The scientific impact

of Danish research 1980–2020

By Jesper Wiborg Schneider & Maria Theresa Norn

Academic report from The Danish Centre for Studies in Research and Research Policy (CFA), Department of Political Science, Aarhus BSS, Aarhus University

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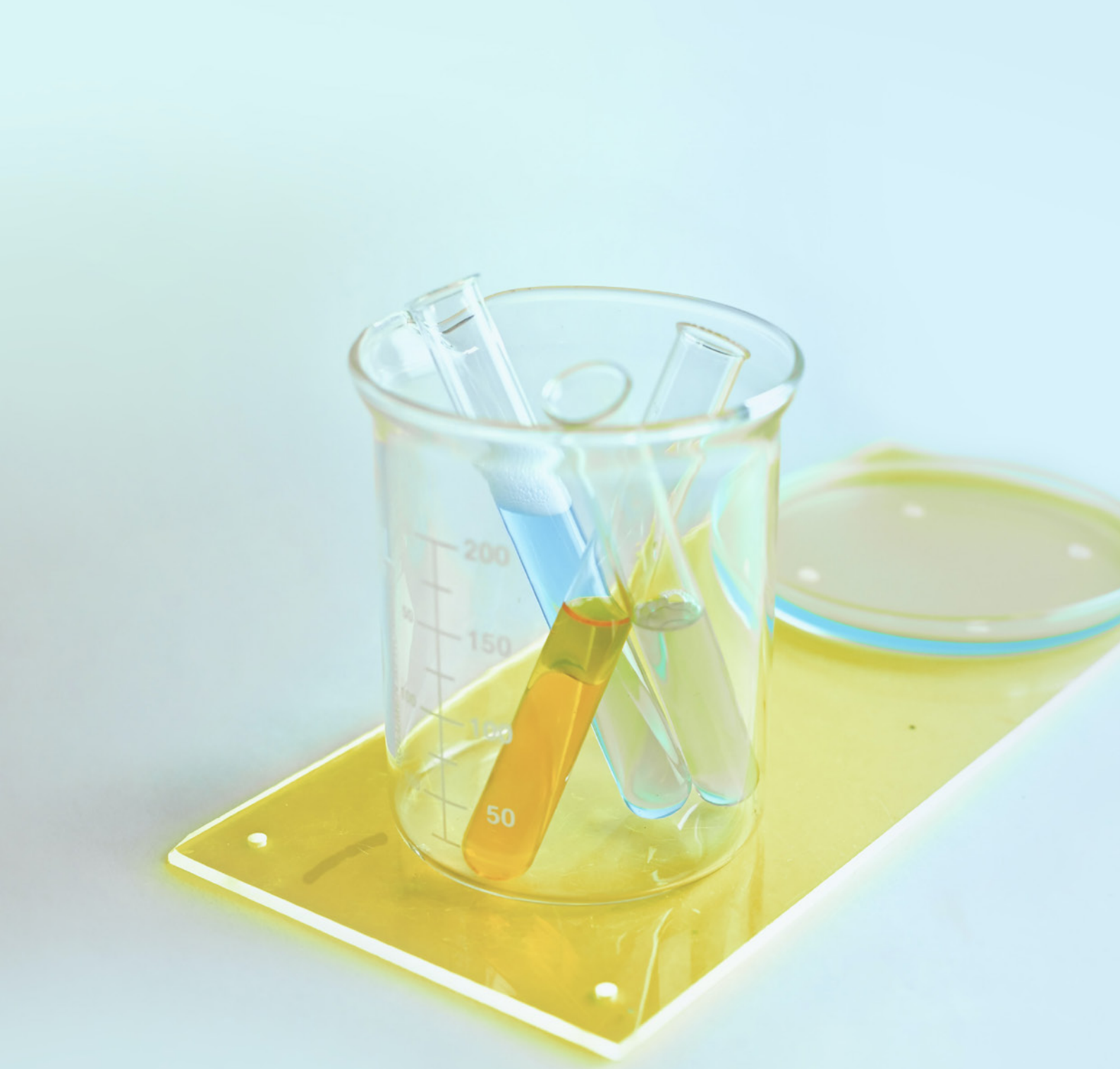

The scientific impact of Danish research 1980-2020

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Year of publication 2023

Financial support
Commissioned and funded by
Novo Nordisk Foundation
VILLUM FOUNDATION

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Acknowledgements

The authors would like to thank Kaare Aagaard, Head of Research Programme for Evaluation and Evidence, VIA University College, for valuable comments on the methods and findings presented in the report.

The authors would also like to thank participants from a series of workshops held from October 2022 to January 2023 for useful comments and reflections on the findings presented in this report.

These participants include representatives from the management of the eight Danish universities, the Royal Danish Academy of Sciences and Letters, the Danish Council for Research and Innovation Policy, public and private research funding foundations in Denmark, the Danish Ministry of Higher Education and Science, and the Danish Agency for Higher Education and Science.

1. Introduction and main findings

1.1 Background and aims

In 2012, Gunnar Öquist and Mats Benner published a report that sought to explain why the relative impact of Swedish research declined, while the relative impact of research from countries like Denmark, the Netherlands and Switzerland had increased.

Their report gained substantial attention in Denmark because it drew attention to the unusual development in Danish research impact in the period 1990 to 2010. Drawing on findings from a bibliometric study covering 39 countries (Karlsson and Persson 2012), it showed an impressive increase in mean citation impact and in the proportion of highly cited papers over the two decades.

This development was particularly remarkable in light of the marked decrease in relative impact of Danish research in the 1980s. The impact had deteriorated so much that a 1990 report warned against an "impending catastrophe" for the Danish research system (Nørretranders and Haaland 1990). Yet, rather than end in "catastrophe", Danish research entered two decades of growing research impact.

The development in Danish research impact from 1990 to 2010 was so exceptional that Öquist and Benner (2012) referred to it as a "Danish miracle" (p. 39). They argued that research policy initiatives in Denmark – for instance increased research resources, reforms of doctoral educations, the university sector and the research funding system – and a "culture of academic excellence" (p. 36) had contributed to this development.

Not surprisingly, these conclusions were warmly received by the Danish research system and policymakers. Attempts to explain the "Danish miracle" generally echoed Öquist and Benner's (2012) argument that it was the result of a fortuitous combination of many developments in research and research funding rather than of a carefully designed political masterplan to strengthen Danish research (Aagaard and Schneider 2014; DEA 2014, 2017; DFiR 2016).

At the beginning of the 2010s, indications that Danish research impact was stagnating (Aagaard and Schneider 2014) gave rise to concerns about the long-term health of the Danish research system (DEA 2014; DFiR 2016).

So how has the relative citation impact of Danish research developed in the last decade? The aim of this study is to update and extend the bibliometric analyses presented in Öquist and Benner's report (Karlsson and Persson 2012) to examine the development since 2009 in the relative citation impact for publications affiliated to Denmark.

1.2 Findings

The main findings of the study are:

- There has been a continuous decline since 2010 in the relative citation impact of publications with Danish affiliations.
- There has also been a decline in relative citation impact for countries with which Denmark is often compared, but the Danish decline sets in earlier and appears to be more pronounced. In 2020, the relative citation impact of Danish research is at the same level as it was in the mid-1990s.
- Around 2010, Denmark belonged to a small group of countries with the highest relative citation impact. Today, Denmark belongs to a much larger group of countries with a lower albeit above-average citation impact.
- The decline appears across major scientific fields and universities, with minor variations and a few exceptions. For instance, it appears more pronounced in scientific fields that are typically considered strongholds in Danish research. It is more pronounced among the three largest universities.
- The decline in citation impact is consistent across co-authorship patterns, although it appears greater for publications that only have authors from Danish institutions than for publications with international co-authors.
- A decline is observed whether researchers with a Danish affiliation are listed as corresponding authors on international publications or not. However, international publications with corresponding authors from other countries exhibit much higher citation impact and lower decline than publications with corresponding authors from Denmark.
- The size of the Danish research system has grown significantly over the past decade, and more than in other countries. Full-count publications have increased fivefold, and ractional-count publications more than threefold since 1990. The number of publishing researchers has increased by 60% from 2009-11 to 2018-20.
- The number of fractionalized publications with Danish affiliations among the 10% most cited increased from 3,350 in 2009-11 to 4,598 in 2018-18, a growth rate of 37%. In comparison, the growth rate for publications outside the top 10 percentile is 63%, resulting in a decline in relative citation impact.
- As the database grows, the number of publications in the 90th percentile grows accordingly. In 2009-11, publications with Danish affiliations among the 10% most cited constituted 1.02% of the database total. In 2018-20, the share had dropped to 1%. Conversely, the overall share of publications with Danish affiliations in the database has grown from 0.71% in 2009-11 to 0.77% in 2018-20.
- The drop in average normalized citation score (MNCS) is most significant for Denmark. In the period from 2009-11 to 2018-20, the average citation score decreased for all publication percentiles except the most cited in the top 1%.
- 31% of publishing researchers from Denmark contribute to at least one highly cited paper in both periods (2009-11 and 2018-20).

The results presented in this report are robust. The analyses have been replicated using other parameters for e.g. length of citation windows and counting methods and yield similar results.

It is worth noting that relative citation impact is measured in a complex, dynamic and evolving system. The database used as the basis for the bibliometric analyses reported here has also grown substantially during the period of study.

Our study shows that the overall system, at the country level, appears to be converging: the differences in the relative citation of impact of countries are becoming smaller. This is no doubt a consequence of substantial international research collaboration. Moreover, almost every second paper in the database now has co-authors from the US and/or China, underlining the growth in volume of research from China over the past decade. When the US and China engage internationally, they most frequently collaborate with each other. Their citing patterns are distinct from those of other countries in that around 50% of their citations are national self-citations. Consequently, given their size and idiosyncrasies, US and China to some extent influence the developments in the short-term citing patterns in the database.

However, changes in the database or the overall system only explain part of the decline in the relative research impact of publications with Danish affiliations.

These findings are presented in more detail in this report, and additional tables and figures are available in the appendix.

The study was undertaken by researchers at the Danish Centre for Studies in Research and Research Policy (CFA) at the Department of Political Science at Aarhus University. The study was commissioned and funded by the Novo Nordisk Foundation and the VILLUM FOUNDATION.

Additional tables and figures are available in the appendix.

1.3 On the use of citation indicators

Citation indicators can be controversial and are often misused or misunderstood. However, when used appropriately, they can provide valuable partial insights about the visibility and impact of research publications, especially at aggregate levels such as countries. Citation patterns indicate social dynamics in scientific discourses and are useful as indicators of contributions to knowledge production at the research front.

Citations are often invoked as an indicator of "research quality", which is problematic. The concept of research quality is complex and multidimensional, and citations cannot encapsulate it *per se*.

Citations indicate the use, visibility or influence of research and offer a window on the immediate or long-term impact of publications on the scientific discourses that shape the research front.

Publications are cited for many, and not only positive, reasons. For instance, a publication may cite research authors disagree with or wish to critique. Thus, publications can have a huge impact on the scientific discourse even if they are controversial, flawed or faulty. This underlines why they cannot be used as indicators of the quality of research.

