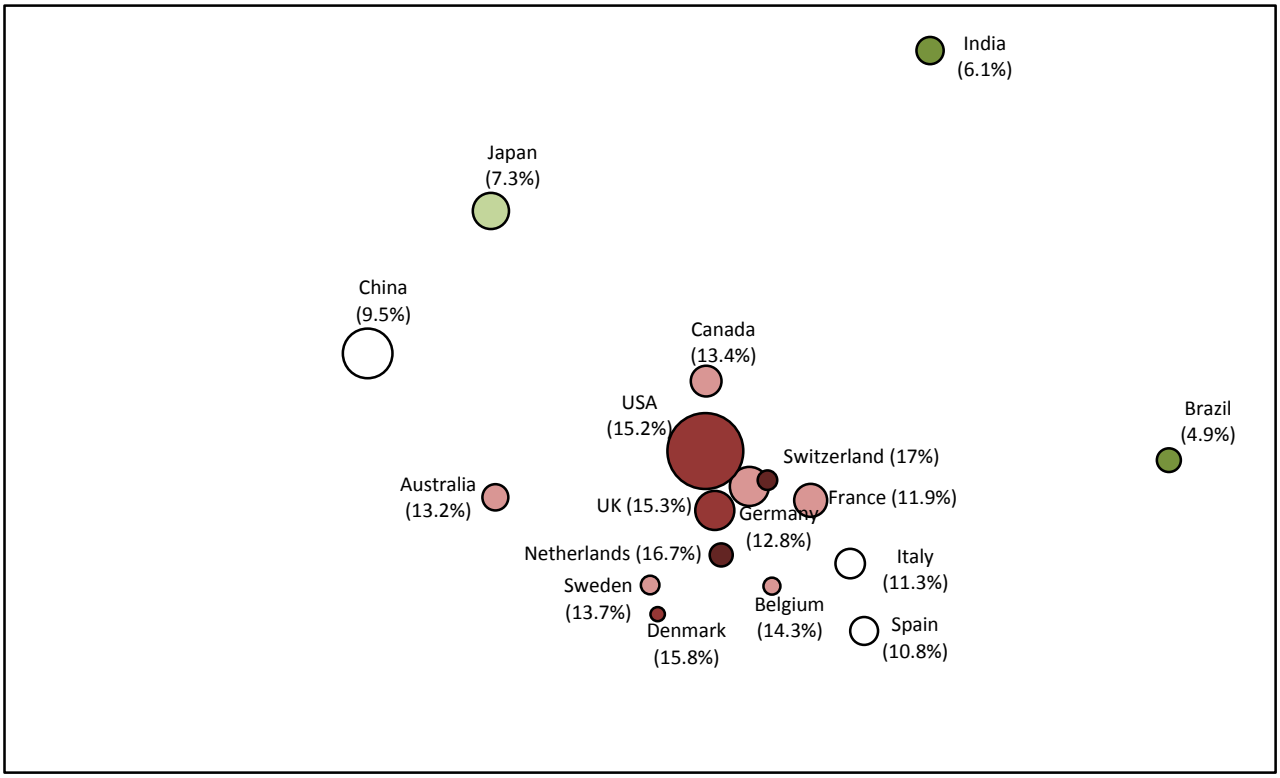
If we then consider that the US is the largest country in the Web of Science database, measured by annual publication volumes, then it becomes less surprising that not only does US articles receive a considerable number of citations from foreign articles; considerable domestic citation traffic also goes on between articles with only US addresses. This is an important reason for the generally high citation impact of the US. Figure 8.7 thus confirms that there clearly is a good correlation between the degree of international collaboration and impact, with the notable exception of the US, and that country size clearly is an indicator for the degree of international collaborative activities. From these findings we can also deduce that especially for smaller countries the so-called "national" performance to a large extent is a "shared one" in as much as in 2010 six out of 10 so-called "Danish papers" also include affiliations to at least one other country.

Figure 8.8 below visualizes the mutual "research collaboration" between the 17 countries when examining their international co-authorship patterns. Again we study the year 2010. Countries close to each other have stronger collaborative links between them. Countries placed towards the centre of the map have broader collaborative patterns, whereas countries on the fringe have more insulate collaborative patterns. Further details concerning the interpretation of the map is given in the caption to the figure.Clearly, the U.S. is at the centre of the map. Looking at the individual countries and their share of co-authored articles with the other countries, the result comes as no surprise. Of 16 countries, 14 have the largest share of international articles with the US, and for 11 countries this share is between 10 and 23 percent. The share for countries in second place is usually considerably lower; exceptions are Switzerland, Netherlands and Belgium. These countries have equally large collaboration shares with at least one other country. Other countries likely to be involved in international research collaborations are the United Kingdom and Germany. Indeed, what is noticeable is the clique of countries in the centre of the map; they have significant mutual international collaboration activities with each other. What is also noticeable is that most of these countries have good, high or very high impact levels, as depicted by the red colour codes of the circles. In a sense everything revolves around the US.

Figure 8.5 showed that Italy and Spain had slightly lower proportions of international collaboration as well as slightly lower impact levels compared to the other Western countries (except Japan). In Figure 8.8 we see that these countries are on the periphery on the "inner circle" or clique of Western countries with high proportions of international collaboration activities and high impact. Indeed, the collaborative activities of the "inner circle" countries with the US are between 14 and 23 percent.

The four countries with modest or low international collaborative activities in Figure 8.5 are naturally placed on the fringe of the map in Figure 8.8. While they all have their highest share of international collaboration with the US, the relative numbers are markedly lower with China's 10 percent as the highest. These are relatively large countries, both in population and publication numbers, but their international collaborative activities when it comes to journal publication is low and so is their impact.

Figure 8.8: Transnational collaboration patterns between 17 countries in 2010. Countries are placed in the map according to their mutual collaboration patterns measured by common co-authorships in articles published in 2010. Countries close to each other have stronger collaborative links between them. Countries placed towards the centre of the map have broader collaborative patterns, whereas countries on the fringe have more insulate collaborative patterns. The size of the circles indicates the 2010 publication output for the individual countries relative to each other. The citation impact for each country is shown in brackets and the colour code of the circles indicate the strength of the impact: White (average impact); shades of green (light: low impact; dark: very low impact); shades of red (light: good impact; darker: high impact; darkest: very high impact).



Source: CWTS Leiden

It is natural to conclude that a country's degree of international co-author activity is more or less proportional to its citation impact. However, we should qualify this since whom you collaborate with seems to matter a great deal. Everybody collaborate with the US, but some more than others and the performance of these countries are clearly the highest. Further, a strong clique of mainly Western countries not only collaborates extensively with the US, they also collaborate with each other. Interestingly, these countries all show high performance levels. Obviously, the US research system as measured in these analyses is the largest.

It is thus clear from the three figures that comparisons of national research performance between countries indeed are challenging. For smaller countries up to 70 percent of the so-called "national" articles can also be described as "national" articles for at least one other country. The matter is further complicated when we consider that the main performance parameter, citation impact, to a large extent is influenced not only by the degree of internationalisation but also by whom you collaborate with. Looking at the 17 countries examined here, the close clique of western European countries revolving around the US is also the top ranked countries when it comes to impact. However, when we compare them, we should remember that a considerable number of the articles that promote these countries to the highest ranks are mutual collaborative works claimed by each country as national research output. Multiple counting is rife, yet technical fixes such as fractional counting does not necessarily solve the essential problem, it only displaces it since with fractional counting, international research collaboration is "punished" and the equalizing bias thus becomes apparent (Aksnes, Schneider & Gunnarsson 2012).

A recent report from Elsevier (Kamalski & Plume, 2013) also examines the potential benefits in impact when collaborating with different types of countries, in this case collaboration with other European countries as a group and countries outside the European region (see figure 9, page 16 in the report[8]). The Elsevier study supports our previous findings. Denmark and the Netherlands come out among the highest performing countries with Sweden somewhat lacking behind. The specific point about figure 9 in the Elsevier report is that Denmark and the Netherlands benefit most in relation to impact when collaborating with European partners, and they are also among the European countries that profit most from collaborating with countries outside Europe. Notice, that all countries in the figure, including Denmark, Sweden and the Netherlands, benefit most from collaborating with countries outside the region. As we documented previously, the US is the main actor here. Indeed, the Elsevier study finds that both European countries and the US benefit most by collaborating outside their regions, but the relative advantage of this is particularly strong for Europe.

We can thus conclude that the development in the degree of internationalisation measured through co-authorships is quite similar for all three countries. Denmark, the smallest of three countries, has the highest degree of internationalisation in 1980, a few percentage points higher than Sweden and the Netherlands. Through most of the period, the degree of internationalisation for Denmark stays slightly ahead of the other two countries. We also demonstrated that smaller countries tend to have the highest incidence for internationalisation when measured as co-authorships. The question is whether the small differences in the degree of internationalisation matter when it comes to the development in overall impact? When it comes to internationalisation, we can observe a slight increase in the Danish trajectory in the period where the impact also begins to rise again. However, we also have to remember that the degree of internationally co-authored papers, while continuously rising during the period, does not constitute the majority of published papers at the time. It is accordingly clear from the analyses that the drop in national impact for Denmark mainly is attributable to the national papers.

[8] http://www.scienceeurope.org/uploads/PublicDocumentsAndSpeeches/SE_and_Elsevier_Report_Final.pdf.

