International Comparative Performance of the Scottish Research Base in Chemical Sciences

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Executive summary

International Comparative Performance of the Scottish Research Base in Chemical Sciences

Scottish output in Chemical Sciences has a relatively low volume of 0.6% article share of all Chemical Sciences publications published world-wide, and is showing slightly below world average growth. However, this growth is accelerating: between 2000 and 2005 the Scottish Research Base in Chemical Sciences grew 4.1% annually and in 2006-2011 the growth rate increased to 5.9% annually where Scotland produced 1971 publications in 2011.

In addition, Scottish Chemical Sciences output is of high quality, as can be measured by several indicators. First, we see that Scotland's field weighted citation impact in the Chemical Sciences has risen from 1.34 in the period 2000-2005, to 1.48 in the period 2006-2011. Second, Scotland ranks high with regard to the percentage of Chemical Sciences articles that are among the highest cited articles world-wide, and this has increased after 2005. Third, Scotland's Chemical Sciences research is on average cited more often by patents than most comparator countries.

An important theme throughout this report is collaboration. Scotland shows high and increasing levels of international collaboration in Chemical Sciences, from 40.5% in 2000-2005 to 49.9% in 2006-2011. These internationally co-authored publications are cited 1.47 times as often as Scottish single author papers in the field.

Collaboration between a university and a corporation is of special interest, as it is known that this particular type of collaboration has strong positive effects on citation impact. For Scottish Chemical Sciences research, we see that the levels of this type of cross-sector collaboration are above world average, but decreasing. Also, it is rarely the case that both parties in the collaboration are from Scotland.

When taking the number of researchers into account, as well as GDP and Gross Expenditure R&D (GERD) levels, Scotland ranks very high, indicating productive use of resources.

Key Findings

GROWTH IN OUTPUT

From 4.1% (2000-2005) annual growth to 5.9% in 2006-2011

FIELD WEIGHTED CITATION IMPACT

48% above world average

PATENT CITATIONS

Frequently cited in patents

INTERNATIONAL COLLABORATION

Frequent and high impact

ACADEMIC- CORPORATE COLLABORATION

Decreasing levels and rarely with both parties in Scotland

PRODUCTIVITY

Highly productive when correcting for number of researchers, GDP and GERD

Preface

This report is part of a series of two reports commissioned by Scottish Enterprise to objectively benchmark the Scottish research base in two research areas that Scotland is renowned for; Life Sciences and Chemical Sciences.

Important themes in these reports are international collaboration, academic and corporate collaboration, and attraction of researchers to Scotland.

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Introduction

Chemical Sciences is an area of research that Scotland is renowned for. In 2005, ScotCHEM was launched, a major collaborative venture for the pooling and enhancement of resources for Chemical Sciences research in Scotland.

The objective of the analysis is to provide objective data driven analyses which benchmark the Scottish research base in Chemical Sciences against selected comparator countries. This study focuses on contrasting the Scottish research base before and after the launch of ScotCHEM in 2005 in order to help understand the impact that ScotCHEM has had on the research environment in the Chemical Sciences.

One of the aims of this report is to focus on the relative position of Scottish Chemical Sciences research compared to selected comparator countries, such as the G8 countries (UK, USA, Canada, France, Germany, Italy, Japan and Russia), western European countries (Belgium, Denmark, Finland, the Netherlands, Spain, Sweden, Switzerland and Ireland), Poland, the EU27 as a whole, and Australia, Brazil, China, India, Iran, Israel, Singapore, South Africa, South Korea, Taiwan and New Zealand.

"Chemical Sciences is a central and vital science. It is the basis of many technological developments in a diversity of fields from medicine to the energy industry. Chemical Sciences also underpins many other sciences. There are strong and fruitful interactions at the interfaces with physics, and with the rapidly developing fields of biology and biomedicine. It is therefore vital to Scotland, both in terms of its intellectual vitality and as a player in the global economy, to sustain a strong academic Chemical Sciences sector within its universities. However, the task of remaining competitive, both within the UK and globally, presents increasing challenges. The complex nature of modern research has led to the most successful teams being concentrated in larger, often interdisciplinary, units supported by the necessary sophisticated facilities".

ScotCHEM.ac.uk

Chapter 1
Output, Growth and Impact

This chapter focuses on two aspects of publication output of the Chemical Sciences output from Scotland: its volume and its citation impact. In addition, a third aspect of output is analysed: how often are research articles cited in patents? Finally, the number of downloads of Scottish publications is compared to those of selected comparator countries.

1.1 Key Findings

OUTPUT

1971

Scotland produced 1971publications related to Chemical Sciences in 2011. This is comparable to countries such as Denmark, Finland and Israel.

GROWTH OF OUTPUT

5.9%

Between 2000 and 2005 the Scottish Research Base in Chemical Sciences grew 4.1% annually. Between 2006-2011 the growth rate increased to 5.9% annually.

FIELD WEIGHTED CITATION IMPACT

1.48

Scotland's field weighted citation impact in the Chemical Sciences has risen from 1.34 in the period 2000-2005, to 1.48 in the period 2006-2011. This may be seen to represent an increase in the overall quality of Scottish publications in the Chemical Sciences.

CITED PUBLICATIONS

88.7%

88.7% of Scottish Chemical Sciences papers published between 2006 and 2011 were cited at least once (leaving 11.3% of those articles un-cited). Scotland clearly ranks high with this regard as only 6 comparator countries have a higher percentage of cited papers

HIGHLY CITED PUBLICATIONS

Star Articles

Scotland has produced a relatively high percentage of highly cited publications, and this has increased after 2005.

1.2 Publication output and growth

Publication Output

We start our analysis by taking a close look at publication output and annual growth rates in Chemical Sciences. Looking at the big picture (illustrated in Figure 1a) it is apparent that China only recently has come to produce the highest volume of Chemical Sciences papers, having overtaken the USA. The fact that these two countries produce more than the rest is not surprising consider that they also produce the highest volumes of publications for all subjects overall (where the USA still produces more than China however).

Japan's is the next largest producer of Chemical Sciences papers, but growth seems to have stagnated compared to other countries, and we see that Germany's publication output is very near the level of Japan's.

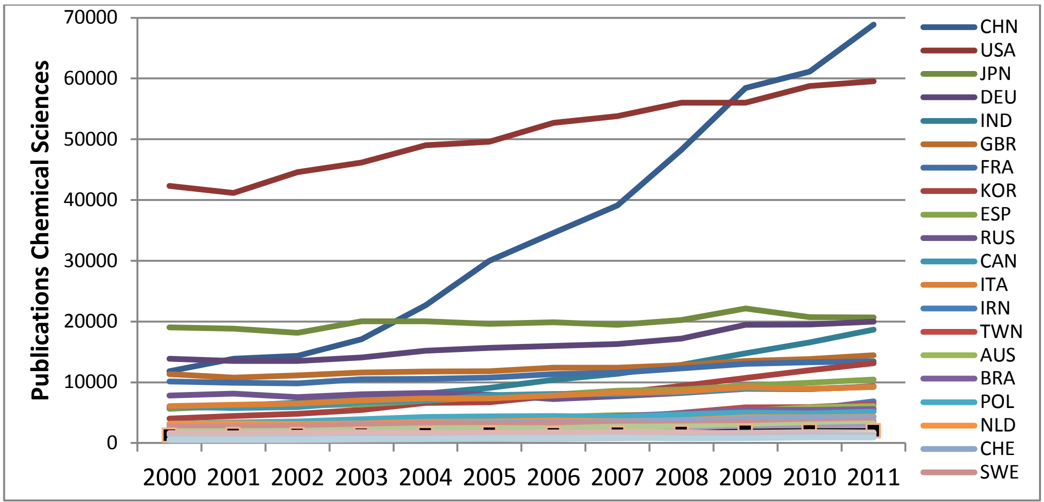


Figure 1a - Publications per year, 2000-2011.

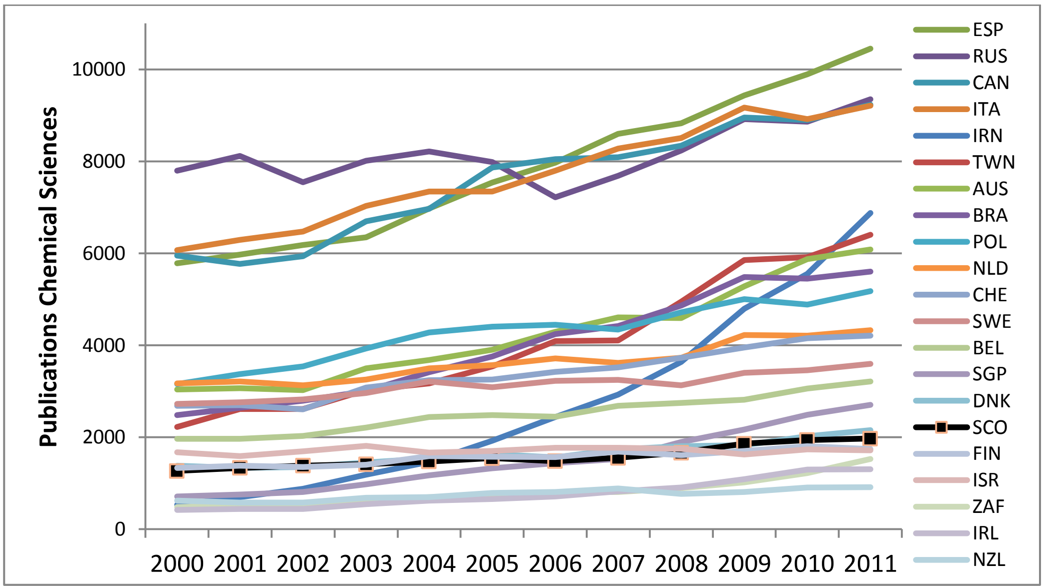


Figure 1b - Zoom of publications per year, 2000-2011.

To allow a closer look at Scotland, Figure 1b zooms in on publication output and thereby excludes the highest volume producing nations. We see that Scotland has produced 1971 Chemical Sciences publications in 2011, and that this is a similar volume to Denmark, Finland and Israel.

Compound Annual Growth Rate

Scotland has grown from producing 1268 publications in Chemical Sciences in 2000 to producing 1971 Chemical Sciences publications in 2011. This represents a compound annual growth rate of 4.1% which is slightly slower than the world growth rate of 4.4% for the same period, but faster than EU27 growth rate.

Looking closer we see that the compound annual growth rate of Scotland's Chemical Sciences has increased from 4.1% for the period 2000-2005 to 5.9% for the period 2006-2011, which represents faster growth than the world, E27, G8 and UK for the same period. It is also faster than most countries including Germany, Switzerland, Italy, France, the UK and United States.

Chemical Sciences | Publications and Growth

	2000	2005	2006	2011	CAGR 2000-2011	CAGR 2000-2005	CAGR 2006-2011
IRN	532	1923	2443	6875	26.2%	29.3%	23.0%
CHN	11816	30017	34561	68895	17.4%	20.5%	14.8%
ZAF	480	674	803	1524	11.1%	7.0%	13.7%
SGP	710	1327	1438	2704	12.9%	13.3%	13.5%
IRL	416	657	711	1307	11.0%	9.6%	12.9%
IND	5661	9103	10397	18689	11.5%	10.0%	12.4%
KOR	4013	6709	7769	13141	11.4%	10.8%	11.1%
TWN	2227	3544	4092	6401	10.1%	9.7%	9.4%
AUS	3041	3904	4291	6087	6.5%	5.1%	7.2%
DNK	1383	1629	1563	2154	4.1%	3.3%	6.6%
SCO	1268	1547	1481	1971	4.1%	4.1%	5.9%
BRA	2483	3754	4246	5605	7.7%	8.6%	5.7%
BEL	1969	2480	2450	3214	4.6%	4.7%	5.6%
ESP	5785	7537	7975	10452	5.5%	5.4%	5.6%
RUS	7797	7983	7220	9354	1.7%	0.5%	5.3%
DEU	13899	15678	15986	19980	3.4%	2.4%	4.6%
CHE	2683	3258	3425	4211	4.2%	4.0%	4.2%
FRA	10108	10790	11354	13441	2.6%	1.3%	3.4%
ITA	6070	7344	7800	9213	3.9%	3.9%	3.4%
POL	3158	4406	4449	5179	4.6%	6.9%	3.1%
NLD	3171	3569	3716	4325	2.9%	2.4%	3.1%
GBR	11340	11832	12409	14426	2.2%	0.9%	3.1%
CAN	5952	7869	8052	9235	4.1%	5.7%	2.8%
NZL	622	789	807	915	3.6%	4.9%	2.5%
USA	42320	49616	52683	59552	3.2%	3.2%	2.5%
SWE	2723	3091	3226	3594	2.6%	2.6%	2.2%
FIN	1329	1578	1568	1745	2.5%	3.5%	2.2%
JPN	19023	19601	19896	20659	0.8%	0.6%	0.8%
ISR	1673	1703	1772	1713	0.2%	0.4%	-0.7%
WLD	189864	218577	232796	306119	4.4%	2.9%	5.6%
G8	107204	118108	122502	140478	2.5%	2.0%	2.8%
E27	61285	69381	72630	87950	3.3%	2.5%	3.9%

Table 1 - Publication counts 2000, 2005, 2006, 2011 and Compound Annual Growth Rate 2000-2011, 2000-2005, 2006-2011

1.3 Citation Analysis

Field Weighted Citation Impact

In addition to publication volume, it is important to include a measure of impact. Citations are widely recognised as a possible proxy for quality[1]. For this study, we used Field Weighted Citation Impact (FWCI) as the measure of citation impact. This is a measure of citation impact that normalises for differences in citation activity by subject field, article type, and publication year. The world is indexed to a value of 1.00, meaning that values above 1.00 indicate above average citation impact. More specifically, a citation impact of 1.80 indicates a citation impact which is 1.8 times the average, or 80% above the average.

