Shifting patterns in international research cooperation

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Preface

The global scientific landscape has changed dramatically since the end of the Cold War. The scientific rise of China, as well as other emerging countries, has coincided with a rapid, perhaps unprecedented, increase in international academic cooperation. However, in recent years, mounting geopolitical friction and other developments are shaping a new context which is starting to affect the trajectory and patterns of scientific collaboration.

This document is part of a series of reports aimed at covering the development of international scientific cooperation against the backdrop of changes in the international rules-based global order, global research ethics and norms, and increasingly urgent global societal challenges which require international coordination and cooperation within research, development, and regulation. We believe that this analysis can provide relevant insights for academia, industry, and government.

This report was authored by Dr Igor Martins, University of Cambridge, and Prof. Sylvia Schwaag Serger, Lund University. The research was funded by the Marianne and Marcus Wallenberg Foundation.

The analysis, conclusions and recommendations are those of the authors alone and STINT does not take a position on these. STINT initiates and presents research-based analyses relevant to policies on the internationalisation of research and higher education. It is our hope that this report may form a knowledge base for decision-makers and contribute to responsible internationalisation of Swedish research and higher education.

Dr Andreas Göthenberg
Executive Director, STINT

June 2023

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Analysis

This document covers trends and collaborative patterns over time and across a range of countries and/or regions. Our analysis has three important frames of reference: US, Chinese, and Swedish-based scholars. From these frames of reference, we analyze the collaborative landscape between the aforementioned scholars and scholars from the United Kingdom, Germany, a selection of Latin American[1] (LatAm) countries, and a selection of African[2] countries. The data was extracted from Scopus[3] and only published articles are considered.

The analysis is divided into three broad sections. In the first section, we retrieved the total number of papers per country of affiliation covering the period from 1980-2021 to understand long-term trends across different academic environments. The second section contains additional detail as we divide the totals into selected fields of study. In the third section, we analyze the trends in academic collaboration between our frames of reference and other countries or regions of interest. We subdivided this section to cover each frame of reference separately.

Total publications

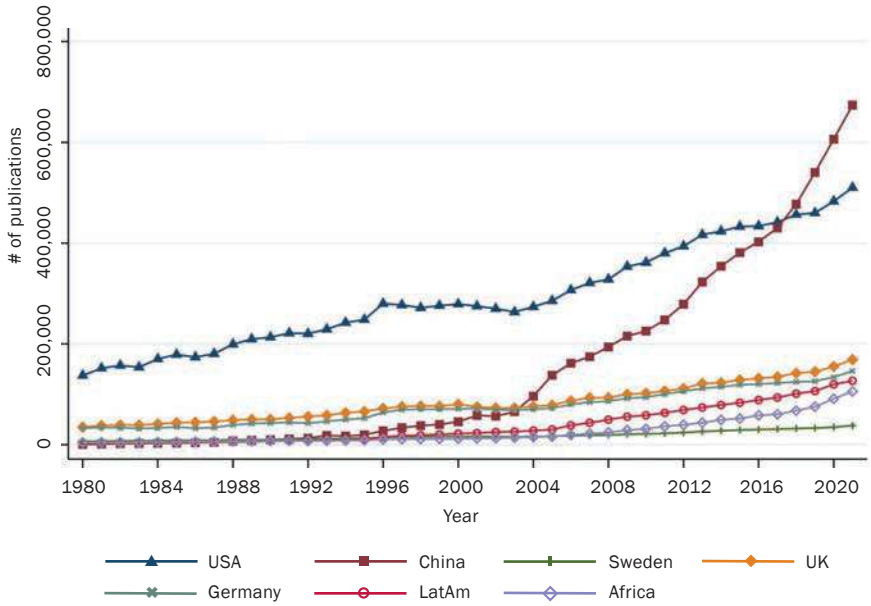
We collected the total number of papers per country of affiliation covering the period from 1980-2021, as described below:

1. All papers involving at least one US-based scholar;
2. All papers involving at least one Chinese-based scholar;
3. All papers involving at least one Swedish-based scholar;
4. All papers involving at least one LatAm-based scholar;
5. All papers involving at least one African-based scholar;
6. All papers involving at least one German-based scholar;
7. All papers involving at least one UK-based scholar.

During this phase, the objective was to collect aggregate values that could inform general trends on how different countries of affiliation are performing over time. These results are displayed in Figure 1. This report, it must be noted, utilizes "whole counts", meaning that articles with authors from several countries are counted as one country for each of the contributing countries. While this has implications when analyzing totals, relative trends remain robust.

[1] Includes Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, and Venezuela.
[2] Includes Algeria, Egypt, Ethiopia, Ghana, Kenya, Morocco, Nigeria, South Africa, Tunisia, and Uganda.
[3] Scopus is Elsevier's abstract and citation database launched in 2004. Scopus covers nearly 36,377 titles from approximately 11,678 publishers, of which 34,346 are peer-reviewed journals in top-level subject fields: life sciences, social sciences, physical sciences and health sciences. See https://www.scopus.com/ for further information.

Figure 1: **Total papers published including at least one author from a given country or region of affiliation, 1980–2021. Source: Scopus Preview (2022).**

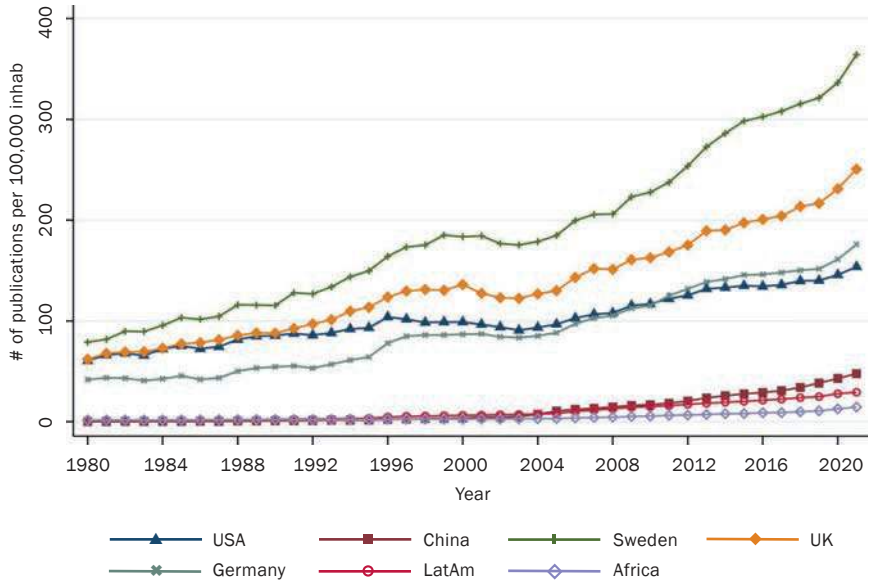


The number of publications authored by at least one Chinese-based scholar grows exponentially after the early 2000s, something already well acknowledged in the literature (Zhou and Leydesdorff 2006; Schwaag Serger et al. 2015). Conversely, the US growth is a lot more modest especially from the mid-90s up to 2004, with this trend only to be broken once China displayed early signs of exponential growth.

It is also possible to note a relative stagnation in the number of publications from Swedish-based scholars. This specific trend, however, is misleading due to Sweden's relatively small population. From 2012 to 2021, published articles involving at least one Swedish-based author went from 24,000 to nearly 38,000, a 57% increase. In comparison, the United Kingdom grew 51%, Germany 38% and the United States 30%. Africa, China, and Latin America grew 168%, 142%, and 84%, respectively. The analysis of published articles per capita in Figure 2 shows that Swedish academia is considerably more prolific than any of our frames of reference and has been so in per capita terms at least since the 1980s, with a widening gap ever since.

While the reasons for this assessment may be merely quantitative – i.e. Sweden has more researchers per capita than the others – the literature has consistently pointed to the role of funding as fundamental to Swedish success (Benner and Sandström

Figure 2: **Total articles published including at least one author from a given country or region of affiliation per 100,000 inhabitants, 1980–2021. Source: Scopus Preview (2022).**



2000; Benner and Sörlin 2007; Hallonsten and Silander 2012; Hallonsten 2022) and, interestingly, it is not the scholars' competition for funding that is driving such productivity but, in fact, *funders' competition for scholars,* especially among the centers of excellence (Borlaug 2016). While research suggests that increased competition for funding does have a positive effect on publication productivity, this relationship is far from straightforward (Auranen and Nieminen 2010). Future lines of inquiry should consider if additional funding is merely translated to more research or if it also has an impact on quality, especially in a landscape where alternative methods to communicate research include social media along with the development of popular professional and scientific websites and blogs. Recent research, however, suggests that papers and patents are becoming less disruptive over time (Park et al. 2023) and this is also true for the most prolific authors (Ioannidis et al. 2018).

Another important conclusion after analyzing Figures 1 and 2 is that China, despite its impressive growth in the absolute number of publications, still has room to grow on per capita terms as it is far behind the United States and the other European nations of this sample. In 2021 Chinese-based scholars published roughly 670,000 articles, representing 47.7 articles per 100,000 inhabitants. If Chinese

publications per capita reach US levels (153 per 100,000 inhabitants), *ceteris paribus*, then Chinese-based scholars would be responsible for roughly 2.1 million publications in a single year. While such a relationship is most certainly not linear and this calculation also includes a plethora of collaborative efforts, the Chinese growth in the absolute number of publications from 2004 to 2021 suggests that this is not at all implausible while efforts to achieve such an objective are well underway (Schwaag Serger and Breidne 2007; Ye 2022).

Totals per field of study

During the second phase, we were interested in segmenting our sample by field of study[4] while considering a restriction pertaining to the country of affiliation to track the development of co-publications and collaborative efforts. There were 7 queries of interest during this phase covering the period from 1980-2021:

1. All papers involving at least one US-based scholar per field of study;
2. All papers involving at least one Chinese-based scholar per field of study;
3. All papers involving at least one Swedish-based scholar per field of study;
4. All papers involving at least one German-based scholar per field of study;
5. All papers involving at least one UK-based scholar per field of study;
6. All papers involving at least one LatAm-based scholar per field of study;
7. All papers involving at least one African-based scholar per field of study.

The results per field of study are, however, slightly more complex to interpret as some articles pertain to multiple fields of study simultaneously (e.g. "Physics and Astronomy" or "Mathematics"). In such cases, an article will appear when the query retrieves all articles in Physics and Astronomy and when it retrieves all articles in Mathematics. Consequently, the sum of the parts is greater than the total but, since the article would be accounted for in both fields, there is no distortion in the relative trends. In this report, we selected a few fields of interest where it is possible to observe important patterns, as demonstrated in Figure 3.

