CRU Logo

SCOTLAND AND INTERNATIONAL RESEARCH COLLABORATION

A BIBLIOGRAPHIC ANALYSIS

SCOTLAND AND INTERNATIONAL RESEARCH COLLABORATION

A BIBLIOGRAPHIC ANALYSIS

Evidence Ltd

Report to the Scottish Executive
June 2007

Patterns of international collaboration

Executive summary and discussion

Background

International research collaboration is a rapidly growing component of core research activity for all countries. It is driven by a consonance between top-down and bottom-up objectives. Collaboration is encouraged at a policy level because it provides access to a wider range of facilities and resources. It enables researchers to participate in networks of cutting-edge and innovative activity. For researchers, collaboration provides opportunities to move further and faster by working with other leading people in their field. It is therefore unsurprising that collaborative research is also identified as contributing to some of the highest impact activity.

This report is an exploratory one and provides a reference benchmark and a resource for further work. It is intended to provide information for policy work within the Office of the Chief Scientific Adviser, part of the Scottish Executive.

Data cover nine countries: Scotland, UK, USA, Canada, France, Germany, Japan, Australia, and China. Data are categorised by seven fields: Clinical sciences, Health and related subjects, Biological sciences, Environmental sciences, Mathematics, Physical sciences, and Engineering. Data cover two time periods: 1996-2000 and 2001-2005. Most analyses make comparisons between the earlier and more recent periods.

The report uses data on research publications. Co-authorship is likely to be good indicator of level of collaboration, although there will be collaborations which do not result in co-authored papers, and co-authored papers which may have required limited collaboration. Alternative data-based approaches, for example using information about co-funding or international exchanges, have serious limitations in terms of both comprehensiveness and validity.

Citation counts for research papers provide an indicator of the quality and impact. They need to be normalised to take account of discipline and of time since publication but they have been shown to correlate reasonably well with other, independent estimates of research significance. However, for internationally co-authored papers, some of the citations may be due to a wider exposure to the scientific communities in each country.

There are differences between disciplines and countries in the culture of publication and citation. There are also significant differences in the location of the research base (in institutes or in universities) and in the balance of the national research portfolio. It is likely that the rapid changes in research culture in China will lead to some degree of volatility in its indicators. For the more mature G7 research economies, the cultural differences are less dramatic and can be absorbed in a cross-country, cross-disciplinary analysis.

The analysis covers data for the periods 1996-2000 and 2001-2005. Therefore, it may not pick up very recent developments or the impact of policies that have only been introduced in the last few years.

Key findings

- The volume of international collaboration has increased significantly between 1996-00 and 2001-05. This trend is apparent across all the countries in this report and across all the main disciplines. The increase – in absolute volume of collaborative papers - varies from 30% for France to 60% for Scotland and over 100% for China.

- The importance of international collaboration within countries' output has increased. This is the case for all countries, and is particularly marked for Scotland where the share of international collaboration has increased relative to domestic volume more rapidly (by over 13.6% in five years) than for other G7 economies and now stands at about 40% of output and in line with European comparators. It is lowest for China (where the share has increased marginally from 25.4% to 26.0%). The rapid volume increase in Chinese international collaboration is largely due to the expansion of its output.

- The average impact of internationally co-authored work is significantly higher than the overall average. Between 96-00 and 01-05 there was a net gain on impact for Scotland in 25 of 42 country-field combinations that are analysed.

- Similarly, the countries covered in this report generally gain from collaborating with Scotland in terms of the quality and impact. This gain tends to be highest in the bio-medical and Physical sciences.

Key implications

Some key implications have become apparent in reviewing the preliminary data and the developing analyses.

- Scotland is a strong international collaborator, with substantial and growing volume and it both receives and gives added value in its partnerships.

- Scotland's value and performance is reflected in good and growing links with Europe and a sound platform of Biological science links with the US. It also has excellent wider links with Canada and Australia.

- Its links with Germany and France, their rate of growth and the quality of outcomes in those partnerships should make Scotland an important contributor to the growth of the European Research Area.

- There is room for improvement in Scotland's position elsewhere. Its position of relative international research strength (see PSA Target Indicators report) should make it an attractive partner but it is not expanding its collaborative links in new economies as rapidly as competitors.

- In China, Scotland currently has a relatively low rate of growth in collaboration across all fields. The situation is complex because China (and India) is affected by unprecedented domestic growth. Nonetheless, a low trajectory might be seen as both a concern and a significant opportunity for increased collaboration, particularly in Biological sciences where China is now increasing its activity.

- Further analysis, at the more detailed levels of specific fields and in respect to the institutional composition of international links, may help to explain the dynamics of these trends and point towards options for response.