Looking at the overall field weighted citation impact of the papers published in the periods 2000-2005 and 2006-2011 we see clearly that Scotland's citation impact in Chemical Sciences has increased from 1.35 to 1.48. Singapore stands out in that their citation impact has risen significantly and is the highest of the comparator countries at 1.9 for the period 2006-2011. Scotland's citation impact in that period is comparable to Sweden, USA, Belgium and Canada. The UK's citation impact rose from 1.40 to 1.49. The Russian Federation has by far the lowest citation impact at just 0.42 for 2006-2011.

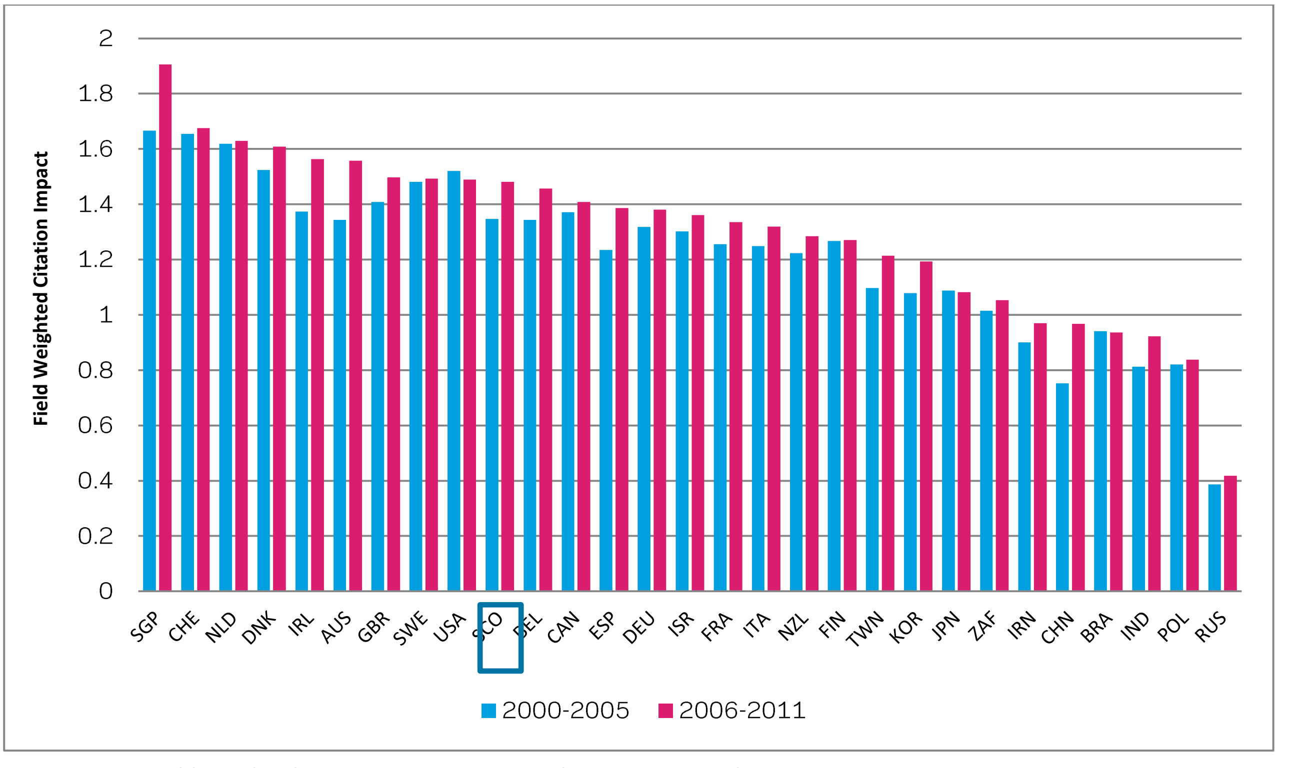


Figure 2 - Field Weighted Citation Impact per period 2000-2005 and 2006-2011

Taking into consideration both publication output and field weighted citation impact (see Figure 3) we see that the United States stands out as having the highest output as well as the highest citation. The red line in Figure 3 represents the world average field weighted citation impact for all publications. Scotland is among the countries to have a relatively low volume of publication output with relatively high citation impact.

[1] Davis, P. (2009) Reward or persuasion? The battle to define the meaning of a citation. Learned Publishing 22(1) pp. 5-11.

Countries with a comparable profile to Scotland in terms of volume and citation impact in Chemical Sciences publications are Switzerland, Ireland, Denmark Belgium and Sweden. The UK produces a higher volume of Chemical Sciences publications than Scotland, but with comparable citation impact.

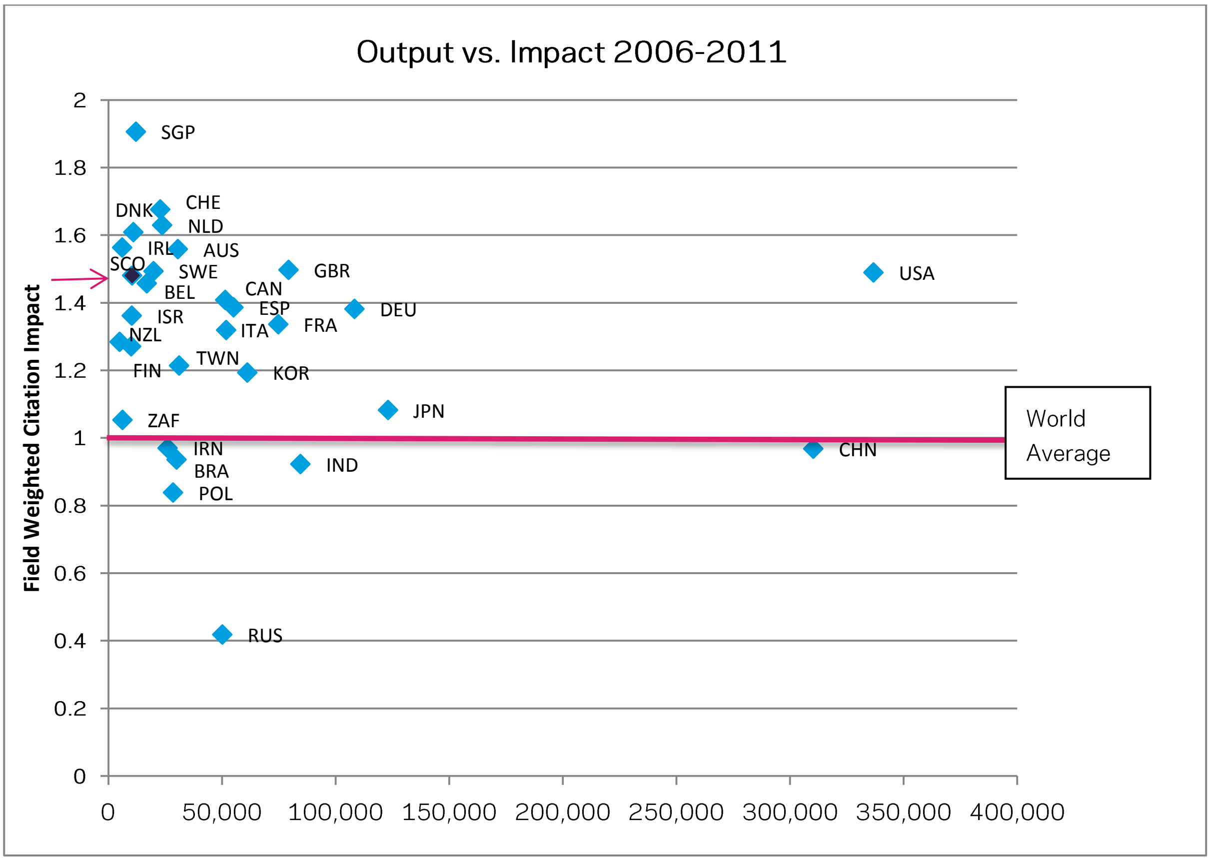
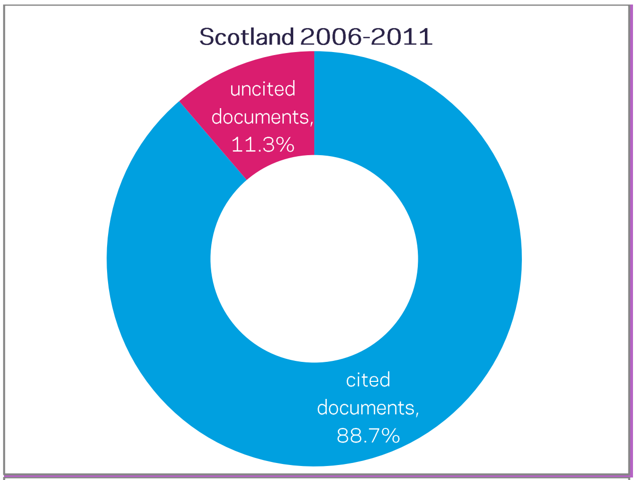


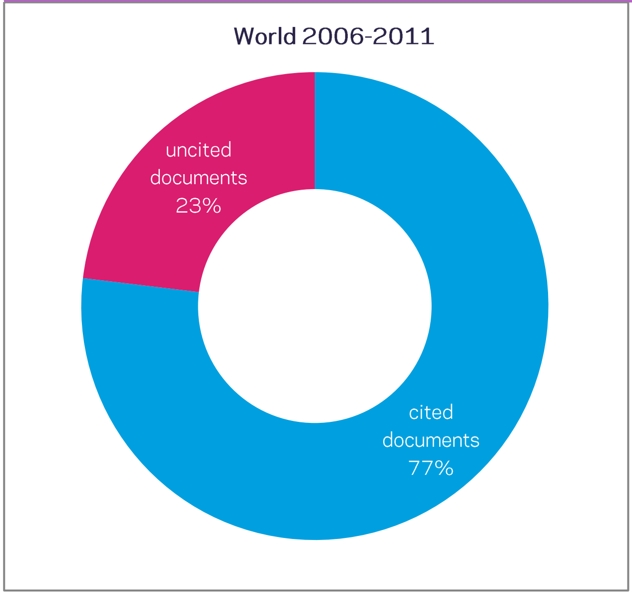
Figure 3 - Publication output vs. Citation Impact 2006-2011

Cited vs. non cited publications

In addition to FWCI, other metrics can be taken as a proxy of quality of research, one of which is the percentage of uncited and cited content. Uncited content has not been referenced in any other publications and is therefore not contributing to the citation impact of a specific country. There may be many reasons why these publications are relevant and important, but from a citation impact perspective it is recommendable to keep this percentage as low as possible.

Figure 4 shows that 88.7% of Scottish Chemical Sciences papers published between 2006 and 2011 were cited at least once (leaving 11.3% of those articles uncited). Scotland clearly ranks high in this regard as only six comparator countries have a higher percentage of cited papers. Countries most comparable to Scotland are Ireland and Belgium, while Sweden shows the highest percentage of cited publications followed by Spain and Denmark.





	2006-2011		
Country	pubs	cited pubs	percentage cited
SWE	20050	18092	90.2%
ESP	55183	49629	89.9%
DNK	11102	9974	89.8%
ISR	10367	9266	89.4%
ITA	51888	46207	89.1%
IRL	6135	5447	88.8%
SCO	10472	9291	88.7%
BEL	16968	15029	88.6%
CHE	22990	20274	88.2%
NLD	23815	20935	87.9%
AUS	30737	26991	87.8%
SGP	12224	10731	87.8%
NZL	5090	4463	87.7%
FRA	74918	65620	87.6%
GBR	79343	69282	87.3%
FIN	10118	8773	86.7%
CAN	51576	44489	86.3%
TWN	31316	26713	85.3%
E27	482590	411333	85.2%
DEU	108413	91955	84.8%
JPN	123164	102640	83.3%
BRA	30071	24754	82.3%
USA	336814	275603	81.8%
G8	791947	648015	81.8%
KOR	61225	49406	80.7%
POL	28576	22941	80.3%
ZAF	6272	4982	79.4%
IND	84674	65447	77.3%
IRN	26230	20213	77.1%
CHN	310361	223177	71.9%
RUS	50287	28685	57.0%
WLD	1614722	1241847	76.9%

Figure 4 - Cited vs. Un-cited percentage of publications for Scotland and selected comparator countries, 2006-2011

Highly Cited Publications

Within the category of cited documents, some publications are cited more frequently than others. Of special interest are publications that fall into so-called highly-cited percentiles: what proportion of articles from Scotland fall into the category of top 1% most cited articles world-wide?

Scotland has produced a relatively high percentage of highly cited publications, and this has increased after 2005. 1.7% of Scotland's Chemical Sciences papers published in 2000-2005 are in the top 1% most cited papers, which is lower than the UK, the Netherlands, USA, and Switzerland. In the period 2006-2011, 2.1% of Scotland's papers are in the top 1% most cited papers, which is higher than the UK, Sweden, and Denmark, on par with the Netherlands and just marginally lower than the USA.