Moreover, some publications may be cited more than others; not due to their inherent qualities, but simply because they are more visible to begin with and therefore more likely to be cited. This may be the case for publications with a high number of co-authors, when they have been undertaken as international collaborations, when they are published in highly cited and therefore particularly visible journals, or when they stem from well-known researchers or research environments.

So motivations for citing can be epistemic and normative, "giving credit where credit is due", but also just perfunctory or even rhetorical aiming to persuade readers. Citations thus rest on a mixed bag of motivations.

Citations are "noisy" but still useful as partial, socially derived indicators of how visible research is, how much it is used by the scientific community, and thus how it presumably contributes to ongoing scientific discourses and the development of the scientific frontier. It is important to remember that a vast majority of citations are concentrated on a small set of papers; as such, visibility and credit are highly skewed in science.

Thus, citations offer a window on aspects of the performance of a research unit or research system. In this report, citations are used to compare the relative impact of national research systems to paint a useful if partial picture of the performance of the Danish research system.

Citations are often invoked as an indicator of "research quality", which is problematic. The concept of research quality is complex and multidimensional, and citations cannot encapsulate it *per se*.

1.4 Method and indicators used in the report

This study was designed to replicate and extend Karlsson and Persson's (2012) study referred to in Öquist and Benner's (2012) report. We therefore use the same approach and main indicators as Karlsson and Persson (2012).

Danish research refers to publications where at least one author has indicated an affiliation with a Danish research institution. Comparing national research systems is to some extent an artificial exercise, given the high level of international collaboration within academia. For instance, 72% of Danish publications in 2020 were co-authored with at least one researcher with a non-Danish affiliation.

Relative citation impact. We produce relative citation impact scores, which means that we weight a country's credit of contribution as a fraction of the whole 1/n. We fractionalize at the country level. Fractional counting indicates *contribution*, and full counting indicates *participation*. When we use full counting, international papers are counted multiple times. This distorts citation indicators, as they no longer sum to unit, and their intuitive thresholds of an average citation score of 1 as the database average or the top 10% as exactly publications on or above the 90th percentile of the citation distribution do not hold. Nevertheless, full and fractional counting represent complementary perspectives and are useful to compare.

Two impact indicators are used in the report:

- *Mean normalized citation score (MNCS)*: the average normalized citation score of (e.g. Danish) publications relative to the average citation score of publications in the same field published in the same year in the database used. Scores above 1 indicate an above-average impact and, accordingly, scores below 1 reflect below-average impact.
- *Top 10%:* the share of (e.g. Danish) publications among the 10% most cited publications. The citation distribution used to identify the 90th percentile is based on publications' Normalized Citation Scores. Each publication's citation score is compared to the average within their field for papers published in the same year.

Both indicators are normalized to, in principle, make it possible to compare impact across fields with different publications, citing patterns and time. The indicators were selected, first, because they are the two most widely accepted and commonly used bibliometric indicators of relative citation impact, and second, to reproduce the Swedish study by Karlsson and Persson (2012).

We present a selection of the findings in this report; additional results can be accessed from the appendix to this report, which is available at: https://cfa-research.au.dk/publications/2023/3/1

We use the Web of Science (WoS) database in its value-added adaption at CWTS, Leiden University. We use similar techniques, indicators and algorithms as used in the Leiden Ranking. We use primary parameters identical to those in Karlsson and Persson (2012). Essentially this means fractional counting, three-year citation windows, field-normalized citation scores, where field-normalization is based on WoS journal subject categories. We include all three citation databases: Science Citation Index, Social Science Citation Index and Arts & Humanities Citation Index. We do not include books, book chapters or conference papers. Consequently, Danish research is represented here as journal publications, i.e. research articles, review articles and letters, indexed in WoS from 1980 to 2020. The premise for the analyses is thus journal publications, but this is not necessarily the main publication activity in all fields included. Notably fields from the social sciences, arts and humanities and engineering have lower coverage in WoS of their publication activities. This limits the comparison of citations indicators across fields.

In our classification, publications that do not belong to one of the eight universities are categorized as "other". We take Danish university mergers and hospitals into account.

1.5 Reflections

Studies of citations provide an imperfect and partial but nonetheless useful window on trends in the relative impact of nations' research, the visibility of their research production and thus the relative performance of their research systems.

The present study indicates that citations of Danish research have decreased, relatively speaking, over the past ten years. The findings are based on an analysis of publications that are at least three years old at the time of study, meaning that the research they disseminate was undertaken even earlier. As such, the findings offer a rear-view perspective on Danish research. In fact, assessing impact of research will always be a historical exercise, as it takes time to evaluate the short-term impact and even more time to evaluate the long-term impact of research[1].

As mentioned in the presentation of the study's findings above, some of the decrease in the relative impact of Danish research can be explained by developments in the global research system and in the database from which our data is drawn. For example, the tendency that nations' relative research impact converges to the mean and the growth in research from China (in volume and impact). However, these developments cannot explain the full decline.

The Danish research system has changed significantly over the past decade. As the results underline, it has expanded in size due to the increasing number of PhD students and postdocs trained at Danish research institutions and a substantial increase in external funding. As such, the nature and aims of the research system are continuously evolving, which may affect how we assess its relative impact.

At the very least, it no longer makes sense to speak of a "Danish miracle". From being in an exclusive group of the most cited research nations in the world, Denmark is today positioned in a larger group of countries with seemingly converging impact levels. Denmark's impact level is still at the higher end of this group, but it is declining, whereas several other countries' levels have increased.

It is also worth noting that – of the countries examined in our study – Denmark has seen the least renewal in the group of researchers that produce highly cited articles from the period 2009-11 to 2018-20. Put differently, the people who were central in driving research impact ten years ago are more likely to drive impact today as well for Denmark than for other countries.

The decline in the relative impact of Danish research that we document is certainly not cause for great *alarm*, but it may be cause for *concern* – a signal of subtle changes in the conditions for knowledge production and the long-term impact of Danish research.

The developments in citation impact may be surprising. As mentioned, the relative impact of Danish research is now at the same level as in the early 1990s. Yet we know from prior studies that small nations can show significantly better or worse citation impact than large nations whose performance is more directly tied to overall international developments in citation impact. Given the exceptional relative citation impact of Danish research in 2010, and given that we in the 2010s began to see the effects of substantial additional investments in Danish research starting in the 2000s, driven by the Globalization Fund (2007-2012) and by the marked increase in private philanthropic research funding, expectations to Danish research performance in 2020 were high.

Meanwhile, other countries are doing better. The UK, Sweden and Norway have seen smaller declines in their relative research impact than Denmark, and Ireland, Australia, Belgium, Greece and Slovenia have managed to increase their relative impact during the period where we and other countries have seen a decline.

The aim of this report is not to speculate on possible explanations of the change in relative Danish research impact but merely to take stock a decade after Öquist and Benner's (2012) report. We hope that our report will contribute to an informed debate on the current state and future prospects of Danish research – and spur further work to better understand the performance of research from Denmark as well as the factors that shape this performance.

[1] The recent case of the Nobel Prize in Chemistry shared by Morten Meldal is a good example. The main paper came out in 2002, research leading to the findings presumably happened in the years before, and the prize was given 20 years later.

2. The development in relative citation impact

Figure 1 shows the development in both mean normalized citation scores (MNCS) and share of top 10% highly cited publications for Danish research papers in WoS from 1980 until 2020.

The graph shows a well-known pattern where Danish citation impact declines substantially in the 1980s, increases continuously through the 1990s and into the 2000s, culminating around 2010. The period of increasing impact, 1990 to 2010, was the focus of Öquist and Benner (2012).

After 2010, the relative impact of Danish publications initially stagnated before dropping considerably to the level of the early 1990s.

To illustrate the decline further, the proportion of top 10% highly cited publications peaked in 2009-10 at 13.8% or 1002 of the Danish fractionalized publications. In 2020, 11.4% or 1,493 fractionalized publications were among the 10% most cited. The absolute number is considerably higher in 2020: 491 more fractionalized publications in the top 10% group, or an increase of 67% compared to 2009.

In the meantime, the overall output of Danish fractionalized publications rose by 81% from 7,239 to 13,078. In other words, the growth in top 10% publications was relatively smaller than the overall growth of Danish publications. For the top 10% index in 2020 to correspond to 2009, Denmark would need another 317 fractionalized publications among the 10% most highly cited in 2020[2].

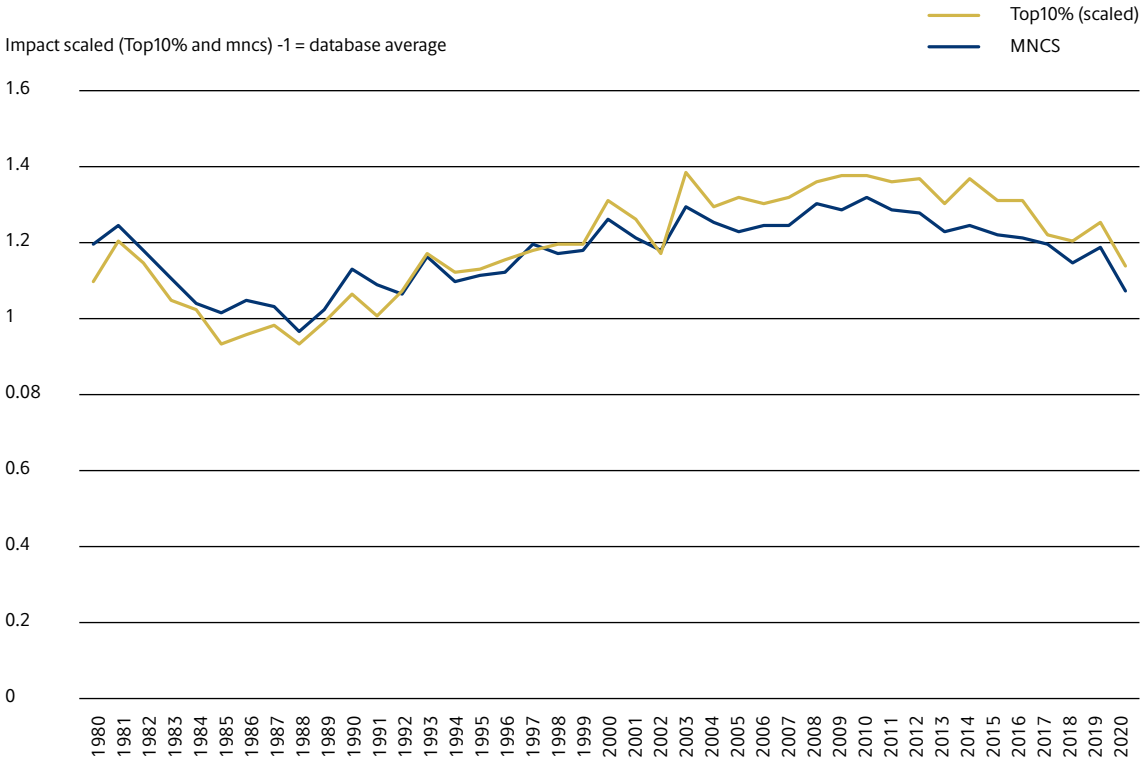
Please note that due to the relative growth in the database in the same period, the number of top 10% publications (the 90th to 99th percentiles of the citation distribution) increases. However the MNCS among top 10% publications drops, indicating that the increase in publications is primarily among relatively less cited publications around the 90th percentile.