SWOT analysis

<table>
<tr>
<td>Scotland is doing well

Between 96-00 and 01-05, Scotland has increased its output and the proportion of its output that is collaborative with other countries. The level of collaboration is in line with major European research economies.

Scotland increased its average relative collaboration faster than the USA, UK, France, Germany or Japan and at a similar rate to Canada and Australia, suggesting that smaller research economies particularly value collaboration.

Scotland has high collaboration rates with Canada and Australia.

Scotland has good collaboration with the US in bio-medicine.

For 25 of 42 field-country partnerships, Scotland has improved the quality of its collaboration in the last five years.

Most countries show significant gains in research impact compared to domestic publications when they partner with Scotland. Canada and Japan gain particular benefit.</td>
<td>Scotland is doing less well

Collaboration with China is relatively infrequent compared to larger economies. Collaboration with other countries in mathematics shows little gain and some quite marked detriments compared to other fields.</td>
</tr>
<tr>
<td>Scotland can improve its profile

China’s expansion into biomedical areas, where Scotland is strong should create scope for increased collaboration.

Scotland has a strong research base in a number of areas and should be an attractive partner for established research groups elsewhere in Europe, providing them with links to its global partners.

Scotland should build on it small but high quality links with France.</td>
<td>Scotland may be under threat

Scotland will need to avoid dropping back in European links.

The underlying quality of engineering research is particularly dependent on international links.

Scotland’s potential for collaboration is limited by its volume rather than its partners. It may therefore need to consider priorities for support and growth.</td>
</tr>
</table>

Contents of this report

The sequence of analysis is as follows:

I Volume of collaboration

II Gains from collaboration

I Volume of collaboration

An index of growth creates a baseline to which changes in collaboration can be referred.
Increased collaboration will be of interest and value whatever its source. An increase in collaboration may be due to an increase in volume by either partner (creating more opportunities for collaboration) or to an increase in relative collaboration within the existing volume because of other factors. The capacity for collaboration is dependent not only on the capability and quality of the national research base but on the existing volume of activity. If there is little activity, thus leading to limited output, then the opportunity for collaboration is naturally constrained. A high prior level of collaboration may mean there is little further capacity to engage.
For G7 nations, volume change is not usually a critical consideration since they have a well established presence in major international research serials (journals) across a wide variety of fields. For newly emergent and expanding research economies the changes in volume from year to year may be much more significant and will influence changes in other indicators.
Scotland's data should be understood in a specific context. Whereas UK international co-authorship relates to all countries outside the UK, Scotland's partners necessarily include England. Because Research Council grants are awarded within a UK context, there is likely to be a higher rate of Scotland-England regional links than is generally true across national borders.

Table 1 Growth of total research output and collaboration

		1996-2000				2001-2005				Change in output	
Country and abbreviation		Output	Output % world	Collaboration	Collab % output	Output	Output % world	Collaboration	Collab % output	Volume increase as % 96-00	Collaboration increase as (%96-00) - (%01-05)
Scotland incl UK links	SCO	44,842	1.2	17,253	38	47,864	1.2	26,547	55	6.7	17.0
Scotland excl UK links				11,478	26			18,767	39		13.6
UK Total	UK	338,391	9.4	97,592	29	358,674	8.9	144,457	40	6.0	11.4
USA	USA	1,262,295	35.0	244,911	19	1,352,443	33.6	334,662	25	7.1	5.3
Canada	CAN	167,224	4.6	55,429	33	184,378	4.6	75,659	41	10.3	7.9
France	FRA	229,843	6.4	82,076	36	244,825	6.1	107,729	44	6.5	8.3
Germany	GER	310,023	8.6	106,821	34	340,882	8.5	146,615	43	10.0	8.6
Japan	JAP	329,430	9.1	54,346	16	360,880	9.0	77,197	21	9.5	4.9
Australia	AUS	100,487	2.8	30,743	31	116,954	2.9	46,502	40	16.4	9.2
China	CHI	101,613	2.8	25,836	25	210,099	5.2	54,529	26	106.8	0.5
WORLD		3,602,597				4,019,419				11.6	

In Table 1 there are two lines for Scotland. The first line includes all collaboration with partners outside Scotland, **including that elsewhere within the UK**. There are 7,780 Scotland – [UK] papers in 2001-2005, which is about one-third of the total (26,547) and are *additional* to the 18,767 international papers which cover all countries outside the UK for the same period. The figure is included for reference comparisons.

For Scotland including links with England, Wales and N Ireland, collaboration as a proportion of output increased more rapidly than for any other country (17%, or about 9,000 papers). On this basis, Scotland would have a higher proportion of its papers with international co-authorship than any other country in the analysis.

When we consider Scotland excluding these links within the UK, collaboration grew by a similar amount to and slightly more than the UK as a whole. On this basis, Scotland's proportion of its papers with international co-authorship is similar to other European countries in the analysis.