On average internationally co-authored papers have higher citation rates compared to national papers. This is largely due to visibility factors. But citation rates for international papers also vary according to which countries collaborate and the numbers involved. What this translates to is the fact that citation rates may reflect some inherent epistemic values in the papers examined, but citation rates are basically an indicator of use. International papers generally have more authors and a tendency to be published in journals with larger audiences. Therefore they tend to have higher citation rates. However, there is one more factor to consider: the "elite mechanism", i.e. the benefits of the Matthew Effect. High impact countries benefit most from international collaboration and they constitute an elite network where cumulative advantages play an important role. All three countries examined here belong to this elite group, but the developments in Sweden show that other factors also influence impact. The drop in Swedish impact is however not due to less internationalisation in the period. Instead structural and exogenous factors may have affected the basic research conditions subsequently affecting publication behaviours and eventually also the overall citation performance for Sweden.

8.3. Mobility

Above we have examined internationalisation in relation to formal collaboration measured by co-authorships. One major advantage of this approach is that citation impact and co-authorships are associated and can be explained rather straightforward and that we have longitudinal and exhaustive data on this. Unfortunately, this is not the case when it comes to mobility. The potential effects of mobility on citation impact are more complicated to extricate.

As outlined in the introduction to this chapter scientists are a highly mobile group of workers. But contrary to the analyses of co-authorships using large-longitudinal publication data sets, cross-country analyses in relation to mobility are very difficult to carry out. Countries have different data collection practices, if indeed they have data at all. Furthermore, the national historical perspective is generally neglected as mobility only in the recent decade has come to the forefront of science policy. An additional technical challenge is to track migration patterns. All in all, this gives us inconsistent and incomplete data where a longitudinal cross-country comparison has been impossible to conduct. However, we are able to bring various pieces of partial evidence together which can provide a description of mobility patterns and link them to collaboration and performance.

Our analyses rely on results from a recent survey among researchers in the natural sciences in 16 countries, including Denmark, Sweden and the Netherlands. We compare these findings to national statistics for Denmark in relation to foreign-born researchers working at Danish research institutions. Finally, to further support these findings, but also to examine the potential link between mobility and performance, we rely on results from an OECD report (OECD, 2013) and a large scale bibliometric analysis done by Elsevier (Kamalski & Plume, 2013). This analysis not only examines mobility patterns among authors registered in their Scopus database, but also collaboration patterns. The findings of the analyses are supported by results from the literature, especially from a recent anthology on researcher mobility (Geuna, 2015).

Does international mobility lead to higher performance? The literature is generally sparse and inconclusive on this matter although there are some indications (for a recent overview see Geuna,

2015). Mobility covers both the inflow of researchers from foreign countries working in a particular country, the outflow of native researchers going abroad to work, and finally native researchers returning home from longer stays abroad. The main assumptions are that mobility is good for the individual researcher; i.e. they become better researchers, they engage in more collaborative work, they become more productive and they are introduced to international networks vital for a successful career in science. Taking in researchers from abroad is likewise assumed to be beneficial, as it not only brings in potential new knowledge but also strengthens competition among domestic researchers presumably also enhancing research performance. In that sense mobility can be seen as enhancing a dynamic competitive knowledge production process. From a 'sociology of science' perspective mobility is seen as something potentially important for the individual researcher in relation to one's placement in the social stratification of science. On an aggregate level, the presumed effects of mobility would therefore be increased performance both in productivity and impact. However, the evidence is certainly not clear on these issues. One important nuance should be pointed out: While mobility in itself may be beneficial to various degrees, it matters a great deal where you go (e.g., country, institution, lab, group etc.) in relation to the socialisation and stratification of researchers into the science system.

Before we examine the results, we should emphasise some important caveats to keep in mind. First of all, (international) mobility is not relevant for all researchers across all fields. Second, pre-selection issues are to be expected, meaning that higher performing researchers are more likely to be mobile in the first place, so their generally higher performance level is not necessarily an effect of their higher incidence rate for mobility.

GlobSci survey

Our point of departure is the GlobSci study presented in several reports by Franzoni and colleagues (Franzoni, Scellato & Stephan 2012; 2015). Based on a survey among researchers in biology, chemistry, materials-, earth- and environmental sciences in 16 core research countries, including Denmark, Sweden and the Netherlands, Franzoni and colleagues examine international mobility patterns. The survey was carried out in 2011. 16,500 researchers fully responded and a further 2,300 partially responded to the questionnaire. According to the authors, the response rate is approximately 35%, which they claim is much higher than most web-surveys, albeit it is still a very low response rate that certainly requires cautionary interpretations.

The authors claim that their results provide compelling evidence that mobile scientist have a higher propensity to participate in international networks and that mobile scientists see international networking as a main result of their mobility experience (Franzoni, Scellatto & Stephan, 2015). Table 1 in Franzoni, Scellato and Stephan (2012, p. 1251) provides the main findings. We summarise the main findings for Denmark, Sweden and the Netherlands in bullets below.

The first three bullets examine questions related to foreign researchers working in the three countries (i.e. the inflow of researchers), where as the last fouf bullets examine questions related to the outflow of native researchers as well as their return rates.

- Proportion of researchers in a foreign country at age 18; the percentage of foreign researchers (including PhDs) in the countries: Denmark 21.8%, Netherlands 27.7% and Sweden 37.6%.
- Countries supplying ≥ 10% foreign workforce to the specific countries: Denmark (Germany 24.4%), the Netherlands (Germany 14.6%, Italy 12.5%), and Sweden (Germany 11.9%, Russia 10.2%).
- Four country concentration rate, i.e. a measure that examines the diversity of countries among the foreign researchers, higher rates means less diversity and more concentration among countries): Denmark 44.5%, the Netherlands 40.6% and Sweden 34.7%.
- Proportion of natives outside a country in 2011, i.e. the outflow or migration of researchers: Denmark 13.3%, the Netherlands 26.4% and Sweden 13.9%.
- Destination countries hosting > 10% of natives outside a country in 2011: Denmark: UK (37.5%) and US (36.4%); the Netherlands: US (22.9%), UK (19.5%) and Germany (18.8%); Sweden: US (23.8%), UK (13.8%) and Germany (11.5%).
- Proportion of native researchers with international experience: Denmark 54.3%, the Netherlands 53.1% and Sweden 53.9%.
- Rate of return of those with international experience: Denmark 75.4%, the Netherlands 50.3% and Sweden 74.2%.

We should re-emphasise that the survey in general has a low response rate which of course is even more noticeable for the individual countries. As a consequence, answers to questions relating to the outflow of native researchers (the last four bullets) are weighted by the inverse of the country response rate. We should therefore be very careful when we interpret these patterns. Before we interpret and as a precaution, we compare the present findings with some related numbers for recruitment of foreign-born researchers working at Danish universities in 2007-2009 and 2011-2013. Notice, these are numbers of new recruitments and not the exact population of foreign-born researchers working in Denmark.

In 2007-2009 approximately 33% of all new researchers at professor, associate and assistant professor levels were foreign-born. Four out of ten of these researchers had already worked at other Danish research institutions before their current position. Notice, there is considerable variation among fields, for the natural sciences the foreign recruitment rate was 44%, technical sciences 48%, and health sciences 22% (Ståhle 2011). The numbers are somewhat higher in the period 2011-2013 where approximately 38% of the new recruitments were foreign-born researchers, where five out of ten of these researcher had already worked at other Danish research institutions. Again there is considerable variation among fields, for the natural sciences the foreign recruitment rate was 53%, technical sciences 47%, and health sciences 28% (Ståhle 2014). In general, for both periods around 21-23% of the new recruitments came from abroad. Finally, we also see a huge inflow of PhDs to Denmark, 34% of the new PhD students who started a PhD education in Denmark in 2010 thus came from abroad (Danmarks Statistik 2011).

If we return to the survey by Franzoni and colleagues, the question is whether the numbers for foreign researchers working in Denmark are representative (and evidently whether the numbers for the other countries are representative as well)? Obviously, the numbers are subject to considerable uncertainty. They are supposed to be a representative sample of the foreign-born researcher

population in a given country in 2011. Our supplementary data are recruitment data and they only give us an indication of current priorities. Hence, it may well be that the actual population of foreign-born researchers is well below the current recruitment rates and that an increase in the population percentages will only change gradually in the coming years. Nevertheless, we do suspect that the numbers for Denmark is slightly below the expected for the natural science fields surveyed. If we look at the three Danish universities that contribute the most to the overall Danish research production then the overall share of foreign researchers employed at Copenhagen University has grown from 18 percent of the total academic staff in 2009 to 22 percent in 2013. At Aarhus University the share has grown from 18 percent to 20 percent within the same period, and in 2013, 35 percent of all employed researchers at the Danish Technical University (DTU) were foreign-born (Svansø 2013). Unfortunately, we do not have these numbers for the natural science faculties at Copenhagen and Aarhus Universities, yet the numbers for the DTU, which in many respects resembles a natural science university, gives us an idea that the population of foreign born researchers working in Denmark in natural science fields are probably slightly higher than the 21.8% reported in the GlobSci survey. However, the numbers are difficult to compare, and below we also present some other mobility statistics that show less difference between the countries than those suggested by the GlobSci survey.

Based on the available data, we can see that presumably there are considerably fewer foreign-born researchers working in Denmark in 2011 in biology, chemistry, materials and earth and environmental sciences, compared to the Netherlands and Sweden. The patterns of emigration are comparable, however, with the main "supplying" country being Germany. Interestingly, Denmark and Sweden resemble each other when it comes to natives working abroad in 2011, albeit the proportions are considerably lower than that for the Netherlands. On the other hand, the outflow migration is very similar for all three countries. The main countries researchers migrate to are the UK and the US. If we look at the proportion of researchers with international experience the three countries are also similar, although they differ on the rate of return where almost 3 out of 4 researchers with international experience return to Denmark and Sweden; this is only 1 in 2 for the Netherlands. Most interestingly, the immigrant researchers seemingly agreed when they were asked to evaluate the importance of 14 possible reasons for coming to work in their current country of residence: "opportunity to improve my future career prospects", the presence of "outstanding faculty, colleagues or research team" and "excellence/prestige of the foreign institution in my area of research".

