Artificial Intelligence – International Collaboration Patterns

STINT
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Preface

The mission of STINT, The Swedish Foundation for International Cooperation in Research and Higher Education, is to internationalise Swedish higher education and research. STINT promotes knowledge and competence development within internationalisation and invests in internationalisation projects proposed by researchers, educators and leaderships at Swedish universities.

Artificial Intelligence (AI) receives much attention worldwide, as AI is expected to revolutionise technological development and business. However, several ethical aspects must be considered.

Many countries are investing in AI and developments are rapid. It is therefore important that Swedish research environments are part of developments and stay connected to relevant foreign research environments in this area. Furthermore, international research cooperation contributes to quality and international networks give access to involvement in the development of AI technology, implementation, standards, and ethical frameworks.

The intention of this study is to provide an overview of current networks in AI that involve Swedish and international researchers, in order to better understand the appropriate initiatives needed to position Sweden as a research and innovation leader in the field.

The project leader of this study is Dr Niklas Z Kviselius, Representative in North America, STINT. Co-authors of this report are Dr Erik Forsberg, Representative in APAC, STINT, and Dr Hans Pohl, Programme Director, STINT. We would like to present our sincere thanks to Prof. Amy Loutfi, Örebro University, who has read and provided valuable comments on draft versions of the report.

Dr Andreas Göthenberg
Executive Director, STINT

Stockholm, September 2022

Summary

Developments in AI affect a wide range of research areas – from medical breakthroughs in cancer research to cutting-edge climate change research. AI will have a substantial impact on the way people live and work in the coming decades. By now most large economies have drafted and released some sort of national AI policy or strategy.

This report focuses on the development of AI research in four countries, Canada, China, Sweden, and the United States, as well as trends in their international research collaborations in the field. International collaboration patterns are mapped via publication analysis based on Scopus publications and Elsevier's definition of AI publications.

AI enjoys increasing interest from researchers, with China dominating the production of AI publications followed by the United States. China and the United States are the largest competitors *and* collaborators in AI. Sweden has in recent years shown a very high growth in AI publications, only topped by China. Overall, AI research is less international than average research but the high numbers of AI publications from China and India contribute to this low overall value. In almost all other listed countries, including Sweden, AI publications are slightly more international than the average. The share of academic – corporate co-publications is higher within AI research. Sweden has the highest share of publications including at least one academic and one corporate actor.

Observations from the Swedish research system includes KTH Royal Institute of Technology as the largest producer of AI publications in Sweden, Chalmers University of Technology showing the strongest positive trend, and Luleå University of Technology having both the highest share of AI publications and the most international AI research. Chalmers University of Technology has the greatest share of co-publications with the corporate sector in Sweden. However, collaboration patterns between institutions do not indicate that Swedish universities have established strategic international collaborations within AI with leading actors abroad.

One clear observation on the global arena of AI research is that the United States and China, however fiercely they compete with each other, clearly are advancing fast together and leaving other countries behind, both in terms of research and the pace of innovation. A combination of strong technology sectors and high government interest and support in these two countries will further widen this gap.

The report concludes in chapter Observations with some commentary on what lies ahead for Sweden on how to best position itself to ensure access to and imple-

mentation of the leading edge of global AI advancements. This would include fostering an AI research and innovation ecosystem that is sufficiently strong to be able to attract leading scientists, innovators, and companies in the AI field to collaborate with, and/or work in Sweden.

Introduction

Artificial intelligence (AI) is crucial to our future because AI forms the very foundation of computer learning. Developments in AI affect a wide range of research areas – from medical breakthroughs in cancer research to cutting-edge climate change research. AI will have a substantial impact on the way people live and work in the coming decades.

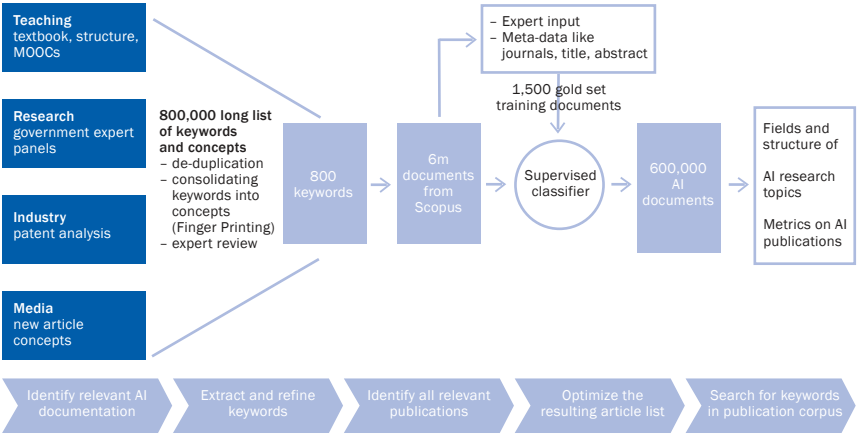
These promises also come with a complex and far-reaching set of risks which regulators must consider. Some of the top ethical issues in AI include unemployment and labour considerations when jobs are automated, diversity and inclusion when AI is designed with unwanted biases, and increased security vulnerabilities when society becomes dependent on ever more complex and autonomous systems acting without human intervention.

The biggest research nations, as well as many of the largest corporations, are well aware of such risks and all try to back up their research community and industries with national policies dedicated to AI, research funding, and the building of attractive ecosystems where cutting-edge research can be translated into societal applications. Nations compete as well as cooperate on AI, and the scarce resource is often human talent. Smaller research nations, such as Sweden, should be aware of this new space race, and ought to try to leverage existing and international collaborations to stay competitive.

The European Commission defines AI as systems that display intelligent behaviour by analysing their environment and taking actions – with some degree of autonomy – to achieve specific goals. In short, AI leverages computers and machines to mimic the problem-solving and decision-making capabilities of the human mind. Applications include self-driving cars, self-learning manufacturing robots, and various types of decision-making systems in healthcare.

Given the wide range of applications for AI and the tendency to add *AI* as a keyword to increase the appeal of a project, clearly defining the scope of AI-related research is challenging. The publication analysis in this report is based on work done by Elsevier, see Figure 1.

Figure 1: **Description of the process to identify AI publications (Elsevier 2020:21)**



Based on keywords from teaching, research, industry and media, Elsevier compiled a shortlist of 800 keywords, which were used to extract 6 million documents from Scopus. These documents were scrutinised by experts and a gold set of 1,500 documents was selected for training the search engine. In the end, the query developed with AI support returned 600,000 documents representing different aspects of AI (Elsevier 2020).

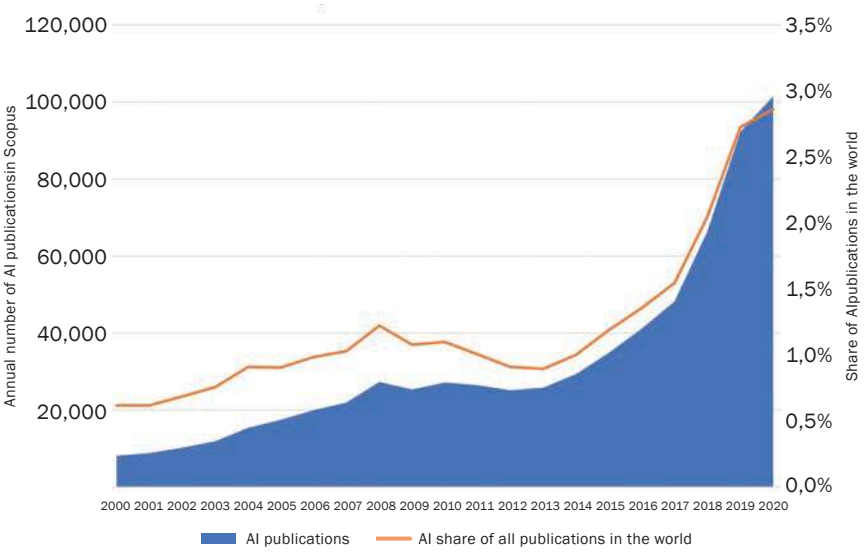
This report focuses on the development of AI research in four countries, Canada, China, Sweden, and the United States, as well as trends in their international research collaborations in the field. A brief overview of national policies in Singapore and the EU is also included. These countries have been selected partly because they are important in the AI field, and partly because STINT has good access to data given its regional representatives in North America and China. China and the United States are at the forefront of funding AI – by sheer research volumes but also because of the prioritised status AI enjoys in their national policies. Canada was perhaps the earliest country to develop a national AI strategy and has built upon decades of continuous funding of the field. Sweden is of obvious interest for STINT.