Two points therefore need to be borne in mind. First, comparisons between Scotland and the UK would not necessarily be like-for-like. Second, Scotland has external links that are not 'international' in the same sense as other countries. Some of these are promoted by the structure of UK funding mechanisms. However, all direct links (such as UK-USA and Scotland-USA) should be comparable.

There has been a relatively rapid collaboration growth for the UK as a whole (11.4%, about 46,000 papers in absolute terms). The UK's output volume increased more slowly than other countries, however, whereas for Scotland the underlying growth rate was in line with the USA and France.

China more than doubled its output between the two five-year windows. Its share of world outputs has increased very significantly, from less than 3% to more than 5% of world outputs. Its relative capacity for collaboration will therefore have risen proportionally so we should predict that most countries would have a greater level of collaboration with China in the later period.

In fact, as the table shows, collaboration as a proportion of activity has increased for all the leading research economies. Japan and the US are less collaborative than the other established research nations, where collaboration has risen from around 30% to around 40% of domestic activity.

China's growth makes it difficult to appreciate the change in collaboration, which is a doubling in absolute terms but a static position (around 25% of output) relative to the domestic activity. That also means that its capacity for further collaboration remains very substantial.

Balance across fields

There are important differences in the balance of 'portfolios' even among well established research economies (see extended report). This affects the relative capacity for collaboration.

Scotland (like the rest of the UK) is most similar to the USA, Canada and Australia in having both a well-developed research base in Higher Education and around 60% of outputs in Bio-Medicine and Health. By contrast, France, Germany and Japan have a research base in which dedicated research institutes play a major role and much more of their output is in Physical sciences and Engineering.

China has the bulk of its research outputs in the Physical sciences and Engineering, which makes a closer 'match' to France/Germany than UK/USA. China has had very little Bio-medical research in the past, though this is now changing.

Table 2 – Changing volume of international collaboration

Table 1 indicated national total volume and the proportion of activity that was internationally collaborative. Table 2 analyses that collaboration between partners.

Table 2 provides evidence for the effects of geography (within Europe and around Pacific-Asia), the effects of increase in baseline volume (with China) and both quality (the primacy of links to the US) and the balance of national portfolios.

The growth in international collaboration is marked and universal. The baseline for the G7 is a growth ratio around 1.5: in other words, the volume of collaborative articles is at least half as much again in the more recent five-year window. This compares with a typical volume growth ratio of 5-10% (Table 1). So, collaboration has not only increased but it has increased relative to the underlying change in volume.

The change in relative levels of collaboration is also albeit less markedly true for China (volume growth of 2.07 and a collaboration growth of 2.13). That China has increased its relative collaboration alongside such a massive expansion in volume activity is quite remarkable and must reflect a wholesale commitment to engagement with the international research community.

Australia's commitment to collaboration is also evident in these data, where its average growth in collaboration is 1.68 compared to the G7 1.5. This growth is also on a significantly greater volume of collaboration than India's, so it is a substantial change.

The smallest rates of increase in collaboration were in the links between the USA and European G7 partners (1.3-1.4). However, within Europe rates of growth were higher (1.4-1.7). This contrast suggests that slow growth is not a consequence of the G7 partnerships being 'saturated'. The increased activity intra-Europe may be both due to overall improvements in research performance and because of policy and financial support from the European Commission.

Scotland has increased its average relative collaboration (by a factor of 1.6) which is more than the USA, UK, France, Germany or Japan and is similar to Canada and Australia. This may suggest that smaller research economies generally have recognised the value of collaboration as a route to gaining gearing against national investment and accessing facilities and expertise.

On average, other countries share about 2% of their collaboration with Scotland (but 5.4% for the rest of the UK). Scotland has a relatively small share of collaboration with the USA (1.8% compared with this 2% average). However, distance does not seem to be a barrier in creating links as collaboration with both Canada (2.4%) and Australia (2.9%) is relatively high. The rate of increase in links between Scotland and Canada is also high.

China collaborates most with the US (as expected) and then with Japan, which is likely to be driven by geographical factors. It collaborates much more with the UK (10.1% of total) and Germany (9.9%) than other EU nations. Collaboration with Scotland is relatively low (1.4%) and the rate of growth (1.7 against an average of 2.1) is the lowest in the group. This may be an area where there is a need to focus on and address the increasing opportunities that East Asia offers.

Geographical proximity evidently plays a key role in partnerships, and not only between Scotland the rest of the UK. This is driving growth between the major players around the Pacific and more widely in Asia (e.g. China-India growth rate) but it is also driving the expansion of strong prior links within Europe.