[2] The difference between the two top 10% indices (2020 vs. 2009) is equal to a p-value = 5.177e-07and a Cohen's h effect size of 0.07.

Figure 1

The development in relative citation impact: Denmark

Two indicators are used: mean normalized citation scores (MNCS) and the share of papers among the 10% most cited in the database (top 10%). The impact of papers published in a given year (horizontal axis) is calculated using a three-year citation window. Both indicators are field normalized, and author contributions are fractionalized and weighted at the country level. Both indices are transformed to the same scale (vertical axis) so that 1 is the database average, 1.2 is 20% above the database average and so forth.



Source: CFA.

Figure 2 compares the development in relative citation impact for Denmark, i.e. the share of top 10% highly cited publications, with that of the Netherlands, Sweden, Switzerland, the UK and the US – five countries that Danish research performance is often benchmarked against.

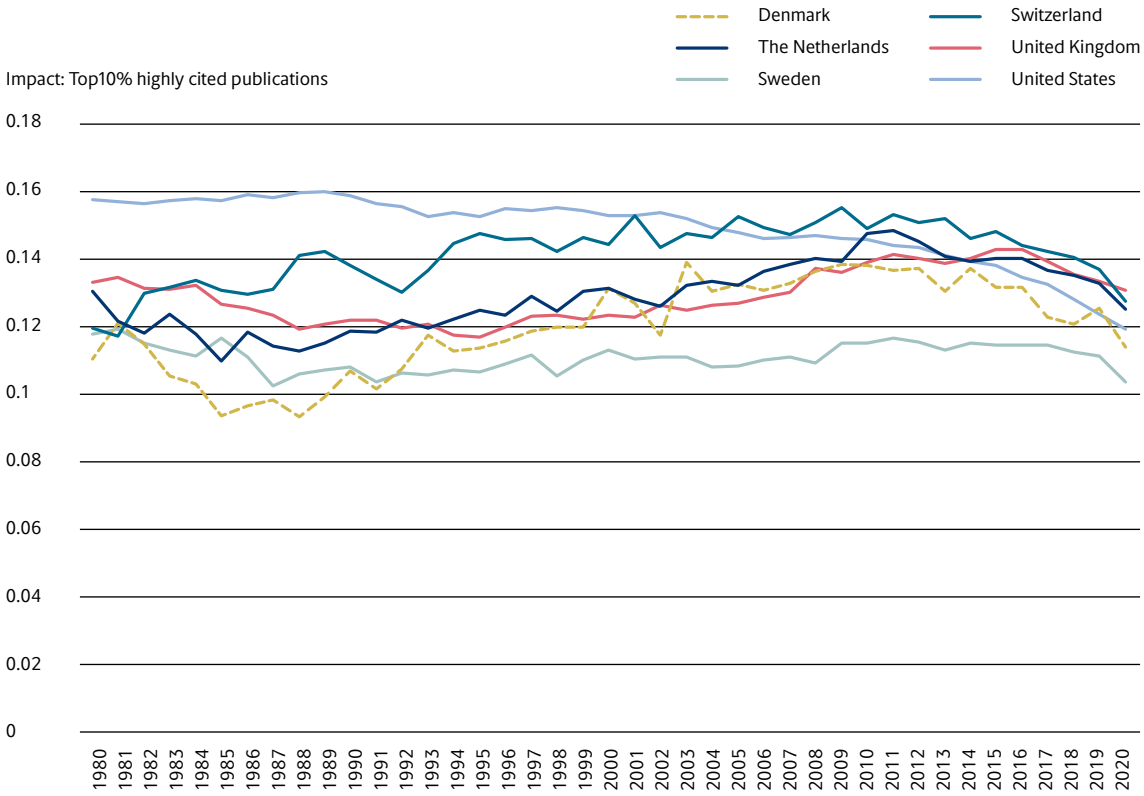
As figure 2 shows, most of the comparable countries also experience a decline in relative impact from 2010 to 2020, with some nuances. The relative citation impact for Sweden has been stable until 2017. The UK has seen a continuous rise until 2016. The US has seen a slow but continuous decline since 1990, albeit with a marked decrease from around 2012. However, the American research system is very large and much more heterogeneous than that of the other countries in the figure.

While most other countries in figure 2 also see declining relative citation impact, the decline is more pronounced for Denmark, especially compared to the Netherlands, Switzerland and the UK. An increasing gap seems to be emerging.

Figure 2

The development in relative citation impact: Selected countries

The indicator is the share of papers among the 10% most cited in the database (top 10%). The impact of papers published in a given year (horizontal axis) is calculated using a three-year citation window. The indicator is field normalized, and author contributions are fractionalized and weighted at the country level.



Source: CFA.

Figure 3 zooms out and shows the development in relative citation impact from 1980 to 2020 for 26 countries in the WoS database. It is apparent that countries' impact scores are converging, particularly during the last decade. Around 2000, the spread of scores was between 2 and 15%, but it narrowed to between 8 and 13% in 2020 with Singapore as a notable exception. Singapore's rise is remarkable, and its relative citation impact (top 10%) is currently close to 18% and the largest in the database.

Corresponding figures for the MNCS indicator show a similar picture as figures 2 and 3 and can be found in figures A1 and A2, respectively, in the appendix.

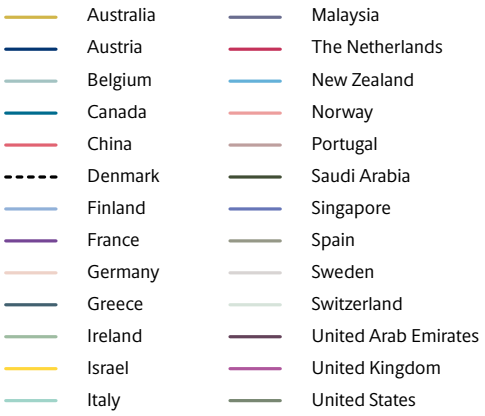
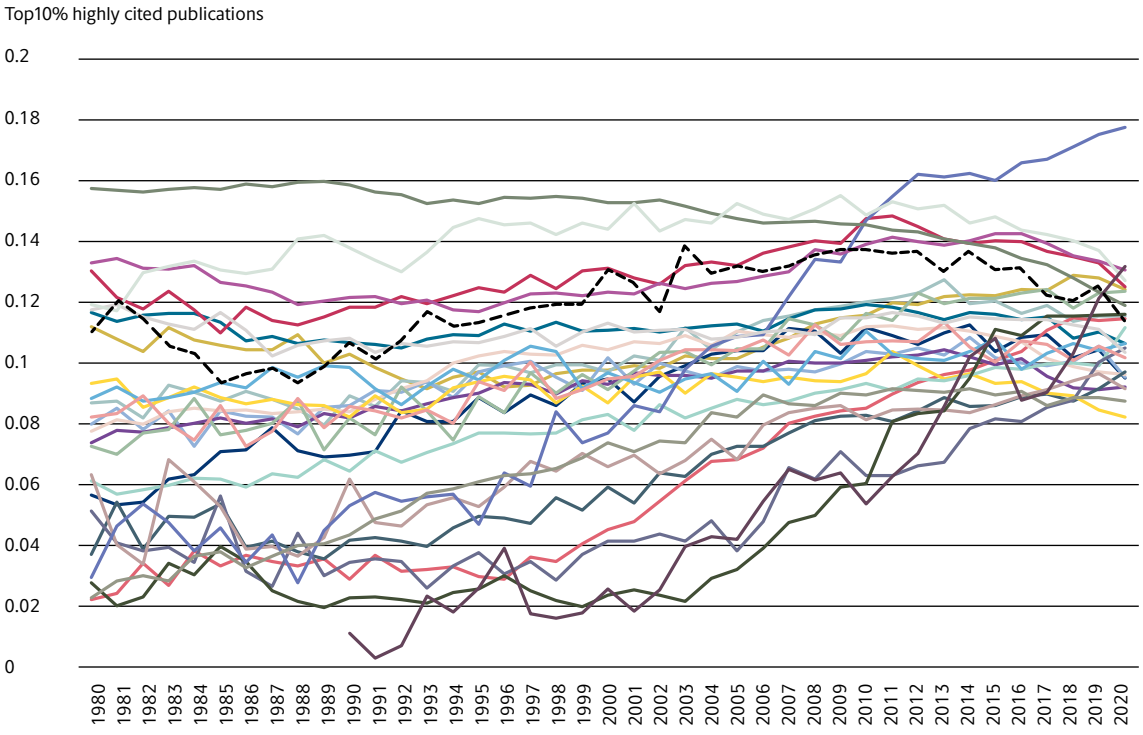


Figure 3

The development in relative citation impact for 26 countries with the highest top 10% in 2018-20 among 51 countries with at least 4,000 fractionalized publications in the period

The indicator is the share of papers among the 10% most cited in the database (top 10%). The impact of papers published in a given year (horizontal axis) is calculated using a three-year citation window. The indicator is field normalized, and author contributions are fractionalized and weighted at the country level.



Source: CFA.

Figure 4 compares the development in the proportionof the 1% most cited publications in the database (top 1%) for Denmark, the Netherlands, Sweden, Switzerland, the UK, China and the US.

In the period of interest in this report, we see a marked drop for Denmark, essentially placing the country in a performance group also comprising Sweden and China, with a considerable gap up to the higher performing group comprising Switzerland, the Netherlands, the UK and the US.