It is obviously assumed that the main reasons for international mobility given by the surveyed researchers will eventually translate into better research performance. It is, however, very difficult to establish this: especially when it comes to citation impact. One noticeable challenge is the inherent selection bias in whom gets to move abroad and where to. It is very likely that high performing researchers are also the most mobile ones and the reason for their initial higher performance may well be cumulative advantages gained locally by already being member of a group with international networks etc. Nevertheless, two recent reports are informative when it comes to getting an indication of how mobility and impact may be correlated.

A recent OECD study (OECD, 2013) claims to be able to trace the actual mobility and publication patterns for researchers moving in and out of countries. A central claim in the study is that

researchers are 1) highly mobile and 2) internationally mobile researchers tend to publish in higher-impact journals compared to their colleagues who stay in the same country throughout their research careers. The study uses data from the Scopus database where individual researchers changing addresses between countries in the period from 1996 to 2011 are examined. The study basically correlates the median journal impact for researchers moving in and out of countries and additionally compares the correlations to the average mobility flows of the countries (i.e. both in- and outflows) (see figure 56, page 61 in the report[9]). Notice, as with the GlobSci survey this analysis is also subject to considerable uncertainty and potential bias. However, in some respects it corroborates the previous findings.

The average inflow-outflow mobility size for Denmark is slightly lower than Sweden whereas the Netherlands is somewhat larger meaning that the country in general has a higher degree of mobility both in and out of the country. Important, all three countries seem to have balanced "median journal impacts" for researcher emigrating and researcher immigrating, however, the degree of impact is clearly larger for the Netherlands. Notice, the impact here is basically an indication of publication behaviour for the researchers and not their actual citation impact level. At the aggregate level of countries, however, a general publication pattern in journals with higher average citation impact will most likely result in higher average impact for individual articles affiliated to a particular country.

Another similar study based on the Scopus database and also utilizing the information about researcher mobility over a longer period of time is the abovementioned Elsevier report by Kamalski and Plume (2013). This study both examines collaboration measured through co-authorship and mobility rates, and links these factors to citation impact. While the study primarily compares Europe and the US some interesting findings also at the national level can give us an indication of the link between mobility and impact. The general findings of the study are that high performing European countries also have high degrees of mobility, whereas high performing US states have low mobility. The study presents proportions of presumably "immobile" researchers in the period from 1996 to 2011 in Europe (Kamalski & Plume, 2013, p. 32). "Immobile researchers" means researchers with affiliations to institutions in the same country during the whole period examined. The proportion of "immobile" reserachers for Denmark is 31.8%, for Sweden it is 31.4% and for the Netherlands it is 36.1%. Interestingly, the proportion of immobile researchers in Switzerland is only 16.2% according to the study.

When the countries' proportion of immobile researchers are correlated with their normalized citation impact in the Scopus database, a generally negative correlation is claimed, albeit with a meagre R2 of 16 percent indicating considerable variation. This is interpreted as higher performing European countries have lower proportions of "immobile" researchers. While perhaps not clear cut, the overall tendency is visible (see Kamalski & Plume, 2013, p. 35). Again we see that Denmark, Sweden and the Netherlands are quite similar, the relatively high impact scores and mutual high rankings correspond to our own analyses based on the Web of Science database, whereas the sedentary rates are very similar. We should emphasize that the studies obviously are also subject to

[9] http://www.oecd-ilibrary.org/science-and-technology/oecd-science-technology-and-industry-scoreboard-2013_sti_scoreboard-2013-en

uncertainty, so the question is whether the small differences between the three countries are detectable and whether they really matter?

More generally, the study gives an impression of how types of mobility may be related to impact and these findings relate to the discussions above where we 1) demonstrate that it matters whom you collaborate with, and 2) demonstrate the different journal publication profiles for mobile researchers going in and out of countries. It seems that mobile researchers generally have higher citation impact scores. But we have to stipulate again that this is merely correlations, we cannot state that high mobility leads to high impact. It may well be that those who are mobile are already performing at higher levels when moving abroad.

8.4. Summary of findings

The fifth hypothesis states that Danish research is particularly internationalized compared to related countries and that there is a relation between the degree of internationalization and research performance measured as citation impact. Two aspects of "internationalization" have been examined empirically for the three countries: 1) the development in the degree of internationally co-authored papers, and 2) the mobility of researchers in and out of the countries.

Co-authorships are perceived as proxies for formal research collaboration. While certainly not a perfect measure, co-authorships are valuable in the sense that they are invariant, verifiable and enables longitudinal comparative analyses. But most importantly for the present hypothesis, co-authorships are closely related to citation impact. It is important to emphasize that citation impact to a large extent are associated with a number of visibility factors, including journal status, number of authors and number of international co-authors, and it is not only how many you collaborate with that matters; whom you collaborate with is also important when it comes to impact. High performers tend to predominately cite other high performers. So on average, internationally co-authored papers have higher impact scores and countries like Denmark, Sweden and the Netherlands benefit from being high performers.

Based on the co-authorship analyses of internationalization we do not find convincing evidence for the claim that Denmark is particularly internationalized compared to related countries. While Denmark consistently has the highest degree of internationalization compared to the Netherlands and Sweden in the period examined, the actual differences are minor. This is not surprising as degrees of international collaboration are related to country size. All three countries experience a considerable continuous growth in internationalization similar to other relatively high performing countries in the period. There is an indication that the growth in the Danish degree of internationalization is steeper during the 1990s widening the gap to the other countries, but this gap is reduced again in the 2000s. Most importantly, the development in the Danish degree of internationalization does not seem to have influenced citation impact in any substantial way. While there is a marked but brief rise in impact for internationally co-authored papers around 1990, the impact level for internationally co-authored papers is by and large stable at a high level during the whole period. It is important to notice that in 1980s and 1990s the proportion of such papers only constituted from 20 to 50 percent of the total Danish output. The decline in Danish impact in 1980s is in fact mainly attributable to marked drops in the impact levels of nationally authored papers at a time when they constituted some 70 to 80 percent of the total output. The subsequent rise in

Danish impact during the 1990s is also mainly attributable to nationally authored papers although at a time when their relative shares were decreasing. At the same time, the relative share of internationally co-authored papers was increasing, and this obviously had a stabilizing effect on the total impact level for Denmark.

The second aspect used to examine the claim that Denmark is particularly internationalized and that this supposedly is a major cause for high performance focuses on researcher mobility. Unfortunately, the mobility analyses are restricted and incomplete due to lack of valid longitudinal data comparable at the country level. We are therefore only able to indicate degrees of mobility with considerable uncertainty and only for cross-sectional data sets of more recent time periods. What seems reasonable to conclude based on the different approaches and data sets examined is that mobility patterns for Denmark, Sweden and the Netherlands seem very similar. One survey study estimates that the number of foreign researchers in five natural science fields is 22 percent for Denmark, 28 percent for the Netherlands, and 38 percent for Sweden. The survey also claims that the proportion of researchers working outside their native country in 2011 in these fields is 13 percent for Denmark, 26 percent for the Netherlands, and 14 percent for Sweden. Similarly, the international experience rates for researchers in all three countries seem identical at 53-54 percent. Based on the survey, it would seem that a substantially lower share of foreign researchers is working in Denmark, and fewer were working outside Denmark in 2011 compared to the Netherlands, but the survey estimates are highly uncertain with a response rate around 30 percent. Other data and studies indicate that the differences between the countries may not be as marked as those suggested in the survey. A study examining research mobility from 1996 to 2011 concludes that the proportion of sedentary (immobile) researchers were 32 percent for Denmark, 36 percent for the Netherlands and 31 percent for Sweden. These numbers cover all fields but are also subjected to uncertainty. A third study suggests that the degree of mobility is slightly higher for the Netherlands compared to Denmark and Sweden. Taken together and considering the uncertainties inherent in these studies, we can state that mobility patterns for the three countries most likely are quite similar. But perhaps most interesting, when relating mobility rates to country impact, the studies do show that 1) lower mobility rates are associated with lower impact levels and 2) that all there countries seem to have balanced impact profiles when it comes to researchers emigrating and immigrating. Two caveats should be taken into consideration: 1) the relation between mobility and impact may well be a selection effect, and 2) the character of the present data and analyses means that we cannot say anything about the historical influences of mobility patterns.

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9. Collaboration

9.1. Introduction

Collaboration in scientific research is generally regarded as being positive and thus something that should be encouraged (Katz & Martin, 1997). Several initiatives accordingly aim at fostering collaboration between various organizations active in research, particularly universities and industries, in order to integrate potential users of research as early as possible in the research process. Along the same lines, Gibbons et al. (1994) and Leydesdorff and Etzkowitz (1996) suggest that the organization of scientific research is changing and that, in contemporary societies, knowledge is more and more produced in collaboration between universities and industries.

The sixth and final DFiR hypothesis deals with cross-sectoral collaboration and in particular public/private research collaboration[10] (UIC). It is stated that a strong Danish tradition of UIC is a contributing factor in explaining the high Danish impact level. This hypothesis is mainly examined through a number of bibliometric analyses where we examine the volume of UIC as well as the impact of such collaborative papers. We do this for all three countries based on the enhanced Web of Science (WoS) database hosted by CWTS, Leiden University. CWTS has coded journal papers in their database from 1980 onwards as to whether the paper contains one or more addresses belonging to a private (profit) organisation mainly "industry". Bibliometric analyses are therefore interesting because we can 1) examine the longitudinal trajectories for UIC for all countries, and 2) we can relate this directly to the countries' citation impact which we have calculated based on the same database for the same period.