Table 2 Changing volume of international collaboration

(a) Collaborative output by Country

	1996-2000 Total	SCO	UK	USA	CAN	FRA	GER	JAP	AUS	CHI	*2001-2005* Total	SCO	UK	USA	CAN	FRA	GER	JAP	AUS	CHI
Scotland	11478			4005	941	1607	1939	631	864	443	18767			5949	1780	2254	3164	957	1370	747
UK	97592			30874	6138	11114	13490	4988	6039	2838	144457			43337	9248	15502	20235	6658	9573	5505
USA	244911	4005	30874		28754	20744	32095	23711	10679	9226	334662	5949	43337		38913	27135	43921	31148	15999	20542
Canada	55429	941	6138	28754		4791	4136	3069	2433	1801	75659	1780	9248	38913		6423	6464	3933	3672	3688
France	82076	1607	11114	20744	4791		11863	3119	1772	1351	107729	2254	15502	27135	6423		16609	4646	2753	2774
Germany	106821	1939	13490	32095	4136	11863		5485	2729	2754	146615	3164	20235	43921	6464	16609		7464	4388	5401
Japan	54346	631	4988	23711	3069	3119	5485		1986	3915	77197	957	6658	31148	3933	4646	7464		2964	8631
Australia	30743	864	6039	10679	2433	1772	2729	1986		1463	46502	1370	9573	15999	3672	2753	4388	2964		3663
China	25836	443	2838	9226	1801	1351	2754	3915	1463		54529	747	5505	20542	3688	2774	5401	8631	3663	

(b) Changing patterns of collaboration

		Relative increase: ratio (01-05)/(96-00)										***Share (%) of collaboration, by partner country (2001-05)***								
Scotland				1.5	1.9	1.4	1.6	1.5	1.6	1.7				31.7	9.5	12.0	16.9	5.1	7.3	4.0
UK				1.4	1.5	1.4	1.5	1.3	1.6	1.9				30.0	6.4	10.7	14.0	4.6	6.6	3.8
USA					1.4	1.3	1.4	1.3	1.5	2.2		1.8	12.9		11.6	8.1	13.1	9.3	4.8	6.1
Canada						1.3	1.6	1.3	1.5	2.0		2.4	12.2	51.4		8.5	8.5	5.2	4.9	4.9
France							1.4	1.5	1.6	2.1		2.1	14.4	25.2	6.0		15.4	4.3	2.6	2.6
Germany								1.4	1.6	2.0		2.2	13.8	30.0	4.4	11.3		5.1	3.0	3.7
Japan									1.5	2.2		1.2	8.6	40.3	5.1	6.0	9.7		3.8	11.2
Australia										2.5		2.9	20.6	34.4	7.9	5.9	9.4	6.4		7.9
China												1.4	10.1	37.7	6.8	5.1	9.9	15.8	6.7	
Average		1.6	1.5	1.5	1.6	1.5	1.5	1.5	1.7	2.1		2.0	13.2	35.1	7.2	8.5	12.1	7.0	5.0	5.5
		SCO	**UK**	**USA**	**CAN**	**FRA**	**GER**	**JAP**	**AUS**	**CHI**		**SCO**	**UK**	**USA**	**CAN**	**FRA**	**GER**	**JAP**	**AUS**	**CHI**

Table 2a indicates the numbers of articles jointly authored between pairs of countries in the earlier and more recent five-year windows. These figures are reciprocal (i.e. collaboration between A-B = between B-A) and so the table is symmetrical.

The first (left) part of Table 2b shows the ratio between early and recent collaborative output between the countries. The absolute volume is affected by the size – and growth - of each partner. The second (right) part of Table 2b shows the recent collaboration as a percentage of national output. This is not symmetrical because A-B as a %age of A is not the same as A-B as a %age of B. Read across rows for national data: thus, 31.7% of Scotland's collaboration is with the USA but only 1.8% of US collaboration is with Scotland. On average, about 2% of a partner's collaboration is with Scotland (average excludes UK).

Table 3 International collaboration for key focus countries analysed by field

Table 3 covers key-focus countries that are leading research economies. The data are configured to enable more ready comparison across fields among these countries.
Note that disaggregated data do not necessarily equal the national totals (in Table 1) because of duplication of journals that cover multiple fields (e.g. in Clinical, Health and Biological sciences). Data are entirely comparable within these fields.

If we compare the growth ratio for Scotland by field and by partner country with the UK as a whole (analysed in a separate report for OSI, London) then there is no consistent difference. There are some areas where Scotland has grown faster than the rest of the UK and others where it is slower, although some of the differences are small. For example, Scottish collaboration with Germany has grown faster than the rest of the UK in five out of seven fields and it has grown faster than the rest of the UK with all partners in Engineering.

One area for of likely interest is collaboration with China. While the UK has increased the volume of its collaboration with China significantly it has done so at a slower rate than other major research-based countries. Scotland has generally expanded its links at a slower rate than the rest of the UK, except in Maths and Engineering.