Publications in Top Citation Percentiles				
	2000-2005		2006-2011	
	1%	5%	1%	5%
SGP	1.7%	8.3%	2.6%	11.6%
CHE	2.1%	10.2%	2.4%	10.8%
USA	2.2%	9.8%	2.2%	9.3%
SCO	1.7%	8.4%	2.1%	9.4%
NLD	1.8%	9.2%	2.1%	10.3%
GBR	1.8%	8.1%	2.0%	8.9%
DNK	2.0%	9.7%	2.0%	9.8%
IRL	1.5%	7.3%	1.9%	8.4%
ISR	1.3%	7.5%	1.8%	8.0%
DEU	1.3%	6.7%	1.6%	7.6%
AUS	1.2%	6.9%	1.6%	7.7%
SWE	1.5%	7.9%	1.5%	8.1%
G8	1.4%	6.9%	1.5%	6.9%
BEL	1.2%	6.8%	1.5%	7.3%
CAN	1.3%	7.2%	1.4%	7.1%
NZL	1.4%	5.5%	1.4%	5.4%
E27	1.1%	5.8%	1.2%	6.2%
ESP	0.8%	5.0%	1.2%	6.3%
FRA	1.1%	5.8%	1.2%	6.3%
ITA	1.0%	5.6%	1.1%	6.0%
FIN	0.7%	5.5%	1.1%	5.4%
WLD	1.0%	5.1%	1.0%	5.2%
KOR	0.8%	4.5%	1.0%	4.8%
JPN	0.9%	4.8%	0.8%	4.6%
CHN	0.5%	3.1%	0.8%	4.3%
TWN	0.5%	3.7%	0.6%	4.1%
ZAF	0.7%	4.1%	0.5%	3.0%
IND	0.5%	2.8%	0.4%	3.0%
IRN	0.2%	2.2%	0.4%	3.1%
BRA	0.4%	2.6%	0.3%	2.3%
POL	0.3%	1.9%	0.3%	2.0%
RUS	**0.1%**	**0.9%**	**0.2%**	**0.9%**

Table 2 - Top 1% and 5% percentiles highly cited Chemical Sciences papers

8.4% of Scotland's Chemical Sciences papers published in 2000-2005 are in the top 5% most cited, which is higher than the UK and Sweden, but lower than the Netherlands and USA. Turning to the more recent period, 9.4% of Scotland's papers published in 2006-2011 are in the top 5% most cited, which again is higher than the UK, Sweden, and now also the USA. Scotland seems to be producing more highly cited Chemical Sciences papers after 2005.

1.4 Patent Citations

In early citation studies technological progress was viewed as more or less a direct result of scientific progress. To paraphrase Bassecoulard & Zitt[2], it had been assumed that there is a diachronic relationship in which the science of today is the technology of tomorrow. However, as many authors have since made clear, there are several issues related to using a linear model. Over the last decades 'science' (being more theoretical) and 'technology' (more practical) have become closely intertwined. It is even becoming increasingly common for a researcher to be active in both worlds; i.e. one may work at a corporate R&D lab, but also hold an academic position (adjunct professorship) or vice versa[3].

In this section, we analyse the number of patent citations per country. The fairest comparison between countries can be made by taking patent data from WIPO, the international patent office. Selecting the US Patent and Trademark Office may show a bias towards US, and the same applies for the other national patent offices. Still, the results for the US may be disadvantaged because we are not looking at the US patent office data, and this office would contain most of the US patent citations.

In Figure 5, the number of patent citations in WIPO is normalised for the size in output volume for each country. The overall ratio of patent citations to a paper is higher during the earlier period 2000-2005 compared to the 2006-2011 period because these publications have had more time to collect patent citations. In Figure 5 below we have ranked the countries by the 2006-2011 value. From this we can see that Scotland's Chemical Sciences research is on average cited more often in patents than most comparator countries. The UK is among the countries that have received more patent citations per paper, while Denmark, Israel and Sweden show the highest levels of patent citations.

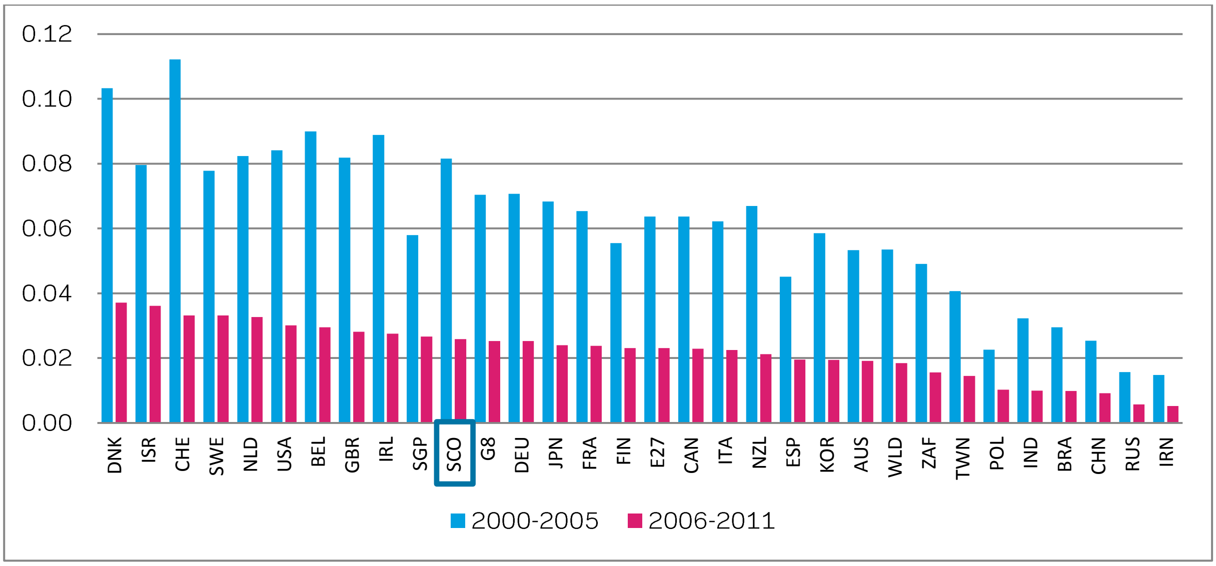


Figure 5 - Patent citations / total number of publications, 2000-2005, 2006-2011

[2] Bassecoulard, E., Zitt, M. (2004). Patents and publications: The Lexical Connection. In: H.F. Moed, W. Glänzel, U. Schmoch. (eds), Handbook of quantitative science and technology research, pp.665-694. Kluwer Academic Publishers, the Netherlands.

[3] See www.research trends.com, upcoming issue 33 for more details on this subject.

1.5 Full Text Article Downloads

"It can be hypothesized that the number of downloads primarily reflects a community's awareness of a paper, in terms of its availability and particularly its face value. Scientists may read – and in this sense use – many papers in their research, but during the research process and the writing their own papers, they sort out the articles worth citing and those that are less so. Thus, downloads and citations relate to distinct phases in the process of collecting and processing relevant scientific information that eventually leads to the publication of a journal article, the former being located more in the beginning, and the latter more towards the end of it." Moed, H. (2005: 1096).

Measuring impact by looking at citations requires time: articles need to be read, after which they might influence studies that will be carried out, which are then written up and published; only after these steps are completed can a citation be counted. For this reason, investigating downloads has become an appealing alternative. When measuring downloads, one can start counting immediately after publication of an article, instead of having to wait months or even years. However, it is not always clear what is being measured when looking at downloads[4].

Here, a download is defined as either downloading a pdf of an article on ScienceDirect, Elsevier's full-text platform, or looking at the full-text online on ScienceDirect, without downloading the actual pdf. Views of Abstract are not included in the definition. Multiple views or downloads of the same article in the same format during a user session, will be filtered out, in accordance with the COUNTER Code of Practice[5].

Figure 6 below displays the average number of full text downloads per publication, of each country in 2000-2005 and 2006-2011. As is the case with citations, downloads accumulate over time whch is why the earlier published papers have acculumated more downloads per paper. There are clear similarities to be seen between the two periods in terms of the relative differences between countries.

[4] Kurtz, M.J., & Bollen, J. (2012). Usage Bibliometrics. Annual Review of Information Science and Technology Volume 44, Issue 1. Retrieved online from http://onlinelibrary.wiley.com/doi/10.1002/aris.2010.1440440108/pdf.

[5] http://usagereports.elsevier.com/asp/main.aspx, WHAT TO COUNT & WHAT NOT? Elsevier White Paper retrieved from: http://www.info.sciverse.com/UserFiles/Files/sciencedirect/sd_white_paper_2004_02.pdf, http://www.projectcounter.org/code_practice.html

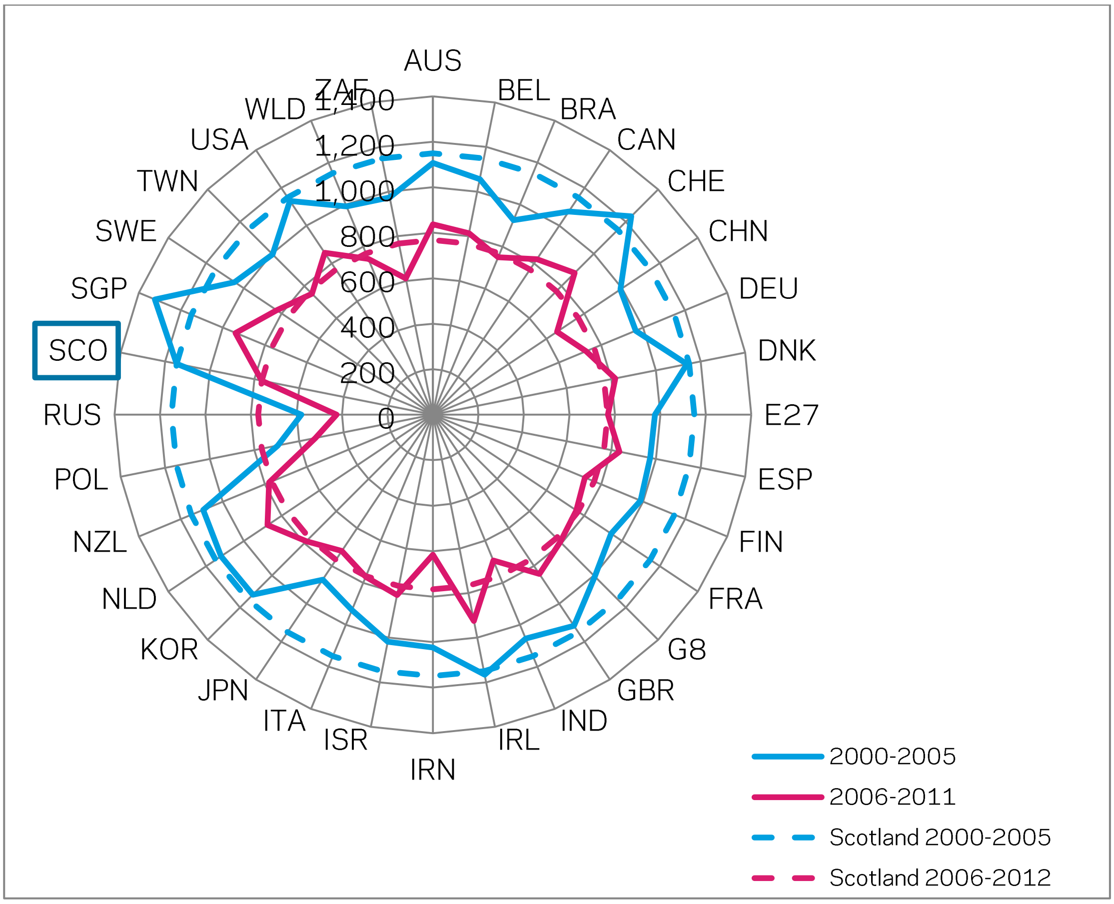


Figure 6 - Number of downloads per paper, per country, 2000-2005, 2006-2011.

Scotland's Chemical Sciences papers published in 2000-2005 have on average been downloaded 1149 times, which is higher than the UK's papers in that period, which were on average downloaded 1116 times; the E27 average was 976 times and world average was 991 times. Singapore stands out as producing Chemical Sciences papers which are downloaded often with an average of 1323 times.

Looking at the more recent period 2006-2011, Scotland's Chemical Sciences papers have on average been downloaded 768 times, which is lower than the UK, whose papers were downloaded 842 times per paper. It is almost on par with the EU27 overall whose papers were on averge downloaded 770 times per paper.