But there are also three clear limitations related to this approach:

- First, the coding is not perfect. However, from random checks and country comparisons, we have good reasons top believe that the overall results are reliable, at least for comparisons.
- Second, and more challenging, what does it mean that at least one author address in a research paper comes from a private company/industry? As already discussed under Hypothesis 5, co-authorships can only be considered a proxy for formal research collaboration. But this assumption is clearly strongest when researchers from two or more non-commercial research institutions co-author papers together because they essentially have similar epistemic aims and similar academic incentive and reward structures. This is not necessarily the case for co-authorships between non-profit research institutions on the hand and profit (research) companies on the other. Nevertheless, co-authorships between "universities" and "industry" (UIC) have been used in several studies under the assumption that these joint scientific publications capture UI-interactions to some extent (e.g. Calvert and Patel 2003; Sun et al. 2007; Abramo et al. 2009; Klitkou et al. 2009; Tijssen et al. 2009, Tijssen 2012; Giunta et al. 2014). Despite this frequent use of UIC as a proxy of UI interaction or collaboration it still remains unclear what these joint publications exactly represent, what type of interactions led to these collaborations, as well as the level of accuracy in which these assumed interactions are captured. Indeed, only a few studies have tried to shed some

[10] We use the internationally acknowledged abbreviation for public-private collaboration UIC although it originally referred to university-industry collaboration. UIC represents non-profit public research institutions' collaboration with profit private organisations or companies.

light on this issue (e.g. Lundberg et al. 2006; Wong and Singh 2013). For example, if we have 10 non-profit research institutions and 1 "industry" company, how are we supposed to treat this UIC? It is also unclear whether actual research collaboration takes place in such interactions, or whether the authorship credit is given for something else, such as funding?

- Third, we only focus on journal articles indexed in WoS leaving out conference papers. This may underestimate the presumed "collaboration" taking place within the technical and computer sciences, where conference papers are the primary form of scholarly communication. Further, limiting the longitudinal analyses to published journal articles, obviously leads to an underestimation of UIC, not only because of limitations in publication types, but also because we must assume that some UIC is informal and not documented in the primary scientific literature.

We should also clarify that in most of our analyses, the initial coding of papers as to whether at least one private/industry organisation is present does not clarify whether such an organisation or organisations are Danish. We only know that among the addresses are at least one Danish address and at least one address for a private/industry organisation.

Several studies have been published on UIC. Most come to the conclusion that university–industry collaborations are advantageous for the two partners. The most tangible benefit for industry is a faster access to the new scientific discoveries most often created by university researchers, whereas in return, university researchers have access to equipment, research funds and an external viewpoint on their own works (Lee 1996). At the individual level, Lee and Bozeman (2005) showed that US researchers who collaborate (all types of collaboration included) are generally more productive in terms of publications than researchers working alone. Although they represent a small percentage of collaborative activities, UIC has a positive effect on productivity. Other researchers, such as Katz and Hicks (1997), obtained similar results for the UK science system. Indeed, UK articles published in collaboration with other institutions (be it universities, industries or government laboratories) received, on average, more citations than articles produced without such collaborations. This was also observed in the particular case of UIC. In the only large scale country analysis we are aware of, similar to the ones presented in this report, Lebeau et al. (2008) show for the Canadian case that the average citation impact of UIC papers is "significantly" above that of both university-only papers and industry-only papers.

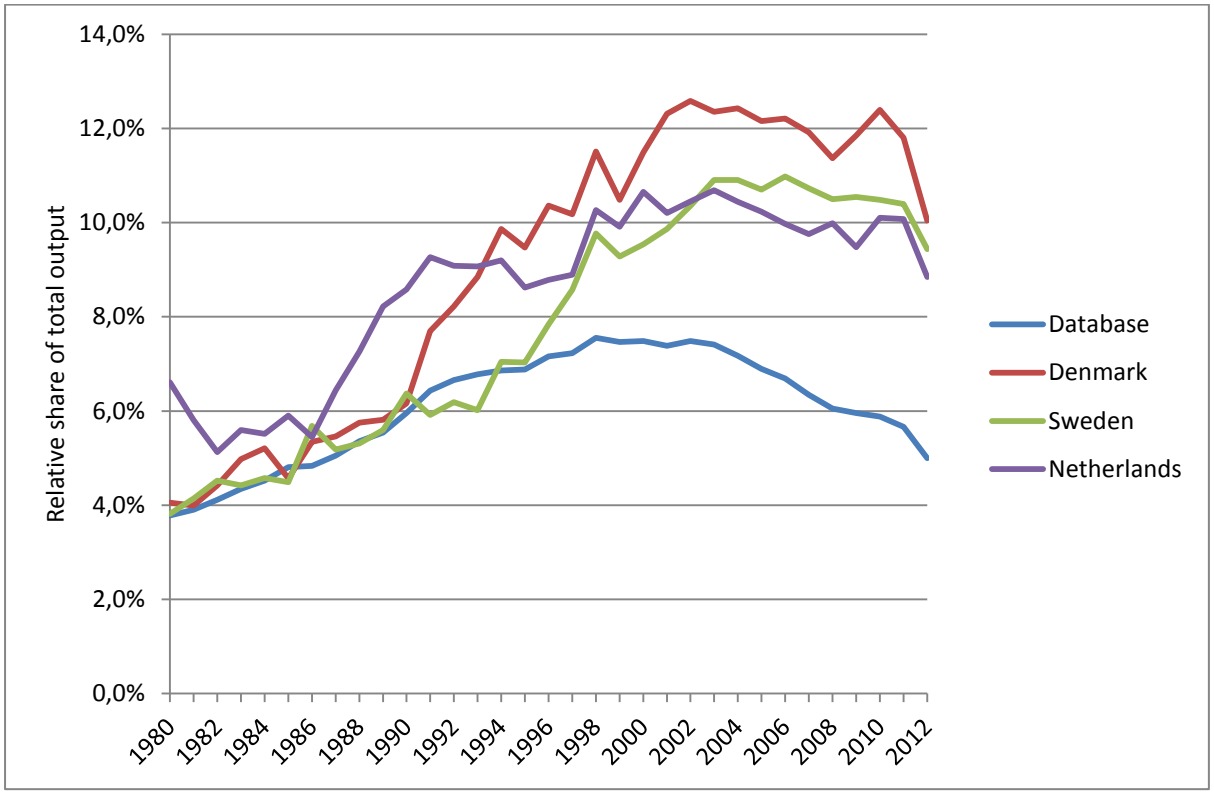
Below we present a number of longitudinal bibliometric analyses where we examine the volume of UIC for Denmark, the Netherlands and Sweden; the impact of UIC papers and their potential influence on total impact for the three countries; and finally we map UI-collaboration patterns for the Danish set of publication for three 10-year periods. The latter analyses are made to provide some context in the Danish case.

9.2. Volume of university-industry collaboration (UIC)

Figure 9.1 below presents the developments in national shares of UIC for the three countries as well as the overall development in the WoS database. The overall developments for the three countries are similar. They all experience large increases from the mid-1980s (the Netherlands) to early 1990s (Sweden) albeit with some displacement in time. From the mid-1990s Danish UIC is the highest among the three countries but the differences are only within two percentage points and therefore

vulnerable to the noise in the data (e.g. coding effects). Noticeable, in the 2000s, there generally seems to be a drop for all countries and in the database. To a large extent, this is most likely an effect of the large increase of papers in the database in these years. However, the marked drops at the end of the period are conjectured by researchers at CWTS to be a genuine drop in UIC caused by the financial crisis in 2008/9.

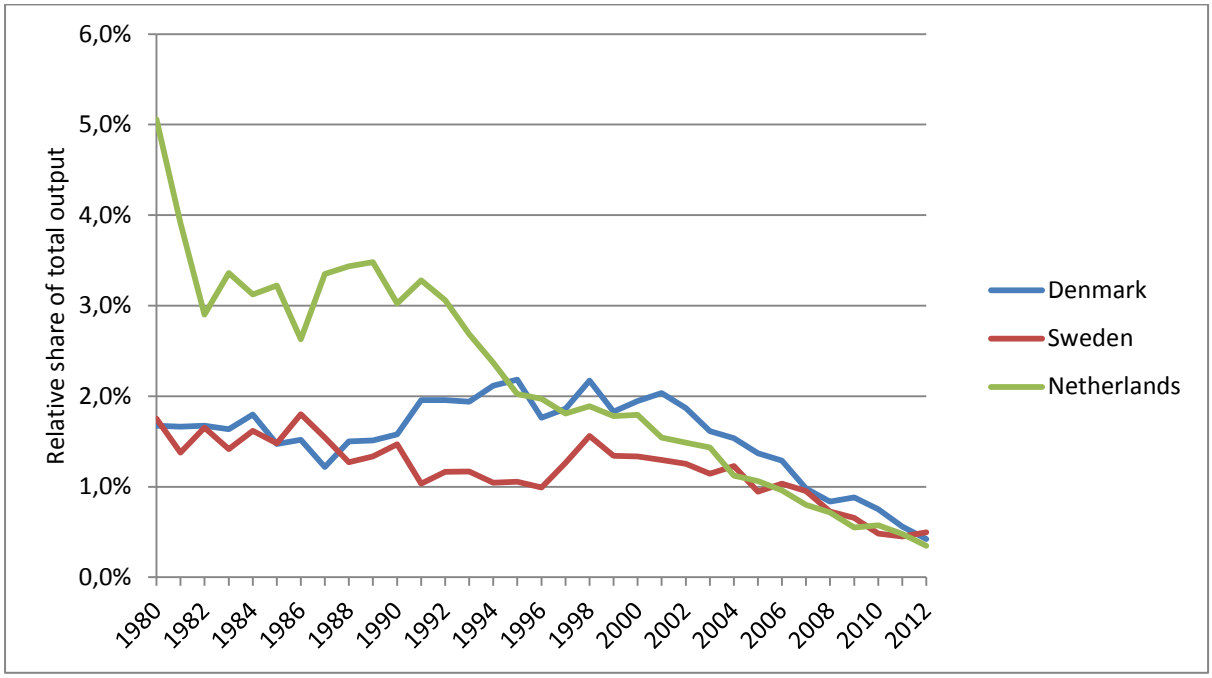
Figure 9.1: Developments in national shares of UIC papers for the three countries as well as the overall development in the database. Collaboration is measured using CWTS' coding of "industry" articles in their enhanced version of the WoS database.