Research

Global and national levels: China and the United States dominate AI publica-tions

Using Scopus publications and Elsevier's definition of AI publications (see above), it is clear that AI enjoys increased interest from researchers. Figure 2 indicates the development of the total volume of such publications as well as the share of AI publications, according to Elsevier's method (2020), among all Scopus publications in the world irrespective of scientific field. This share rose from 0.6% in 2000 to 2.9% in 2020.

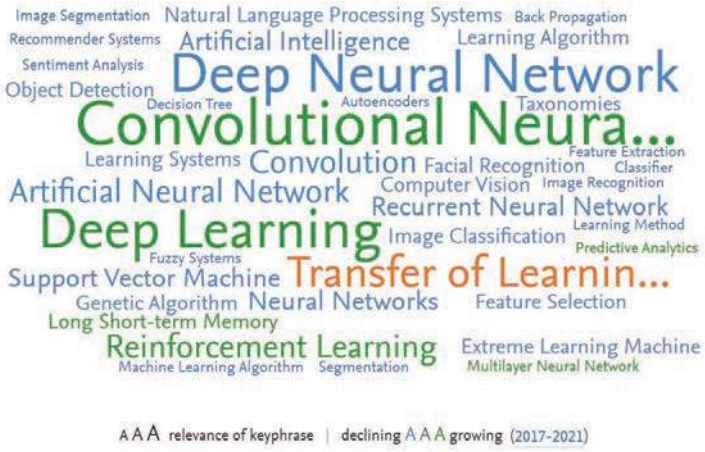
Figure 2: **World production of AI publications and their share of all scientific publications**



One interesting detail is that AI publications to a very high extent (~99%) have ten or fewer co-authors. Typically, hyper-authored publications require a special approach when for example collaborations are studied. However, since hyper-authored AI publications are so rare, this is not deemed necessary.

Based on the content of their titles, keywords and abstracts, Elsevier generates a fingerprint of the publications. In Figure 3, a fingerprint of all AI publications for 2016–2020 is presented. The dominance of the green colour reflects rapid growth and the size of the keyphrases their relevance. Deep learning and neural networks appear to have been the most relevant keyphrases during this period.

Figure 3: **Fingerprint of AI publications in the world, 2016–2020**



During the period 2016–2020, China dominated the production of AI publications with almost 100,000 articles, conference papers, reviews, books and book chapters, see Table 1. China is followed by the United States. The table lists a selection of countries and these are used for comparisons below. The selection was guided by the ambition to include some of the main collaborators with Sweden and the other countries specifically addressed in this report. Sweden's share of global AI publications was 0.7% during this period. In comparison, Sweden's overall share of all publications was 1.4% for the same period.

Table 1: **Main producers of AI publications and some other countries, 2016–2020**

Rank	Country	AI publications	Share of all AI publications in the world
1	China	98,257	28,1%
2	United States	63,031	18,0%
3	India	36,673	10,5%
4	United Kingdom	18,343	5,2%
5	Germany	13,625	3,9%
6	Japan	11,752	3,4%
7	Canada	10,971	3,1%
13	Iran	8,171	2,3%
19	Singapore	4,743	1,4%
32	Sweden	2,435	0,7%
35	Finland	1,916	0,5%
48	Denmark	1,443	0,4%

In Table 2, some other important indicators for the same countries are listed. The trend figure in the third column indicates the average annual growth in AI publications over the five-year period. It reveals that Sweden has shown a very high growth, only topped by China. The share of AI publications relates to the national volume. India has the highest share, which means that 4.1% of all publications with at least one Indian (co-)author is within the AI field.

The field-weighted citation impact (FWCI) is a normalised indicator of how often the publications are cited. A value above 1.00 means that the publications are more cited than the world average. For all countries, the AI publications has a much higher FWCI than the national average. Singapore has the highest FWCI for the period and the very high value for the United States should also be noted, given the large overall volume of publications in the country.

Table 2: **AI publication indicators for selected countries**

Publications 2016–2020				Citation impact FWCI		Publications in top 1% percentile		Int'l co-publications FWIS		Share of academic-corporate co-publications	
Country	**AI publ.**	**Growth rate**	**Share AI**	**AI**	**ALL**	**AI**	**ALL**	**AI**	**ALL**	**AI**	**ALL**
Canada	10,971	26%	1,9%	2,54	1,8	4,1%	2,1%	1,41	1,32	7,0%	4,3%
China	98,252	32%	3,1%	1,63	1,06	2,8%	1,6%	0,66	0,55	5,0%	2,7%
Denmark	1,441	28%	1,0%	2,36	1,79	4,0%	2,8%	1,64	1,54	9,6%	10,5%
Finland	1,919	23%	1,7%	2,16	1,66	3,6%	2,1%	1,64	1,51	10,8%	8,5%
Germany	13,625	22%	1,5%	2,20	1,35	3,5%	1,8%	1,18	1,20	11,5%	6,5%
India	36,672	24%	4,1%	1,30	0,87	1,0%	0,8%	0,33	0,44	1,9%	1,3%
Iran	8,171	12%	2,7%	1,79	1,07	3,1%	1,3%	0,86	0,62	0,7%	0,7%
Japan	11,752	17%	1,7%	1,46	0,94	2,0%	1,0%	0,89	0,71	9,2%	6,0%
Singapore	4,743	16%	4,0%	3,26	1,85	7,1%	3,9%	1,83	1,64	9,7%	8,0%
Sweden	2,434	30%	1,1%	2,34	1,65	3,5%	2,4%	1,65	1,56	13,1%	7,9%
United Kingdom	18,342	20%	1,7%	2,56	1,56	4,3%	2,2%	1,64	1,37	9,6%	5,7%
United States	63,060	21%	1,8%	2,94	1,39	4,7%	1,9%	1,04	0,87	11,5%	4,7%
World	349,415	23%	2,1%	1,75	1,00	2,3%	1,0%	0,55	1,00	4,9%	2,7%

The share of publications in the first percentile is another indicator related to the quality of the publications. This share covariates with the citation impact and Singapore's very high share of such publications indicates that AI research in Singapore is highly cited by other researchers.

International co-publications normalised for the scientific field and other aspects are indicated in the following columns. Overall, AI research is less international

than average research, as 0.55 for all publications is clearly lower than 1.00. The high numbers of AI publications from China and India contribute to this low overall value. In almost all other listed countries, including Sweden, AI publications are slightly more international than the average.

Finally, the share of academic–corporate co-publications is higher within AI research. Sweden has the highest share which means that 13.1% of the publications include at least one academic and one corporate actor.

A closer look at the proportion of each scientific field in the total publication volume reveals differences between the priorities in each country's AI research. In Figure 4, the height of the bars indicates the size of the share of all AI publications in the country related to each scientific field, using the OECD definitions. The sum of all six bars per country is 100%. Iran, for example, invests much more in AI research related to Agricultural Sciences than the other countries and the world, see Figure 4.