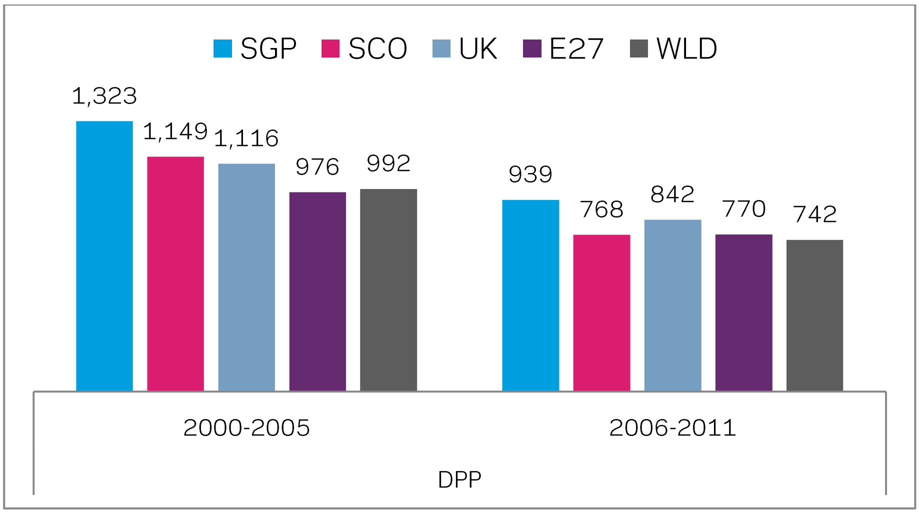
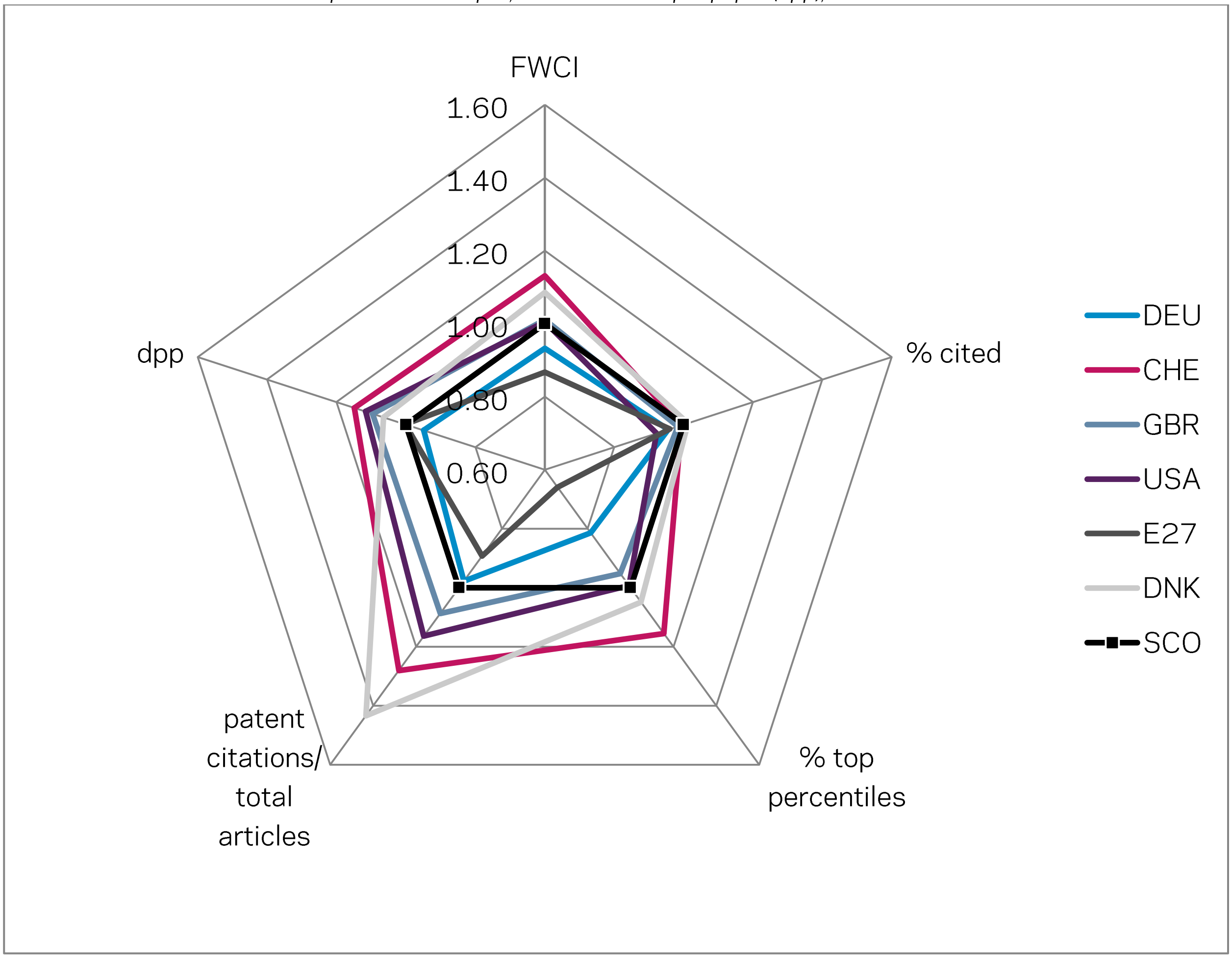


Figure 7 – Number of downloads per paper for Scotland and selected comparators, 2000-2005, 2006-2011.

1.6 Summary

Below Figure 8 summarizes results on most metrics presented in this section of the report, by visualising Scotland's position relative to Germany, Switzerland, Denmark, UK, USA, and EU27 as a whole. All measurements have been indexed to the value of Scotland, meaning that Scotland's position on all metrics equals 1, and all other countries are positioned relative to Scotland.

Figure 8 – Relative position of Germany, Switzerland, UK, USA, EU27, and Denmark compared to Scotland in Chemical Sciences research, on FWCI, percentage of cited publications, percentage of publications in top percentile, patent citations normalised for total publication output, and downloads per paper (dpp), 2006-2011.



Clearly Scotland holds a leading position in terms percentage cited publications. For all other indicators, Scotland ranks more in the middle.

Chapter 2
Collaboration

This chapter focuses on the collaboration of Scottish authors in Chemical Sciences with a focus on both international collaboration and collaboration between academia and corporations.

2.1 Key Findings

"[...] the increase of citation impact by international collaboration became almost a commonplace notion. Indeed, publications with one or more co-authors from institutions in different countries seem to be the results of greater efforts than those by authors from one and the same country or institute. However the reasons for international collaboration are manifold. Some of the factors influencing co-publications [are]intra-scientific, economic and (geo-)political."
Double Effort = Double Impact? A critical view at international co-authorship in chemistry. Glänzel, W., & Schubert, A. (2001), Scientometrics, 50(2) p.199.

INTERNATIONAL COLLABORATION

49.9%

Scotland shows high and increasing levels of international collaboration from 40.5% to 49.9%.

FIELD WEIGHTED CITATION IMPACT

1.63

Scottish Chemical Sciences publications resulting from international collaboration show the highest citation impact.

ACADEMIC-CORORATE COLLABORATION

5.7% → 4.9 %

Scotland shows decreasing levels of collaboration between academia and corporate in the Chemical Sciences, from 5.7% (2000-2005) to 4.9% (2006-2011). Countries that stand out as having high levels of academic corporate collaboration are Switzerland, Denmark, and the Netherlands. Interestingly, it seems that Scotland has almost no collaboration between academia and corporate where both of the institutions are in Scotland.

2.2 International collaboration

This section of the report focuses on collaboration between countries, most commonly referred to as international collaboration. International collaboration rates are consistently rising[6] and internationally co-authored papers have been shown to have a positive effect on citations[7]. In *Nature*, Thijssen et al[8] looked at international collaborations for different countries. Overall, the average collaboration distance increased more or less linearly from 334 kilometres in 1980 to 1,553 km in 2009.

In the context of this report, collaboration refers to co-authorship on articles. Several levels of collaboration are distinguished for the purpose of this analysis:

- Single author, technically not a collaboration type but serving as a benchmark;
- Scotland, where all authors are from a Scottish institution;
- UK, where all authors are from an institute within the UK and one or more are from a different constituent;
- International, where at least one affiliation is outside the UK; and
- Non-academic, which refers to collaboration between the academic sector on the one hand, and other sectors such as industry or government on the other.

In Scottish Chemical Sciences output, the majority of publications result from international collaboration, see Figure 9. This percentage is also increasing. The percentage of Scottish papers which have at least one non-Scottish UK co-author was 16.9% in the 2000-2005 period and has decreased to 15.1% in 2006-2011. The level of collaboration between different institutions within Scotland has remained relatively stable at around 5%, while the percentage of single author papers has decreased from 6.2% to 4.7%.

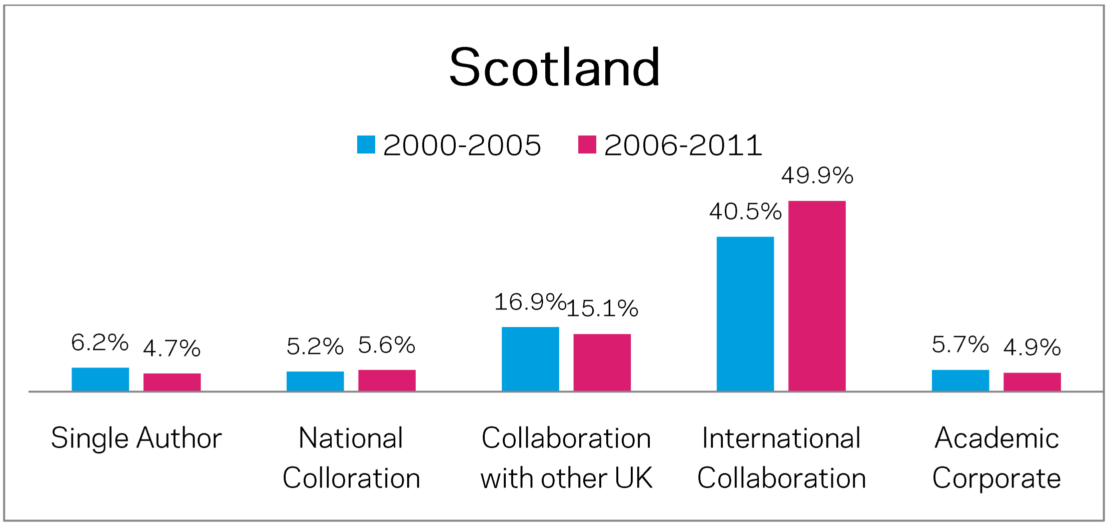


Figure 9 - Different collaboration types in Scottish publications, 2000-2005 and 2006-2011.

[6] He. T. (2009). International scientific collaboration of China with the G7 countries. *Scientometrics*, 80(3), 571-582.

[7] Glänzel, W. (2001). National characteristics in international scientific co-authorship relations. *Scientometrics*, 51 (1), 69-115.

[8] Tijssen, R., Waltman, L, & van Eck, N.J. (2011). Collaborations span 1,533 kilometres. *Nature*, 473, 12 May, 154

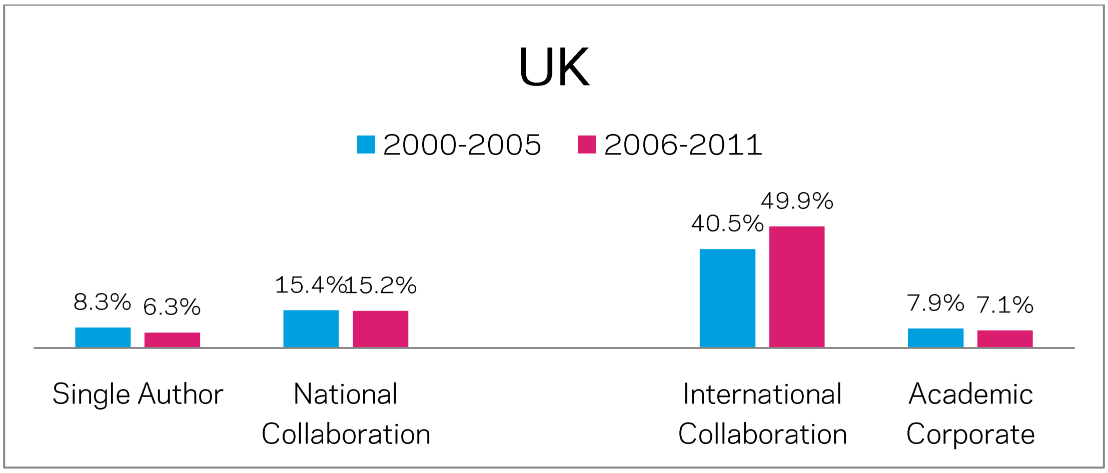


Figure 10 - Different collaboration types in UK publications, 2000-2005 and 2006-2011.

The UK shows exactly the same levels of international collaboration as Scotland in both periods, but much higher levels of national collaboration, at approximately 15%.

Scotland shows high and increasing levels of international collaboration from 40.5% to 49.9%, as can be seen in Figure 9. Below Figure 11 adds context to these numbers and shows the percentage of international publications for all selected comparator countries. The US shows a relatively low percentage of publications resulting from international collaboration in Chemical Sciences, whereas Belgium, the Netherlands and Switzerland show high percentages.

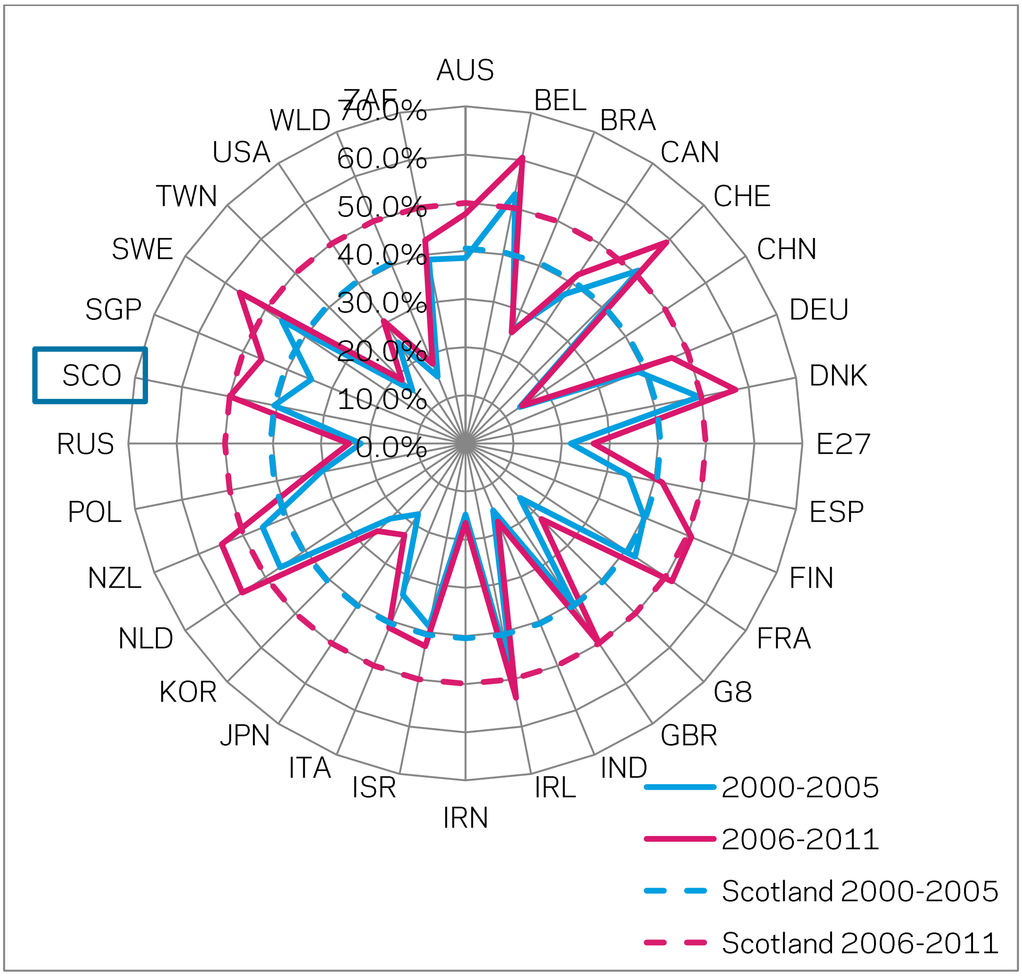


Figure 11 - International collaboration as a percentage of total publication output, per country, 2000-2005, 2006-2011.