Source: CWTS Leiden

Figure 9.2 below shows the developments in national shares of "industry" papers (I) for the three countries as well as the overall development in the database. These are papers where there are no public research institutions affiliated. In the early period, the Netherlands clearly had relatively higher shares of industry papers (i.e. the Philips Lab is a major contributor). In the 1990s when Danish impact begins to rise again we also see a minor rise in volume of industry papers, but then from the late 1990s all countries see a continuous marked drop so that the volume of sole-authored industry papers today is only around 0.5%. It is also noteworthy that the Swedish continuous decline in volume sets in already around 1990. We should emphasise that the relative volume is generally low (the Netherlands in the early period is perhaps an outlier in that sense). The overall continuous decline for all countries is most likely a consequence of 1) more collaboration in the database and therefore also more UIC, and 2) the general increase of journals in the database.

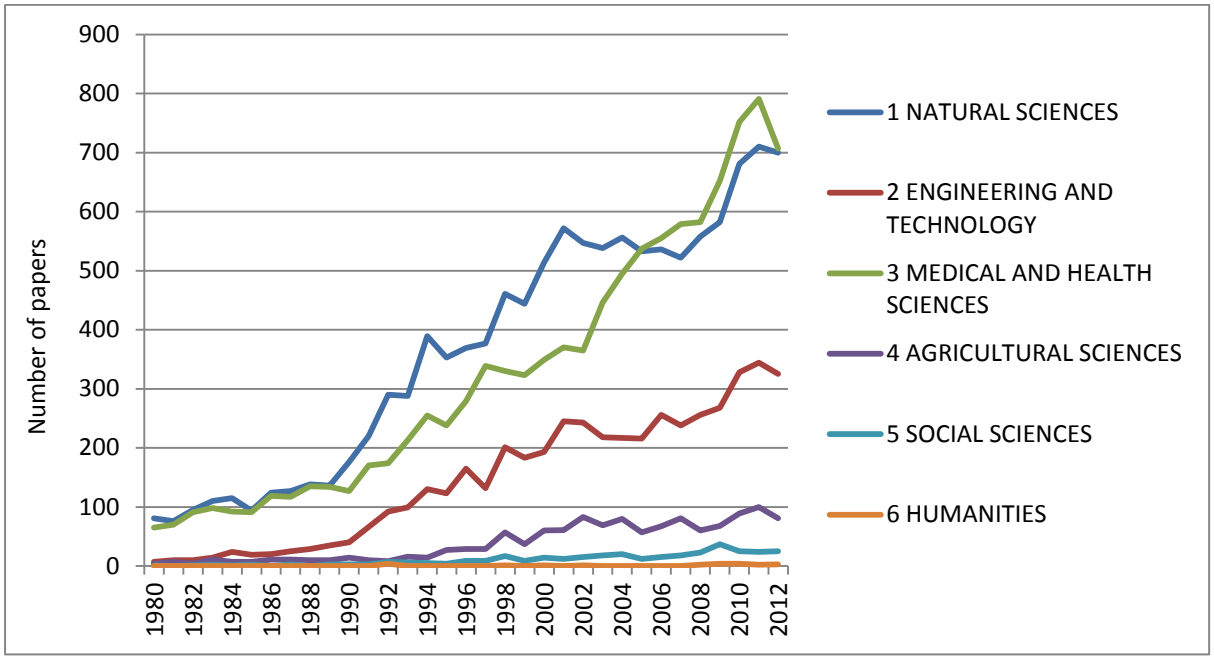
Figure 9.2: Developments in national shares of private/industry papers (I) for the three countries as well as the overall development in the database. Collaboration is measured using CWTS' coding of "industry" articles in their enhanced version of the WoS database.



Source: CWTS Leiden

Figure 9.3 below show the development in both public-private collaborations (UIC) and sole industry papers (I) for Denmark broken down to main OECD fields of research. The developments for three main fields are similar as the marked increase sets in around 1990.

Figure 9.3: Annual output of all types of Danish "industry papers" (both UIC and I) broken down to main OECD fields of research. Notice, Danish means that at least one affiliation in the papers have a Danish address, we cannot specify whether it is a public research institution (U) or a private industry (I).

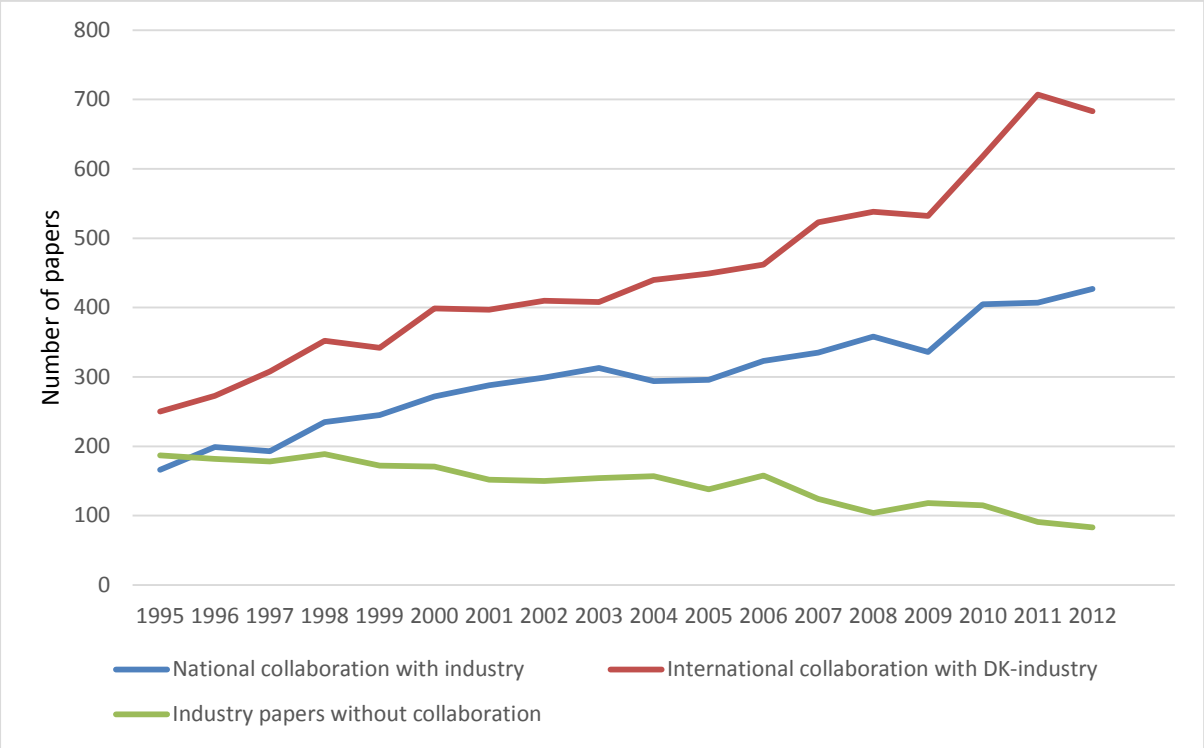


Source: CWTS Leiden

Obviously, the increase is clearly larger for the natural science and the medical and health sciences. In the early period the volume for the natural sciences is larger although around 2000 the growth stagnates and in 2005 the volume for the medical and health sciences passes that of the natural sciences.

Finally, Figure 9.4 below shows the developments for specific types of collaborations. This is a specially coded Danish sub-set of papers published between 1995 and 2012. We have manually coded this sub-set as to whether the collaborations are national (i.e. Danish public institutions and Danish private companies) or whether it is international collaboration with Danish private companies.