Figure 4: **Agricultural Sciences**

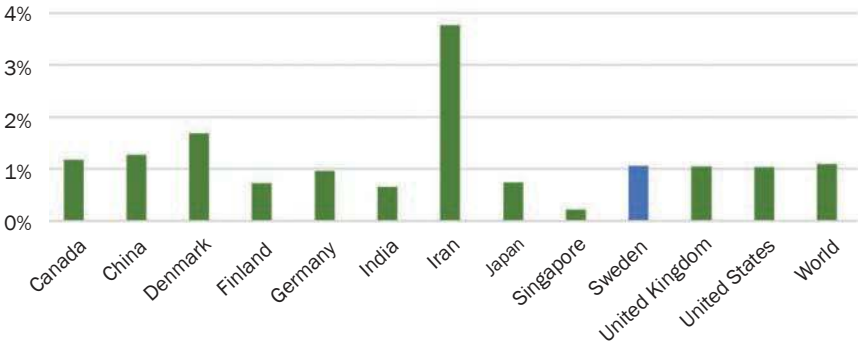


Figure 5: **Engineering & Technologies**

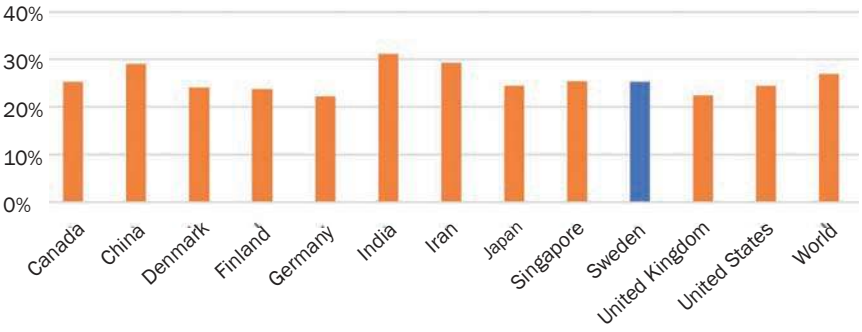


Figure 6: **Humanities**

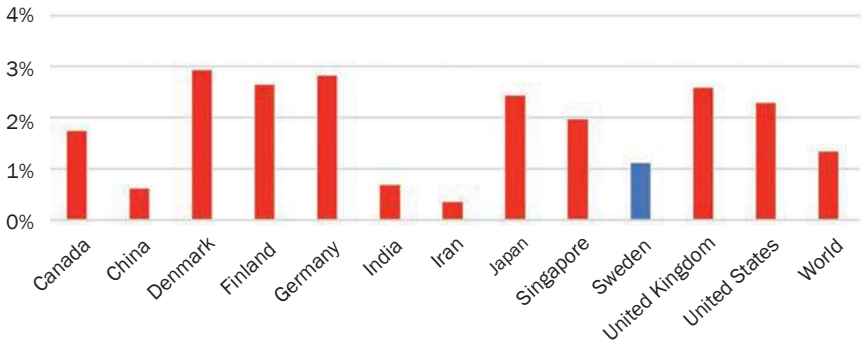


Figure 7: **Medicine**

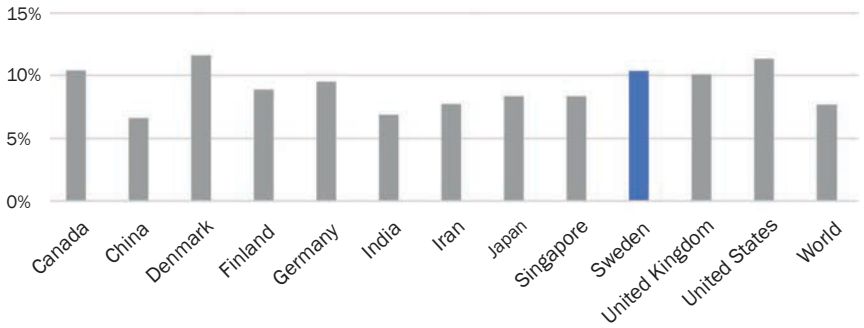


Figure 8: **Natural Sciences**

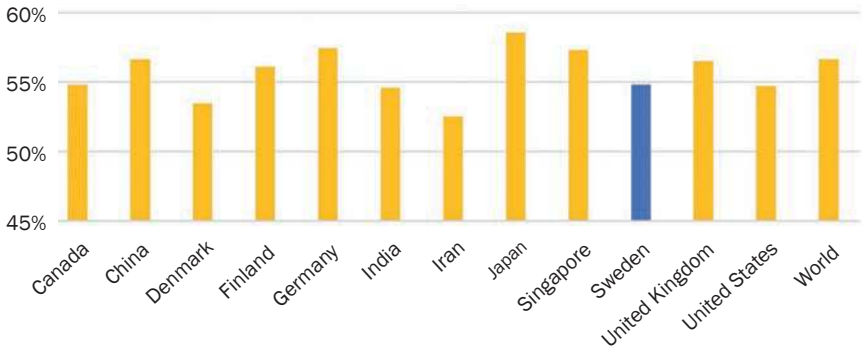
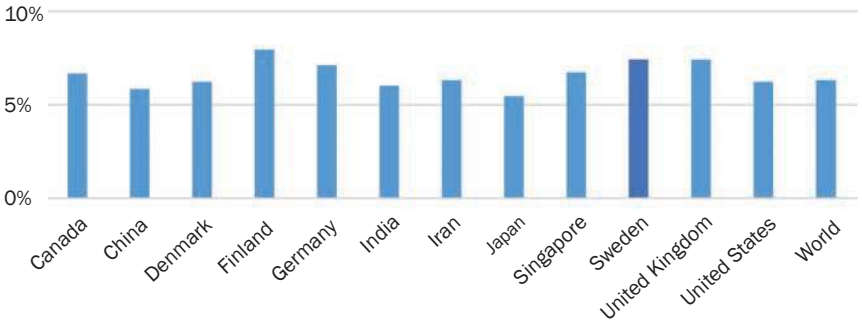


Figure 9: **Social Sciences**



Whereas Engineering and Technologies (Figure 5) and the Natural Sciences (Figure 8) could be considered at the core of AI research, investments in fields such as Medicine (Figure 7) might be interpreted as more applied research. Overall, Sweden's AI research profile is similar to the global profile but with a slightly stronger emphasis on Medicine.

One interesting, but difficult to study, dimension is dual-use AI research with both civil and military applications. Even though it is possible to break down the scientific fields further, this dimension is probably impossible to identify in normal studies of publication data.

Institutional level: KTH Royal Institute of Technology, Chalmers University of Technology and Luleå Institute of Technology are the most active in Sweden

Moving to the institutional level, some indicators were calculated for the five institutions with the largest number of AI publications in each of the countries specifically addressed in this report. In addition, five corporate actors were also included following the same selection criterion. Four of them are based in the United States and one in China.

The University of Toronto has the highest number of AI publications in Canada and the most rapid increase in volume, see Table 3. The trend, as mentioned above, is calculated as the annual growth rate between 2016 and 2020, using linear regression to calculate the endpoints of the interval. The University of Toronto's AI publications have a very high citation impact and include corporate actors to a rather high extent, in comparison with the other universities. However,

Table 3: **Academic institutions in Canada**

Publications 2016–2020					Citation impact FWCI		Int'l co-publications FWIS		Share of academic-corporate co-publications	
Institution	**Country**	**AI publ.**	**Trend**	**Share AI**	**AI**	**ALL**	**AI**	**ALL**	**AI**	**ALL**
University of Toronto	Canada	1,070	31%	1,1%	4,23	1,97	1,34	1,34	11,8%	8,0%
University of Waterloo	Canada	857	24%	3,6%	2,43	1,56	1,50	1,33	7,5%	4,4%
University of British Columbia	Canada	788	21%	1,4%	2,67	1,95	1,51	1,38	8,9%	4,7%
University of Alberta	Canada	763	18%	1,9%	2,20	1,64	1,56	1,27	6,6%	4,3%
McGill University	Canada	622	28%	1,4%	3,07	1,80	1,44	1,36	9,5%	4,4%

this is also the university with the highest number of publications overall; the four other universities are all more focused on AI, with the University of Waterloo having the highest share of AI publications at 3.6%.