It may be particularly surprising that Scotland has not been able to expand its links more rapidly in Biological sciences, both because this is an area of strength and an area where China is now expanding its effort most rapidly from a relatively low base. The US has expanded substantially in this area and Scotland may wish to look for similar opportunities. It is notable that Scotland's links with the US in Biological sciences have grown faster than the rest of the UK, and make up 17% of UK collaboration in this subject with the US (compared to 13% overall) which may be taken to reflect a view in the US of relative research strength.

The data show that Scotland has been prominent in the UK's growing collaboration with Germany. It has done so at a better rate than the US or France. Its links with France also expanded at a satisfactory rate, but more so in fields such as the Physical sciences than in others. The data suggest that established nations are responding to Scottish research strengths, which is support for metrics reported elsewhere.

For the US, collaboration with the UK is twice as great as with France in bio-medical fields but more even elsewhere. US links with UK vs. Germany are balanced. They are generally tilted to the UK - and particularly to Scotland - in bio-medicine and to Germany in Physical science and Engineering. This has been interpreted to reflect the balance of national portfolios. However, Scotland also has relatively good US links in Physical sciences.

France's balance of collaboration is driven by similar factors to Germany, favouring the UK in bio-medical fields and Germany in physico-technological fields. But it too has relatively faster growth in links with Scotland physico-technological fields compared to the rest of the UK.
The patterns are complex and require further reflection. For future analyses it would be appropriate to produce more detailed snapshots for countries and fields.

Table 3 International collaboration for key focus countries analysed by grouped fields