It is important to add the dimension of citation impact and look at collaboration from both angles. Is it indeed the case that international collaboration causes the largest increase in citation impact, as often hypothesized and found in studies?

When looking at the field weighted citation impact of each type of collaboration it is clear that Scottish Chemical Sciences papers with at least one international author are on average cited most often in the 2006-2011 period. This was not the case in the previous period, when academic-corporate co-authored papers were on average cited most often.

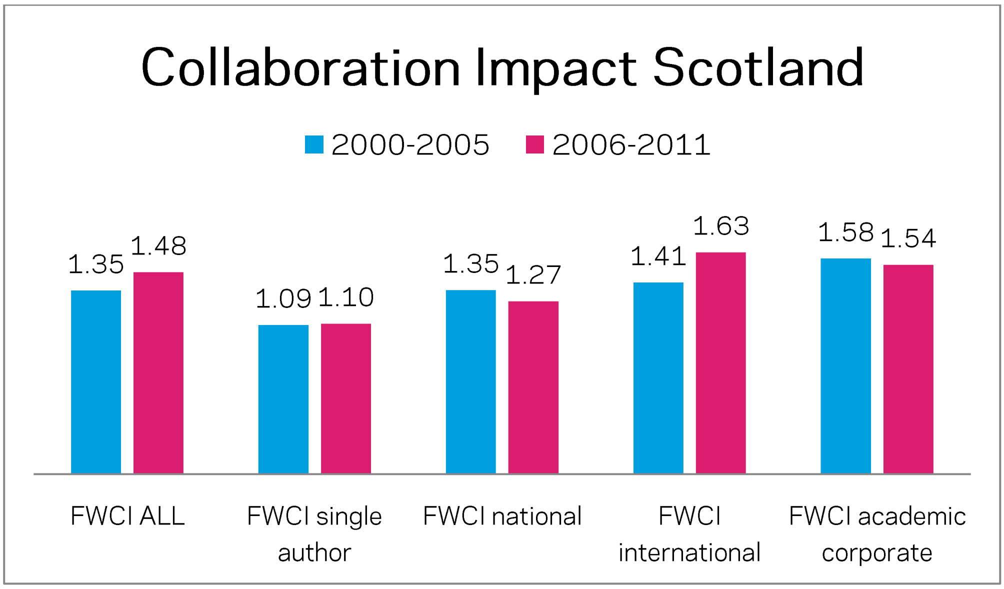


Figure 12 - Field weighted citation impact of each type of collaboration Scotland

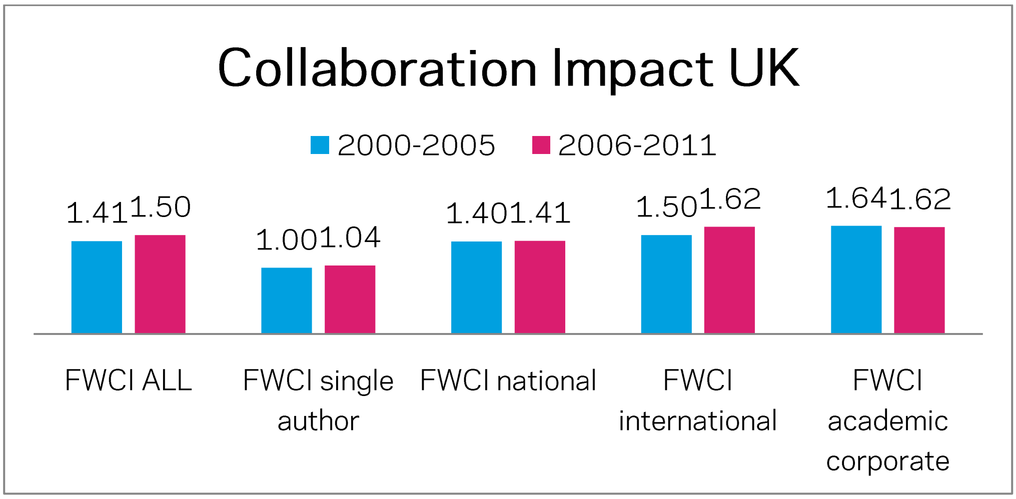


Figure 13 - Field weighted citation impact of each type of collaboration UK

This is further demonstrated in Table 3 which displays the citation fold increase each type of collaboration has over single authorship. We see for example that Scotland's international publications in Chemical Sciences are cited 1.47 times as often as its single author papers in the field. International and academic-corporate collaborations are also cited more frequently, indicating that any type of collaboration has a positive effect on citation impact.

	Single Author	National	International	Academic Corporate
AUS	1	1.27	1.55	1.59
BEL	1	1.68	2.08	2.26
BRA	1	1.32	1.88	1.64
CAN	1	1.36	1.60	1.68
CHE	1	1.70	1.81	1.81
CHN	1	2.44	4.39	2.34
DEU	1	1.72	2.03	2.15
DNK	1	1.44	1.70	1.72
E27	1	1.47	1.69	1.72
ESP	1	1.19	1.39	1.40
FIN	1	1.62	2.09	1.87
FRA	1	1.18	1.36	1.42
G8	1	1.72	1.88	1.89
GBR	1	1.36	1.57	1.56
IND	1	1.49	2.31	1.51
IRL	1	1.05	1.24	1.55
IRN	1	1.20	1.46	1.32
ISR	1	1.12	1.58	1.80
ITA	1	1.17	1.64	1.70
JPN	1	1.48	2.10	1.71
KOR	1	1.50	2.18	1.78
NLD	1	1.29	1.49	1.52
NZL	1	1.30	1.51	1.47
POL	1	1.08	1.73	2.38
RUS	1	1.23	4.30	4.27
SCO	1	1.15	1.47	1.39
SGP	1	1.02	1.25	1.16
SWE	1	1.22	1.52	1.54
TWN	1	1.25	1.48	1.31
USA	1	1.99	2.11	2.15
ZAF	1	0.95	1.35	1.33

Table 3 - Citation fold increase over single authorship

As a final overview, it is now possible to combine output and impact in one graph, see Figure 14. Looking at the share of total output and field weighted impact of each collaboration type, for both the period 2000-2005 and 2006-2011 Scottish international collaboration has increased both in terms of its share of total output as well as the citation impact those articles achieve.

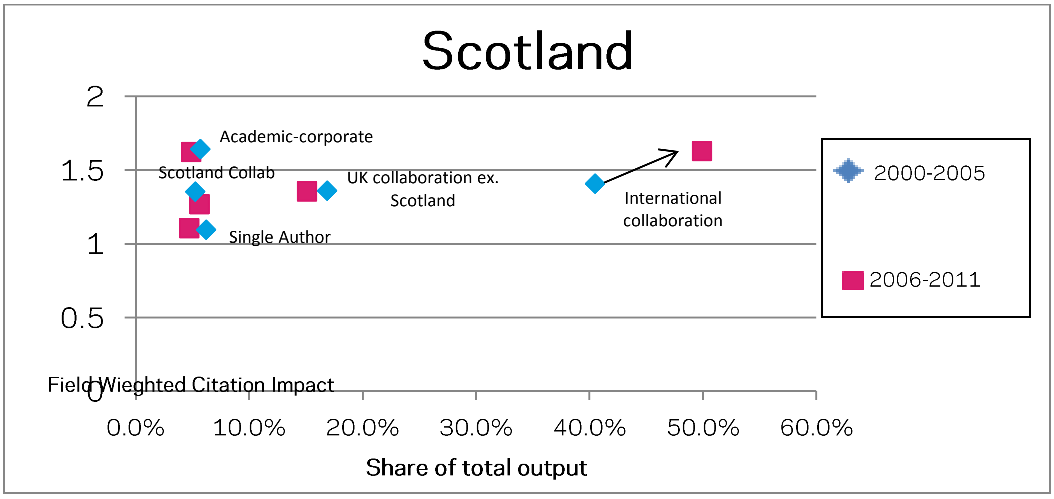


Figure 14 - Scotland's collaboration output vs. collaboration impact

2.3 Academic – Corporate collaboration

This section of the report focuses on a special type of collaboration: that between an academic institution on the one hand and a corporate institution on the other. This type of collaboration is expected to be highly beneficial for citation impact, as it brings together two different sectors and two different worlds of research.

Scotland shows decreasing levels of collaboration between academia and corporate in the Chemical Sciences; its share of the total output went from 5.7% (2000-2005) to 4.9% (2006-2011). Countries that stand out as having high levels of academic-corporate collaboration are Switzerland, Denmark, and the Netherlands.

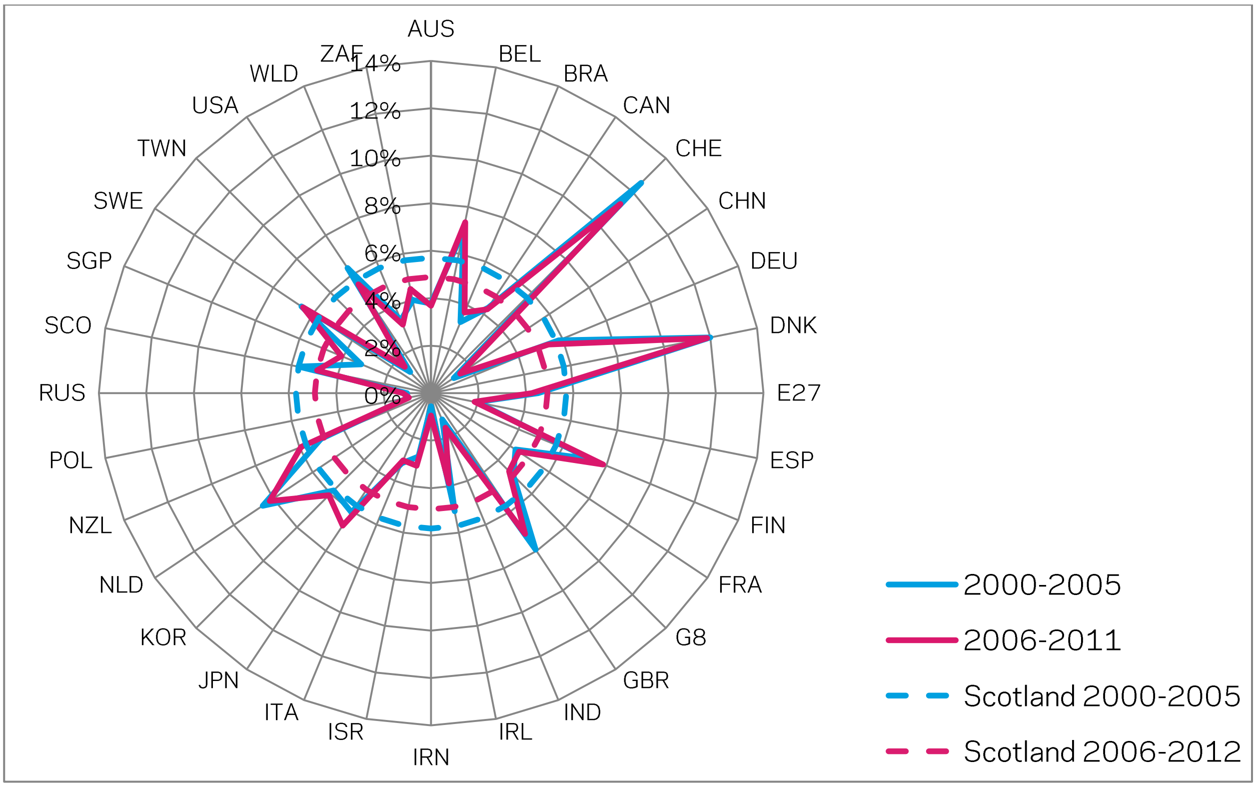
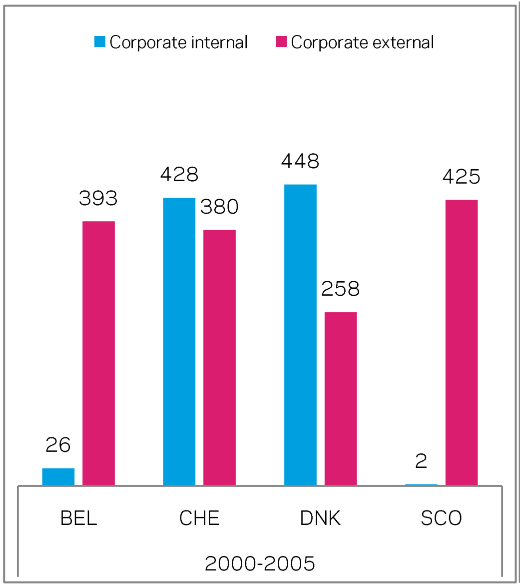


Figure 15 – Academic-corporate collaboration as a percentage of total output

Interestingly, it seems that Scotland has almost no collaboration between academia and corporate where both of the institutions are in Scotland. This is illustrated in Figure 16 where 'corporate internal' represents collaboration between academic and corporate sectors where both organizations are affiliated to the same country.



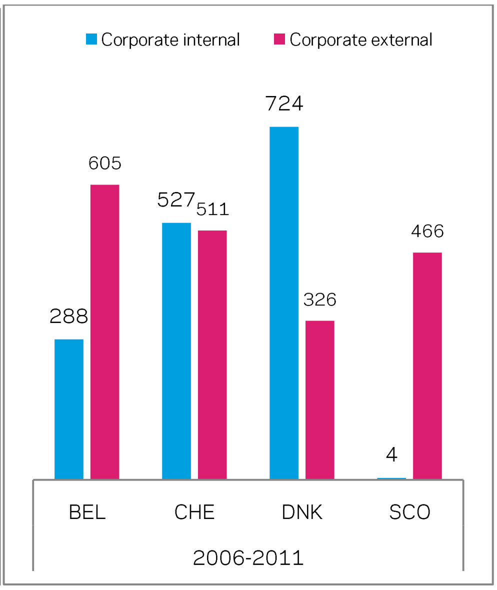


Figure 16 - Internal vs. External Academic Corporate collaboration.