Table 4: **Academic institutions in China**

Publications 2016–2020					Citation impact FWCI		Int'l co-publications FWIS		Share of academic-corporate co-publications	
Institution	**Country**	**AI publ.**	**Trend**	**Share AI**	**AI**	**ALL**	**AI**	**ALL**	**AI**	**ALL**
Chinese Academy of Sciences	China	6,735	23%	2,4%	2,13	1,40	0,68	0,64	6,0%	2,4%
Tsinghua University	China	3,621	21%	4,3%	2,93	1,72	0,96	0,78	12,0%	5,6%
University of Chinese Academy Sciences	China	3,278	37%	2,9	1,96	1,34	0,53	0,50	5,5%	2,2%
Zhejiang University	China	2,704	35%	3,1%	1,96	1,33	0,89	0,71	8,4%	3,1%
Shanghai Jiao Tong University	China	2,683	34%	3,0%	1,96	1,36	0,85	0,70	8,1%	3,6%

The Chinese universities are large producers of publications, see Table 4. The fifth Chinese university produced more publications than the leading ones in all of the other countries. Tsinghua University has the highest share of AI publications and the highest citation impact. Its publications are also the most international, and they include corporate actors to a high extent. The top five producers of AI publications in China are also the largest producers of scientific publications overall. However, below the top five producers of AI publications in China one finds several of the 'Seven Sons of National Defence' (the universities in China

with the closest ties to the military) higher up in the list than in the overall ranking. While the traditionally top Chinese universities dominate AI research in the country, several new highprofile AI institutes have been established and can be expected to make significant contributions. These include the Zhejiang Lab, the Beijing Academy of Artificial Intelligence, the Shanghai Artificial Intelligence Lab, and the Peng Cheng Laboratory.

Table 5: **Academic institutions in Sweden**

Publications 2016–2020					Citation impact FWCI		Int'l co-publications FWIS		Share of academic-corporate co-publications	
Institution	**Country**	**AI publ.**	**Trend**	**Share AI**	**AI**	**ALL**	**AI**	**ALL**	**AI**	**ALL**
KTH Royal Institute of Technology	Sweden	489	32%	2,2%	2,41	1,57	1,60	1,60	13,9%	10,2%
Chalmers University of Technology	Sweden	242	42%	1,6%	2,43	1,57	1,56	1,47	23,1%	16,8%
Luleå University of Technology	Sweden	229	37%	3,9	2,65	1,51	2,13	1,65	5,7%	9,6%
Linköping University	Sweden	206	17%	1,4%	2,79	1,75	1,48	1,39	11,2%	6,2%
Uppsala University	Sweden	184	21%	0,6%	2,36	1,78	1,59	1,45	8,7%	6,8%

As can be seen in Table 5, KTH Royal Institute of Technology is clearly the largest producer of AI publications in Sweden, but it is still smaller than all top five institutions in the other countries. Chalmers University of Technology shows the strongest positive trend and Luleå University of Technology has the highest share of AI publications. It also has the most international AI research. Finally, Chalmers University of Technology has the greatest share of co-publications with the corporate sector in Sweden, also in comparison with all academic institutions in this section. A longer list of Swedish institutions is available in the Appendix.

Massachusetts Institute of Technology is the largest AI publication producer in the United States whereas Carnegie Mellon University has the highest share of such publications and shows a relatively modest positive trend, see Table 6. The citation impact is very high for all five. All academic institutions in the United States collaborate extensively with corporate actors within AI, some of which are listed below.

Three main US competence centres stand out: Stanford, powered by Google, literally created the modern AI research field and the ecosystem around Stanford is vibrant; MIT; the University of Washington, powered by Microsoft.

Table 6: **Academic institutions in the United States**

Publications 2016–2020					Citation impact FWCI		Int'l co-publications FWIS		Share of academic-corporate co-publications	
Institution	**Country**	**AI publ.**	**Trend**	**Share AI**	**AI**	**ALL**	**AI**	**ALL**	**AI**	**ALL**
Massachusetts Institute of Technology	United States	2,183	18%	3,7%	4,18	2,40	1,15	1,20	16,5%	9,0%
Carnegie Mellon University	U.S.	1,822	5%	8,8%	4,10	2,29	1,04	1,01	18,7%	10,6%
Stanford University	U.S.	1,756	24%	2,3%	5,44	2,50	0,96	1,00	11,1%	6,6%
Harvard University	U.S.	1,704	36%	1,0%	3,45	2,25	1,22	1,10	11,1%	6,6%
Georgia Institute of Technology	U.S.	1,428	22%	4,6%	3,35	1,93	0,95	1,02	16,5%	8,6%

IBM has the highest number of AI publications, whereas Tencent's publication volume grew 80% annually during these five years, which is a substantially higher rate than that of the other corporate actors, see Table 7. Tencent has also the

Table 7: **Academic institutions in the United States**

Publications 2016–2020					Citation impact FWCI		Int'l co-publications FWIS		Share of academic-corporate co-publications	
Institution	**Country**	**AI publ.**	**Trend**	**Share AI**	**AI**	**ALL**	**AI**	**ALL**	**AI**	**ALL**
IBM	Corporate	1,951	10%	14,6%	2,59	1,81	1,06	1,11	62,8%	65,6%
Microsoft USA	Corporate	1,641	4%	17,6%	6,57	3,59	1,11	1,21	80,5%	82,3%
Alphabet Inc.	Corporate	1,558	11%	20,7%	10,32	5,08	0,97	1,02	63,2%	71,5%
Tencent	Corporate	613	80%	30,7%	4,00	3,28	1,51	1,56	90,5%	90,8%
Facebook Inc.	Corporate	533	27%	23,0%	10,89	6,22	1,10	1,07	77,5%	74,6%

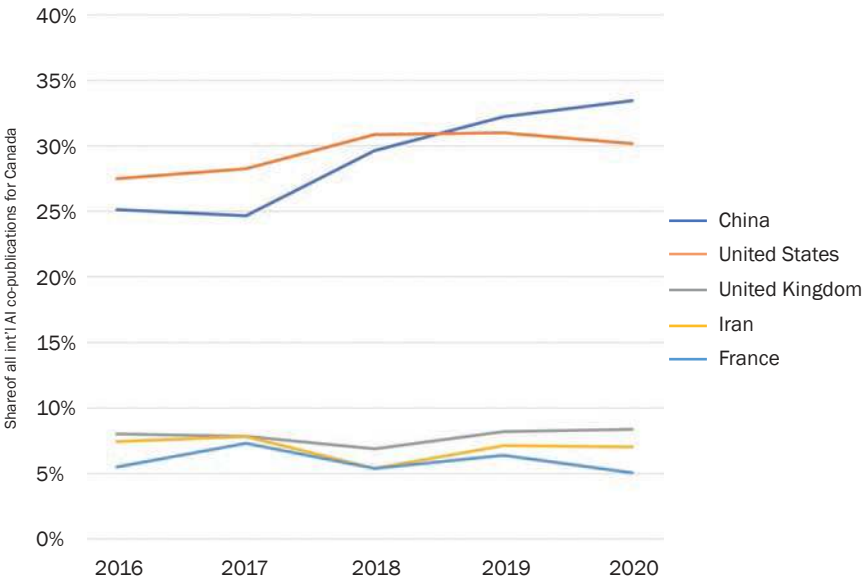
highest share of AI publications. The citation impact of all corporate actors is very high.

Tencent has the highest share of international AI co-publications as well as publications including academic actors. A high share indicates extensive collaboration with the academy, but it could also mean that the actor has a somewhat limited capacity or willingness to carry out in-house research leading to publications.

International collaboration: China and the United States are the largest com-petitors *and* collaborators in AI

Scientific co-publications between countries or actors provide a good indicator of their collaborations. In Figure 10 – Figure 13, the development over five years for the five largest collaborations for each of the countries in focus is presented. To facilitate this comparison, the volumes have been normalised using the total number of international AI publications each year. For example, this means that in 2020, approximately 30% of the international Canadian AI publications included at least one US co-author.