Figure 9.4: Developments in specific collaboration types for a sub-set of Danish UIC and I papers



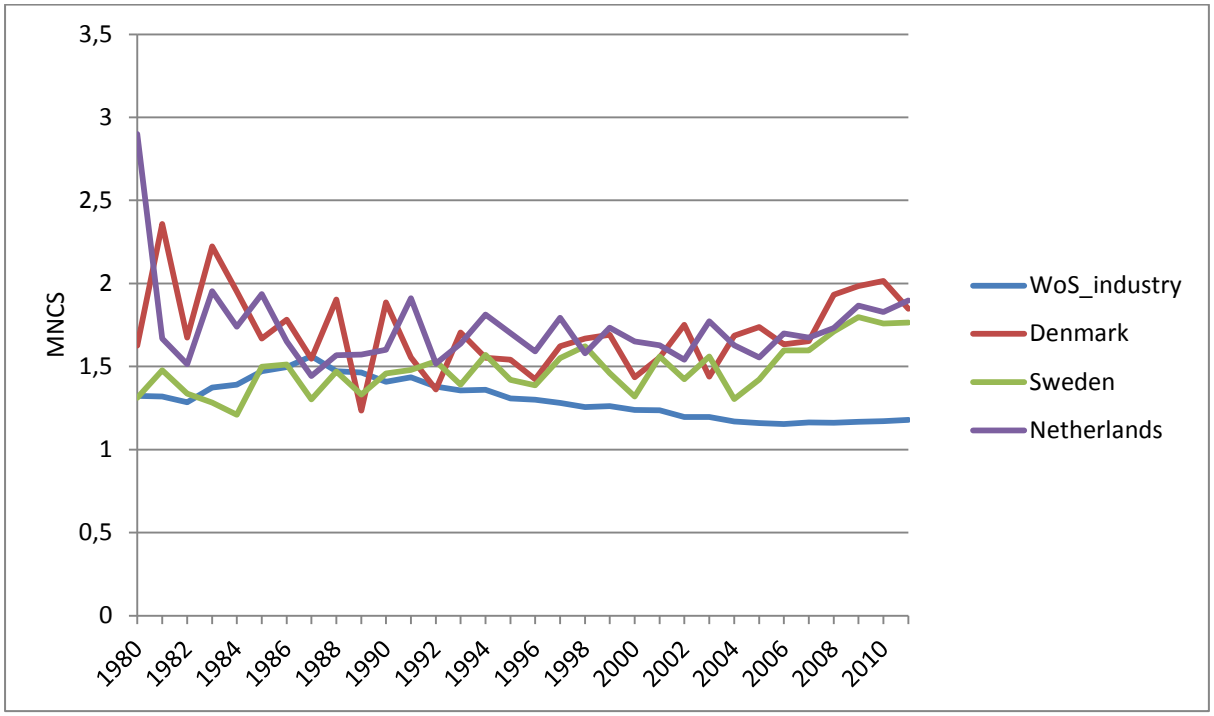
Source: CWTS Leiden

The trends basically support the previous findings where we see generally increasing volumes for UIC papers and a continuous drop of sole industry papers from around 2000. However, Figure 9.4 also shows that the volume on international collaborations where at least one Danish private company is affiliated is by far the largest set. This is an important observation because international collaboration is good predictor for higher citation impact. In other words, we can expect that the citation impact of the total Danish set of UIC papers will be positively influenced due to the larger proportion of international collaborative papers in the set.

9.3. Citation impact of university-industry collaboration (UIC)

In this section we present two analyses in four figures. The first analysis demonstrates the development in Mean Normalized Citation Scores (MNCS) for the national sets of all-industry related papers (i.e. Denmark, the Netherlands and Sweden) as well as the overall WoS database impact for such papers. The results are shown in Figure 9.5. Subsequently, we examine the developments in national MNCS scores with and without the industry papers; these results are presented in Figures 9.6 (Denmark), 9.7 (Sweden) and 9.8 (the Netherlands).

Figure 9.5: Developments in mean normalized citation scores (MNCS) for all types of "industry" papers for all three countries as well as the WoS database average.

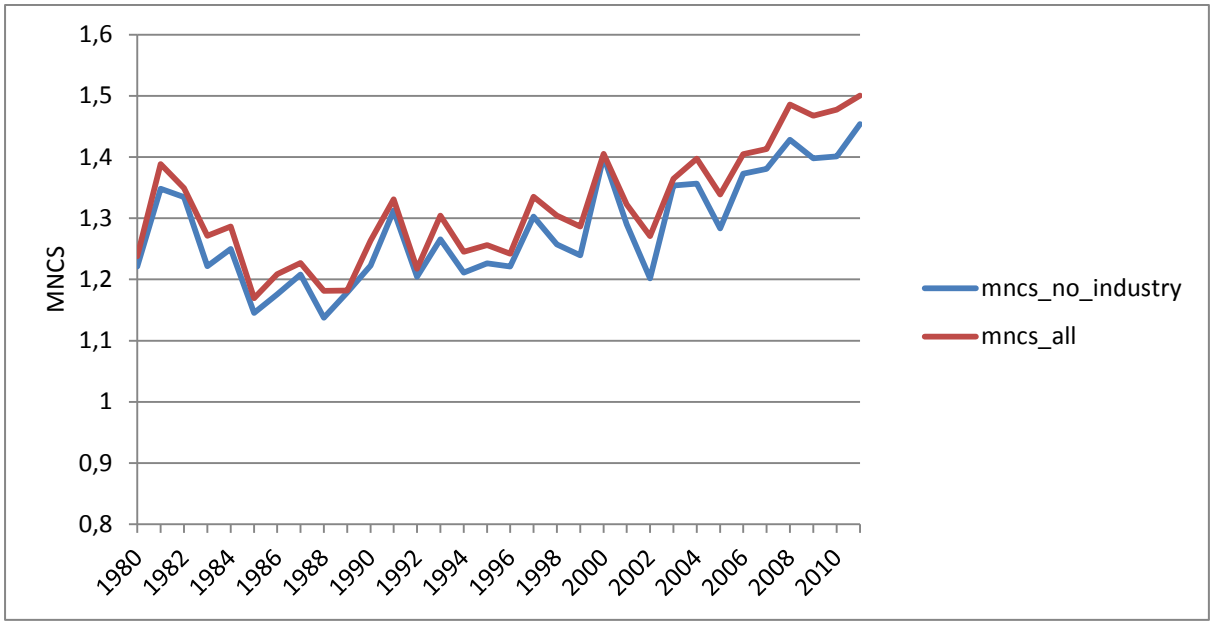


Source: CWTS Leiden

Figure 9.5 shows the developments in the MNCS scores for all types of industry papers. There are fluctuations in the early period especially for Danish and Dutch papers although their impact is generally higher than the database average, as well as the impact level of Sweden. Some very highly cited papers in one year and the general low volume most likely cause the fluctuations. As volume increases, the MNCS scores become less vulnerable to highly cited outliers. From the late 1980s the impact levels for the three countries stabilize and become almost similar. The impact levels follow a stable path around an MNCS of 1.5 and the rise at the end of the period is most likely related to the general database effects also visible for the total impacts for these countries. So, for most of period examined the countries' industry-related papers have similar impact levels.

Next we show three figures depicting the effects in MNCS values when we remove the national set of "industry" papers from the total national set of papers.

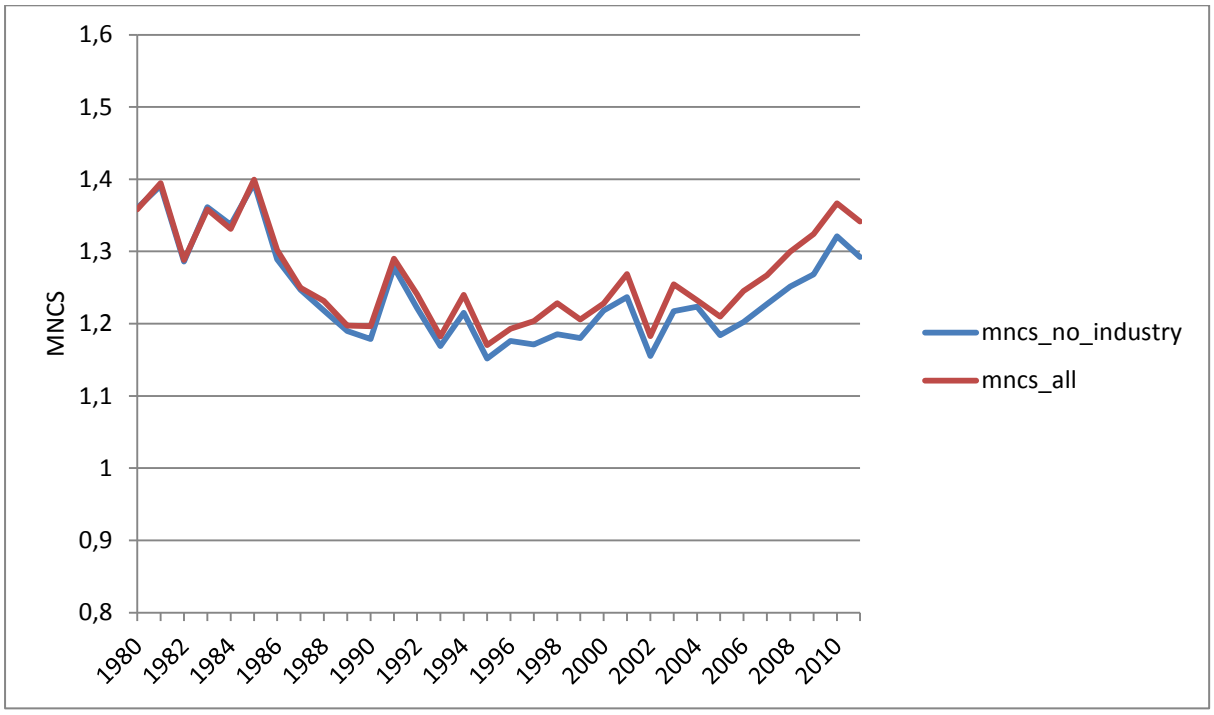
Figure 9.6: Differences in mean normalized citation scores (MNCS) for Denmark with and without "industry" papers



Source: CWTS Leiden

In the Danish case, national MNCS scores are mainly affected negatively on the second decimal. It is clear that the impact levels drop somewhat, yet the development trends are close to identical. There is nothing in this graph which suggests that developments in UIC have "driven" the increase in Danish impact – the set of industry-papers fluctuates with the general Danish impact and we have to stipulate the relatively small volume, at least in the 1980s and 1990s.