First, the exponential growth in the number of publications involving a Chinese-based author is verified in most of the fields including the ones pertaining to the Humanities albeit this growth has not been as pronounced, in line with expectations (Zhou et al. 2009). While Figure 3 only contains Social Sciences as a representative of such field, it does offer a good indication of the lower propensity, relatively speaking, of Chinese-based scholars to publish in the Humanities. When it comes to Science, Technology, Engineering and Medicine (STEM)

[4] See Appendix A for a list of all fields considered by this report.

fields, however, Chinese growth is impressive, especially when considering the period in which such growth occurred, suggesting that the United States is not the leader it once was, something also supported by recent research (Wagner et al. 2021). It is also interesting to note the growth in Environmental Sciences.

Second, the trend of papers involving at least one US-based scholar seems to be only modestly growing in Engineering as well as Physics and Astronomy. On the other hand, Social Sciences are experiencing robust growth. The same applies to According to the tables and Appendix, "Business, Management, and Accounting" which displayed growth after nearly a decade of modest developments during the early 2000s. The rise in medical publications is likely to be driven by windfall funding towards studying the recent COVID-19 pandemic yet both the United States and China were already displaying growth in the number of publications before 2019.

Such assessments are enhanced when analyzed together with Figure 4. The same fields are displayed but now the analysis is conducted on per capita terms. Once population differences are accounted for, we get a much more interesting interpretation. First, Sweden appears as a leader in articles published per capita in all selected fields, with a particularly strong trend observed among Social Sciences. The United Kingdom also shows robust growth, especially in Engineering as well as Business, Management, and Accounting. Second, the number of publications per capita by Chinese-based scholars is growing steadily in Engineering, and Physics and Astronomy but other fields seem to be relatively stagnant, especially Medicine. Lastly, the United States is consistently stagnant in Business, Management, and Accounting, Engineering, and Physics and Astronomy in per capita terms. While this analysis cannot account for the quality of the research produced in such fields, future lines of inquiry must consider 1) if these fields are saturated, 2) what type of incentive structure the funding schemes are producing, and 3) what such a trend means for future collaborative efforts with US-based scholars.

Figure 5 may cast some light on the answer to this last question. Collaborative efforts between US and Chinese-based scholars are either declining or stagnant in all selected fields. While one could attribute such a decline to the effects of COVID-19, it is interesting to note that no other collaborative endeavor has experienced the same decline or, in fact, any decline at all, suggesting that there may be an effect stemming from policy and a general unwillingness to foster collaboration between US and Chinese-based scholars. Interestingly, however, the sharpest declines in this partnership are found in STEM fields, further suggesting that a targeted policy cannot be discarded as the causal mechanism behind such

a trend. If this is true, it becomes paramount to understand what is driving the policy change and what it means for the wider academic collaborative ecosystem. Could the US funding and academic cooperation initiatives spill over onto the European landscape? To further highlight the importance of this question, Figures 6 and 7 replicate the exercise of Figure 5 but this time using China as a frame of reference. Figure 6 displays Sino-US, Sino-UK, Sino-German, Sino-LatAm, Sino-African and Sino-Swedish co-publications in the selected fields while Figure 7 displays Sino-Japanese and Sino-South Korean collaborative endeavors. As may be inferred the only significant trend in co-publications in the selected fields is within the US-Chinese partnership as all other partnerships across both aforementioned figures have either continued to grow or showed minimal signs of slowing down in the aftermath of COVID-19, reproducing a pattern that has been widely acknowledged in the literature (Adams 2012; Adams 2013; Wagner et al. 2017). Predictions suggesting that academic collaboration may be reaching a saturation point (Ponds 2009) have not materialized.

Figure 3: **Total papers published including at least one author from a given country or region of affiliation per field of study, 1980–2021. Source: Scopus Preview (2022). Note the different scales in each graph.**

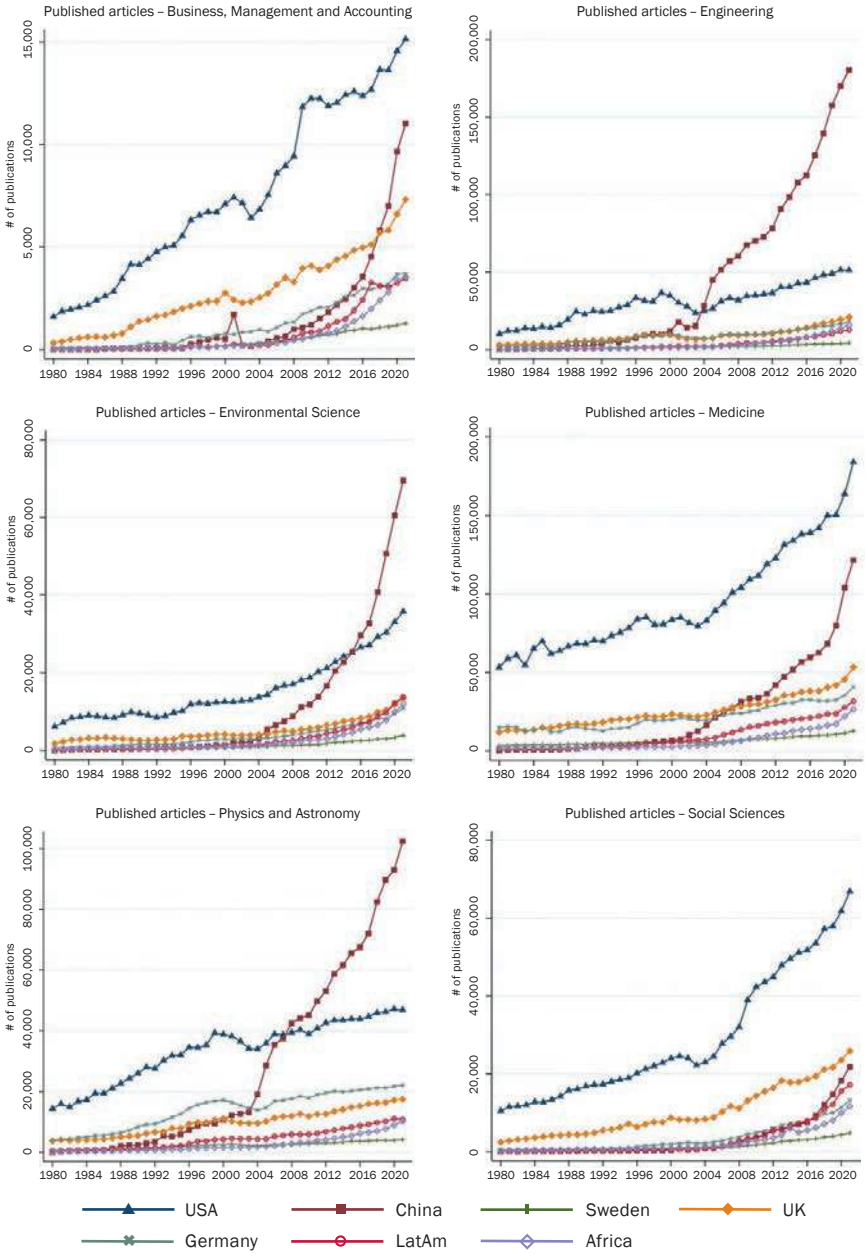


Figure 4: **Total articles published per capita including at least one author from a given country or region of affiliation per field of study, 1980–2021. Source: Scopus Preview (2022). Note the different scales in each graph.**

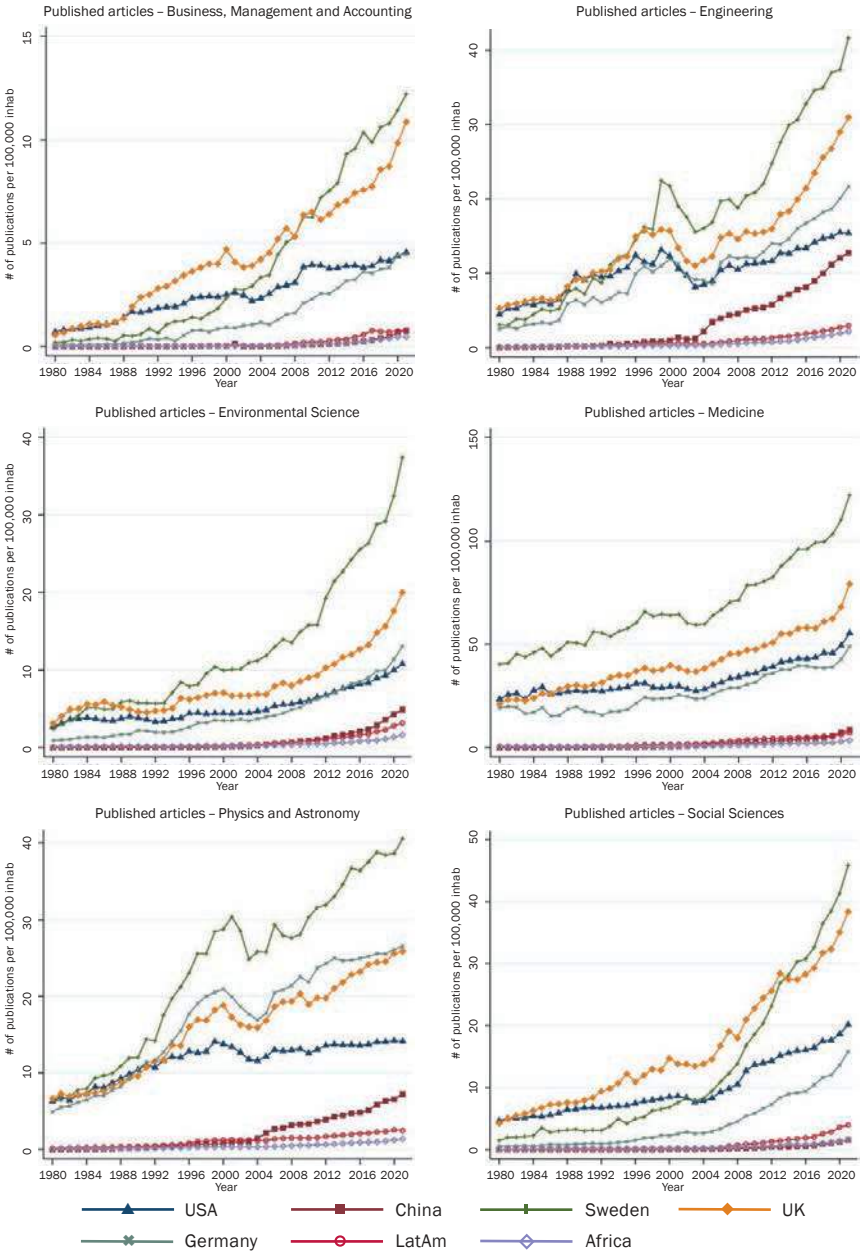


Figure 5: **US collaboration rate per field of study, 1980–2021. Source: Scopus Preview (2022).**