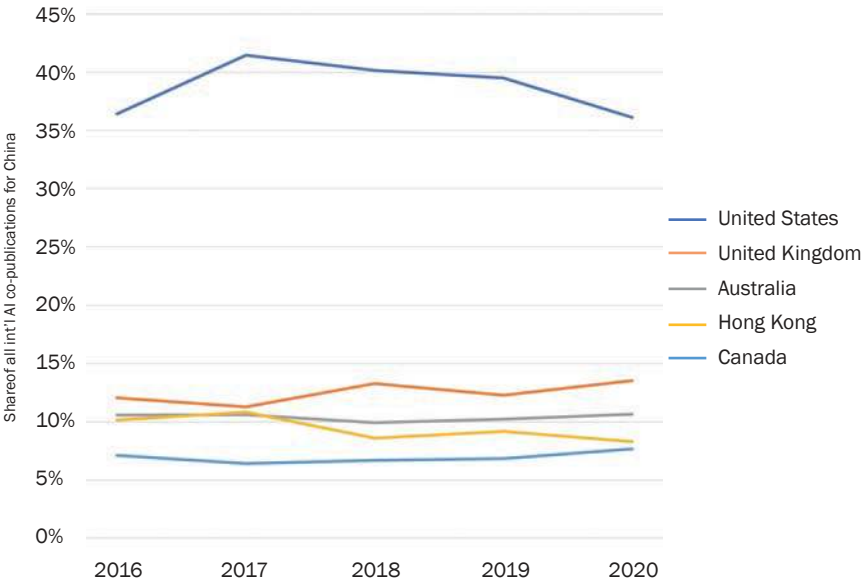
Figure 10: **Canada, top collaboration countries**



Most international collaborations are bilateral. Every third international AI publication with an author with a Canadian affiliation also includes an author with a Chinese or US affiliation, see Figure 10. However, only 225 of the 1,774 co-publications with China during the period included a US author. France, ranked eleventh in the world in terms of AI publications, shares a language with Canada, whereas Iran, ranked thirteenth, does not.

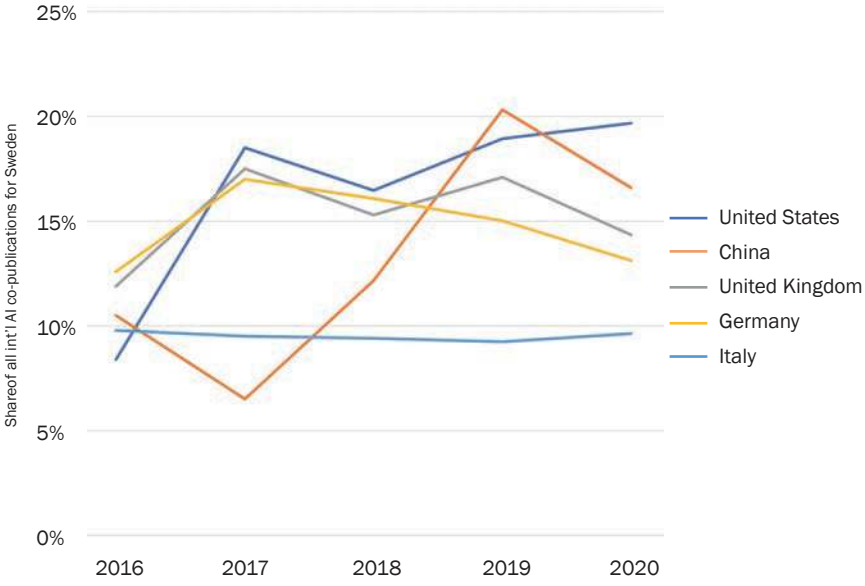
China has a relatively low share of international AI co-publications at 25%. Among them, the United States clearly dominates, even though the share has dropped slightly since the peak in 2017, see Figure 11. Given the rapid growth in AI publications, the number of co-publications including China and the

Figure 11: **China, top collaboration countries**



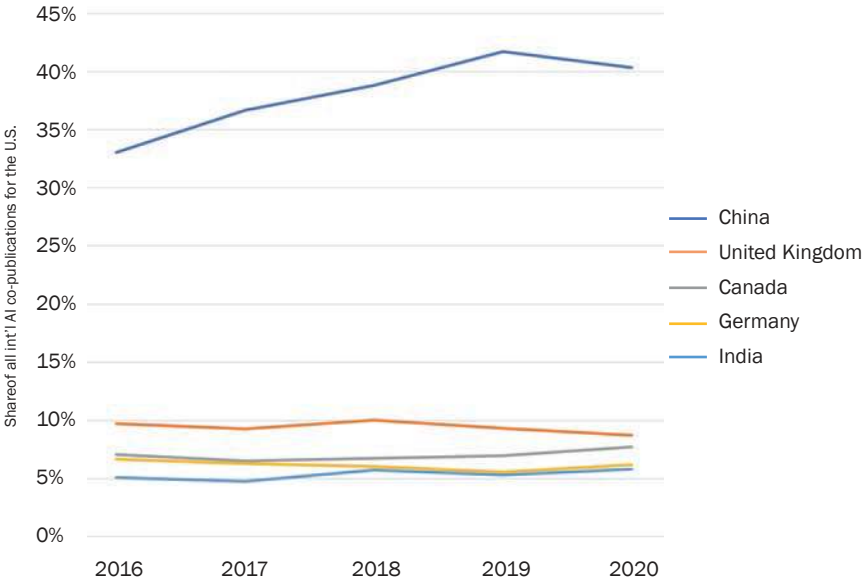
United States has increased in absolute terms. Australia is ranked ninth in AI publication volumes and Hong Kong 22nd.

Figure 12: **Sweden, top collaboration countries**



Whereas Sweden has relatively similar shares of co-publications with four countries, see Figure 12, the other three countries' collaborations are dominated by the United States and China. AI collaboration with China has varied considerably in intensity over the years and overall. Given that the share of international AI co-publications has been relatively stable at 60% during this period, Sweden's collaboration appears to have become slightly more dominated by some of the largest AI countries in the world.

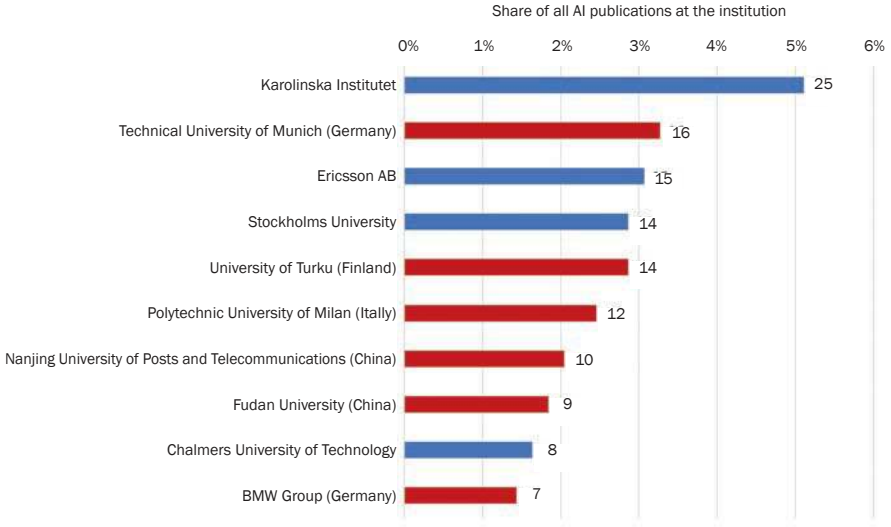
Figure 13: **United States, top collaboration countries**



From a US perspective, AI collaboration with China has increased over this period, potentially peaking in 2019, see Figure 13. Four of ten international AI co-publications with a US author also include a Chinese one. Thereafter follow four other large AI countries with considerably lower shares.

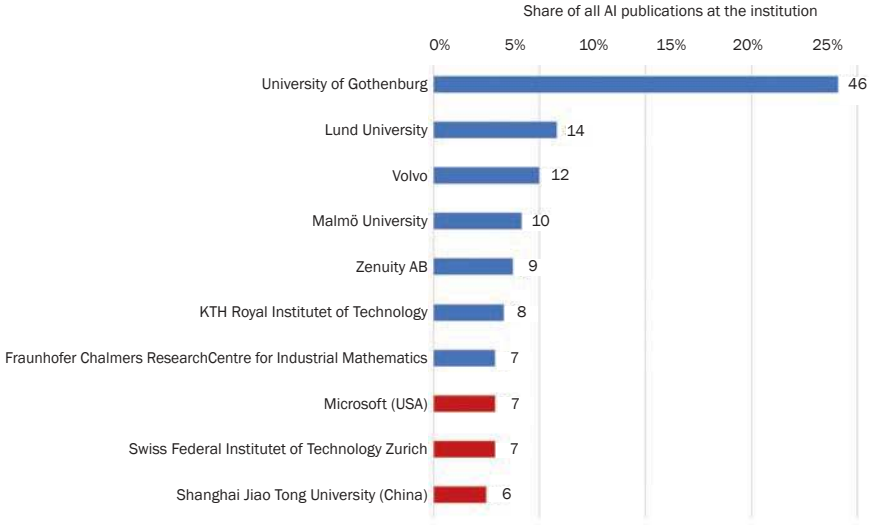
A closer look at the collaborations at the five largest AI institutions in Sweden reveals further details as to the nature of these collaborations. Do they collaborate with the leading universities and countries? KTH Royal Institute of Technology had the highest number of publications and in Figure 14, its top ten collaborators are listed. The figure at each bar indicates the number of co-publications during 2016–2020 and the length of the bar relates this number to all AI publications at KTH Royal Institute of Technology. Blue bars indicate national collaboration and red bars international collaboration.