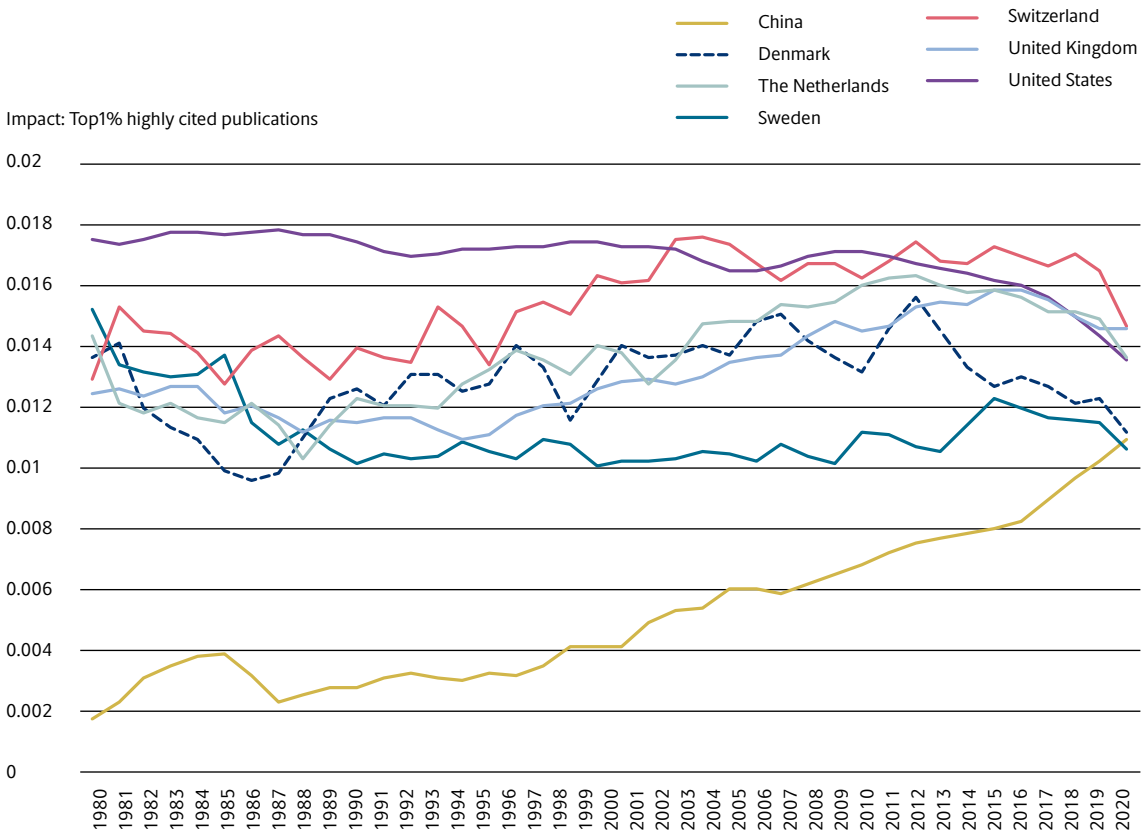
Generally, we see similar trends in relative citation impact for different percentile groups (top 1%, 2%, 5%, 10%, 20% and 50%, see appendix figures A3a-3f).

The general decline in relative impact for Denmark is visible in all percentile groups and consistently sets in around 2009-10. The drop seems more pronounced in the sense that Denmark distances itself from countries such as the Netherlands, Switzerland and the UK.

Figure 4

The development in relative citation impact for the highest cited papers: Selected

The indicator is the share of papers among the 1% most cited in the database (top 1%).The impact of papers published in a given year (horizontal axis) is calculated using a three-year citation window. The indicator is field normalized, and author contributions are fractionalized and weighted at the country level.



Source: CFA.

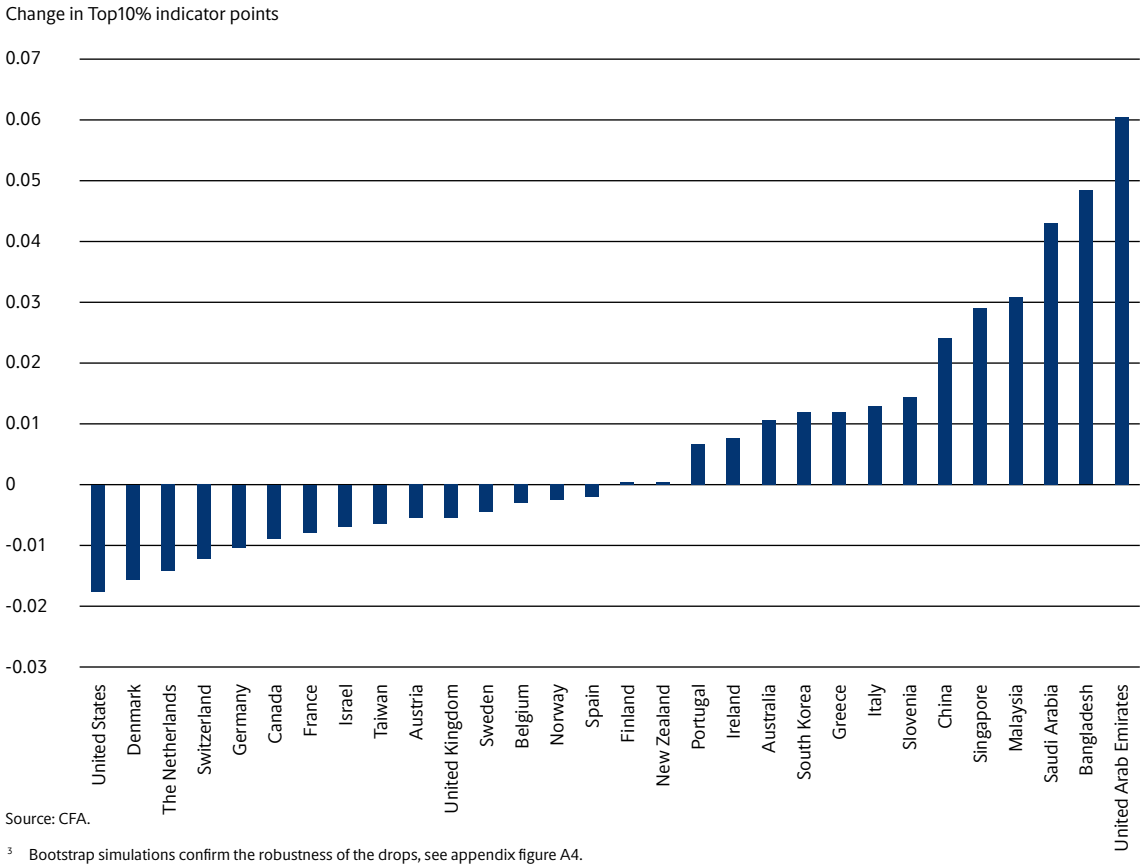
Figure 5 shows the change in indicator points (top 10%) from the period 2009-11 to the period 2018-20 for the 30 highest performing countries in 2018-20 with at least 4,000 fractionalized publications. Countries are ranked from left to right according to the change in top 10% indicator points. Denmark has seen the second largest drop between the two periods, after the US.

Figure 5 thus supports previous findings that many, primarily Western countries, with which Denmark is most often compared, also experience a drop in indicator points between the two periods[3]. Notice that Australia, Portugal, Ireland, Slovenia, South Korea, Greece and Italy see an increase or no change in their relative impact from the first to the second period.

The largest increases are found in China, Singapore, Malaysia, Saudi Arabia, Bangladesh and the United Arab Emirates (UAE). The factors behind these developments are very different. China's development is mainly driven by its massive growth in size, citing and collaborative patterns, whereas the developments for Saudi Arabia and UAE likely are driven mainly by strategic affiliation of or co-authorships with researchers from internationally renowned universities.

Figure 5

Change in top 10% indicator points for 30 countries with highest top 10% indicator in 2018-20 among 51 countries with at least 4,000 fractionalized publications in 2018-20



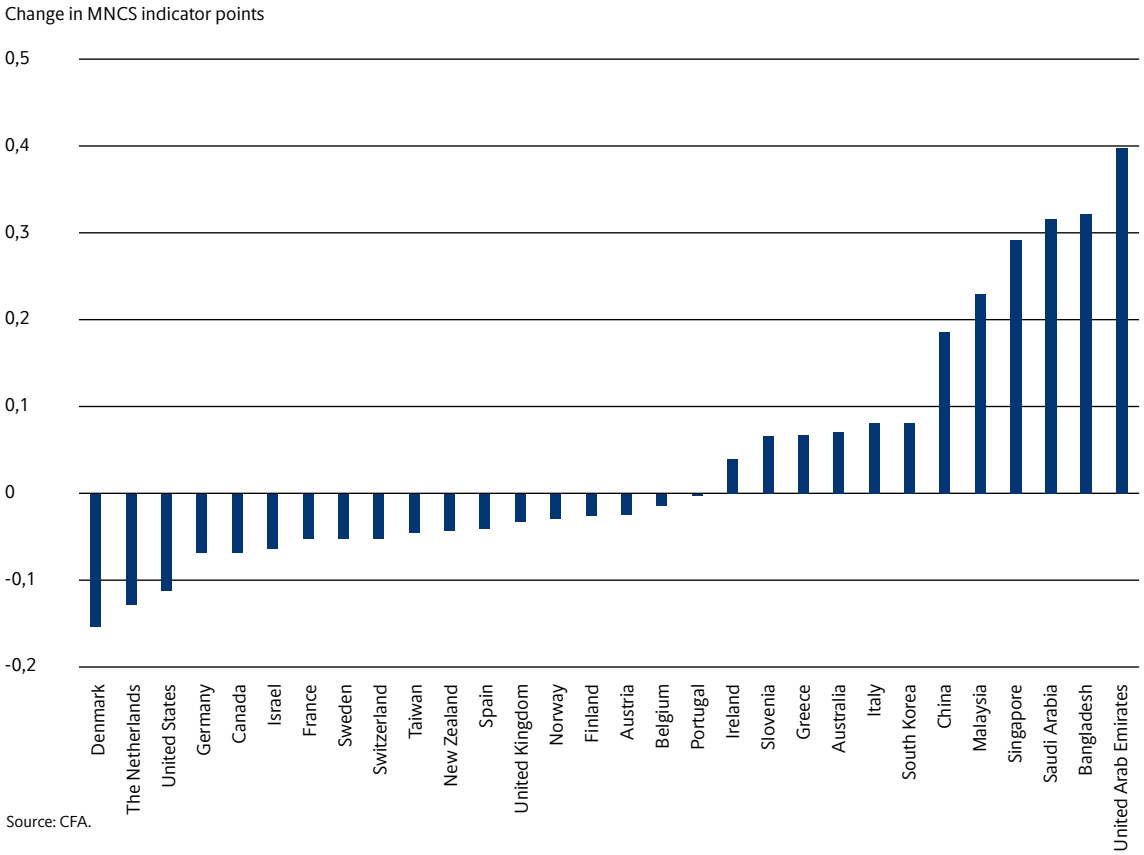
Source: CFA.

[3] Bootstrap simulations confirm the robustness of the drops, see appendix figure A4.