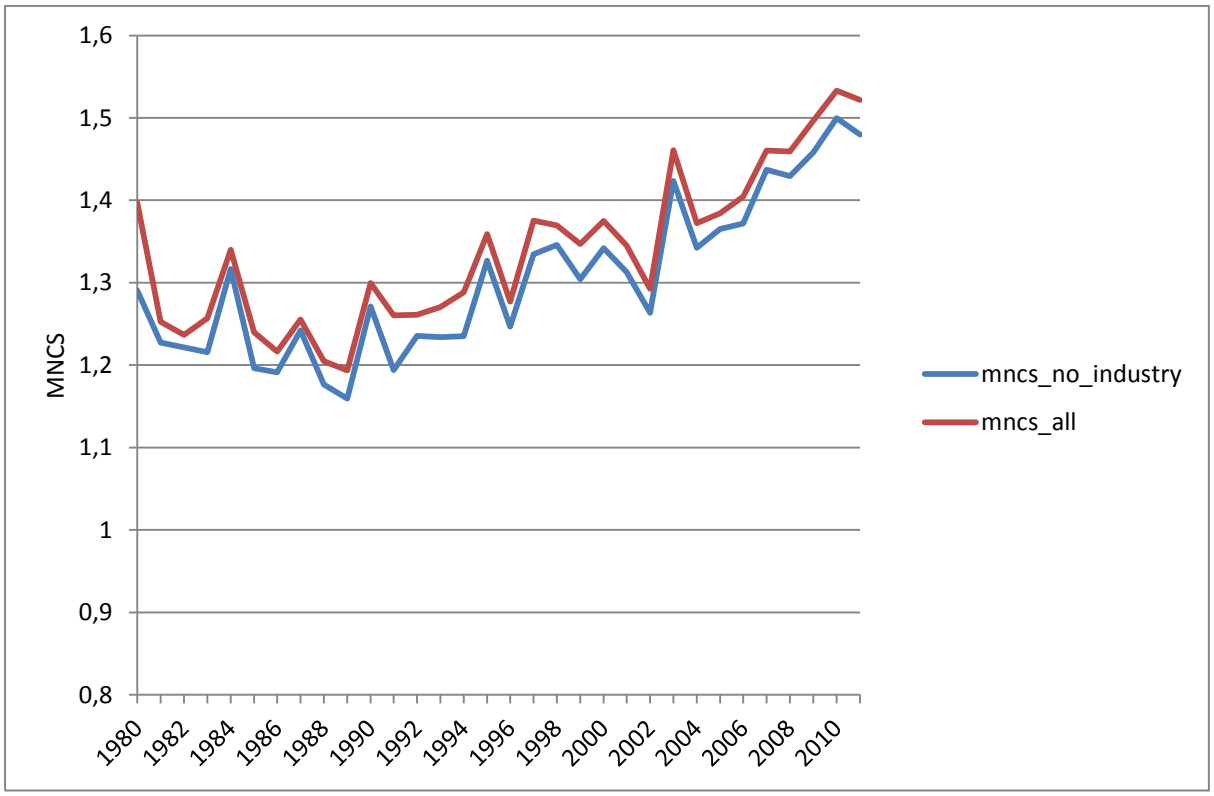
Figure 9.7: Differences in mean normalized citation scores (MNCS) for Sweden with and without "industry" papers



Source: CWTS Leiden

The Swedish case is somewhat different as the impact levels are indistinguishable in the first decade (i.e. 1980s). Hereafter we see a small difference on the second decimal, but the effect of removing the industry-papers is clearly lower for Sweden compared to Denmark. But again the general trends are close to identical.

Figure 9.8: Differences in mean normalized citation scores (MNCS) for the Netherlands with and without "industry" papers



Source: CWTS Leiden

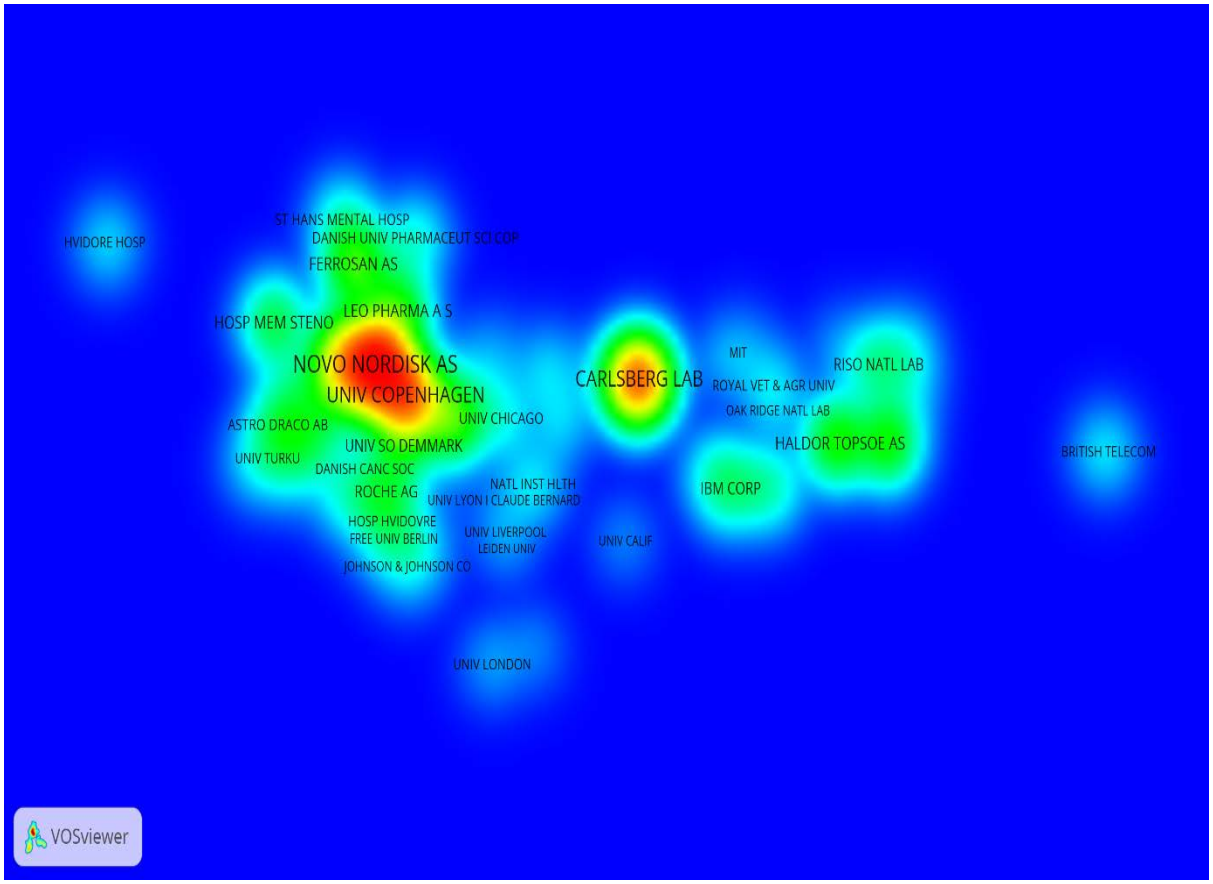
The case of the Netherlands is comparable to Denmark, perhaps even more distinct in the early period which corresponds with findings shown in Figure 9.5, and the gap becomes smaller in the latter period. Like Denmark, we see somewhat larger effects when the industry-papers are removed, yet the influence of these papers on the national trends is not discernible.

9.4. Danish UI-collaboration patterns

In order to contextualise the previous analyses of developments in volume and impact for industry-related papers we map the Danish UI-collaborations. We do this for three pooled periods: papers from 1980-89, 1990-99 and 2000-09. We have refined and standardized institutional and corporate names in the address fields of the Danish papers and subject the three pooled sub-sets to mapping analyses using VOSviewer (www.vosviewer.com). VOSviewer incorporates multidimensional scaling, cluster and network techniques to provide similarity maps and network graphs. We have kept the analyses fairly simple in as much as we have tried to "only" include around 150 unique institutions in each map (notice, due to the heat map visualisation in the figures not all institutions are visible, only those with the strongest relations). The interesting observation in that respect is that the threshold for being included in the first map is 25 collaborations, whereas the threshold in the last map is 200 collaborations. This huge increase in threshold testifies to the general development in collaboration

measured as co-authorships, and as Figure 9.9 shows, especially international collaboration. We visualize the results in so-called heat maps where closer proximity between institutions means stronger collaboration patterns, the size of the labels indicate volume of papers, and the colour codes general show the intensity of volume and collaboration.