Figure 14: **KTH Royal Institute of Technology, top ten AI collaborators, 2016–2020**



Interestingly, the top collaborator is a medical university, with 25 co-publications. However, this only represents about 5% of all AI publications at KTH Royal Institute of Technology. The second and the final one in the list are probably both related to AI in automotive applications.

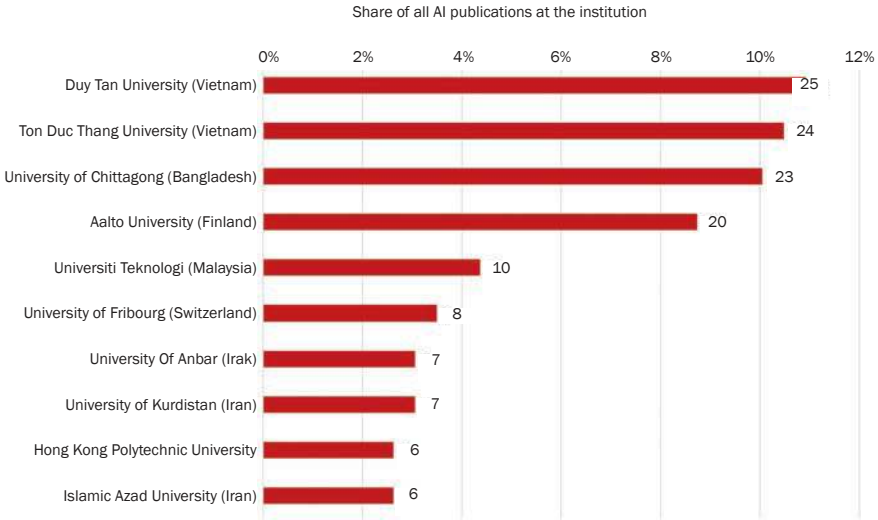
Figure 15: **Chalmers University of Technology, top ten AI collaborators, 2016–2020**



Like KTH Royal Institute of Technology, Chalmers University of Technology has a main collaborator of a complementary type in the same city, see Figure 15. The University of Gothenburg participates in almost every fifth AI publication. International partners are at the lower end of the list. AI for automotive applications is also prominent for Chalmers University of Technology, with two automotive corporates among the top ten collaborators. In Scopus, *Volvo* includes both AB Volvo and Volvo Cars.

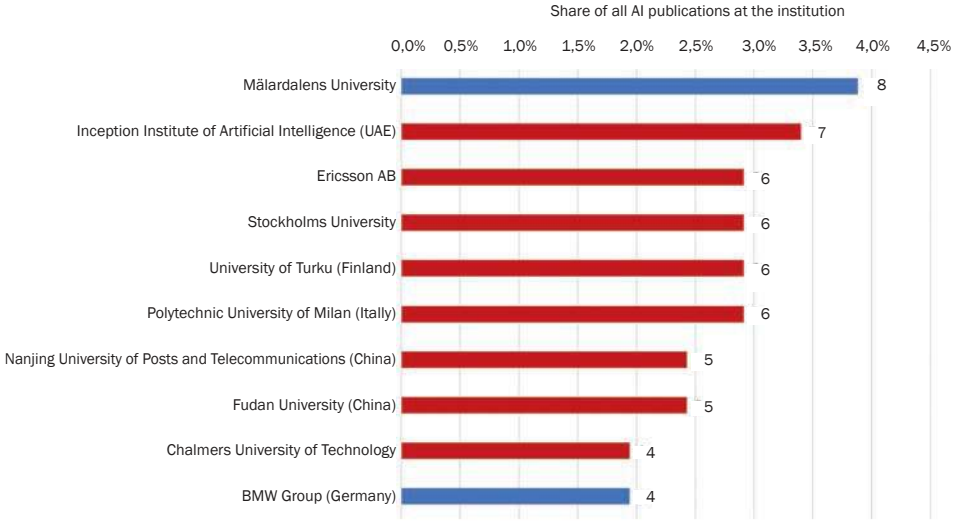
Luleå University of Technology features a clearly different set of top collaborators within AI, see Figure 16. Countries with emerging academic research are represented at the top, including Vietnam and Bangladesh. All collaborators are international and some of them represent a relatively large share of all AI-related publications.

Figure 16: **Luleå University of Technology, top ten AI collaborators, 2016–2020**



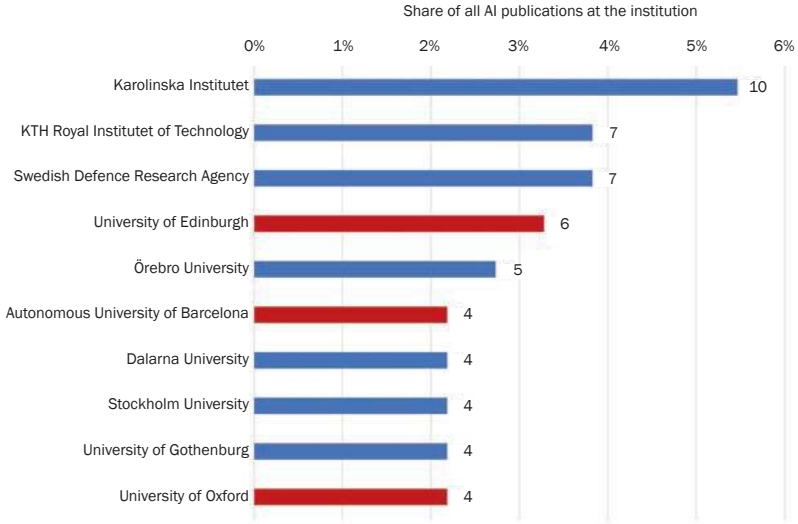
Linköping University also has a very international set of top collaborators, but they represent only a very small share of the total volume, see Figure 17. The Inception Institute of Artificial Intelligence is based in Abu Dhabi and the Computer Vision Centre in Barcelona, Spain.

Figure 17: **Linköping University, top ten AI collaborators, 2016–2020**



Finally, the AI co-publications at Uppsala University comprise Swedish and European institutions, each with a relatively low share of the total volume, see Figure 18. As is the case for KTH Royal Institute of Technology, Karolinska Institutet is the largest collaborator.

Figure 18: **Uppsala University, top ten AI collaborators, 2016–2020**



Overall, their collaboration patterns do not indicate that Swedish universities have established strategic international collaborations within AI with leading actors abroad. A report by Sweden's innovation agency (Vinnova) and others recommended the establishment and development of internationally leading environments for collaboration (Vinnova, 2018).

Geopolitically, it is interesting that the controversies between China, Canada and the United States are not more visible in the development of research collaboration. As previously mentioned, the number of co-authors in AI publications is relatively low; almost all have a maximum of ten co-authors, which means that the collaborations are probably fairly balanced with active participation in both/all countries. The personal relationships on which these collaborations are based can most likely explain the continuation of collaborative work despite pandemic travel restrictions and increased technological competition between the United States and China. When interviewed for this report, one of the authors of China's national AI strategy noted that research exchange between China and the United States in the field was still "business as usual", but also expressed concern that Chinese AI students overall no longer were being granted US student visas. Conjecturing how the currently shifting geopolitical landscape will affect future collaborations is therefore a challenge.