	Collaborative output by country 1996-2000							*Collaborative output by country 2001-2005*							*Growth ration between 96-00 and 01-05*					
Scotland	**Total 96-00**	**SCO**	**UK**	**USA**	**FRA**	**GER**	**CHI**	**Total 01-05**	**SCO**	**UK**	**USA**	**FRA**	**GER**	**CHI**	**SCO**	**UK**	**USA**	**FRA**	**GER**	**CHI**
Clinical	9093			2062	728	881	146	13315			2798	966	1271	166			1.36	1.33	1.44	1.14
Health & Medically Related Subjects	1116			238	111	85	12	1486			329	108	131	16			1.38	0.97	1.54	1.33
Biological Sciences	6421			1320	546	592	95	9338			1929	725	896	139			1.46	1.33	1.51	1.46
Environment	2081			379	143	156	24	3330			572	227	266	50			1.51	1.59	1.71	2.08
Mathematics	448			154	14	34	30	717			129	33	51	57			0.84	2.36	1.50	1.90
Physical Sciences	4348			1154	663	876	219	7362			2083	943	1476	430			1.81	1.42	1.68	1.96
Engineering	2766			529	190	285	109	4411			699	287	453	221			1.32	1.51	1.59	2.03
UK																				
Clinical	50119			16147	5345	6443	886	70706			23362	7264	10041	1564			1.45	1.36	1.56	1.77
Health & Medically Related Subjects	6468			1933	689	671	118	8356			2695	847	957	169			1.39	1.23	1.43	1.43
Biological Sciences	29109			8235	2994	3457	539	39269			11230	4008	4816	1129			1.36	1.34	1.39	2.09
Environment	9867			2598	1101	1101	273	15470			4299	1689	2070	588			1.65	1.53	1.88	2.15
Mathematics	3746			1143	237	347	272	5309			1324	421	499	463			1.16	1.78	1.44	1.70
Physical Sciences	35066			10036	4650	5946	1166	44758			13252	6438	8057	2314			1.32	1.38	1.36	1.98
Engineering	22537			4428	2186	2724	1102	28927			5797	2817	3513	2058			1.31	1.29	1.29	1.87
USA																				
Clinical	118719	2062	16147		8487	14537	2530	163821	2798	23362		11530	22173	6478	1.36	1.45		1.36	1.53	2.56
Health & Medically Related Subjects	13320	238	1933		901	1341	340	17049	329	2695		1073	1744	663	1.38	1.39		1.19	1.30	1.95
Biological Sciences	61506	1320	8235		4947	6714	1492	84984	1929	11230		6234	9283	4163	1.46	1.36		1.26	1.38	2.79
Environment	20281	379	2598		1834	2117	807	32461	572	4299		2806	3556	2350	1.51	1.65		1.53	1.68	2.91
Mathematics	12136	154	1143		1068	1184	873	15541	129	1324		1494	1431	1652	0.84	1.16		1.40	1.21	1.89
Physical Sciences	82710	1154	10036		8785	14887	3946	105977	2083	13252		10947	17998	7932	1.81	1.32		1.25	1.21	2.01
Engineering	52897	529	4428		4066	6795	3348	71224	699	5797		4882	8193	6330	1.32	1.31		1.20	1.21	1.89
France																				
Clinical	27907	728	5345	8487		3844	275	36073	966	7264	11530		5702	508	1.33	1.36	1.36		1.48	1.85
Health & Medically Related Subjects	3672	111	689	901		426	27	4065	108	847	1073		528	63	0.97	1.23	1.19		1.24	2.33
Biological Sciences	19885	546	2994	4947		2468	185	26029	725	4008	6234		3283	433	1.33	1.34	1.26		1.33	2.34
Environment	7482	143	1101	1834		807	138	11062	227	1689	2806		1451	320	1.59	1.53	1.53		1.80	2.32
Mathematics	3880	14	237	1068		336	99	5943	33	421	1494		515	202	2.36	1.78	1.40		1.53	2.04
Physical Sciences	40507	663	4650	8785		7138	839	51615	943	6438	10947		9493	1726	1.42	1.38	1.25		1.33	2.06
Engineering	22868	190	2186	4066		3300	367	29719	287	2817	4882		4250	837	1.51	1.29	1.20		1.29	2.28
Germany																				
Clinical	38323	881	6443	14537	3844		334	56171	1271	10041	22173	5702		883	1.44	1.56	1.53	1.48		2.64
Health & Medically Related Subjects	4340	85	671	1341	426		54	5288	131	957	1744	528		122	1.54	1.43	1.30	1.24		2.26
Biological Sciences	24606	592	3457	6714	2468		353	32830	896	4816	9283	3283		880	1.51	1.39	1.38	1.33		2.49
Environment	7434	156	1101	2117	807		215	12591	266	2070	3556	1451		528	1.71	1.88	1.68	1.80		2.46
Mathematics	4097	34	347	1184	336		225	5484	51	499	1431	515		364	1.50	1.44	1.21	1.53		1.62
Physical Sciences	55995	876	5946	14887	7138		1962	71572	1476	8057	17998	9493		3551	1.68	1.36	1.21	1.33		1.81
Engineering	29051	285	2724	6795	3300		1143	37714	453	3513	8193	4250		1856	1.59	1.29	1.21	1.29		1.62
China																				
Clinical	5810	146	886	2530	275	334		12590	166	1564	6478	508	883		1.14	1.77	2.56	1.85	2.64	
Health & Medically Related Subjects	953	12	118	340	27	54		1689	16	169	663	63	122		1.33	1.43	1.95	2.33	2.26	
Biological Sciences	4271	95	539	1492	185	353		10507	139	1129	4163	433	880		1.46	2.09	2.79	2.34	2.49	
Environment	2202	24	273	807	138	215		5873	50	588	2350	320	528		2.08	2.15	2.91	2.32	2.46	
Mathematics	2499	30	272	873	99	225		4779	57	463	1652	202	364		1.90	1.70	1.89	2.04	1.62	
Physical Sciences	13162	219	1166	3946	839	1962		26114	430	2314	7932	1726	3551		1.96	1.98	2.01	2.06	1.81	
Engineering	11203	109	1102	3348	367	1143		21696	221	2058	6330	837	1856		2.03	1.87	1.89	2.28	1.62	

II Gain from collaboration

This part of our report focuses on the relative quality of Scottish authored papers that have or have not been co-authored with another researcher based at a non-Scotland address outside the UK.

We consider the gains to Scotland in terms of collaboration by field and by partner country. Finally, we analyse the gains each country gets from partnering with the UK.

The measure of quality used here is based on the number of citations that each paper receives from subsequent publications. We first provide an overview of UK data as a charted profile ands we then analyse the data by field and by partner country.

Diversity of competence within collaborators

Discussions with the OSI secretariat, around an early version of a related report, drew attention to the issue of balance of competence in relation to the diversity of 'gain' from collaboration.

First, it is obvious that not all added value is being measured by bibliometrics which focus solely on a metric related to publication quality. Other gains include access to knowledge and facilities and the establishment of a longer term relationship. For new researchers they also offer the experience of working in and managing international links.

Second, while many links revolves around leading researchers, because of limited capacity for collaboration it is inevitable that a 'second-tier' of researchers will have opportunities to become involved. The Internet enables this wider collaboration at relatively low resource cost. (The 'second-tier' concept originates with Professor Ben Martin, SPRU, University of Sussex). This will happen in some countries and in some fields more quickly than elsewhere.

The consequence of the diversity of competence is that links that engage the second-tier rather than lead researchers may well produce outcomes of lower bibliometric impact. Nonetheless, they may be worth sustaining if Scotland gains access of longer term value and if Scotland second-tier researchers gain experience that raises their potential. We cannot test this with the present data, but more detailed analyses would enable an exploration of associations between impact, fields and institutions.