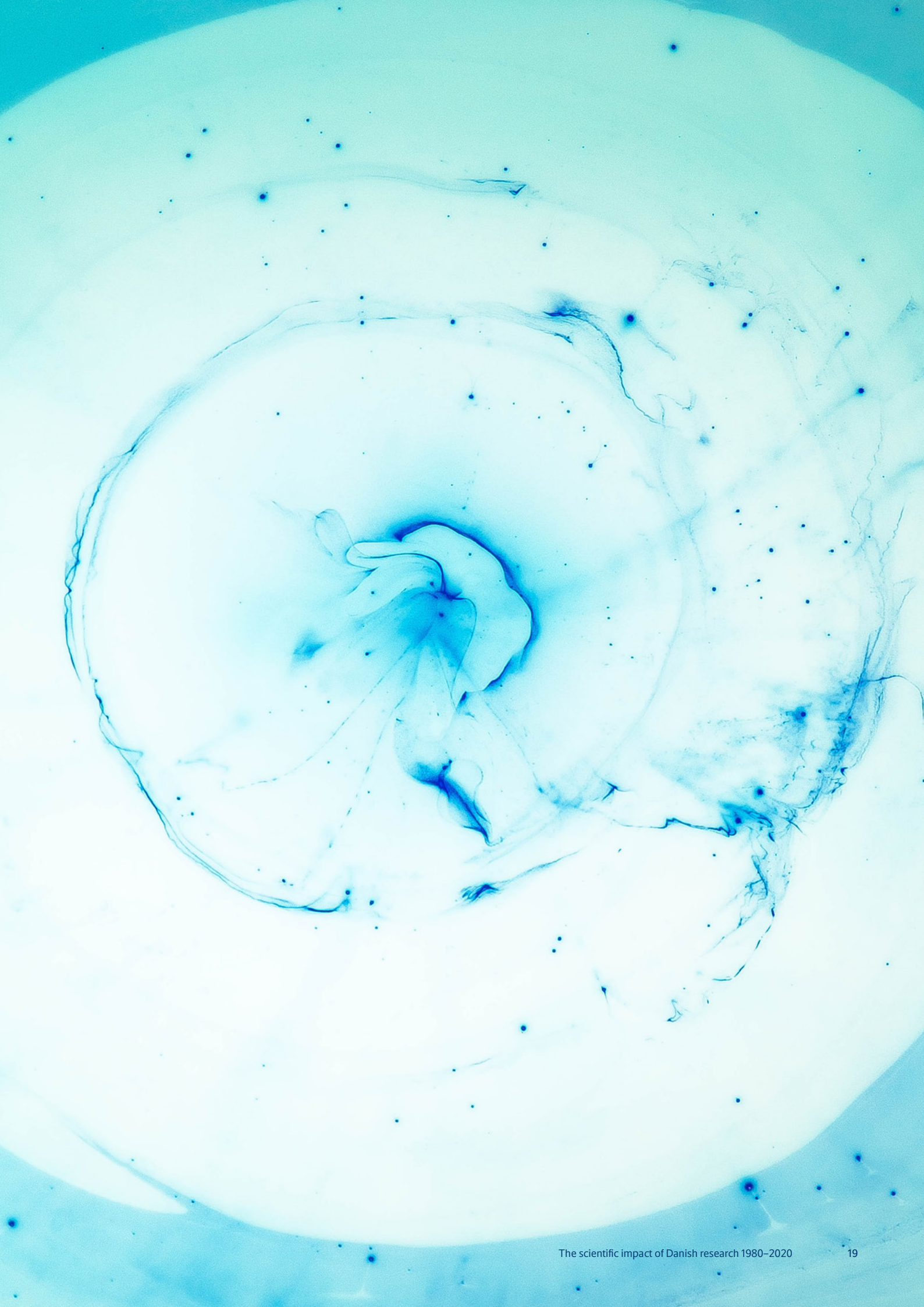
Figure 6 provides a corresponding result for the MNCS indicator; here Denmark sees the largest drop in average citation rate points between the two periods. Figure A5 illustrates the developments in citation impact using full counting; please note that while the numeric values are different, the patterns are the same.

Figure 6

Change in Mean Normalized Citation Scores (MNCS) indicator points for 30 countries with highest top 10% indicator in 2018-20 among 51 countries with at least 4,000 fractionalized publications in 2018-20



Source: CFA.



3. Development in publication output

Developments in citation impact should always be juxtaposed with developments in publication output. It is well known that the scientific literature expands rapidly, and publication databases grow correspondingly. Essentially, relative citation indicators are a fraction of impact and output, i.e. a country's impact is relative to its output.

When we examine the developments in publication growth in WoS from 1990 to 2020, we find that among six countries (Denmark, the Netherlands, Sweden, Switzerland, the UK and the US), Denmark has seen a fivefold – the relatively largest – increase in full-count publications from 1990 to 2020, half of it in the last decade. Switzerland comes in second with a 4.8 increase from 1990 to 2010, and the Netherlands third with a fourfold increase and a 3.5 relative growth rate in the database (see appendix, figure A5).

Full counts at the country level can be seen as reflecting *participation*, i.e. multi-country co-authorships, which clearly increase generally in the database, especially for Denmark (see also section 5.0). Fractionalized counts credit a country's *contribution* to a publication as a fraction of the whole. Consequently, as international co-authorships are weighted, growth rates drop. Nevertheless, of the six countries, Denmark saw slightly more than a threefold – the relatively largest – increase in fractionalized publications from 1990 to 2020, again with a substantial growth in the last decade (see appendix figure A6).

While other countries, such as China, see larger growth rates, also in the last decade, the Danish trajectory is interesting when benchmarked against countries with which Denmark is most often compared.

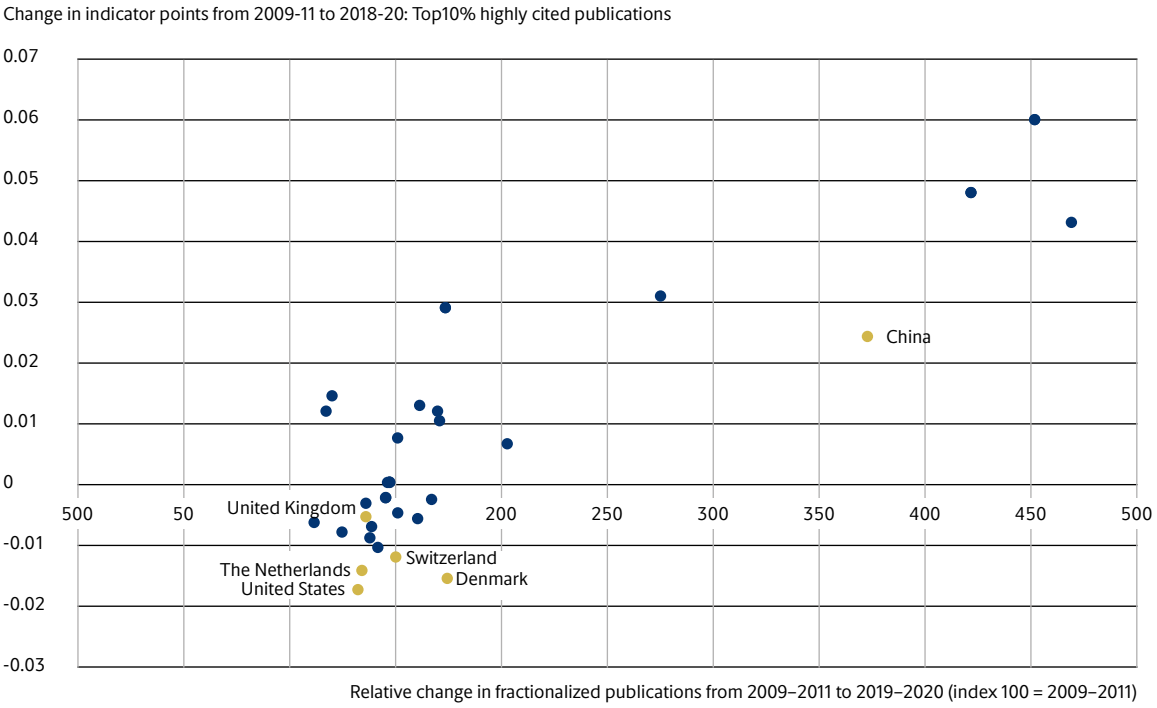
Figure 7 maps the change in indicator points (top 10%) from the period 2009-11 to 2018-20 as a function of relative fractionalized publication growth for the same period.

The plot illustrates that among these countries, Denmark has the largest relative growth in publication output and the second largest drop in indicator points, more than the Netherlands and Switzerland (see appendix for a similar figure A7 showing results based on the MNCS indicator).

Figure 7

Change in top 10% indicator points from 2009-11 to 2018-20 as a function of publication growth for 30 countries

Countries are those with highest top 10% indicator in 2018-20 among 51 countries with at least 4,000 fractionalized publications in the period. The vertical axis shows change in indicator points. The horizontal axis shows the relative growth in fractionalized publication output from 2009-11 to 2018-20. Index 100 = output in 2009-11.



Source: CFA.

4. Development in the research system

Growth in national publication output is largely driven by a general expansion in a country's research system. More resources lead to more researchers, which eventually lead to higher publication output.

Reliable international comparable data on the size of research systems based on the number of researchers does not exist. We have tried to establish a proxy for this size by identifying active authors with more than three publications in the database and linking them to primary affiliations in the two periods 2009-11 and 2018-20.

In figure 8, we use this proxy to compare the size of the research systems in Denmark, the Netherlands, Switzerland, Sweden and the UK, and their relative growth from 2009-11 to 2018-20.

Of the five countries, Denmark has the smallest research system when proxied as unique active authors. In 2009-11, Sweden and Switzerland were almost twice as large, the Netherlands almost three times, and the UK eight times larger than Denmark.

However, as expected given the developments in publication growth described in the previous section, the relative growth in the Danish research system between the two periods is larger compared to the other countries, effectively reducing the size differences between Denmark and the other countries somewhat, most notably the UK, the Netherlands and Sweden.

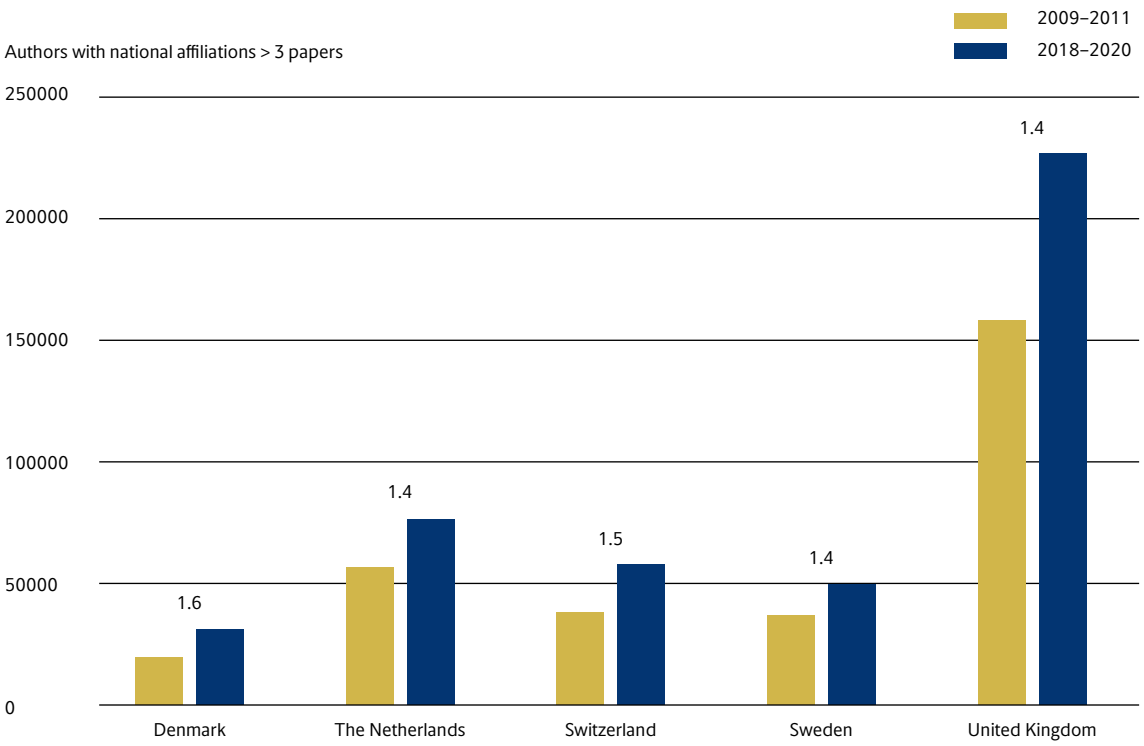
A further contributing and interacting factor of publication growth is the growing number of authors on journal papers. Since 1980, the average number of authors per paper in the WoS database has doubled in all fields and more than doubled in some fields.