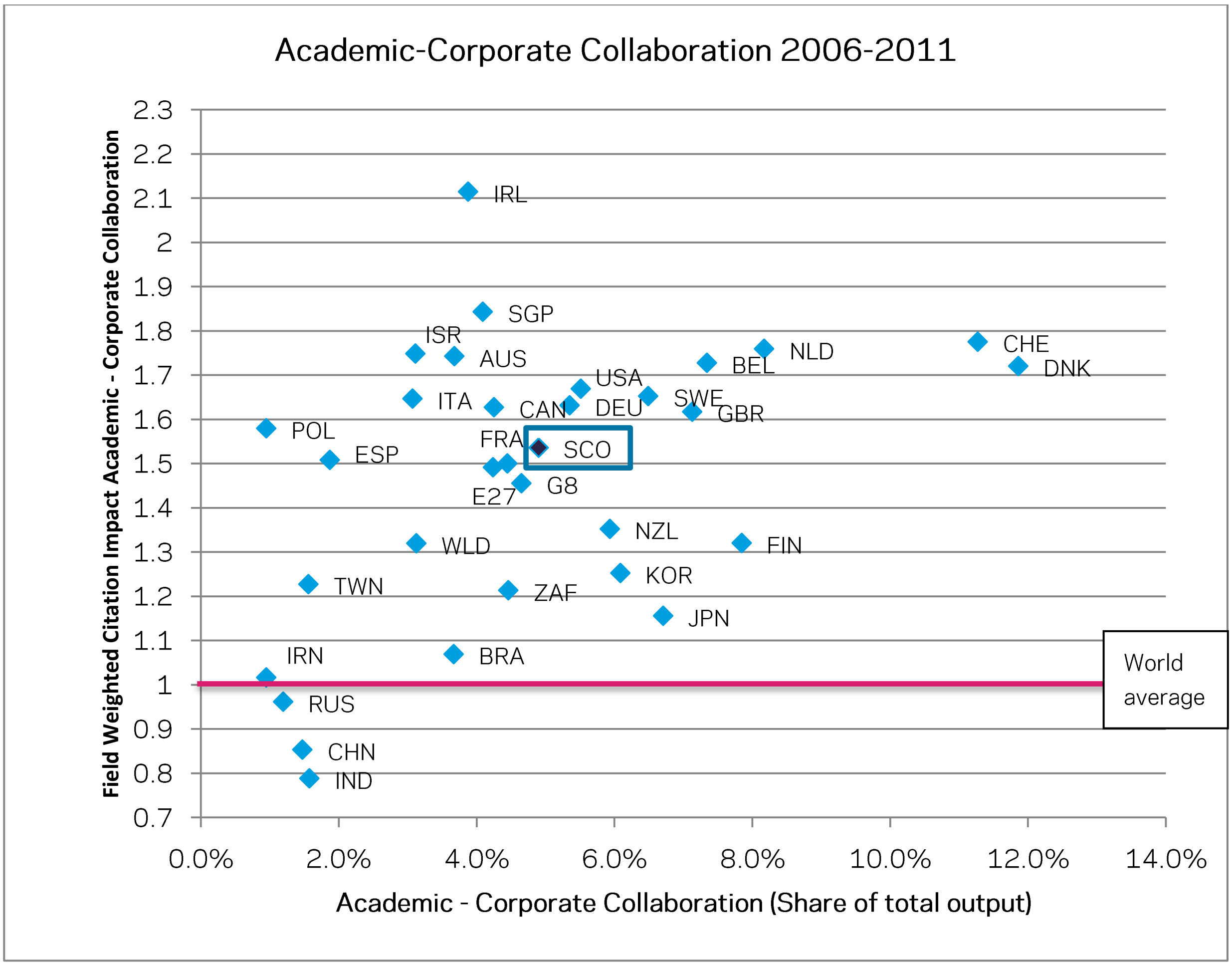


Figure 17 - Academic-corporate collaboration as share of total output vs. the field weighted citation impact of those co-publications for the period 2006-2011.

In most countries, including Scotland, collaboration between academic and corporate organizations represents a relatively small share of total publications but those publications tend to be highly cited on average. This is demonstrated in Figure 16 where we see that in the period 2006-2011 4.9% of Scottish publications were an academic and corporate co-authorship, and these publications achieved a citation impact of 1.53.

2.4 Collaboration partners for Scotland

Which countries collaborate often with Scotland in the Chemical Sciences discipline? Below analysis presents the Top 20 in terms of most prolific collaborations, and divides these into categories, depending on the effect that this collaboration has on both countries' impact.

For Scotland's Chemical Sciences collaborations, many most prolific collaborations fall into the upper right quadrant, indicating that these collaborations are associated with higher citation impact for both collaboration impact. However, if we take the example of England, it is only having a very small effect in both Scotland's and England's citation impact.

A few smaller collaborations result in impact that is below par for Scotland, situated to the left of the horizontal line. The collaborations in the top left quadrant do have a positive effect on the impact of the collaborating country (Russia, India, Malaysia). The collaborations in the lower left quadrant are associated with lower impact for both collaborators (Brazil, Portugal, Northern Ireland).

Figure 18 shows in addition how international Scotland's collaboration in Chemical Sciences is. Aside from Wales, England, and Northern Ireland, we see European partners such as the Netherlands, Switzerland, Denmark and Belgium, global partners such as USA, Canada, and Australia, and also emerging countries such as Brazil, China and India.

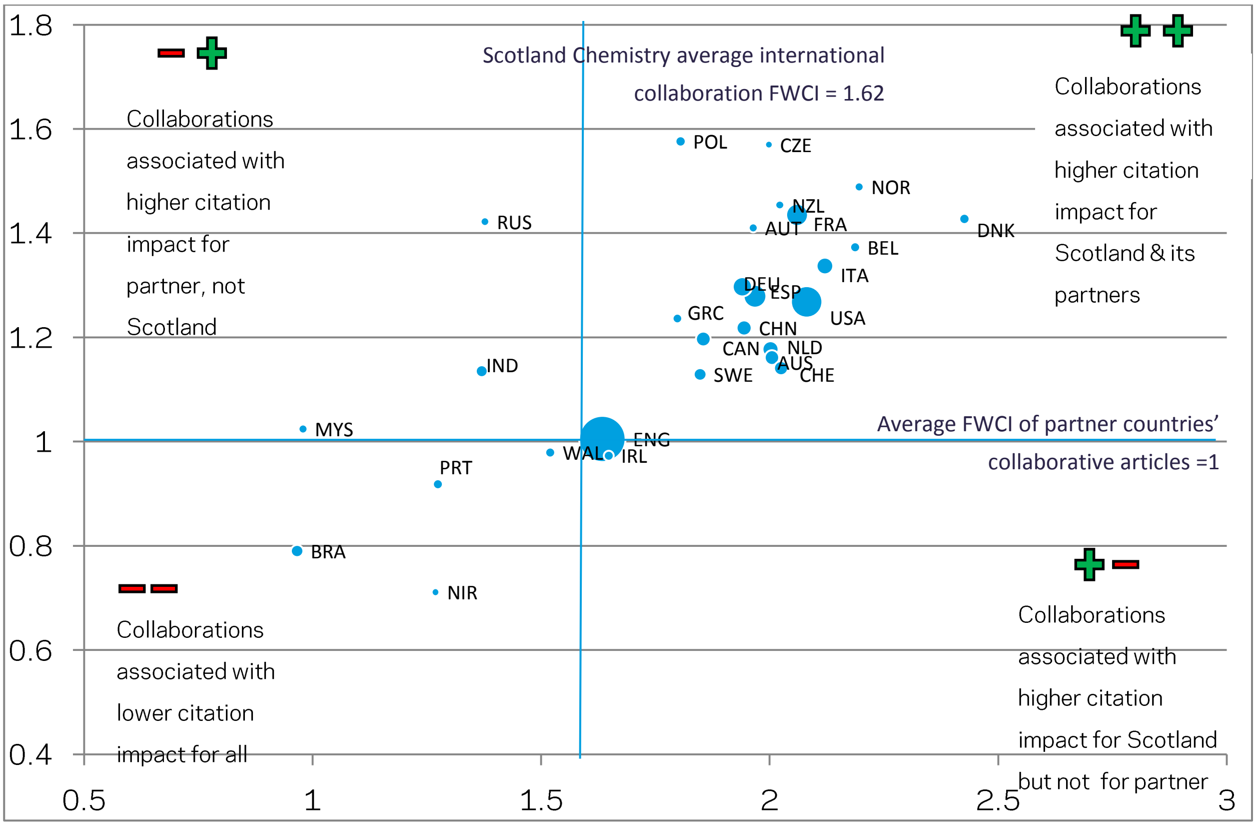


Figure 18 - Collaboration partners for Scotland, Chemical Sciences, 2007-2012

Chapter 3
Input, Human Capital and Productivity

This chapter focuses on the input and resources of Scotland's Chemical Sciences research base, and how these are affecting volume and quality of the research.

3.1 Key Findings

“R&D Expenditures are a key driver of research output. (…) countries vary in the efficiency and quality of their research output”

International Comparative Performance of the UK Research Base – 2011. Elsevier report prepared for the Department of Business, Innovation and Skills.

PUBLICATIONS AND CITATIONS RELATIVE TO NUMBER OF RESEARCHERS, GERD AND GDP

High productivity, highly efficient

When taking the size of the researcher population as well as the R&D expenditure into account, Scotland’s output and citations are among the top of all comparator countries.

RESEARCHER MIGRATION

High transitory, low sedentary %

If we look at researcher migration in Scotland, we see a remarkably high percentage of researchers with short stays in or outside of the country (transitory researchers), and a remarkably low percentage of researchers who stay within the country and do not show change in their affiliation (sedentary researchers).

3.2 Human Capital

In this section, we evaluate a country's output by taking into consideration the number of researchers in each country[9].

Both for publications relative to the size of the researcher base, as for citations relative to the researcher base, we see that Scotland occupies a place in the top 3 of each of these rankings.

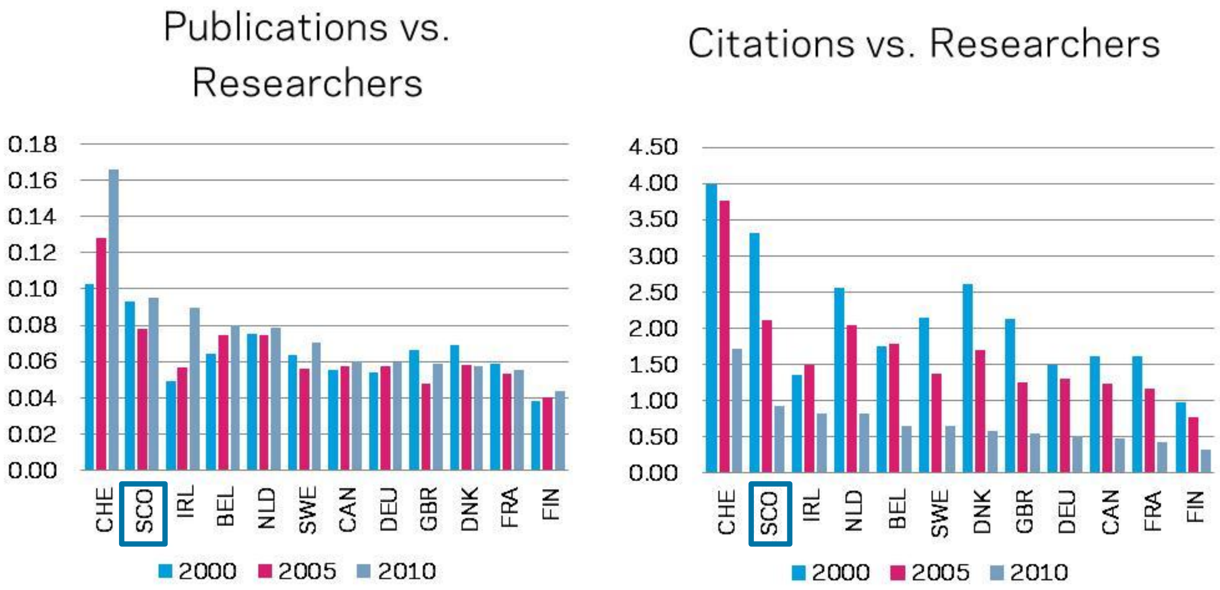


Figure 19 - Publications versus number of researchers and citations versus the number of researchers for selected comparator countries, for the years 2000, 2005, and 2010

[9] It is important to note that the number of researchers, available from OECD, is not split into research disciplines and therefore applies to all disciplines combined. The number of publications only takes Chemical Sciences publications into account. Therefore, the absolute number in Figure 17 is meaningless, but the relative position is of interest.

3.3 R&D Expenditures

In this section, we evaluate a country's output by taking into consideration the Gross Expenditure on R&D (GERD), and the country's Gross Domestic Product (GDP)[10].

Similarly to what section 3.2 showed, Scotland ranks very high when correcting for R&D expenditure and GDP. Scotland ranks second after Switzerland when normalising publications for GDP, and third after Switzerland and Denmark when normalising citations for GDP.