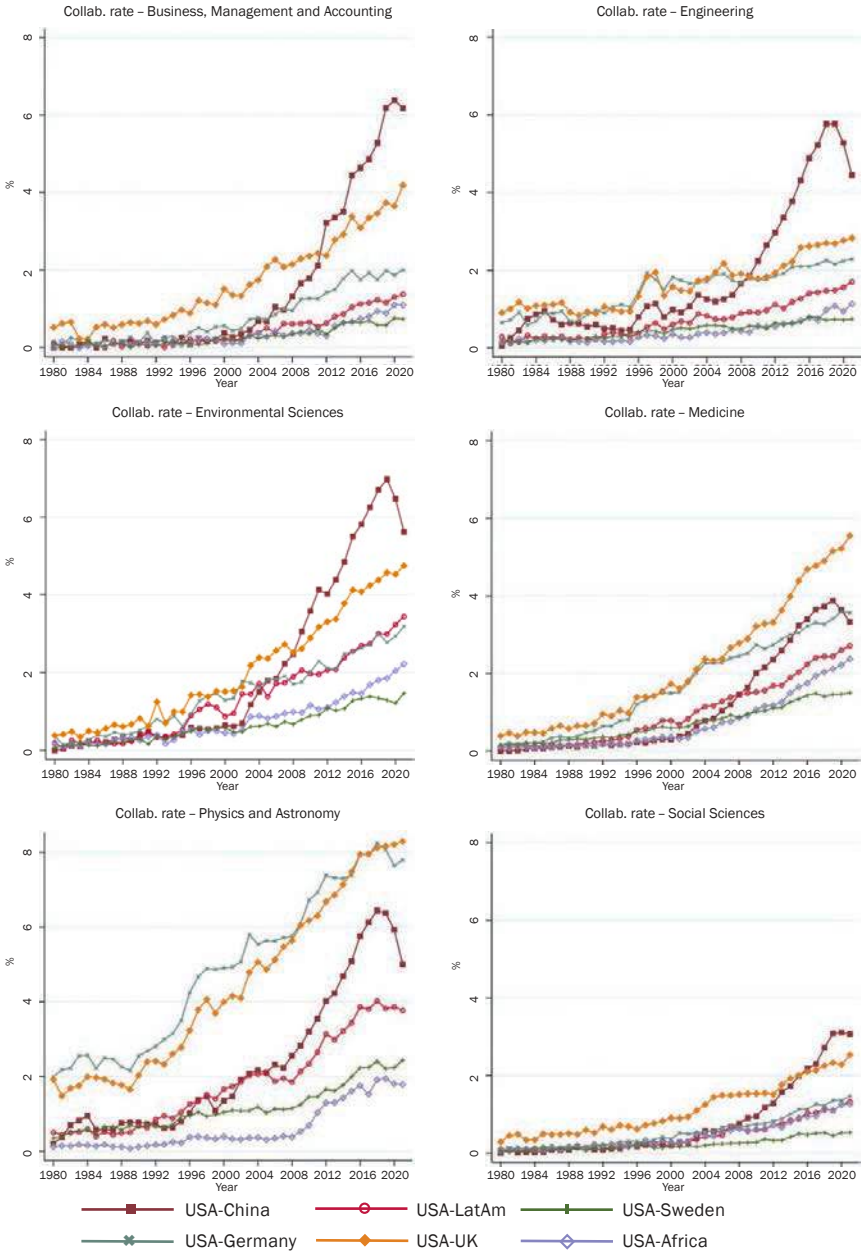


Figure 6: **Chinese collaboration rate per field of study, 1980–2021. Source: Scopus Preview (2022).**

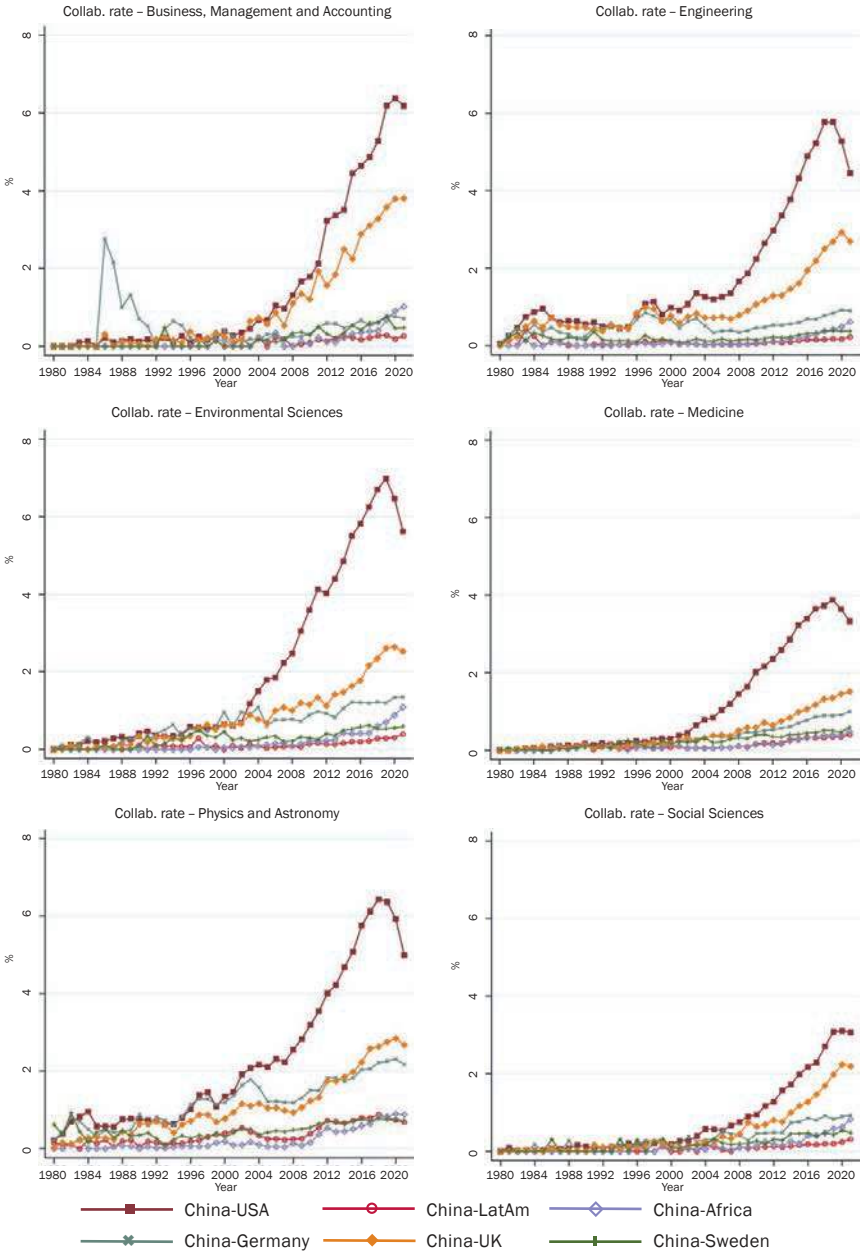
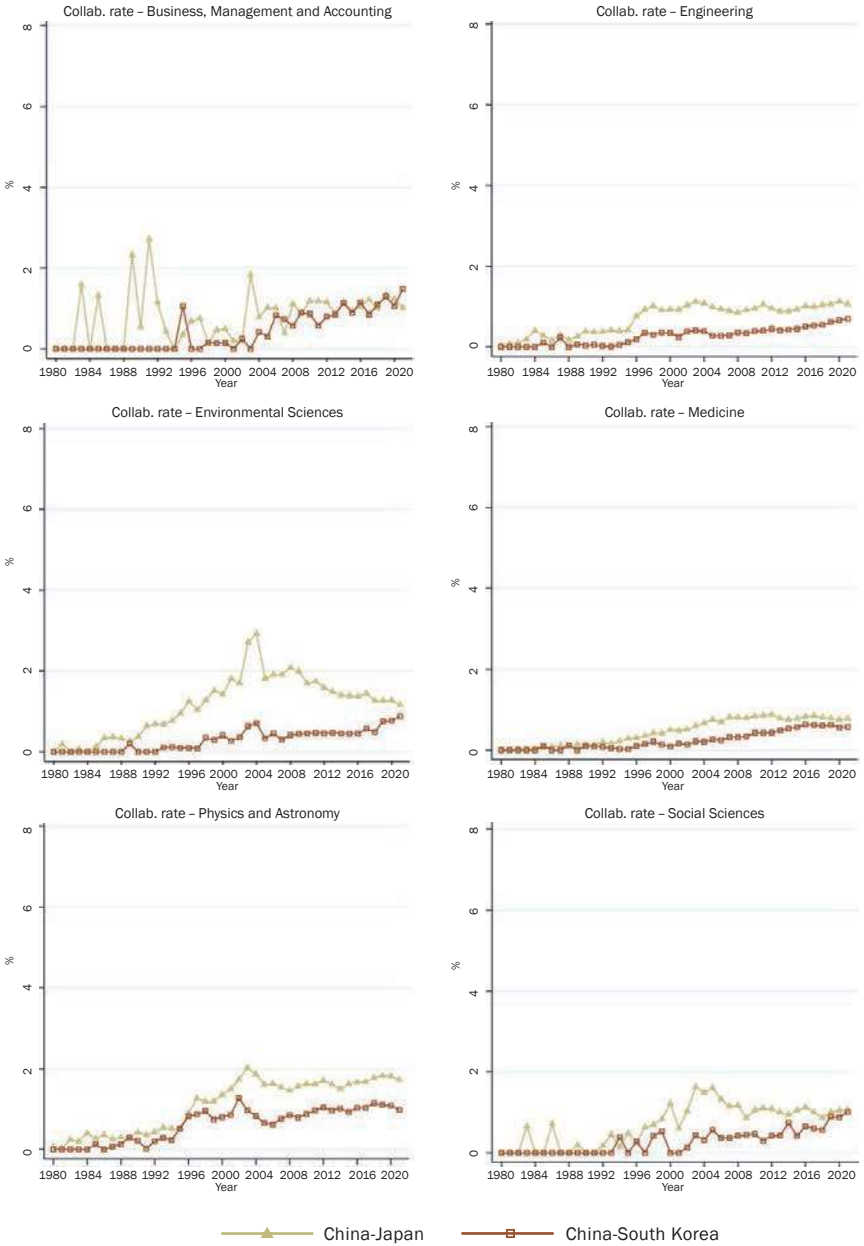