Canada and France are working with the international community to create the International Panel on Artificial Intelligence (IPAI) to support and guide the responsible development of AI that is grounded in human rights, inclusion, diversity, innovation, and economic growth. The Panel will be an organisation dedicated to AI and will bring together many of the leading global AI experts. It will form a global reference point on AI, fostering international collaboration and coordination on AI policy development. Members include Australia, Canada, France, Germany, India, Italy, Japan, Mexico, New Zealand, the Republic of Korea, Singapore, Slovenia, the United Kingdom, and the United States. The European Union is also in negotiations to enter the partnership.

US AI policy also recognises the importance of international cooperation on AI. The American AI Initiative recognises partnerships with US allies; partners represent a key "source of strategic competitive advantage," and the Initiative identifies the need to "engage internationally to promote a global environment that supports American AI research and innovation and opens markets for American AI industries."

China also emphasises the importance of international cooperation in the AI field. There are several reasons for this. On the one hand, it is for the good of the overall development of the AI field, e.g., in relation to ethical issues and the safe development of AI as well as the utilisation of the complementary strengths of different nations. On the other hand, it is an effort to ensure that China has access to aspects of AI development where it considers itself to still be lagging (behind the United States), mainly in advanced chip technology, basic research, and education.

National research policies

By now most large economies have drafted and released some sort of national AI policy or strategy. Since Canada published the world's first national AI strategy in 2017, more than 60 other countries and regions have published similar documents. As in all strategies, there are trade-offs and priorities. PwC (2019) mentions three main types of trade-offs, or rather degrees of emphasis in these national policies: innovation versus regulation, the individual versus the state, and transparency versus vulnerability. Here we summarise the key aspects of the national AI strategies (or equivalent) of the four countries studied above, as well as that of Singapore, which is of interest as it is a small, scientifically advanced nation with good relations to both the United States and China, and that of the European Union, which is of obvious importance to Sweden.

Canada

Canada's long-term investments in AI have positioned the country as one of the leading national innovation systems in the area. Radical Ventures (2021) describes Canada's AI pedigree as based on decades of research funding. Research funding agencies such as the Canadian Institute for Advanced Research (CIFAR) and the Natural Sciences and Engineering Research Council of Canada (NSERC) provided early funding for the work of AI pioneers Geoffrey Hinton, Yoshua Bengio, and Richard Sutton. These individuals' laboratory breakthroughs and subsequent collaborations with private companies, including translation into real-world applications, were the direct precedents of the vibrant innovation ecosystems which gravitated towards Canada's AI luminaries.

Focused government investment, paired with commitments from the private sector, anchored this community in Canada, establishing centres of excellence with the shared mission of attracting world-leading research talent. Today, the Vector Institute for Artificial Intelligence (Vector Institute), the Quebec Artificial Intelligence Institute (Mila) and the Alberta Machine Intelligence Institute (Amii) are major hubs in the hyper-competitive global AI talent landscape.

Canada had, and still has, a choice between either building an AI ecosystem or keeping buying AI technology from the United States. The government promotes and funds the ecosystem approach. The Canadian government has managed to recruit and retain a fair number of AI experts across its departments, which is regarded positively by researchers and industry alike. In recent years, the Canadian national strategy involves emphasising innovation via AI 'superclusters' to attract private funding and talent, with great hopes that knowledge transfer from the ac-

ademic sector to these superclusters will speed up the rate of innovation. In 2017, the Canadian government created the Innovation Superclusters Initiative (ISI). The combined funding from private sector partners (US$ 700 million) and the federal (US$ 230 million) and provincial (US$ 60 million) governments was approximately US$ 990 million. Three central positive results from government policies and strategies have been facilitating the speedy immigration of top international talent, unlocking valuable public data, and incentivising private sector investments in AI technologies and startups. In Canada's 2021 budget, commercialisation was added as a new element for all AI funding.

One interesting aspect of the Canadian AI policy landscape involves ethics. Canada is currently involved in leading a global online consultation on AI ethics spearheaded by Mila and the Algora Lab (Université de Montréal) in partnership with UNESCO. This builds on the 2017 Montreal Declaration for a Responsible Development of Artificial Intelligence which articulated ten fundamental values to underpin ethics principles for AI. Canada also co-leads the Global Partnership on AI (GPAI) with France. This is the first global initiative bringing together 14 countries and the European Union to guide the responsible use and development of AI.

The Canadian government has in recent years focused funding into three research institutes that in turn determine which universities to fund. This is seen as a significant step away from the spray-and-pray mentality of the past. The Vector Institute, Mila and Amii are major hubs in the hyper-competitive global AI talent landscape. Mila has some 50 professors and in total about 700 academics and is looking to develop pre-competitive stage consortia.

Despite Canada's successful positioning in AI, global competition is ramping up quickly. Radical Ventures (2021) highlights the competition via recent results from the Tortoise AI Index. In the 2020 updates of this international benchmarking ranking state capacity for AI, Canada held the fourth place on the global stage, but the country has significantly shifted down the ranks in multiple categories across implementation, innovation and investment. Most notably, Canada's operating environment fell from fifth to thirty-second place. Additionally, Canada slipped nine places in terms of development, a category requiring industry collaboration to support contributions to new models, techniques and products. The report also cites dwindling incentives to seek patents as a contributing factor in slipping down the rankings. Industry experts claim that larger Canadian companies are paying inadequate attention to AI – as far as AI is concerned, these companies are quite immature and unprepared for data and skills.

China

While several policies and white papers relevant to AI exist, the key national AI policy document is the Next Generation Artificial Intelligence Development Plan (NGAI), which was launched in 2017 by the Chinese State Council. The plan was developed in a project initiated a year earlier by the Chinese Academy of Engineering (CAE). A large group of stakeholders from academia, industry, and government led by the Ministry of Science and Technology (MoST) contributed to the drafting of NGAI.

Some of the challenges China faces in the development of AI identified in the NGAI include basic AI research, high-end chips, a well-developed ecosystem for AI development, and talent supply, i.e., AI education. In parallel to technology development aims, the NAGI emphasises the importance of the ethical development of AI and that China is to become a leader in the development of ethical norms and standards for AI.

Despite being launched in 2017, the NGAI plan covers the period 2015–2030 and outlines three consecutive steps which all have specific target outcomes:

– By 2020, to have closed the technological gap with world-leading countries and for China's AI industry to compete at the highest international level.
– By 2025, to achieve significant breakthroughs in fundamental AI research, to have developed some world-leading AI technologies and applications, and for AI to have become the main driving force for industrial development and economic transformation in China.
– By 2030, to have become one of the world's leading AI innovation centres and to have developed comprehensive regulatory, legal, and ethical principles for AI development.

As part of the implementation of the plan, a range of national AI platforms has been established. These include fifteen application-driven National Open Innovation Platforms supported by MoST. Each platform focuses on a specific application area and is led by a leading company in that area, e.g., Urban Cognition led by Alibaba, Image Perception led by Megvii and Autonomous driving led by Baidu. By 2023, twenty National NGAI Development Experimental Zones supported by MoST will have been established, as well as several Pilot Zones for Innovation Application of AI supported by the Ministry of Industry and Information Technology. The aim of the National NGAI Development Experimental Zones is to push cooperation with local governments to implement AI technologies in practice, both to demonstrate its usability as well as to experiment with AI policy development.

In addition to the national AI development plan, local governments in China have developed, or are developing, their own AI development plans, which play an important role in delivering on the goals of the NGAI in practice. While coordinated by MoST through the AI Plan Promotion Office, the implementation of the NGAI can be characterised as quite distributed; a broad range of stakeholders act largely autonomously to meet the targets of the plan.

Singapore

Prior to the launch of Singapore's National AI Strategy, in 2017 the government established AI Singapore, a programme funded by the National Research Foundation, which supports AI development through a range of initiatives and aims to pool the resources of Singapore's research institutions and private sector. The National AI Strategy was launched in 2019 with the vision to, by 2030, have established Singapore as a "leader in developing and deploying scalable, impactful AI solutions, in key sectors of high value and relevance to our citizens and businesses." Through the plan Singapore aims to become a global hub for AI development and deployment with the purpose of generating economic gains and improving lives. Part of the plan aims to ensure that Singaporeans understand AI, its uses and benefits as well as to upskill the workforce to enable its participation in the AI economy.