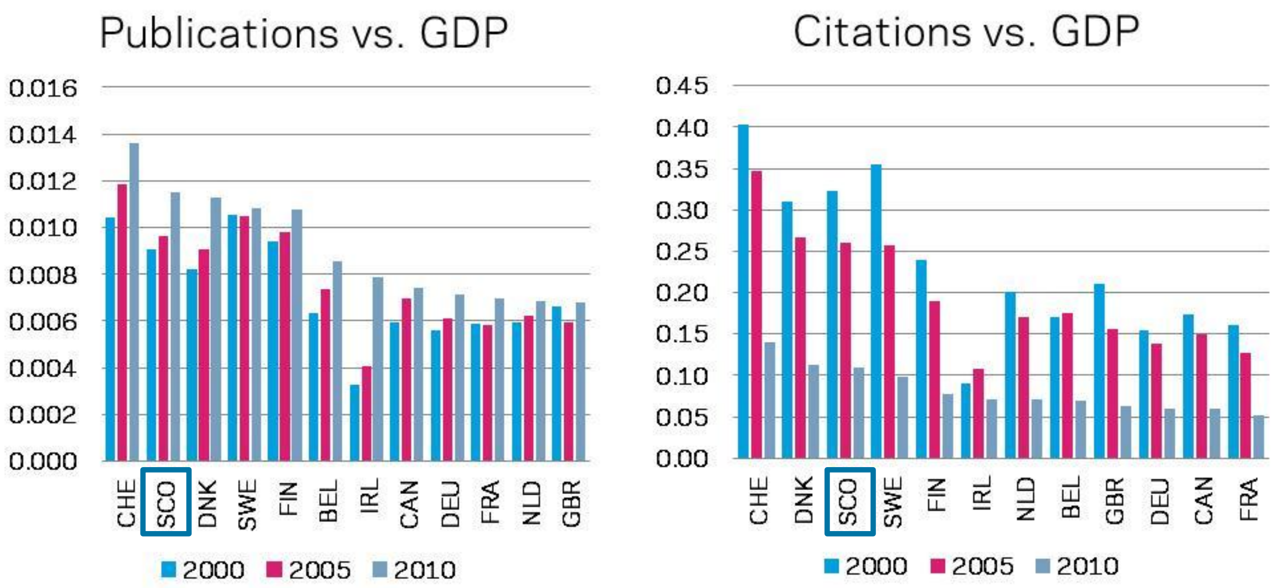


Figure 20 - Publications versus GDP and citations versus GDP for selected comparator countries, for the years 2000, 2005, and 2010

When looking at Chemical Sciences publications and citations versus GERD, Scotland ranks first among the selected comparator countries.

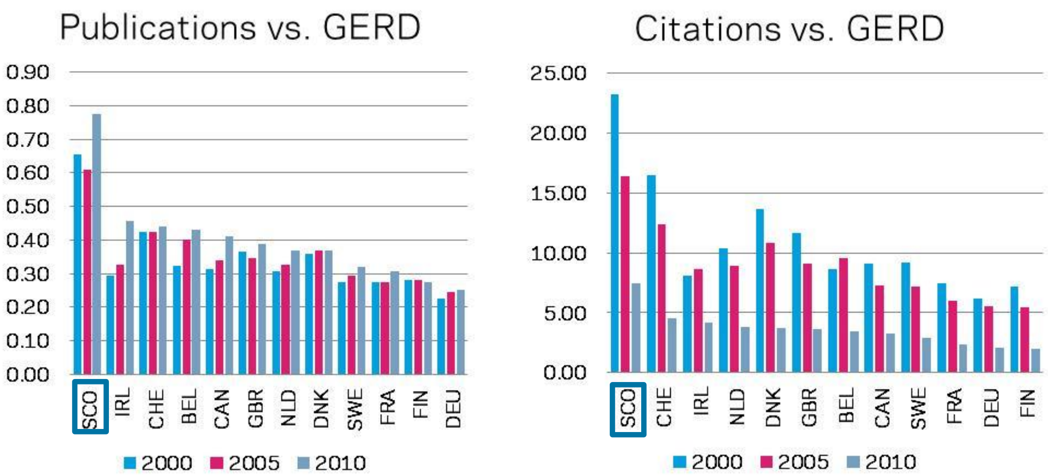


Figure 21 - Publications versus GERD and citations versus GERD for selected comparator countries, for the years 2000, 2005, and 2010

[10] This data is only available from OECD for all research areas combined and therefore not specific for Chemical Sciences. However, because this is identical for all countries within the scope of this report, we consider this a useful proxy.

GERD can be split further into BERD (Expenditure on R&D in the Business Enterprise sector), HERD (Expenditure on R&D in the Higher Education sector) and GOVERD (Government Intramural Expenditure on R&D).

- For publications relative to BERD, Scotland ranks second after Poland.
- For publications relative to HERD, Scotland ranks 14th, above the UK but below China, Russia, Taiwan, Korea, New Zealand, Singapore, etc.
- For publications relative to GOVERD Scotland ranks 6th after Switzerland, Denmark, Ireland, Sweden and Israel.

3.4 Researcher Migration

How attractive is Scotland for researchers? Figure 22 presents the results from an analysis on the migration behaviour of researchers.

For the current analysis, all active researchers have been identified that have published within the timeframe 1996-2011 with at least one Scottish affiliation. In order to be considered an active author, a researcher has to have at least one publication in the latest five year period and more than 10 articles in the complete timeframe of the analysis, or more than 3 articles in the last five years but less than 10 in the complete period 1996-2011. By looking at the affiliations an author has listed on his or her publications, it is possible to track his or her movement. An author who for instance publishes first with an affiliation in Scotland, but after a few years publishes no longer with this Scottish affiliation but with an US affiliation, will be considered "brain outflow". For a glossary on all categories and metrics, see Appendix A.

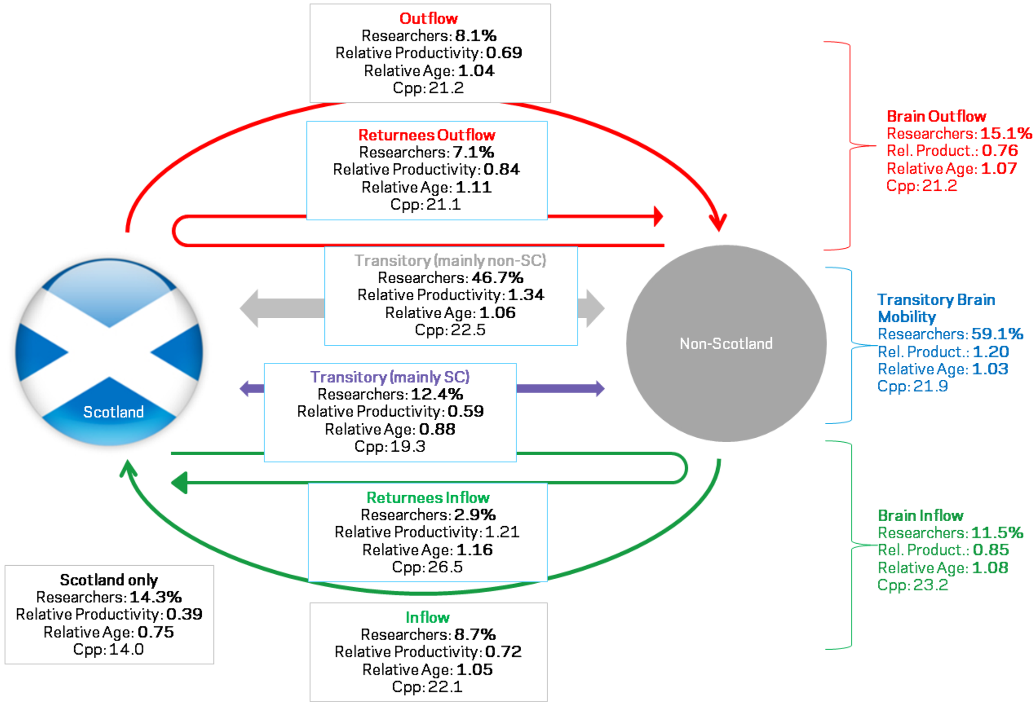


Figure 22 – Brain Circulation for Scotland, all subjects combined, 1996-2011.

In short, there are three main categories in the Brain Circulation flow: outflow (researchers who leave the country), inflow (researchers who arrive in the country) and transitory (researchers with short stays of less than two years in the country). An additional category is formed by those researchers who stay in the country and do not seem to move, also referred to as sedentary researchers.

We can see in Figure 22 that 14.3% of all active researchers in Scotland appear to never have left the country. They may have shown international mobility, but this did not result in published articles with a different affiliation. This group has relatively low relative productivity and age, meaning that this group on average consist of less experienced and less productive researchers. Their citation impact, measured by citations per paper (cpp), is relatively low compared to the other categories represented in Figure 22.

The largest group are the transitory researchers, with 59.1% of all active researchers. Their age is about average, but their productivity is above average. The cpp is higher than for the sedentary researchers, similar to that of the outflow researchers but lower than that of the inflow researchers. Within the group of transitory researchers, the majority is coming from another country with a short stay in Scotland. Their impact is higher than that of researchers coming from Scotland but spending a short stay of less than two years abroad. There are two categories of transitory researchers, the ones that start out in Scotland and have a short stay abroad (the mainly Sco category) and the researchers starting abroad and spending a short time in Scotland (mainly non-Sco). The latter is of importance to the research in Scotland, judging from the high percentage of active researchers (almost 47%). This percentage indicates the relative attractiveness of Scotland for a short research stay.

Brain outflow occurs for just over 15% of all active Scottish researchers. They are below average productive, but above average in seniority. The Brain Inflow category is of smaller size at 11.5%. Again, these researchers show below average productivity but above average seniority. Impact is higher for inflow researchers than for outflow researchers.

The Brain outflow and inflow results in a net change of -3.6%.This difference indicates that more researchers leave the country than enter. The profiles of these researchers are very similar: below average productivity, above average age and slightly higher cpp for the inflow than for the outflow.

Among these inflow and outflow groups are also the Returnees, the researchers who either leave and return, or the researchers who come to Scotland from abroad but return to the country of departure. These groups are relatively large, in comparison to other countries, especially the returnees outflow at over 7%. Those researchers have started their career outside of Scotland, then spent more than 2 years in Scotland and left again.

Brain Circulation comparator countries

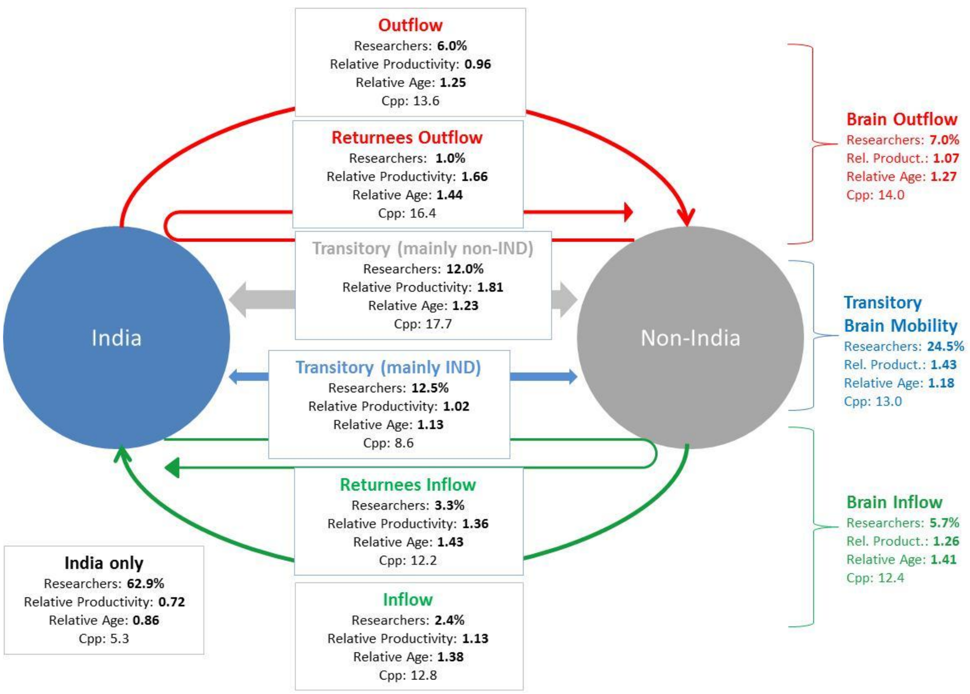


Figure 23 - Brain Circulation of India all subjects combined, 1996-2011.

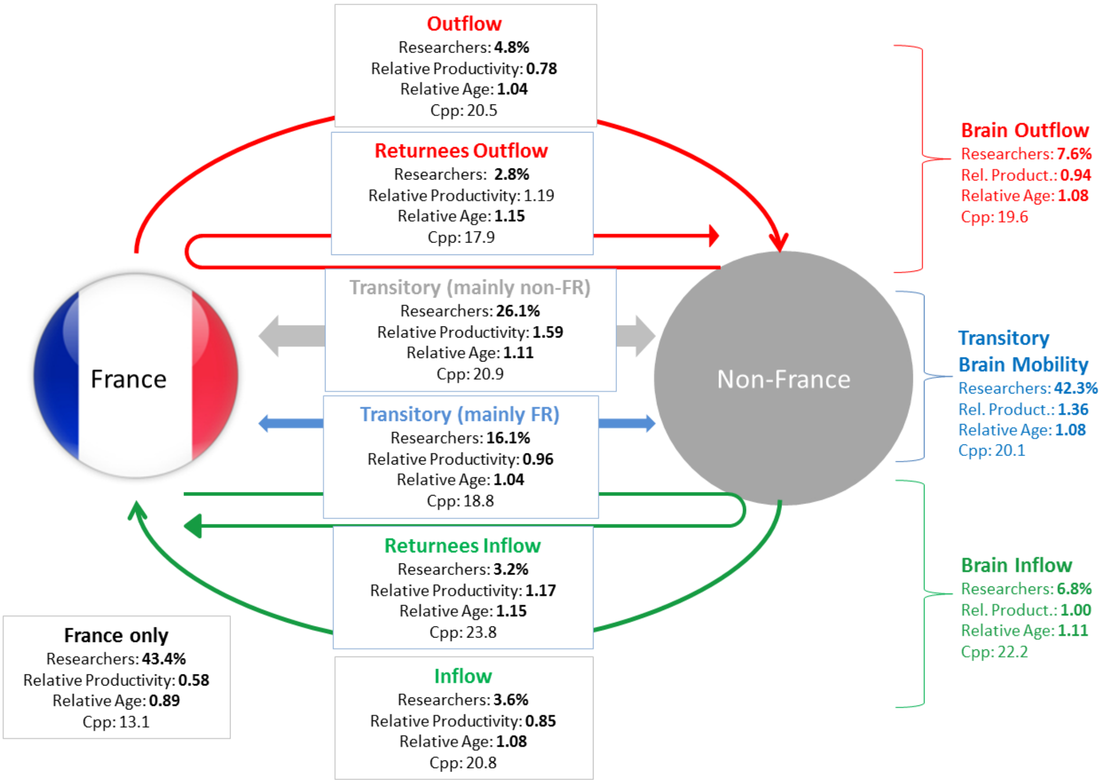


Figure 24- Brain Circulation of France all subjects combined, 1996-2011.