Figure 7: **Chinese collaboration rate per field of study (Japan and South Korea), 1980–2021. Source: Scopus Preview (2022).**



Collaborative endeavors

Collaborations of US-based scholars

Alongside the totals and the totals per field, we were also interested in collaborative efforts. During this stage, we used the United States as a frame of reference. With that in mind, we wrote four[5] queries of interest:

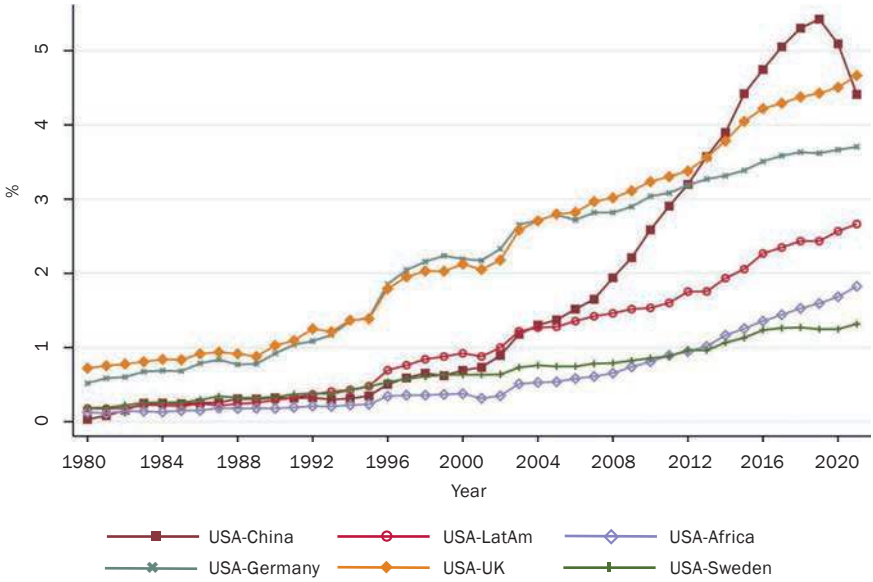
1. All papers involving at least one US-based scholar AND at least one Chinese-based scholar per field of study;
2. All papers involving at least one US-based scholar AND at least one LatAm-based scholar per field of study;
3. All papers involving at least one US-based scholar AND at least one African-based scholar per field of study;
4. All papers involving at least one US-based scholar AND at least one Swedish-based scholar per field of study.

One challenge when retrieving results in such a way concerns multi-affiliated scholars (Van Noorden et al. 2022). If a scholar published a paper while affiliated, for example, with both a Chinese and a US institute, it counts as a collaborative effort even if the article was single-authored. While we appreciate that this may produce some inconsistencies, it is worth noting that these are rare occurrences and unlikely to generate significant discrepancies in the trends analyzed. With that in mind, Figure 8 shows the relevant trends.

Generally speaking, collaborative efforts are increasing as a proportion of total publications. In 2017, for example, around 5% of all academic documents produced by US and Chinese-based scholars included a collaborative effort between the two. In the same year, this number was 2% among US and LatAm-based scholars and around 1.5% among US and African-based scholars. Interestingly enough, US-China collaborative research experienced a slowdown around 2018, persisting until, at least, 2020. It is not yet clear if COVID-19 accounts for the decline, especially when collaborative research with other partners continued increasing. If anything, the data suggests that some peculiarity of the US-China relationship – and not necessarily a global phenomenon – is behind the reversal of the trend, echoing the findings of recent studies on the subject (Cai et al. 2021; Silver 2020; Wagner and Cai 2022a; Wagner and Cai 2022b).

[5] We also retrieved information on all papers containing at least one US-based scholar AND at least one UK-based scholar as well as papers containing at least one US-based scholar AND at least one German-based scholar. Such regions, however, received only limited attention in the report.

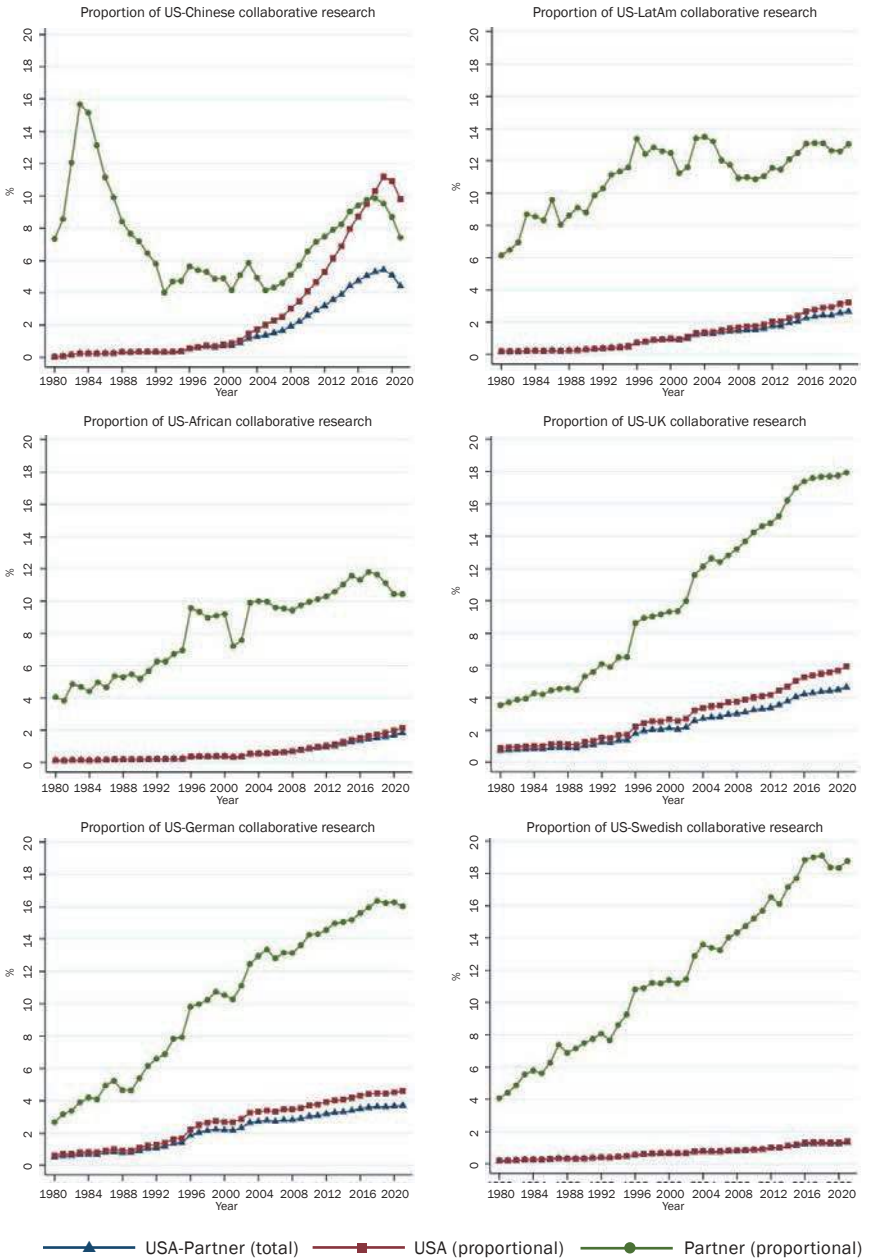
Figure 8: **Proportion of collaborative efforts from total publications between US-based scholars and partners of interest. Source: Scopus Preview (2022).**



It is important to note that the general increase in collaborative research is not the result of declining domestic production. This may be inferred using Figure 9, where we observe the proportion of collaborative research as a share of total publications among two partners and the proportion of collaborative research when considering only a country or region's domestic production. For example, the first graph at the top left corner of Figure 9 shows that in 2020 around 4% of all published articles by both US and Chinese-based scholars were collaborative efforts among these two nations. This represents around 8% of the Chinese domestic production and 10% of the US domestic production. US-China collaborative research, therefore, represents a greater proportion of documents produced by US-based scholars than it does for their Chinese-based counterparts. In short, it seems that as of 2020, US-China collaborative research is more important to US-based scholars in quantitative terms than to Chinese-based scholars. From a qualitative perspective, however, research indicates that internationally co-authored papers enjoy a higher citation impact than other types of publications (Pohl 2020; Pohl 2021). If these represent a larger proportion of papers produced by US-based scholars, then it is possible to infer that they are currently the biggest beneficiaries of such co-publications.

A similar analysis may be conducted using all graphs represented in Figure 9. The notable case is US-Swedish collaboration, which despite accounting for around 2% of the total production, represents roughly 20% of the research produced by Swedish-based scholars, highlighting how dependent the Swedish academic landscape is on co-publications, similar to the trends observed among UK and German-based scholars in relation to the United States.

Figure 9: **Total and proportional collaborative research between US-based scholars and partners of interest. Source: Scopus Preview (2022).**



Collaborative efforts may also be disaggregated per field of study. In this section, we set the United States as our frame of reference using Tables 1, 2, 3 and 4 to understand which fields are driving the collaborative efforts. The next two sections produce the same analysis but use China and Sweden, respectively, as the frame of reference.

Each table has three columns. The first represents the number of articles published in a given field proportional to all articles published by the regions of interest. The second column shows the number of collaborative efforts proportional to all collaborative efforts of the regions of interest. The last column calculates

Table 1: **Proportion from total articles and US-Chinese collaborations per field of study, 1980–2021**

Field	% of total	% of collabs.	Delta
Computer Science	3.6%	5.1%	1.5%
Physics and Astronomy	8.0%	9.4%	1.4%
Materials Science	6.5%	7.8%	1.4%
Earth and Planetary Sciences	3.4%	4.7%	1.3%
Environmental Science	3.4%	4.6%	1.2%
Multidisciplinary	1.3%	2.5%	1.1%
Chemistry	6.5%	7.4%	0.9%
Biochemistry, Genetics, and Molecular Biology	9.5%	10.4%	0.9%
Engineering	9.7%	10.4%	0.7%
Energy	1.9%	2.5%	0.7%
Mathematics	3.4%	4.0%	0.6%
Chemical Engineering	3.1%	3.6%	0.6%
Agricultural and Biological Sciences	4.6%	5.1%	0.5%
Decision Sciences	0.5%	0.8%	0.3%
Immunology and Microbiology	2.2%	2.1%	0.0%
Economics, Econometrics, and Finance	0.9%	0.8%	–0.1%
Business, Management, and Accounting	1.2%	1.1%	–0.1%
Dentistry	0.3%	0.2%	–0.1%
Neuroscience	2.1%	1.9%	–0.2%
Veterinary	0.4%	0.2%	–0.2%
Pharmacology, Toxicology, and Pharmaceutics	2.2%	1.9%	–0.4%
Health Professions	0.7%	0.3%	–0.4%
Nursing	1.0%	0.4%	–0.6%
Psychology	2.0%	0.8%	–1.2%
Arts and Humanities	1.6%	0.4%	–1.2%
Social Sciences	4.3%	2.0%	–2.3%
Medicine	15.8%	9.6%	–6.2%

[Source] Scopus Preview (2022)

the difference between the second and first columns, generating a delta. The greater the delta, the more collaborative efforts occur proportionally to the field size. The tables are sorted by decreasing delta.