Figure A18 in the appendix illustrates this tendency for publications with Danish authors since 2000.

Figure 8

Growth in national research systems from 2009-11 to 2018-20: Selected countries

The number of publishing researchers with a main affiliation to a national institution in each period and who has produced more than three publications in total are used as a proxy for system size.



Source: CFA.

5. Citation impact based on co-authorship forms

Since 1980, the degree of internationalization in authorships has grown substantially for papers in the WoS database, particularly in small countries such as Denmark. As internationally co-authored publications generally have higher citation impact, it is worthwhile to examine developments in internationalization for Denmark and relate this to the general decline in relative citation impact from 2010 to 2020.

Figure 9 shows the growth in volume of Danish publications (the bar graph) and the development in relative citation impact (top 10%, the line graph). Danish publications are divided into three categories: publications with authors from one Danish institution; publications with authors from two or more Danish institutions; and international publications with authors from at least one Danish and at least one international institution. Publication volume is shown in full counts[4] indicating Danish participation, whereas impact is based on fractional counts reflecting credit of contributions.

Patterns are quite clear. Most of the increase in publication volume is in internationally co-authored papers. The increase is continuous from 1990 onwards. In 1990, 18% of publications had at least one international co-author, in 2000, 48%, in 2010, 59% and in 2020, 72%. Put differently, in 2020, seven out of ten publications with a Danish affiliation also have at least one international affiliation. Such publications are therefore also counted in other countries' research portfolios.

[4] Full counts depict the differences between collaboration types more intuitively than fractional counting.

The patterns of and developments in relative citation are also as expected. Publications without international co-authors have lower visibility and therefore lower citation impact. We can see from the line graphs that when Danish impact was rising, so was the impact of the national publications. When the decline in relative citation impact sets in around 2010, the most marked drops are among the national publications.

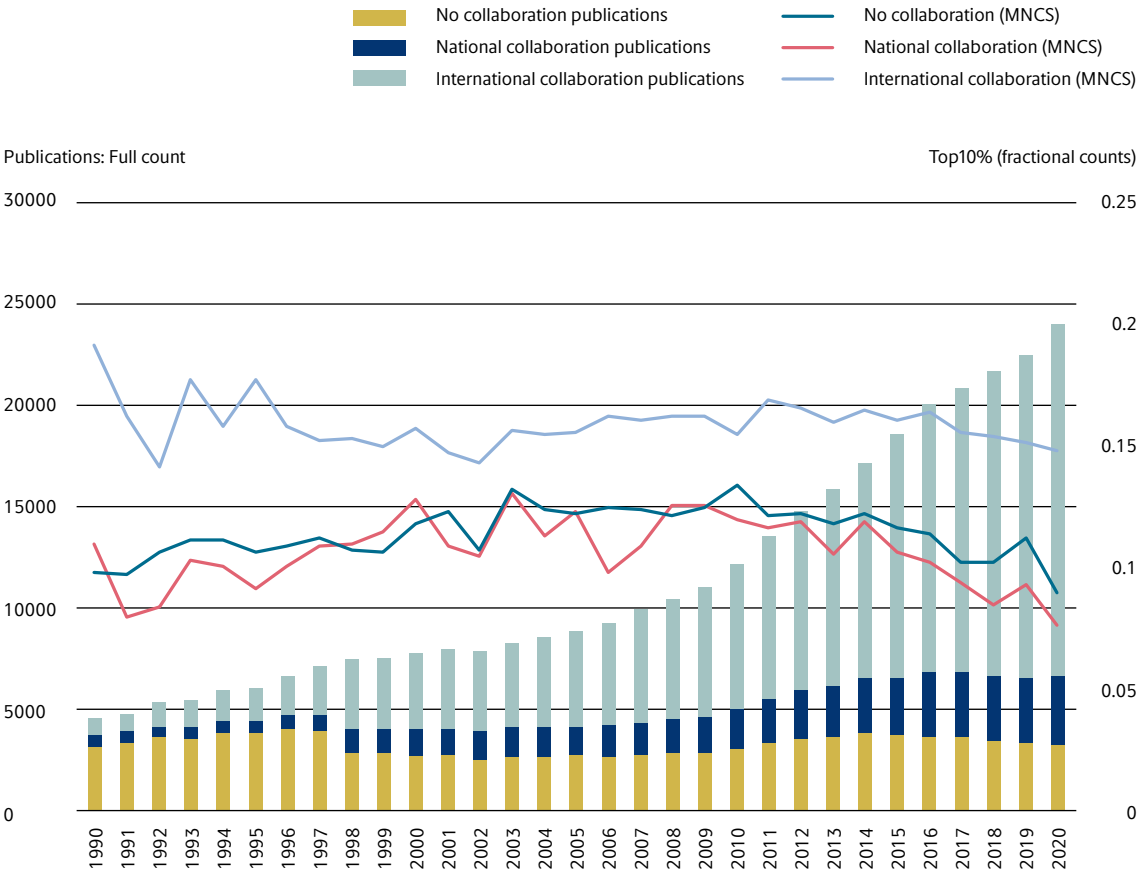
From 2010 to 2020, the two types of national publications dropped from 13.4% and 12% to respectively 9% and 8% of the papers among the top 10% most cited, whereas internationally co-authored papers only dropped from 16.2% to 14.8%. Yet all types of publications have seen a decline in relative citation impact (see appendix A7 for comparisons to the Netherlands, Switzerland, Sweden and the UK).

In an attempt to pinpoint the potential centre of gravity for international collaborative papers, we identify countries listed as corresponding author affiliations on papers and classify them as: 1) internationally co-authored papers, corresponding authors do not have Danish affiliation; 2) internationally co-authored papers, corresponding authors have Danish affiliation; and 3) national papers, corresponding authors necessarily have Danish affiliation.

Obviously, such an analysis is motivated by an assumption that corresponding author addresses can indicate main responsibilities of a paper or perhaps anchoring of projects. This is certainly a "noisy" assumption, but we think it is a reasonable proxy for this aggregate analysis and comparative perspective.

Figure 9

Development of publication volume and citation impact according to collaborative publication types for Danish publications from 1990 to 2020



Source: CFA.

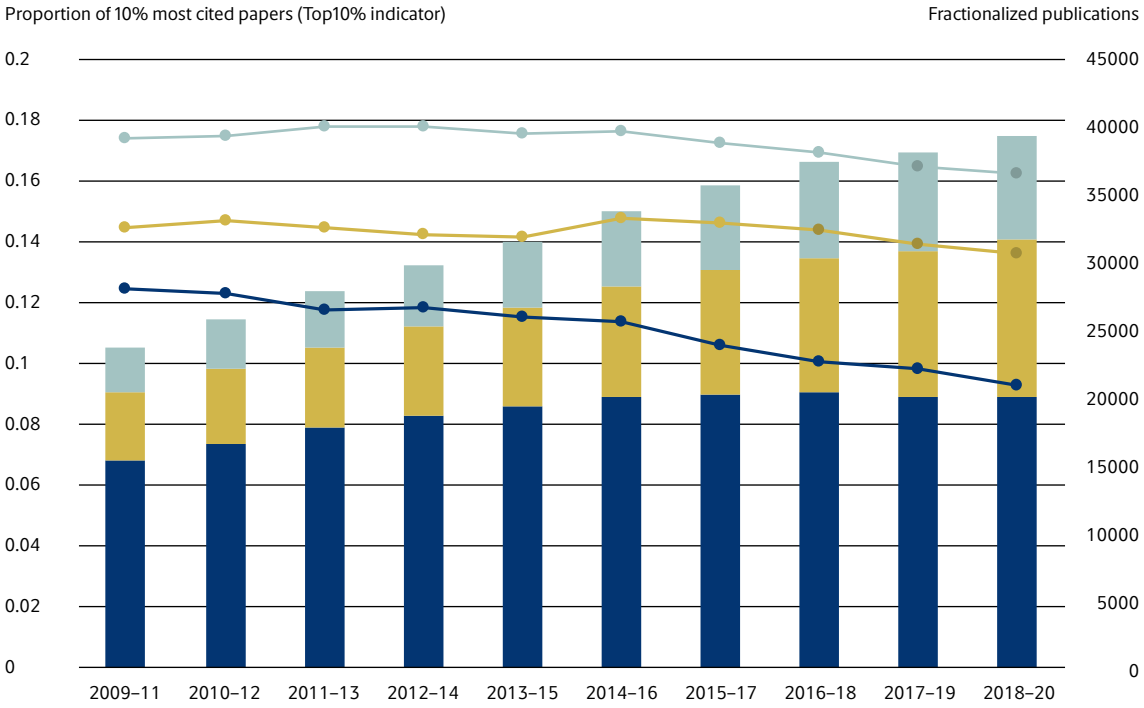
Figure 10 shows the growth in volume of Danish publications (the bar graph) and the development in relative citation impact (top 10%, the line graph) from 2009-11 to 2018-20. Publications are categorized based on whether they are internationally co-authored or national publications, and whether they have international or Danish corresponding addresses. The fact that publication output is fractionalized indicates the weights attached to each publication. For example, a national publication that is among the 10% most cited will have a weight of 1, whereas a top 10% paper with two authors from two different countries will have a weight of 0.5.

It is not surprising that internationally co-authored papers overall have higher relative citation impact than national papers. Nevertheless, it is also clear from Figure 10 that there is a difference between internationally co-authored papers with and without Danish corresponding addresses, as the latter has somewhat lower impact levels compared to the former. All three publication types see a decline in relative impact in this period, but the decline is most marked among national papers, which in 2018-20 still comprise around half of the fractionalized publications.

Figure 10

Development of publication volume and citation impact according to corresponding address publication types for Danish publications from 2009-11 to 2018-2018

Moving publication windows of three years are used to make robust indicators.



Source: CFA.

In Figures 11 below, we compare the developments in relative citation impact for the three publication types for Denmark, the Netherlands, Sweden, Switzerland and the UK.

Figure 11

Developments in top10% indicators for five selected countries according to three corresponding address publication types

A: Internationally co-authored papers with international corresponding addresses;
B: Internationally co-authored papers with national corresponding addresses; and
C: National papers with national corresponding addresses.

Again, we see international developments similar to the Danish case, but where the Danish decline basically follows the international decline rate in (A), the picture is somewhat different in (B) where internationally co-authored publications with Danish corresponding authors have lower relative citation impact compared to Switzerland, the Netherlands and the UK for the whole period.

In (C), it is quite clear that while national publications were almost on the same performance level as Switzerland, the Netherlands and the UK in 2009-11, they dropped considerably until 2018-20, which clearly sets them apart from the above-mentioned countries.