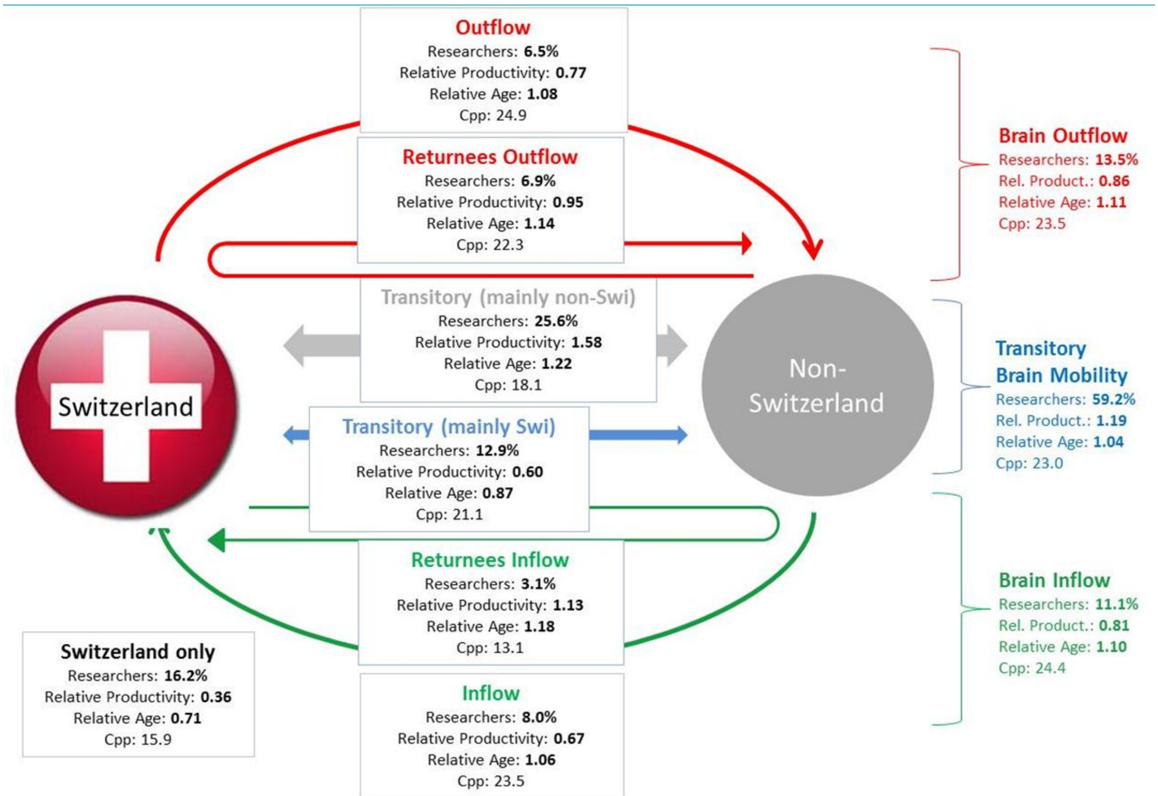


Figure 25 - Brain Circulation of Switzerland all subjects combined, 1996-2011.

3.5 Summary

Below Figure 26 summarizes results on most metrics presented in this section of the report, by visualising Scotland's position relative to Germany, Switzerland, Denmark, UK, and USA. All measurements have been indexed to the value of Scotland, meaning that Scotland's position on all metrics equals 1, and all other countries are positioned relative to Scotland.

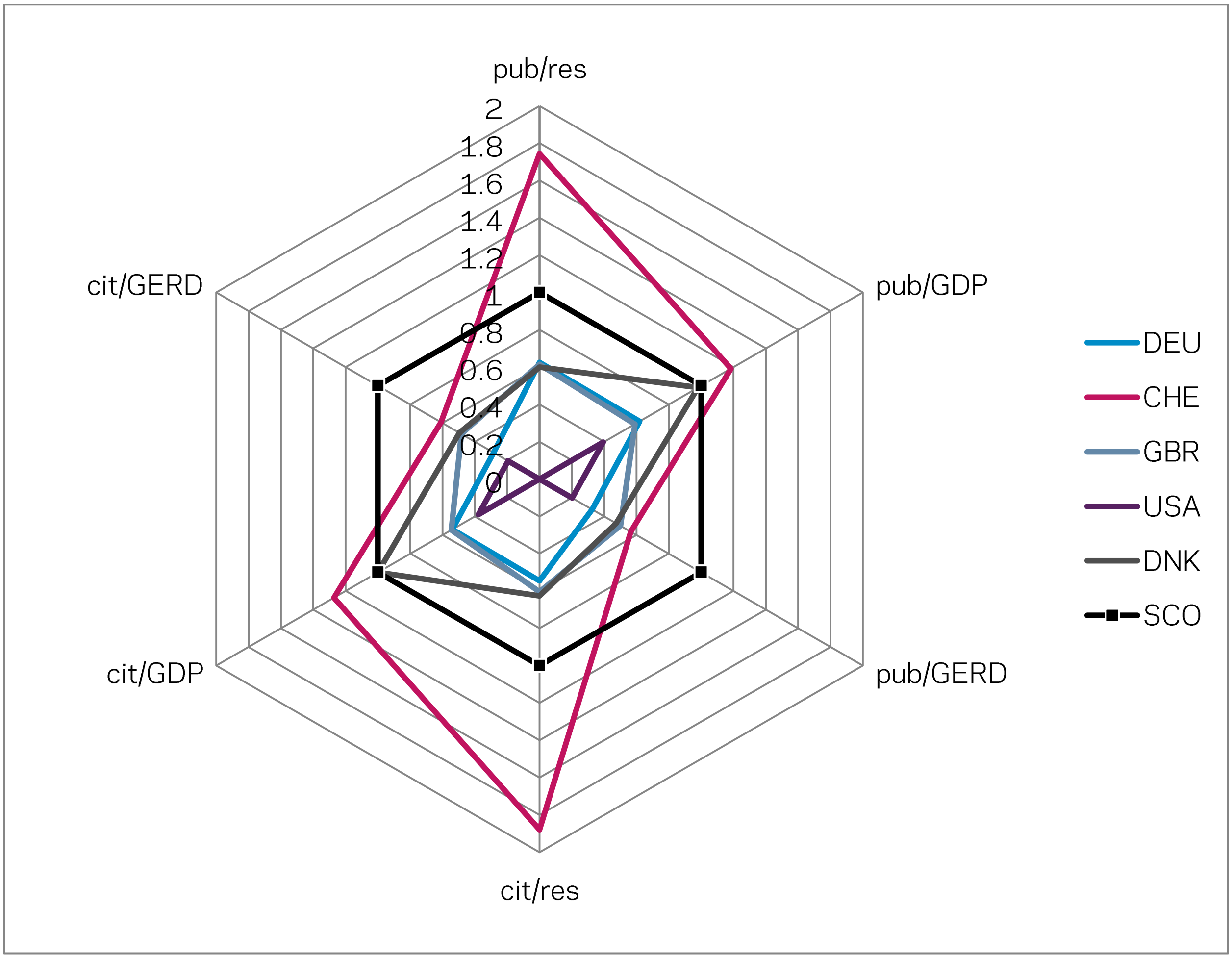


Figure 26 - Relative position of Germany, Switzerland, UK, USA, and Denmark compared to Scotland in Life Sciences research, on publications and citations per researcher, GDP and GERD[11], 2006-2011.

[11] For USA, no researcher counts for 2010 are available from OECD.

Appendix A
Methodology

Methodology and rationale

Our methodology is based on the theoretical principles and best practices developed in the field of quantitative science and technology studies, particularly in science and technology indicators research. The Handbook of Quantitative Science and Technology Research: The Use of Publication and Patent Statistics in Studies of S&T Systems (Moed, Glänzel and Schmoch, 2004) gives a good overview of this field and is based on the pioneering work of Derek de Solla Price (1978) , Eugene Garfield (1979) and Francis Narin (1976) in the USA, and Christopher Freeman, Ben Martin and John Irvine in the UK (1981, 1987) , and in several European institutions including the Centre for Science and Technology Studies at Leiden University, the Netherlands, and the Library of the Academy of Sciences in Budapest, Hungary.

The analyses of bibliometric data in this report are based upon recognised advanced indicators (e.g., the concept of relative citation impact rates). Our base assumption is that such indicators are useful and valid, though imperfect and partial measures, in the sense that their numerical values are determined by research performance and related concepts, but also by other, influencing factors that may cause systematic biases. In the past decade, the field of indicators research has developed a best practices which state how indicator results should be interpreted and which influencing factors should be taken into account. Our methodology builds on these practices.

Article types

For all bibliometric analysis, only the following document types are considered:

- Article (ar)
- Review (re)
- Conference Proceeding (cp)

Defining Chemical Sciences

Chemical Sciences is defined as all articles from the following Scopus subject categories: Chemical Engineering, Chemistry, Environmental Chemistry, Materials Chemistry, and Biochemistry.

Counting

All analyses make use of whole counting rather than fractional counting. For example, if a paper has been co-authored by one author from the UK and one author from the Netherlands, then that paper counts towards both the publication count of the UK, as well as the publication count of the Netherlands. Total counts for each country are the unique count of publications.

Data Sources

Scopus was developed by and is owned by Elsevier. It is the largest abstract and citation database of peer reviewed research literature in the world, with abstracts and citation information from more than 45 million scientific research articles in 20,000 peer-reviewed journals published by over 5,000 publishers spanning all science sectors, including the Arts & Humanities. (Scopus covers more than 3,000 publications in the field of Arts & Humanities). Scopus covers approximately 5900 titles from North-America, 8400 from Europe, 2800 from Asia-Pacific and 800 from Latin-America and Africa. Scopus.com is used by 1,900 customers, with more than 3 million users in 2010. The average click through to full-text rate is 2.1M per month, with over 25.5M in 2010. Scopus currently includes over 47M publications from more than 4000 global publishers. See http://info.scopus.com for more information.

Publication output: The number of publications per country, which have at least one author affiliated to an institution in that country. A publication which is co-authored by authors from different countries, thus counts towards the publication output of each country.

CAGR: Compound Annual Growth Rate
The Compound Annual Growth Rate is defined as the year-over-year constant growth rate over a specified period of time. Starting with the first value in any series and applying this rate for each of the time intervals yields the amount in the final value of the series.

$$\mathrm{CAGR}(t_0, t_n) = (V(t_n)/V(t_0))^{\frac{1}{t_n - t_0}}$$

$V(t_0)$: start value, $V(t_n)$: finish value, $t_n - t_0$: number of years.

Publication share: The global share of publications for a specific country expressed as a percentage of the total output within the field of Chemical Sciences. Using a global share in addition to absolute numbers of publications provides insight by normalizing for increases in world publication growth and expansion of the field in question or the whole Scopus database.

Field Weighted Citation Impact: A measure of citation impact, based on the average number of citations received by a group of publications compared to the world number of citations received by the same type of publications. This metric is field weighted in that it adjusts for differing citation practices in different subject fields and therefore for the different subject emphases of comparator countries. FWCI for each year looks at the citations that publications in that particular year have received in that same year up to 4 years after publication, and compares this value of actual citations to the number of expected citations based on the subject in question, the year in question and the article types in question.

Macro-economic terms (OECD)
Gross domestic expenditure on research and development (GERD) is total intramural expenditure on research and development performed on the national territory during a given period. GERD can be split further into BERD (Expenditure on R&D in the Business Enterprise sector), HERD (Expenditure on R&D in the Higher Education sector) and GOVERD (Government Intramural Expenditure on R&D).

Gross domestic product is an aggregate measure of production equal to the sum of the gross values added of all resident institutional units engaged in production (plus any taxes, and minus any subsidies, on products not included in the value of their outputs). The sum of the final uses of goods and services (all uses except intermediate consumption) measured in purchasers' prices, less the value of imports of goods and services, or the sum of primary incomes distributed by resident producer units.

Researcher Migration
Brain inflow: inflow and returnees inflow added together

Brain outflow: outflow and returnees outflow added together

Citations per paper (cpp): the simplest method to calculate citation impact is to look at average citations per article. In this report, we look at citations in 1996-2011 and articles in 1996-2011 and divide the former by the latter.

(Country) only: researchers who appear to never have been affiliated with an institute outside the country where they first published.

Inflow: researchers who have started to publish with an affiliation in a different country, but moved into the country.
Outflow: researchers who started to publish within the country, but have left and now publish in a different country.

Relative productivity: represents articles per year since the first appearance of each researcher as an author in the database during the period 1996-2011, relative to all researchers in that country in the same period.

Relative seniority: represents years since the first appearance of each researcher as an author in the database, during 1996-2011, relative to all researchers in that country in the same period.

Returnees inflow: researchers who move out of the country and subsequently returned after more than two years.

Returnees outflow: researchers who move into the country and subsequently left after more than two years in the country.

Transitory Brain Mobility: researchers who stay less than two years either in the country of outside of the country. Transitory (mainly non-country) indicates the researchers who are based in other countries and have transitory mobility into the country of interest, whereas Transitory (mainly country) indicate researchers from within the country of interest who have shown transitory mobility to other countries.

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