The collaborative efforts among Chinese and US-based scholars, despite a general equilibrium across fields of study, mostly occur in STEM fields. The deltas are generally small and the proportion of positive and negative deltas is roughly the same. Nevertheless, the fields with the largest deltas are Computer Science, Physics and Astronomy, Materials Science, Earth and Planetary Sciences, and Environmental Sciences, suggesting that there is a particular willingness for collaboration in these fields within Chinese and US academia since they are more than proportionally represented among collaborative studies than their share of the total. Interestingly, Medicine has the lowest delta. This is not to say that few collaborative studies are produced. In fact, more than 9% of all collaborative efforts between Chinese and US academia came from Medicine. However, this field represents nearly 16% of all articles produced by these academic environments, suggesting that the willingness to collaborate – or even opportunities to do so – in Medicine is quite low proportional to the size of the field. It is also worth noting that Social Sciences as well as Arts and Humanities also show small deltas on top of representing very few of the collaborative efforts. Lastly, Engineering represents around 10% of the publications and also roughly 10% of the collaborative efforts. Generally speaking, the picture that emerges is one of intense collaboration in STEM fields, surprisingly little collaboration in Medicine proportional to its size, and little interest in collaboration in the Social Sciences or Arts and Humanities. Finally, it is important to note that only six fields of study are responsible for more than 50% of all collaborative efforts: Biochemistry, Genetics, and Molecular Biology (10.4%), Engineering (10.4%), Medicine (9.6%), Physics and Astronomy (9.4%), Materials Science (7.8%), and Chemistry (7.4%).

Table 2: **Proportion from total articles and US-LatAm collaborations per field of study, 1980–2021**

Field	% of total	% of collabs.	Delta
Agricultural and Biological Sciences	5.7%	11.5%	5.9%
Earth and Planetary Sciences	3.2%	7.1%	3.9%
Physics and Astronomy	6.9%	10.7%	3.8%
Immunology and Microbiology	2.6%	3.9%	1.3%
Environmental Science	3.3%	4.5%	1.2%
Multidisciplinary	1.3%	2.3%	0.9%
Dentistry	0.4%	1.2%	0.8%
Veterinary	0.7%	1.2%	0.5%
Decision Sciences	0.6%	0.5%	–0.2%
Energy	1.1%	0.9%	–0.2%
Economics, Econometrics, and Finance	1.2%	0.9%	–0.2%
Neuroscience	2.7%	2.5%	–0.3%
Health Professions	1.0%	0.7%	–0.3%
Mathematics	3.0%	2.7%	–0.3%
Biochemistry, Genetics, and Molecular Biology	10.6%	10.0%	–0.6%
Nursing	1.5%	0.9%	–0.6%
Pharmacology, Toxicology, and Pharmaceutics	2.3%	1.6%	–0.6%
Chemical Engineering	2.1%	1.4%	–0.7%
Business, Management, and Accounting	1.5%	0.7%	–0.8%
Computer Science	2.7%	1.8%	–0.9%
Medicine	19.2%	18.1%	–1.1%
Materials Science	4.1%	2.9%	–1.3%
Arts and Humanities	2.3%	0.8%	–1.5%
Psychology	2.7%	1.2%	–1.6%
Chemistry	5.1%	3.2%	–1.8%
Engineering	6.1%	3.8%	–2.2%
Social Sciences	5.9%	2.9%	–3.1%

[Source] Scopus Preview (2022)

The collaborative dynamics between LatAm and US-based scholars (shown in Table 2) are markedly distinct from those of their Chinese-based colleagues. Despite the tendency of collaborative efforts to be concentrated within STEM fields, it is noteworthy how the deltas are much less scattered and how the majority of deltas are negative, suggesting that collaborative efforts are concentrated in a few fields, namely Medicine (18.1%), Agricultural and Biological Sciences (11.5%), Physics and Astronomy (10.7%), and Biochemistry, Genetics, and Molecular Biology (10%), which together represent more than 50% of all collaborative articles between US and LatAm-based scholars. Considering only the biggest deltas, Agricultural and Biological Sciences, Earth and Planetary Sciences, and Physics and Astronomy, these are responsible for responsible for nearly one-third of all collaborative efforts

between these two academic environments. It is particularly noteworthy that Agricultural and Biological Sciences alone represent more than 11% of all collaborative efforts, despite representing merely 5.7% of all articles published. On the lower end, Chemistry, Engineering, and Social Sciences represent the fields with the smallest deltas, suggesting several possibilities – especially for LatAm-based scholars – to seek further collaboration in technical fields with their US counterparts.

Concerning African and US-based collaborations represented in Table 3, the situation is similar to that of Table 2 where the deltas are scattered and there is an overwhelming majority of negative deltas. Here, the fields that lead the collaborative land-

Table 3: **Proportion from total articles and US-African collaborations per field of study, 1980–2021**

Field	% of total	% of collabs.	Delta
Agricultural and Biological Sciences	5.2%	9.8%	4.6%
Medicine	19.2%	23.7%	4.4%
Immunology and Microbiology	2.6%	5.6%	3.0%
Earth and Planetary Sciences	3.2%	4.8%	1.6%
Multidisciplinary	1.4%	2.9%	1.6%
Environmental Science	3.4%	4.7%	1.3%
Veterinary	0.6%	1.2%	0.6%
Pharmacology, Toxicology, and Pharmaceutics	2.3%	2.4%	0.1%
Physics and Astronomy	6.9%	6.9%	0.0%
Dentistry	0.3%	0.3%	-0.1%
Energy	1.1%	1.0%	-0.1%
Economics, Econometrics, and Finance	1.2%	1.0%	-0.2%
Decision Sciences	0.6%	0.3%	-0.3%
Nursing	1.4%	1.1%	-0.3%
Health Professions	1.0%	0.6%	-0.4%
Business, Management, and Accounting	1.6%	1.0%	-0.6%
Mathematics	3.1%	2.3%	-0.7%
Chemical Engineering	2.1%	1.3%	-0.8%
Computer Science	2.8%	1.8%	-1.0%
Social Sciences	6.0%	5.0%	-1.0%
Psychology	2.7%	1.7%	-1.0%
Arts and Humanities	2.3%	1.1%	-1.2%
Neuroscience	2.7%	1.1%	-1.6%
Materials Science	4.3%	2.7%	-1.6%
Chemistry	5.1%	3.4%	-1.7%
Engineering	6.3%	4.1%	-2.2%
Biochemistry, Genetics, and Molecular Biology	10.6%	8.2%	-2.4%

[Source] Scopus Preview (2022)

scape are Agricultural and Biological Sciences, Medicine, and Immunology and Microbiology. Differently from the US-Chinese and US-LatAm collaborations here collaborative efforts seem to be more concentrated among medical and biological sciences, with Medicine representing nearly one-quarter of all collaborations by itself. Chemistry, Engineering, as well as Biochemistry, Genetics, and Molecular Biology are the fields with the smallest deltas, partially resembling the case of US-LatAm collaboration where collaboration in technical fields tends to be scarcer. Lastly, the high rate of collaboration in Physics and Astronomy verified between US, Chinese, and LatAm-based scholars is not verified here.

Table 4: **Proportion from total articles and US-Swedish collaborations per field of study, 1980–2021**

Field	% of total	% of collabs.	Delta
Physics and Astronomy	6.9%	11.7%	4.7%
Biochemistry, Genetics, and Molecular Biology	11.0%	13.9%	2.9%
Earth and Planetary Sciences	3.2%	5.6%	2.5%
Medicine	19.7%	21.7%	2.0%
Multidisciplinary	1.4%	3.0%	1.6%
Neuroscience	2.8%	3.6%	0.8%
Immunology and Microbiology	2.6%	3.4%	0.8%
Environmental Science	3.3%	3.5%	0.2%
Dentistry	0.4%	0.5%	0.2%
Agricultural and Biological Sciences	4.9%	4.9%	−0.1%
Veterinary	0.5%	0.3%	−0.2%
Energy	1.1%	0.9%	−0.2%
Decision Sciences	0.6%	0.3%	−0.3%
Pharmacology, Toxicology, and Pharmaceutics	2.3%	1.9%	−0.3%
Health Professions	1.0%	0.7%	−0.4%
Economics, Econometrics, and Finance	1.2%	0.8%	−0.4%
Nursing	1.5%	1.0%	−0.5%
Chemical Engineering	2.1%	1.3%	−0.7%
Computer Science	2.7%	2.0%	−0.8%
Mathematics	3.0%	2.2%	−0.8%
Business, Management, and Accounting	1.6%	0.8%	−0.8%
Materials Science	4.2%	3.4%	−0.8%
Chemistry	5.0%	4.1%	−0.9%
Psychology	2.8%	1.4%	−1.4%
Arts and Humanities	2.3%	0.8%	−1.5%
Engineering	6.2%	4.1%	−2.1%
Social Sciences	5.9%	2.3%	−3.6%

[Source] Scopus Preview (2022)