Consequently, Danish publications with international co-authors and without Danish corresponding addresses have impact levels on par with similar papers from Switzerland, the Netherlands and the UK. However, when internationally co-authored papers have Danish corresponding addresses, the impact is lower than in Switzerland, the Netherlands and the UK, and this pattern becomes even more pronounced when we compare national publications between these countries.

Figure 11A

International publications with international corresponding authors

Indicator: Top10% highly cited papers

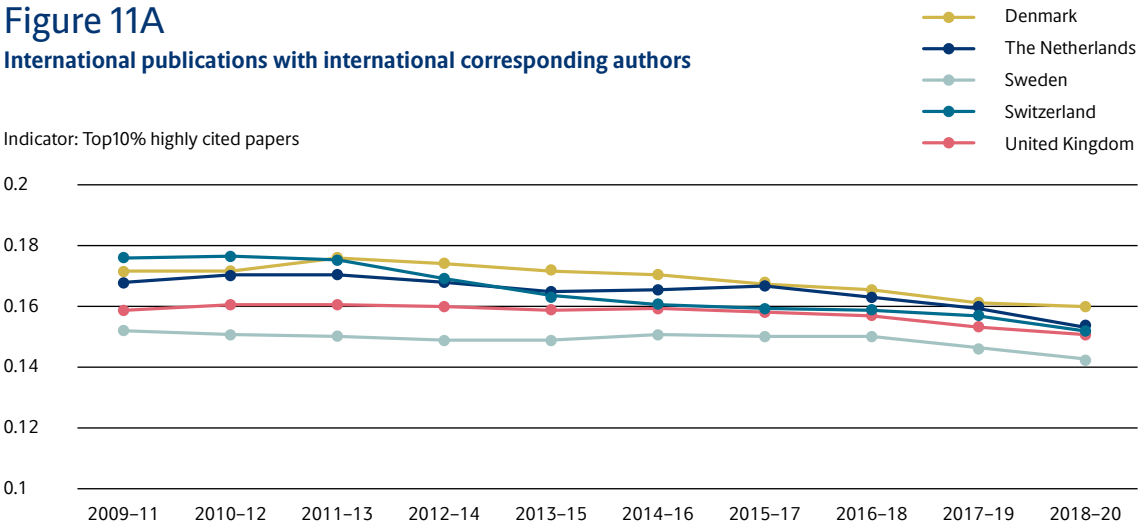


Figure 11B

International publications with national corresponding authors

Indicator: Top10% highly cited papers

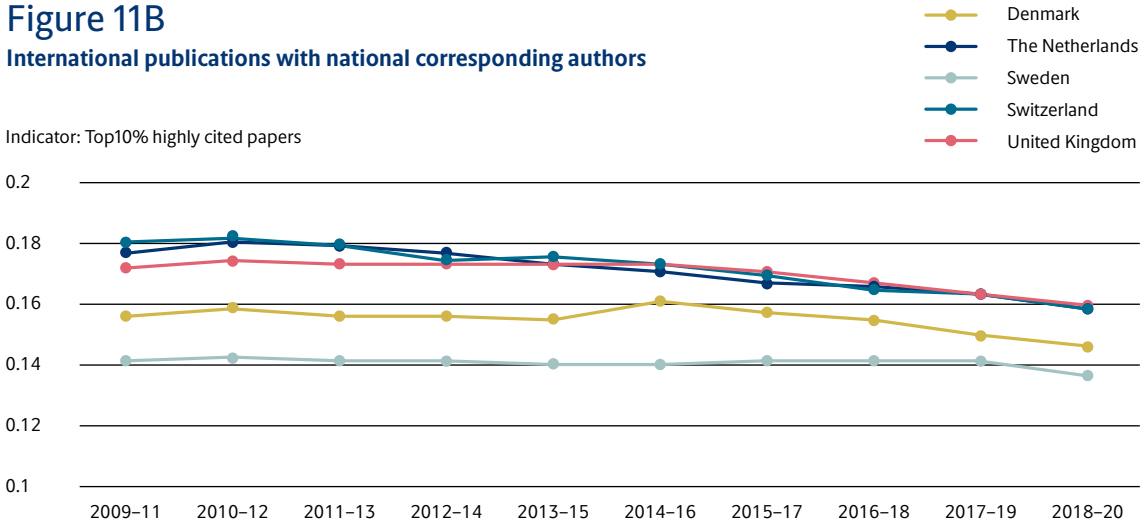
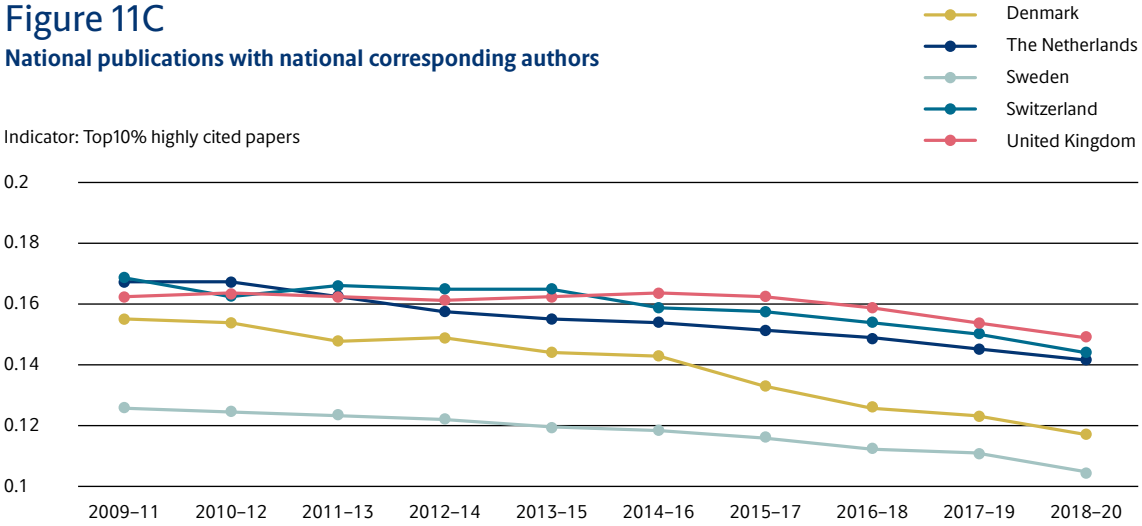


Figure 11C

National publications with national corresponding authors

Indicator: Top10% highly cited papers



Source: CFA.

6. Citation impact according to fields of research

So far, we have documented that Denmark has a relatively large increase in publication output and one of the largest drops in relative impact. The pattern is similar for comparable countries, but the decline sets in earlier and is more pronounced in Denmark. In the previous section, we also demonstrated that while impact levels differ according to forms of co-authorship, the decline in relative impact is discernible across all types of papers, regardless of the form of co-authorship.

In this section, we examine how visible this decline is across major fields of research.

Figure 12 shows the size of 14 major fields based on fractionalized publication outputs indexed in WoS in two periods for Denmark (bar charts). The dots represent the relative citation impact (top 10%) for the field in the two periods indicated by different colours.

At the field level, there is no unique pattern between growth in fractionalized publication volume and decrease in citation impact. Among fields where impact has dropped considerably between the two periods, there are both some with marked growth in publication volume (e.g., clinical medicine) and some with more modest growth (e.g., chemical sciences). Only computer and information sciences sees an increase in relative impact, but it is a small field, and the increase comes from a low starting point.

Clinical medicine is generally the largest field in the database, also for Danish publications.

The growth in fractionalized publications between the two periods is substantial, and so is the 2.6 drop in indicator points. The latter means that in order to maintain the impact level from 2009-11, clinical medicine would need another 219 fractionalized publications among the 10% most cited in 2018-20, roughly 330 full-count publications. Since clinical medicine constitutes around 25% of all publications in both periods, one might wonder to what extent it affected the overall decline. In fact, when clinical medicine is removed from the national indicator calculations in the first period, the overall score drops by 0.2 indicator points. If the same is done for the last period, the national top 10% indicator score goes up by 0.2 points. The latter is meagre in light of a general drop of almost 3 points.

Engineering and technical sciences also see a large increase in fractionalized publications between the two periods, albeit with only a small drop in impact.

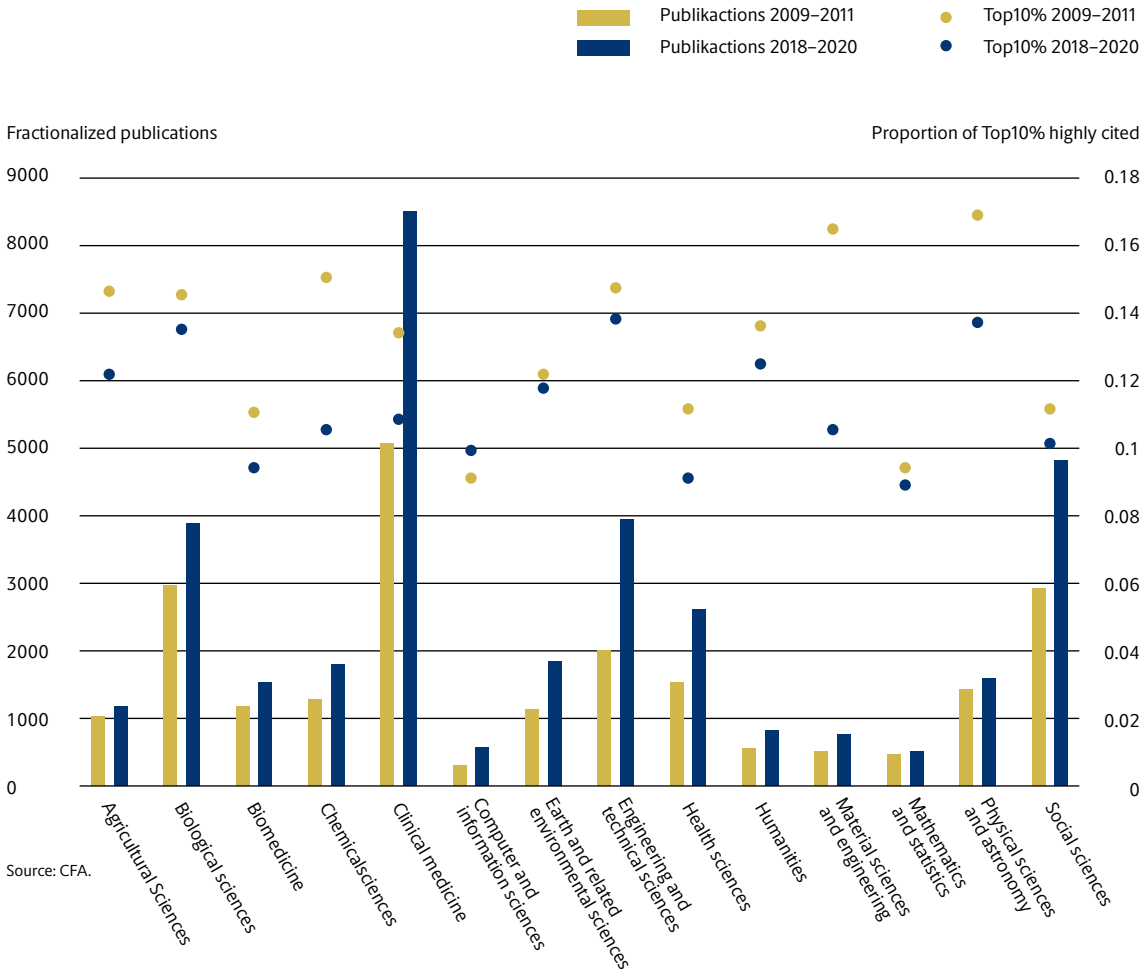
Also domains where Denmark often claims positions of strength such as material sciences, chemistry and physics generally see marked drops in relative citation impact and only minuscule increases in fractionalized publication outputs, the latter no doubt a function of a high degree of international collaboration.