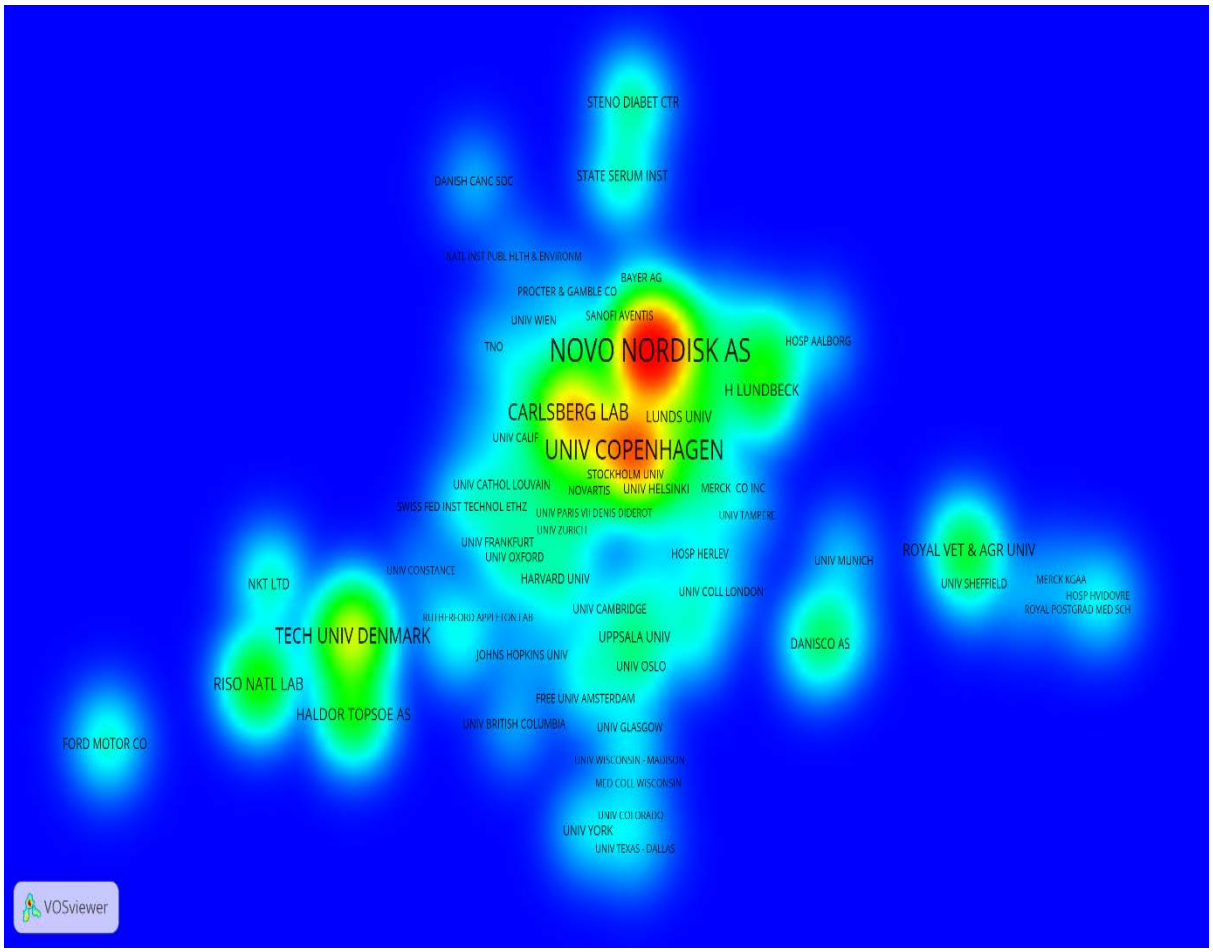
Figure 9.9: UI-collaboration patterns for Danish papers coded as "industry" in the period 1980-1989.



Source: CWTS Leiden

In the first period from 1980 to 1989 we see three main clusters: 1) a biomedical cluster with major intensity around Copenhagen University and Novo Nordisk. Other pharmaceutical companies as well as hospitals and public research institutions are linked to this cluster. 2) A more isolated biochemistry cluster around the Carlsberg Lab; in fact, collaboration activities are not high since most of the papers are authored by Carlsberg researchers themselves. Finally 3) a weaker technical cluster represented by Haldor Topsøe and Risø (i.e. the Technical University is also in the cluster). Notice, the intensity in both in volume and collaboration for this cluster is not strong. A general observation form this period is the few international public and private organisations present in the map.

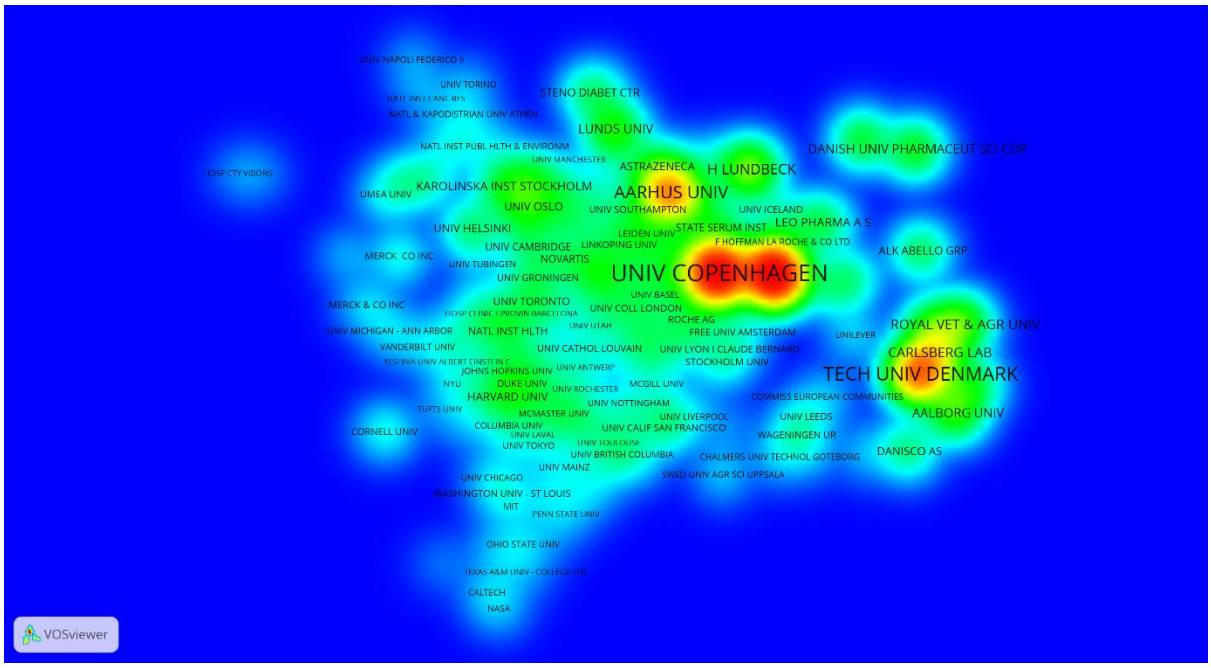
Figure 9.10: UI-collaboration patterns for Danish papers coded as "industry" in the period 1990-1999.



Source: CWTS Leiden

In the second period we see some interesting changes. First, more institutions become visible meaning that the collaboration network becomes tighter. Second, most of the "new" visible institutions are international non-profit research institutions. Third, again we see three main clusters, where the largest and most intense cluster still is the biomedical cluster centred around Copenhagen University and Novo Nordisk. Interestingly, the Carlsberg Lab is now part of this general cluster. However, Carlsberg Lab could still represent a sub-cluster of biochemistry with close collaboration activities with Copenhagen University. 2) The technical cluster is also visible in this map, it has grown in size and also slightly in intensity, and the Technical University has become visible and is the central node in the cluster. Finally 3) a new rather weak cluster related to food/nutrition and animal research represented by DANISCO and the Royal Veterinary and Agricultural University emerges.

Figure 9.11: UI-collaboration patterns for Danish papers coded as "industry" in the period 2000-2009.



Source: CWTS Leiden

In the final period examined, a much more blurred map arises. The same tendencies as in the second period is visible: more institutions become visible due to ever tighter collaboration patterns (i.e. more authors per paper and more internationally co-authored papers); and most of the new institutions are non-profit international research institutions. We can still discern an intensive biomedical cluster centred around Copenhagen University, but we can also see that Aarhus University is now visible and the placement is most probably also influenced by strong collaborations in the biomedical area. We also see that the technical cluster and the food/nutrition and animal cluster have almost merged. Interestingly, the Carlsberg Lab has now moved to this cluster and Aalborg University has become visible. As already mentioned above, what is noticeable from this final map is the fact that many foreign universities are now present among the collaborators. Indeed, the maps are generally of the same size when it comes to institutions, but in order to be connected in the first map only 25 collaborations where needed, in the last map 200 was the criterion. This is clearly an example of how collaboration has increased dramatically during this period.

9.5. Summary of findings.

The sixth hypothesis deals specifically with public-private research collaboration (UIC). The hypothesis states that basic conditions in Denmark and a supposedly stronger Danish tradition for collaboration are contributing factors in explaining the high impact. Based on our bibliometric analyses, we find no support for this claim. The overall developments in volume for the three countries are very similar with some minor displacements and while the share of UIC is highest for Denmark beginning in the early 1990s, it is never more than 1 to 2 percentage points above Sweden or the Netherlands. But more importantly, the overall developments in citation impact for UIC papers between the three countries are even more similar, disregarding annual fluctuations. There is no indication that Danish UIC papers played any major role in the continuous impact increase from the early 1990s onwards. The impact level of such papers is fairly constant although the volume did

increase substantially in the 1990s. Nevertheless, while removing these papers from the total Danish publication set does reduce the overall impact level somewhat on the second decimal, it does not influence the general development. These observations are similar to those of the Netherlands where the impact level is also reduced somewhat when UIC papers are removed, but it does not affect the general development in Dutch impact. In other words, there is nothing peculiar about Danish UIC papers compared to the Netherlands and Sweden.

It is important to emphasize that collaborative papers generally have higher impact compared to non-collaborative papers, and that international collaborative papers generally have higher impact than national and non-collaborative papers. A majority of the UIC papers is internationally co-authored and this generally benefits their impact level. But there is a more challenging issue in relation to the supposed citation impact benefits of UIC papers. We know very little about the assumed "collaborative" activities implied by the co-authorships counted between public research institutions and private profit organisations. Co-authorships are considered a proxy for formal research collaboration. But this assumption is clearly strongest when researchers from two or more non-profit research institutions co-author papers together because they essentially share similar epistemic aims, academic incentives and reward structures. This is not necessarily the case for co-authorships between public research intuitions on the hand and private profit (research) institutions on the other. In the present analysis we are not able to examine the assumed "collaborative" efforts in detail so we are not able to categorise the different types of co-authorships or the intensity with which the public and private organisations contribute to such collaborative research efforts in the individual papers. We can only infer general trends for papers where we know that at least one public and one private institution is credited in the author byline and in as much as this indicate public-private research collaboration, the performance developments for Denmark, Sweden and the Netherlands are very similar. The findings here are furthermore comparable to the Canadian case examined by Lebeau et al (2008).

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