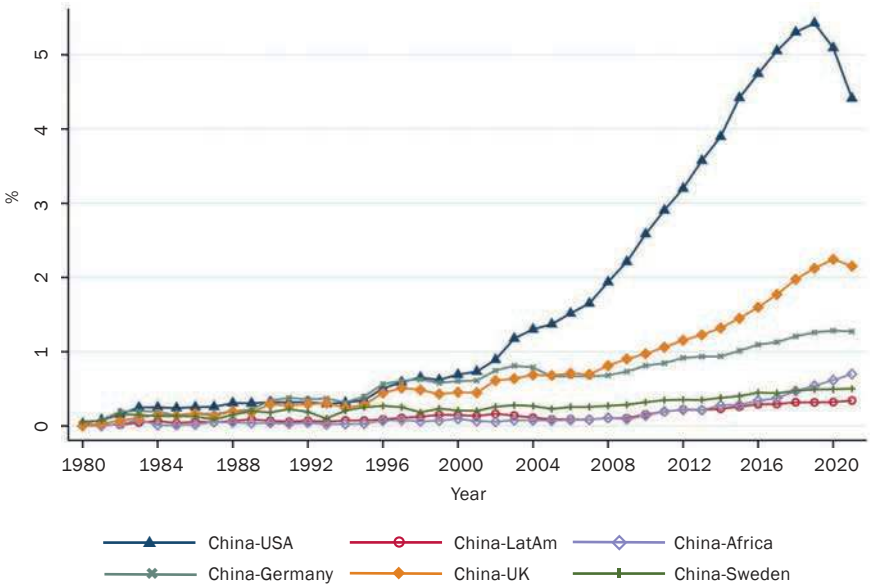
Finally, the collaborative landscape between Swedish and US-based scholars also displays signs of concentration. While medical fields seem to dominate the proportion of collaborations – Medicine (21.7%), and Biochemistry, Genetics, and Molecular Biology (13.9%) represent more than one-third of all collaborations – technical fields have little relevance in this regard. Physics and Astronomy, on the other hand, represent a high share of collaborative efforts and confirm a pattern already verified in Tables 1 and 2, whereby US-based physicists and astronomers are particularly keen on producing multilateral research. While part of this pattern may be explained by the location of particular observatories – therefore "forcing" collaboration with local scholars – future lines of inquiry into the funding and incentive structures in this field could hint at effective mechanisms to increase collaboration across other fields, especially Social Sciences where collaboration seems really incipient regardless of the partnership analyzed so far.

Collaboration of Chinese-based scholars

In this subsection, China is used as the frame of reference. Sino-US collaborations were already analyzed using the United States as a frame of reference and, therefore, are not addressed in this section. The queries here were:

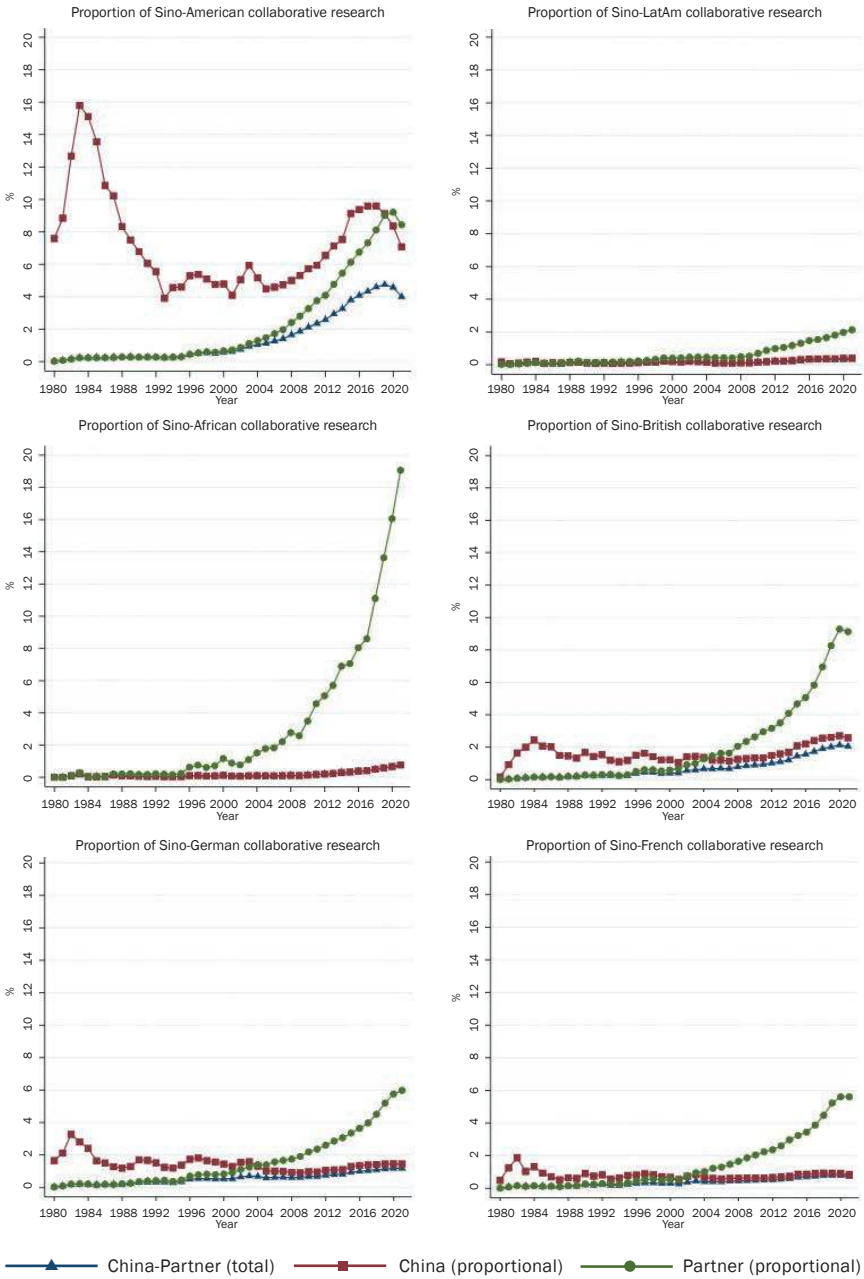
1. All papers involving at least one Chinese-based scholar AND at least one LatAm-based scholar per field of study;
2. All papers involving at least one Chinese-based scholar AND at least one African-based scholar per field of study;
3. All papers involving at least one Chinese-based scholar AND at least one Swedish-based scholar per field of study.

Figure 10: **Proportion of collaborative efforts from total publications between Chinese-based scholars and regions of interest. Source: Scopus Preview (2022).**



Starting from Figure 10, we note that the proportion of collaborative works in relation to Chinese domestic production is considerably lower when compared to Figure 8. Collaborations with Sweden, Africa, and Latin America represent less than 1% of the entirety of articles produced by Chinese-based scholars. Germany is slightly over a single percent. The United Kingdom appears with more intensity, albeit collaboration with this partner only represents 2% of all works produced by Chinese-based scholars. This number was over 4% when considering the United

Figure 11: **Total and proportional collaborative research between Chinese-based scholars and partners of interest. Source: Scopus Preview (2022).**



States as a frame of reference, for example. The conclusion here, then, is that the collaborative landscape of Chinese academia is a lot narrower and less international when compared to that of the United States.

A similar level of granularity as that presented in Figure 9 may be added using China as a frame of reference (see Figure 11). There, we observe the same relationship we did for the United States, i.e. collaboration between the selected partners and Chinese-based scholars is increasing as a proportion of the partner's domestic production. In other words, the number of documents produced by the selected partners that also include Chinese-based scholars is increasing over time. Interestingly, however, the trends are not as acute as the ones verified when analyzing the United States. Here, we would also like to draw attention to Sino-Swedish collaboration whereby 10% of the Swedish academic production also includes a Chinese-based author. The same metric concerning Swedish-US collaboration was roughly 20%. While it is possible to conclude that Chinese influence in Swedish academia is increasing, it is still far from the current influence of the United States.

These numbers may also be disaggregated to obtain a field-level analysis. This is done in Tables 5, 6 and 7. Similar to the analysis pertaining to the United States, each table has three columns. The first represents the number of documents published in a given field proportional to all documents published by the regions of interest. The second column shows the number of collaborative efforts proportional to all collaborative efforts of the regions of interest. The last column calculates the difference between the second and first columns, generating a delta. The greater the delta, the more collaborative efforts occur proportionally to the field size. The tables are sorted by decreasing delta. The analysis of US-Chinese collaborations was presented made in Table 1 and is therefore not repeated in this section.

The analysis of Table 5 reveals an interesting phenomenon. Almost a quarter of all collaborative efforts between Chinese and LatAm-based scholars came from Physics and Astronomy, a field that represents no more than 9% of all publications produced by these two regions combined. In short, Physics and Astronomy are disproportionately represented in the collaborative landscape between these regions. One potential explanation is the Atacama Cosmology Telescope located in Chile. As one of the highest permanent, ground-based telescopes in the world it is certainly an attractive instrument that could boost collaborative efforts, especially when we consider that the telescope has been operative since 2007, the year when the proportion of LatAm publications involving a Chinese-based collaborator start to increase consistently as per Figure 11.

Other fields where collaboration seems fruitful include Earth and Planetary Sciences as well as Medicine and Agricultural and Biological Sciences. STEM fields appear firmly at the bottom of the collaborative landscape, with Chemical Engineering, Chemistry, Computer Sciences, Materials Science, and Engineering representing far fewer collaborative endeavors proportional to the size of these fields. The conclusion is straightforward: Chinese-based scholars are less likely to collaborate with their LatAm counterparts in such fields, a phenomenon not entirely distinct when using the United States as a frame of reference.[6] Collaboration is also highly concentrated. Only three fields, Physics and Astronomy (23.1%), Medicine (12.3%),

Table 5: **Proportion from total articles and Sino-LatAm collaborations per field of study, 1980–2021**

Field	% of total	% of collabs.	Delta
Physics and Astronomy	8.9%	23.1%	14.2%
Earth and Planetary Sciences	3.5%	7.8%	4.3%
Medicine	9.0%	12.3%	3.3%
Agricultural and Biological Sciences	4.7%	6.1%	1.4%
Multidisciplinary	1.1%	2.0%	0.9%
Environmental Science	3.6%	4.3%	0.7%
Psychology	0.4%	0.8%	0.5%
Immunology and Microbiology	1.5%	2.0%	0.4%
Neuroscience	0.9%	1.3%	0.4%
Nursing	0.4%	0.6%	0.2%
Dentistry	0.3%	0.4%	0.2%
Health Professions	0.3%	0.4%	0.1%
Biochemistry, Genetics, and Molecular Biology	6.1%	6.2%	0.0%
Economics, Econometrics, and Finance	0.4%	0.4%	0.0%
Business, Management, and Accounting	0.8%	0.7%	–0.1%
Veterinary	0.4%	0.3%	–0.2%
Arts and Humanities	0.6%	0.3%	–0.3%
Social Sciences	2.1%	1.7%	–0.3%
Decision Sciences	0.9%	0.5%	–0.3%
Mathematics	4.9%	4.5%	–0.5%
Pharmacology, Toxicology, and Pharmaceutics	1.9%	1.1%	–0.7%
Energy	3.0%	1.8%	–1.2%
Chemical Engineering	3.7%	1.5%	–2.2%
Chemistry	6.9%	3.4%	–3.5%
Computer Science	8.4%	4.0%	–4.4%
Materials Science	8.7%	3.9%	–4.8%
Engineering	16.6%	8.5%	–8.1%

[Source] Scopus Preview (2022)

[6] As analyzed in Table 2

and Earth and Planetary Sciences (7.8%), cover roughly half of all collaborative efforts.