Citations as an index of excellence

Every research publication makes reference to prior work, sometimes as a 'short-hand' to refer to an authority on methodology or fact or sometimes as part of the process of developing ideas. It has long been recognised that the number of times a paper is subsequently referred to or 'cited' is a reflection of its 'impact' on related work. Thus, a citation count reflects impact, higher impact reflects higher quality, and impact indices become a proxy for relative performance or excellence.

Citation behaviour varies between fields. Older papers have more time to accumulate citations. Initial citation counts for each paper analysed are therefore normalised (or rebased) to take account of year of publication and the field within which the journal is located. We therefore refer to ReBased Impact (RBI) at various points to indicate indices that may be readily used or comparative purposes.

Citation counts for single papers are usually less informative for policy purposes than averages. However, research performance data tend to be skewed and averages are not necessarily a good guide to the centre of a distribution.

Commentary on Tables 4 and 5

The next two tables analyse the specific gain made at the field level by collaboration with different partner countries. Within Europe it is likely that many papers will be 'triangular' including three (or more) partner countries. We have made no attempt to account for the subtleties of these effects but looked simply at pair-wise relationships, whether or not they included additional partners.

Table 4 focuses on Scotland and breaks out the data for the earlier period 1996-2000 and the recent period 2001-2005, analysed by the same main STEM fields as in the previous tables. The first row looks at Scotland's overall performance.

In the body of the Table, there has been improvement in the relative impact of cited papers between the early and recent periods. For 25 of 42 combinations of partner country and field, average impact rose in the recent period. This was most consistent in Engineering and Biological sciences.

Table 4 reveals subtle changes that will need further reflection to interpret. Previous work has suggested that the US is usually the partner that confers the greatest benefit. Scotland certainly appeared to gain significantly across fields from that collaboration in the early period (2.71 average rank) but the pattern was far from consistent. France was a strong partner in Clinical (impact = 2.93) and Health while collaboration in Physical sciences with Japan stood out (impact = 4.4).

Data for the more recent period indicate that the Physical science's link with Japan is sustained and that the US position remains inconsistent. There are collaborative links with other countries that now provide equal or greater benefit compared to that gained from the US. For example, Scotland-France collaboration is usually less by volume and is growing more slowly than with Germany but the average gain is on average greater (rank = 2.71 cf US rank = 2.86).

It is also evident that collaboration 'gain' varies by field. Health related subjects showed a strong gain but have fallen back markedly in the later period. Physical sciences usually show a markedly greater gain than Engineering (e.g. for the US = 2.81 cf 2.00).

Scotland, as we have also reported for the UK as a whole, appears to suffer an actual detriment in some areas when it collaborates. Mathematics is an area that seems particularly prone to this problem, and only collaboration with France (1.35) and Germany (1.23) show a gain over average (1.17).

Links with China show a number of areas of detriment in the early and later periods. This pattern is at least partly because China has a low domestic impact at present. Indeed, China's collaboration with the US has an average impact that is uniformly lower across fields than US domestic impact. Professor Ben Martin (SPRU, Sussex) has suggested that this may be because the peak of collaborative capacity is absorbed in some links leaving a second-tier to engage in other links. Partners do not actually lose from this, since the benefit is as much through the experience of collaboration and the potential for higher quality partnerships in the future.

What must also be examined is the extent to which some partnerships are based on other gains than research excellence. While excellence is certainly the basis of collaboration in established economies, priorities may differ in newly emerging economies with low present impact.

Table 5 looks at the gain made by countries when they partner with Scotland. The gain in impact from collaboration raises their impact in bio-medical areas (e.g. Japan from 0.85 rebased impact to 2.84) and in Physical sciences (e.g. USA from 1.55 to 2.81) compared with their average. These areas reflect those where Scotland has increased its relative volume of collaboration and suggest that this growth may be linked to relative success.

There are, as in Table 4, examples of lower impact in collaboration than in domestic research. Most countries appear to gain rather little benefit from their Mathematical links to Scotland (e.g. US reduction from 1.32 to 1.09). This may again be explained by ‘second-tier’ activity, where limited capacity is stretched by major collaborations in Europe (France and Germany both gain from Scotland links in Maths).