In the appendix figures A8-A15, we present activity indexes for eight countries similar to the ones presented in Öquist and Benner (2012). An activity index relates national publication growth to the growth of a field in the database. In figures A8-A15, changes in activity indexes between the two periods for the 14 fields are mapped to changes in relative citation impact for these fields. Scrutiny of these figures reveals that the relative activity in the database and its potential implications for citation impact are driven largely by the developments in China, especially in the traditional physical and chemical sciences.

Figure 12

Developments in publication output and top 10% citation impact from 2009-11 to 2018-20 across 14 major scholarly fields

Developments in fractionalized publication counts are depicted by the bars and shown on the primary vertical axis; citation impact (top 10%) is depicted by the dots and shown on the secondary axis. The first period is shown in yellow, and the second period is shown in blue. The fields are an adapted version of an NSF classification where journals are linked to major fields.



Source: CFA.

7. Citation impact according to institutions

Figure 13 shows the development in relative citation impact (top 10%) for seven of the eight Danish universities. The IT University is left out due to an unreliably small publication dataset. The category "other" includes publications that are not affiliated to one of the universities[5].

The developments for the three largest universities (KU, DTU and AU) generally follow the pattern of more or less continuous decline in relative citation impact. The same goes for SDU and RUC, whereas the development for CBS fluctuates more with an increase in the latest years but not yet to the level reached in 2013-14.

AAU had the lowest impact level in 2009-10 and is, together with DTU and CBS, the highest performing Danish university in 2019-20. However, the overall performance level is lower for all universities compared to 2009-10.

Figures A16-A17 in the appendix show publication growth in the database for the eight universities. Most notably, AAU has the relatively highest increase in fractionalized publications from 2009-10 to 2019-20. Figure A18 shows the size and relative impact for a number of national universities included in the Leiden Ranking. The figure illustrates the variation among national universities and provides an indication of the degree of homogeneity of national research systems.

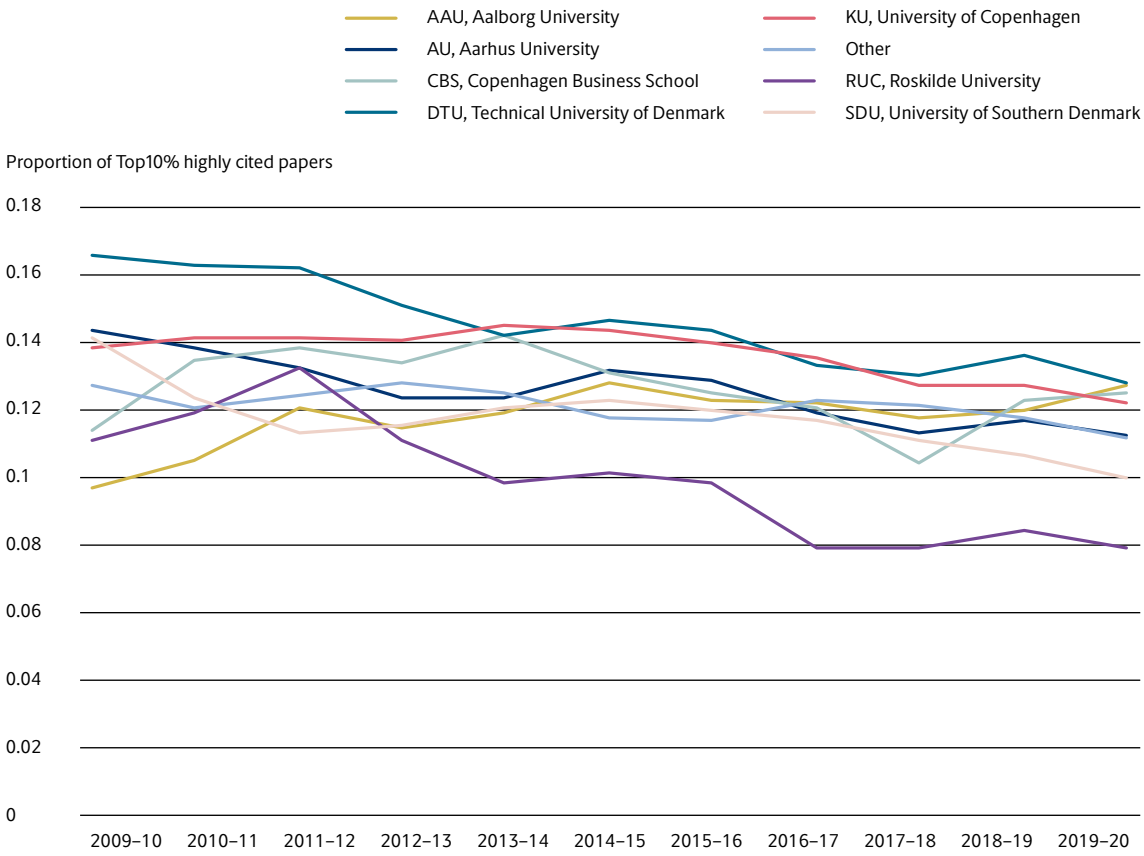
The findings presented in sections 5-7 illustrate that the decline in relative citation impact for Danish research is largely consistent across collaboration forms, research fields and universities. Put differently, we cannot upfront point to one factor that may be driving the decline.

[5] Hospitals with a university affiliation, i.e. university hospitals, are grouped with their generic university.

Figure 13

Development in relative citation impact (top 10%) for seven Danish universities from 2009-10 to 2019-20

Two-year moving publication windows are used to stabilize indicators. ITU is removed due to too few publications. "Other" refers to publications with Danish non-university affiliations. AAU: Aalborg University; AU: Aarhus University; CBS: Copenhagen Business School; DTU: The Technical University of Denmark; KU: University of Copenhagen; RUC: Roskilde University; SDU: University of Southern Denmark.



Source: CFA.

8. Researchers producing highly cited papers

The final analysis examines (1) the cohort of active researchers in selected national systems in two periods to examine how many researchers in the system contribute to producing highly cited papers and (2) the dynamics among these researchers between the two periods.

We are particularly interested in exploring how dynamic replacement at "the top" is. We do this by comparing Denmark to the Netherlands, Switzerland, Sweden and the UK. Researchers are identified in the same manner as in section 4, but the requirement is narrowed to at least one top 10% cited publication in the period in question.

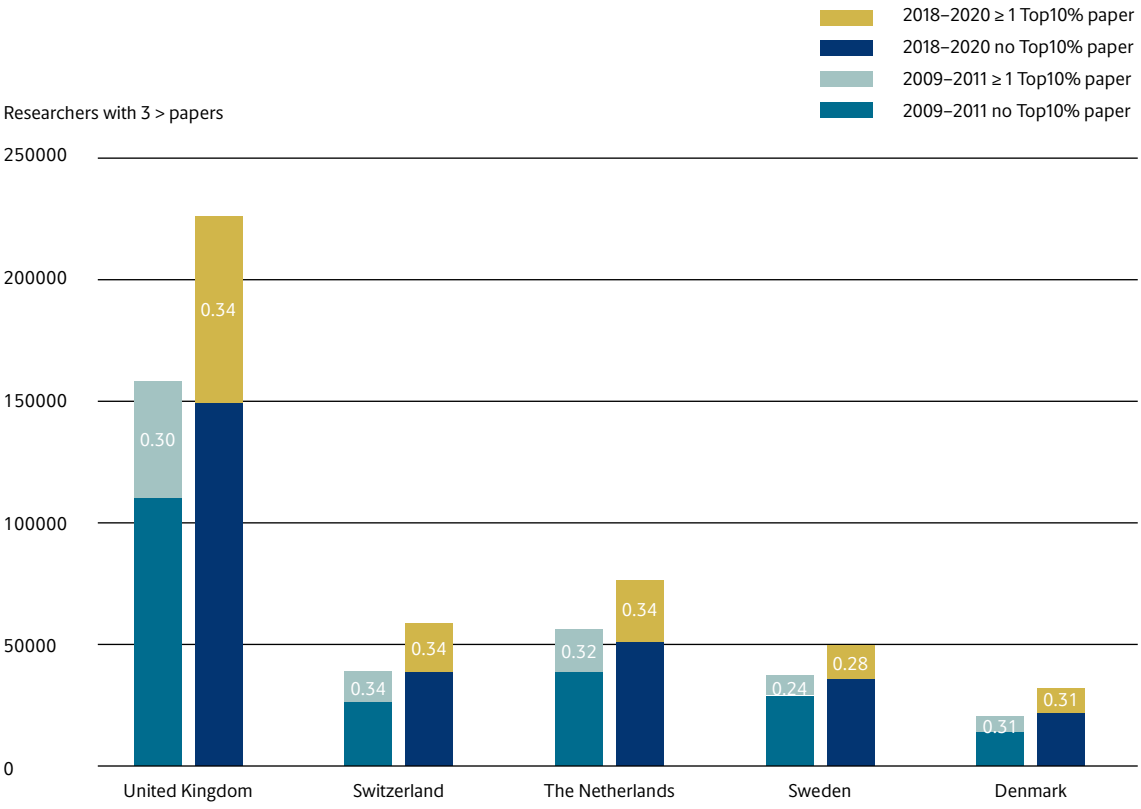
Figure 14 shows the growth in the number of researchers (authors) from 2009-11 to 2018-20. The stacked bars show how many of these researchers produced at least one highly cited paper in the three-year period. The numbers indicate the share of the cohort.

As already shown in section 4, the Danish system grows between the two periods, but the share of researchers producing at least one highly cited publication is 31% in both periods. Switzerland maintains status quo at 34%.

The differences are generally small but robust, and it seems that in the group of countries Denmark is moving away from in terms of impact levels, a slightly higher share of the researcher cohorts produce at least one highly cited paper in the last period. For all these countries, the share is 34% compared to 31% for Denmark.

Figure 14

Growth in number of publishing researchers in five selected countries from 2009-11 to 2018-20 divided between researchers contributing (turquoise and not contributing (yellow) to at least one highly cited paper. The numbers in the upper area of the bars are the share of researchers contributing to at least one highly cited paper



Source: CFA.

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Appendix

Here you can find the appendix:

https://cfa-research.au.dk/publications/2023/3/1