As for the Sino-African breakdown in Table 6, we see a much more equally distributed collaborative landscape, especially when compared to Chinese-LatAm collaboration. The deltas offer smaller amplitude and the overwhelming majority of fields collaborate quite proportionately to their percentage of the total. The few exceptions would be Agricultural and Biological Sciences, Physics and Astronomy and Environmental Sciences at the top and Computer Science, Materials Science and Engineering at the bottom. Interestingly, however, Engineering still represents a significant proportion of the collaborative landscape, with 11%

Table 6: **Proportion from total articles and Sino-African collaborations per field of study, 1980–2021**

Field	% of total	% of collabs.	Delta
Agricultural and Biological Sciences	4.0%	8.5%	4.5%
Physics and Astronomy	8.9%	12.3%	3.4%
Environmental Science	3.7%	6.3%	2.6%
Immunology and Microbiology	1.4%	2.4%	1.0%
Earth and Planetary Sciences	3.5%	4.2%	0.7%
Multidisciplinary	1.1%	1.7%	0.6%
Veterinary	0.3%	0.8%	0.5%
Biochemistry, Genetics, and Molecular Biology	5.9%	6.4%	0.4%
Social Sciences	2.0%	2.3%	0.3%
Energy	3.2%	3.4%	0.2%
Economics, Econometrics, and Finance	0.5%	0.7%	0.2%
Nursing	0.3%	0.4%	0.2%
Psychology	0.3%	0.5%	0.2%
Business, Management, and Accounting	0.8%	1.0%	0.2%
Health Professions	0.2%	0.3%	0.1%
Chemical Engineering	3.8%	3.8%	0.0%
Dentistry	0.1%	0.1%	0.0%
Neuroscience	0.8%	0.7%	−0.1%
Medicine	8.5%	8.4%	−0.1%
Arts and Humanities	0.5%	0.4%	−0.2%
Decision Sciences	0.9%	0.7%	−0.2%
Mathematics	5.1%	4.8%	−0.2%
Pharmacology, Toxicology, and Pharmaceutics	1.9%	1.7%	−0.2%
Chemistry	7.1%	5.7%	−1.4%
Computer Science	8.7%	5.5%	−3.2%
Materials Science	9.1%	5.8%	−3.3%
Engineering	17.4%	11.2%	−6.2%

[Source] Scopus Preview (2022)

of all Sino-African collaborations stemming from it. The problem here is that this field is relatively larger, representing over 17% of all works produced by these regions combined, which ultimately results in a small delta.

Physics and Astronomy appear as intense contributors to the Sino-African collaborative landscape, covering over 12% of all collaborations. This is markedly different when compared to the US-African collaborations[7] where Physics and Astronomy represented 7% of all collaborations and did not appear as a field disproportionately collaborative. It is clear that Chinese-based scholars in such fields see more relative potential in Africa than their US counterparts albeit the reasons for such are not entirely clear even though political influence cannot be discounted (Iwata 2017; Wu 2019).

Finally, STEM fields remain underrepresented in the African collaborative landscape, a situation not much different from Latin America regardless of the frame of reference. This unsurprising result demonstrates how the notion of one globalized academia is still very much contingent on certain fields or certain bilateral exchanges.

The Sino-Swedish partnership is mostly proportional to its respective fields. Deltas are mostly concentrated around zero with little deviation except for Engineering – as a representative of a group where collaboration is less likely to occur proportional to the size of the field – and Physics and Astronomy which, as already verified in most tables, is always a field where collaborative efforts take place disproportionately more. Despite this equilibrium in proportionality, six fields correspond to more than 50% of all collaborative efforts, namely Physics and Astronomy (15.8%), Engineering (10.3%), Medicine (9.9%), Materials Science (9.0%), and Biochemistry, Genetics, and Molecular Biology (8.4%).

[7] As analyzed in Table 3.

Table 7: **Proportion from total articles and Sino-Swedish collaborations per field of study, 1980–2021**

Field	% of total	% of collabs.	Delta
Physics and Astronomy	9.8%	15.8%	6.1%
Multidisciplinary	1.4%	2.6%	1.2%
Biochemistry, Genetics, and Molecular Biology	7.4%	8.4%	1.0%
Environmental Science	3.9%	4.9%	1.0%
Earth and Planetary Sciences	3.7%	4.3%	0.6%
Energy	3.1%	3.7%	0.6%
Neuroscience	1.1%	1.6%	0.5%
Immunology and Microbiology	1.6%	2.0%	0.3%
Nursing	0.3%	0.5%	0.2%
Business, Management, and Accounting	0.6%	0.7%	0.1%
Economics, Econometrics, and Finance	0.4%	0.5%	0.1%
Psychology	0.4%	0.4%	0.1%
Decision Sciences	0.4%	0.4%	0.0%
Medicine	9.8%	9.9%	0.0%
Social Sciences	1.4%	1.4%	0.0%
Health Professions	0.2%	0.3%	0.0%
Dentistry	0.2%	0.2%	0.0%
Veterinary	0.2%	0.1%	–0.1%
Arts and Humanities	0.4%	0.3%	–0.1%
Chemistry	8.7%	8.4%	–0.3%
Agricultural and Biological Sciences	4.2%	3.8%	–0.4%
Chemical Engineering	4.6%	3.9%	–0.7%
Pharmacology, Toxicology, and Pharmaceutics	2.1%	1.2%	–1.0%
Materials Science	10.1%	9.0%	–1.1%
Computer Science	4.9%	3.3%	–1.6%
Mathematics	4.0%	2.2%	–1.8%
Engineering	14.9%	10.3%	–4.6%

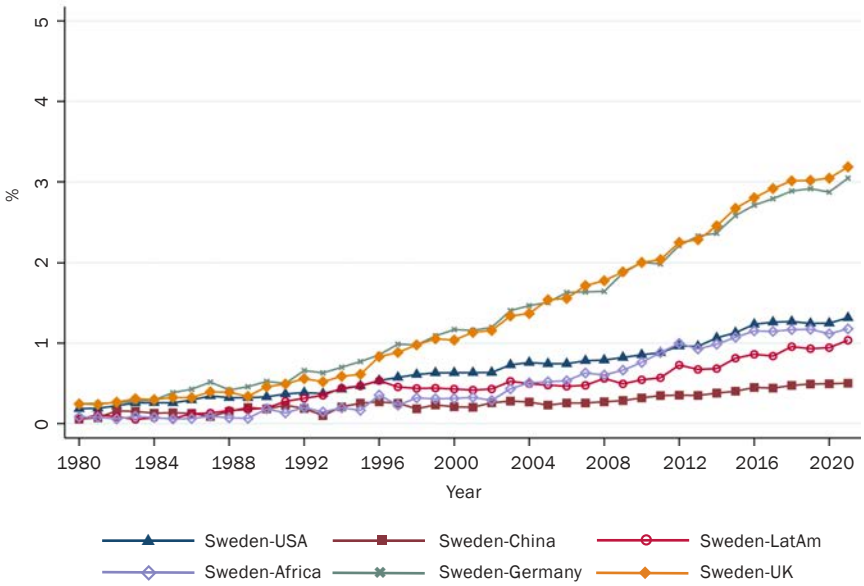
[Source] Scopus Preview (2022)

Collaboration of Swedish-based scholars

In this subsection, Sweden is used as the frame of reference. Since US-Swedish and Swedish-Chinese collaborations were already covered in previous subsections, this subsection will only analyzes Swedish-LatAm and Swedish-African co-publications. The retrieved queries were:

1. All papers involving at least one Swedish-based scholar AND at least one LatAm-based scholar per field of study;
2. All papers involving at least one Swedish-based scholar AND at least one African-based scholar per field of study.

Figure 12: **Proportion of collaborative efforts from total publications between Swedish-based scholars and regions of interest. Source: Scopus Preview (2022).**



The Swedish collaborative landscape is mostly dominated by other European partners. Roughly 3% of all papers that involved UK or German-based scholars also involved a Swedish-based scholar. Other regions of interest are found around the one percent mark. Not surprisingly, Swedish-Chinese co-publications only represent half a percent of the entirety of papers produced by these two nations combined due to the considerably bigger absolute number of papers published by Chinese-based scholars on account of demographic differences between these nations.

Figure 13 provides a more nuanced approach. Here we observe that Swedish-Chinese collaborative research, while representing around half a percent of the total number of papers produced, represents roughly 10% of all papers involving a Swedish-based author. More significant, however, is the Swedish-UK and Swedish-German co-publications proportional to the Swedish total, respectively reaching nearly 18% and 16% of the articles published in 2021. These, combined with Swedish-US collaboration – the most relevant of all in quantitative terms – show that Swedish-Chinese collaborative endeavors, while important, are not yet on par with other historical collaborators. It lends credence to the notion that collaborative ties have a "proximity effect" (Katz 1994; Glänzel and Schubert

2005) albeit this appears to be eroding over time (Frenken et al. 2010; Choi 2012). Lastly, Swedish-LatAm and Swedish-African co-publications are still incipient but have displayed consistent proportional growth since the early 2000s, with both representing 4% of all papers where a Swedish-based author is identified.

Tables 8 and 9 display the proportion of publications and co-publication per each field of study. Similar to the analyses pertaining to the United States and China, each table has three columns. The first represents the number of documents published in a given field proportional to all documents published by the regions of interest. The second column shows the number of collaborative efforts proportional to all collaborative efforts of the regions of interest. The last column calculates the difference between the second and first columns, generating a delta. The greater the delta, the more collaborative efforts occur proportionally to the field size. The tables are sorted by decreasing delta.

Starting with Table 8, it is clear that Swedish collaborative efforts with LatAm-based scholars are overwhelmingly concentrated in Physics and Astronomy as well as Medicine, representing more than one-third of all collaboration. Physics and Astronomy, however, display a remarkable tendency for co-publication as they represent merely 7% of all papers but 20% of all co-publications among Swedish and LatAm-based scholars. Another field with an interesting track record is Earth and Planetary Sciences where collaboration is disproportionately greater than the field's size. As for all other collaborative endeavors analyzed so far, Social Sciences is consistently the field where collaborative endeavors are the most incipient.