Table 4 Relative impact of papers comparing Scotland as a whole with Scotland-coauthored, analysing by STEM category

Partner country	Clinical		Health		Biological		Environment		Mathematics		Physical		Engineering		Average rank in terms of Scotland gain
1996-2000	Impact	Rank													
SCOTLAND	1.23		1.53		1.08		1.10		0.98		1.30		0.99		
+ USA	2.59	3	3.58	4	2.11	1	2.10	2	1.33	2	3.18	3	1.55	4	2.71
+ CANADA	2.47	4	3.54	5	1.69	4	1.85	4	1.34	1	3.42	2	1.66	3	3.29
+ FRANCE	2.93	1	4.65	1	1.53	5	1.60	6	0.71	5	3.18	4	2.10	1	3.29
+ GERMANY	2.70	2	4.28	2	1.82	3	2.02	3	1.24	3	3.03	5	2.08	2	2.86
+ JAPAN	2.45	5	3.65	3	1.90	2	1.78	5	0.98	4	4.40	1	1.31	5	3.57
+ AUSTRALIA	2.02	6	2.59	7	1.27	6	1.57	7	0.70	6	1.42	7	1.03	6	6.43
+ CHINA	1.83	7	3.31	6	0.95	7	3.18	1	0.41	7	2.08	6	0.63	7	5.86
2001-2005															
SCOTLAND	1.29		1.47		1.30		1.27		1.17		1.44		1.15		
+ USA	2.47	4	2.94	2	2.08	2	2.14	1	1.09	3	2.81	4	2.00	4	2.86
+ CANADA	2.48	3	4.84	1	1.52	6	1.48	5	0.85	4	3.06	3	2.89	1	3.29
+ FRANCE	2.66	2	2.83	3	1.88	3	1.83	3	1.35	1	2.79	5	2.40	2	2.71
+ GERMANY	2.37	5	2.56	4	1.88	4	2.07	2	1.23	2	2.49	6	2.35	3	3.71
+ JAPAN	2.84	1	2.27	5	2.28	1	1.23	6	0.23	7	3.74	2	1.59	6	4.00
+ AUSTRALIA	2.21	6	1.55	7	1.62	5	1.80	4	0.70	6	3.83	1	0.96	7	5.14
+ CHINA	2.10	7	1.76	6	1.32	7	0.73	7	0.72	5	2.27	7	1.80	5	6.29

While Scotland's greatest co-publication gains have often been with the USA, this pattern is changing. Sometimes other countries now offer greater gains: for example, France also adds significant value. By contrast gains are much less with China.

To provide a simple index of relative 'gain', the impact data within subjects is ranked by country and the average rank in terms of Scottish gain for each country is in the right-most column. This indicates that in 96-00 the US average rank by subject was best at 2.71, with France on 3.29 and Germany on 2.86. Recently, in 01-05, the average US rank fell to 2.86, France rose to 2.71 while Germany fell to 3.71.

The country rank positions of 'gain' are much less consistent than for the UK as a whole, where the US position was 1.7 in the early period and 2.6 recently.

Table 5 Relative impact of papers co-authored with Scotland (2001-2005), analysing collaboration gain by STEM category for countries of non-Scotland co-author

		Clinical	Health	Biological	Envir'nt	Maths	Physical	Eng'ing	Average
USA	Overall	1.32	1.45	1.43	1.29	1.32	1.55	1.33	
	With Scotland	2.47	2.94	2.08	2.14	1.09	2.81	2.00	
	Gain from Scotland	1.15	1.49	0.66	0.85	-0.24	1.26	0.67	0.83
Canada	Overall	1.22	1.41	1.02	1.18	0.99	1.26	0.98	
	With Scotland	2.48	4.84	1.52	1.48	0.85	3.06	2.89	
	Gain from Scotland	1.26	3.43	0.50	0.30	-0.14	1.79	1.91	1.29
France	Overall	1.12	1.05	1.17	1.22	1.13	1.11	1.14	
	With Scotland	2.66	2.83	1.88	1.83	1.35	2.79	2.40	
	Gain from Scotland	1.55	1.78	0.71	0.61	0.22	1.68	1.26	1.12
Germany	Overall	1.11	1.19	1.28	1.28	1.10	1.26	1.31	
	With Scotland	2.37	2.56	1.88	2.07	1.23	2.49	2.35	
	Gain from Scotland	1.26	1.36	0.60	0.79	0.13	1.23	1.04	0.92
Japan	Overall	0.85	0.69	0.94	0.87	0.75	0.97	1.03	
	With Scotland	2.84	2.27	2.28	1.23	0.23	3.74	1.59	
	Gain from Scotland	1.99	1.58	1.34	0.37	-0.52	2.77	0.57	1.16
Australia	Overall	1.07	1.08	0.93	1.18	1.17	1.14	0.98	
	With Scotland	2.21	1.55	1.62	1.80	0.70	3.83	0.96	
	Gain from Scotland	1.14	0.47	0.69	0.62	-0.46	2.68	-0.02	0.73
China	Overall	0.73	0.62	0.55	0.71	0.85	0.66	0.78	
	With Scotland	2.10	1.76	1.32	0.73	0.72	2.27	1.80	
	Gain from Scotland	1.38	1.14	0.77	0.02	-0.13	1.60	1.01	0.83