Figure 13: **Total and proportional collaborative research between Swedish-based scholars and partners of interest. Source: Scopus Preview (2022).**

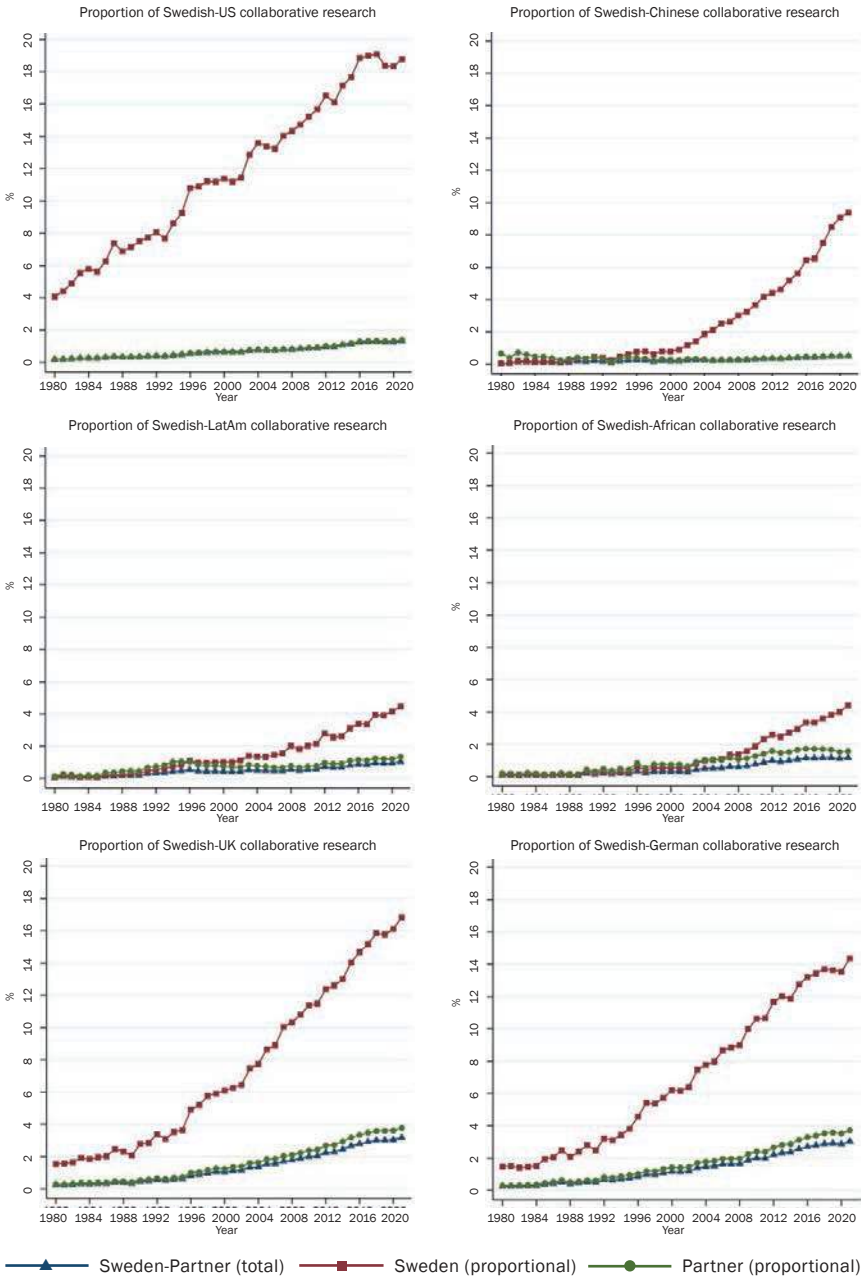


Table 8: **Proportion from total articles and Swedish-LatAm collaborations per field of study, 1980–2021**

Field	% of total	% of collabs.	Delta
Physics and Astronomy	7.2%	20.1%	12.9%
Earth and Planetary Sciences	3.5%	7.7%	4.2%
Multidisciplinary	1.3%	2.4%	1.1%
Environmental Science	4.3%	5.0%	0.6%
Immunology and Microbiology	3.2%	3.6%	0.3%
Dentistry	1.1%	1.2%	0.0%
Energy	1.4%	1.4%	0.0%
Neuroscience	2.1%	2.0%	–0.1%
Biochemistry, Genetics, and Molecular Biology	8.8%	8.6%	–0.2%
Decision Sciences	0.6%	0.3%	–0.3%
Economics, Econometrics, and Finance	0.9%	0.5%	–0.4%
Psychology	1.3%	0.8%	–0.4%
Health Professions	0.9%	0.5%	–0.4%
Nursing	1.3%	0.9%	–0.5%
Business, Management, and Accounting	1.2%	0.7%	–0.6%
Engineering	5.3%	4.8%	–0.6%
Computer Science	2.3%	1.6%	–0.7%
Pharmacology, Toxicology, and Pharmaceutics	2.3%	1.5%	–0.8%
Veterinary	1.5%	0.7%	–0.8%
Chemical Engineering	2.3%	1.3%	–1.0%
Mathematics	2.9%	1.6%	–1.2%
Arts and Humanities	1.7%	0.5%	–1.3%
Materials Science	4.4%	2.9%	–1.5%
Medicine	17.7%	16.0%	–1.7%
Chemistry	5.4%	3.7%	–1.7%
Agricultural and Biological Sciences	10.2%	7.9%	–2.3%
Social Sciences	4.6%	2.0%	–2.6%

[Source] Scopus Preview (2022)

The partnership between Swedish and African-based scholars has very similar contours when compared to Swedish-LatAm collaboration. As Table 9 shows, Physics and Astronomy as well as Medicine dominate the collaborative landscape. Interestingly, however, Medicine is even more prevalent in Swedish-African co-publications than the Swedish-LatAm counterpart. Social Sciences also emerge as a field with collaborations proportional to its size, a feature only observed in this relationship across our regions and countries of interest. STEM fields, however, have consistently the lowest deltas, with Computer Science, Mathematics, Chemistry, Materials Science, and Engineering displaying a much reduced co-publication pattern relative to the fields' sizes. Such results suggest that Swedish

academics have a very narrow set of interests when engaging with their African-based counterparts.

Table 9: **Proportion from total articles and Swedish-African collaborations per field of study, 1980–2021**

Field	% of total	% of collabs.	Delta
Physics and Astronomy	6.8%	12.0%	5.3%
Medicine	17.9%	20.3%	2.4%
Earth and Planetary Sciences	3.3%	5.3%	2.0%
Environmental Science	5.0%	6.8%	1.8%
Multidisciplinary	1.4%	2.8%	1.4%
Immunology and Microbiology	3.1%	4.3%	1.2%
Agricultural and Biological Sciences	7.8%	8.7%	0.9%
Psychology	1.1%	1.3%	0.3%
Nursing	1.0%	1.0%	0.0%
Social Sciences	5.1%	5.0%	0.0%
Veterinary	1.0%	0.9%	–0.1%
Health Professions	0.7%	0.7%	–0.1%
Energy	1.7%	1.5%	–0.2%
Neuroscience	1.5%	1.2%	–0.3%
Decision Sciences	0.5%	0.2%	–0.3%
Economics, Econometrics, and Finance	1.2%	0.8%	–0.3%
Dentistry	0.5%	0.2%	–0.3%
Business, Management, and Accounting	1.4%	1.0%	–0.4%
Pharmacology, Toxicology, and Pharmaceutics	2.6%	2.0%	–0.6%
Arts and Humanities	1.7%	1.0%	–0.7%
Biochemistry, Genetics, and Molecular Biology	8.3%	7.4%	–0.9%
Chemical Engineering	2.5%	1.6%	–0.9%
Computer Science	2.8%	1.3%	–1.4%
Mathematics	3.3%	1.5%	–1.8%
Chemistry	5.9%	3.9%	–2.1%
Materials Science	5.4%	2.9%	–2.5%
Engineering	6.8%	4.3%	–2.5%

[Source] Scopus Preview (2022)

Final remarks

This report is the first of a series of documents aiming to produce an overview of the collaborative landscape between the US and Chinese-based scholars and their counterparts in Latin America and Africa as well as, of course, the academic collaboration among US and Chinese-based scholars. When viewed from an aggregate perspective, it is notable how Chinese-based scholars have increased their academic production exponentially since at least the early 2000s. Consequently, they nowadays dominate the academic landscape, where they surpass their US-based colleagues in the volume of publications in nearly every STEM and medical sub-field, with few exceptions. Meanwhile, there is room for Chinese growth on per capita terms. For now, our sample of European nations – and more specifically, Sweden – seem to be the most prolific academic environments. The analysis also suggests that while Chinese growth has been exponential, the US academic environments are stagnant in per capita terms when it comes to the yearly number of published articles. We were not yet able to introduce a metric of quality, therefore, we cannot comment on how the volume of new publications by Chinese-based scholars is effectively reshaping science. Some studies, however, suggest that in some metrics China is edging out the United States in the number of most cited papers (Stenberg 2013; Brainard and Normile 2022).

Concerning the collaborative landscape, it is possible to note clear patterns between the regions of interest. Collaboration between US and Chinese-based scholars is concentrated in STEM fields but the number of collaborative works generally aligns well proportional to the size of each field, except for Medicine. This is significantly different when compared to collaboration between US-based scholars and their counterparts in Latin America, Africa, or Sweden where few fields drive most of the collaboration, suggesting the existence of pockets of global networks but, so far, with few linkages to other fields, especially Social Sciences, a field that remains relatively closed for international collaboration. Finally, we note a sharp decline in Sino-US collaboration during the time coinciding with the COVID-19 pandemic while the same pattern was not verified in Latin America, Africa, or even when we add European-based scholars to broaden our frame of reference. Future developments will indicate if this setback is temporary or a symptom of a larger, potentially structural break, in the collaborative efforts between both academic giants.

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Appendix

1. Agricultural and Biological Sciences
2. Arts and Humanities
3. Biochemistry, Genetics, and Molecular Biology
4. Business, Management, and Accounting
5. Chemical Engineering
6. Chemistry
7. Computer Science
8. Decision Sciences
9. Dentistry
10. Earth and Planetary Sciences
11. Economics, Econometrics, and Finance
12. Energy
13. Engineering
14. Environmental Science
15. Health Professions
16. Immunology and Microbiology
17. Materials Science
18. Mathematics 19. Medicine
20. Neuroscience
21. Nursing
22. Pharmacology, Toxicology, and Pharmaceutics
23. Physics and Astronomy
24. Psychology
25. Social Sciences
26. Veterinary
27. Multidisciplinary

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