An initial set of five national AI projects was established at the launch of the National AI Strategy, focusing on areas that were expected to deliver strong social and/or economic impact. The approach is for the national projects to guide investment in AI research, generate lead demand and develop necessary human resource and capabilities. The number of national AI projects has since expanded to seven. These are in the fields of government, healthcare, smart estates, education, border security, logistics, and finance.

In parallel, the National AI Strategy aims to develop and support the AI ecosystem, which is done by focusing on five key ecosystem enablers: triple helix partnerships between the research community, industry, and government; talent and education; data architecture (to en-ables quick and secure access to high-quality datasets); establishing a progressive and trusted environment for test-bedding, developing, and deploying AI solutions; and international collaborations.

Singapore's National AI Strategy is implemented through a range of programmes aiming at supporting businesses' AI transformations, investments in AI development as well as AI edu-cation. The website of the Prime Minister's Office also has a form through which anyone can submit proposals to the existing national projects or propose a new one.

The United States

The White House sees AI as a prioritised strategic area. The Trump administration stated that each agency should put out an AI strategy and there is also strong continuity between the Trump and Biden administrations on AI. The National Artificial Intelligence Initiative Act 2021 established the White House National Artificial Intelligence Initiative Office charged with coordinating the national AI strategy. The National Security Commission on Artificial Intelligence estimates that the United States needs to spend US$ 32 billion over the next few years to win the AI race with China, among other rivals.

The 2021 National Defense Authorization Act further develops AI policy in the defence and non-defence sectors. The National Security Commission on Artificial Intelligence Final Report, published in 2021, outlines several concrete actions for the president including defining and prioritising the key emerging technologies such as quantum computing in which US leadership is essential. It also details organisational changes in the responsibilities for AI within government agencies, and states explicitly how China's influence is to be curbed.

A major part of the research funding strategy for AI in the United States rests on the US National Science Foundation (NSF). In 2021, the NSF announced the establishment of eleven new NSF National Artificial Intelligence Research Institutes, building on the first round of seven institutes funded in 2020. The combined investment of US$ 220 million, building upon the first selection of seven institutes and US$ 140 million in allocated funding in 2020, expands the reach of these institutes to include a total of 40 states and the District of Columbia. Through the NSF-led AI Research Institutes, as well as a range of ongoing programmes, the NSF supports fundamental research, education and workforce development, and advanced, scalable computing resources that collectively enhance fundamental research in AI.

According to technology consultant Deltek (2021), identifiable federal spending on AI rose to nearly US$ 1 billion in the 2020 financial year, up 50% from 2018, making it one of the fastest growing emerging technology investment areas. The Department of Defense spends nearly twice the amount the civilian sector spends on AI.

Sweden

In May 2018, the Swedish government adopted a national focus on AI, which for example emphasises the importance of disseminating and using AI to

strengthen competitiveness. This is not a strategy but a document that sets out the direction of Swedish AI efforts and lays the foundation for future priorities. The policy goals outlined are similar to the digitisation goals and the Swedish government believes that the document complements the digitisation strategy. The policy approach has not been to single out AI as a separate strategy, but rather to regard this area as part of a broader need to digitalise considerable parts of society. The Swedish government identifies four areas that are assumed to be particularly important to utilise AI: education, research, innovation and use, as well as frameworks and infrastructure.

Due to the involvement of various stakeholders in national AI policy, the situation in Sweden is complex. The ministries concerned are mainly the Ministry of Infrastructure, the Ministry of Trade and Industry and the Ministry of Education. Implementing authorities include Vinnova and the Swedish Digital Administration Authority (DIGG). Vinnova has launched a national AI hub called AI Sweden. The Research Institutes of Sweden (RISE) has gathered the players in the Swedish AI ecosystem to develop an AI agenda for Sweden. Research on AI is mainly conducted at six universities: the University of Gothenburg, KTH Royal Institute of Technology, Linköping University, Lund University, Umeå University, Örebro University and Chalmers University of Technology.

The largest Swedish funder of AI research is not the state, but the private Wallenberg Artificial Intelligence, Autonomous Systems and Software Program (WASP). The Knut and Alice Wallenberg Foundation will have invested SEK 4.2 billion in AI research by 2030. Together with co-funding from universities and companies, the entire investment covers SEK 5.5 billion. The programme funds basic research on AI and autonomous systems. WASP aims to bring together various higher education institutions through financial support to build internationally competitive AI research environments. WASP was established in 2015 and has since 2017 been supplemented with an expanded AI investment in machine and deep learning and next-generation AI, as well as basic mathematical principles behind AI and robotics and visual recognition. Funding has been allocated for basic research at Chalmers and KTH Royal Institute of Technology as well as Linköping, Lund and Umeå universities. WASP also attracts global AI expertise to Sweden through key recruitments. The goal is to create 100 AI research groups. Nine international AI professors have been recruited. In collaboration with industry, the programme has started a graduate school, opened research arenas and launched test beds. WASP has also recruited 337 doctoral students to the doctoral school, 101 of whom are industrial doctoral students.

The European Union

Sweden's national strategy must be seen in the light of policy development in the European Union. The European Union approach to AI focuses on two areas: excellence in AI and trustworthy AI. The main underlying philosophy is that AI improvements should be based on rules that safeguard the functioning of markets and the public sector, and people's safety and fundamental rights.

The effort to develop an AI-strategy started in earnest in 2017. In May 2017, the European Commission published its mid-term review of the Digital Single Market strategy. It then highlighted the importance of building on Europe's scientific and industrial strengths, as well as on its innovative start-ups, to be in a leading position in the development of AI technologies, platforms, and applications. Later in 2017, policy statements were made on the sense of urgency in addressing emerging trends such as AI while at the same time ensuring a high level of data protection, digital rights and ethical standards. The Commission was invited to present a European approach to AI. The European Parliament has made wide-ranging recommendations on civil law rules on robotics and the European Economic and Social Committee has also issued an opinion on the topic.

In April 2021, the European Commission published its AI Package, proposing new rules and actions to turn Europe into the global hub for trustworthy AI. This package consists of:

– a Communication on Fostering a European Approach to Artificial Intelligence;
– the Coordinated Plan with Member States: 2021 update;
– a proposal for an AI Regulation laying down harmonised rules for the European Union (Artificial Intelligence Act).

Geopolitics and AI

One clear observation on the global arena of AI research is that the United States and China, however fiercely they compete with each other, clearly are advancing fast together and leaving other countries behind, both in terms of research and the pace of innovation. A combination of strong technology sectors and high government interest and support in these two countries will further widen this gap.

EU policy and opinion makers fear that European countries are losing ground to the United States and China in the field of AI. This is one of the rationales behind the European Union's policies on AI. The US government teams up with large software companies to set the tone in its AI development, and while the Chinese government is working to drive the AI development in China it too turns to private enterprises for implementation, e.g., through the National Open Innovation Platforms. In the United States, large corporations control the data, while in China the state ultimately controls the data. In China and in the United States, as well as in other nations, there exist strong interest from the military to utilize AI, though the amount of military AI research spending in China notoriously difficult to estimate (CSET 2019).

The US approach is that other national policies – China's above all – seek to erect barriers to the free and open development of AI, appropriating the benefits for their national champions and applying AI as a geopolitical lever. Such policies could distort the development and benefits of AI for humanity, making the world less secure for the United States and its allies, and markets less receptive to US products and services. The second perceived challenge for the United States comes from other governments whose AI policies could lead to prescriptive regulation that may stifle AI innovation and discriminate against US technology firms. Western thinktanks such as the Brookings Institute point out that AI will continue to exert both immense stress on the US – China relationship as well as create opportunities for potential collaboration. There will be a higher degree of scrutinising US – Chinese academic exchanges from both these countries and their allies.

China certainly desires to become a world leader in the AI field and looks to develop and support national champions (notwithstanding recent crackdowns on major domestic technology behemoths by the Chinese government). Authors of the Chinese AI strategy prefer to point out that, while it focuses on the development of AI in China and the path to the international forefront, the United States' AI strategies seem more focused on countering Chinese developments. It could be argued that as the country catching up it is natural that China focuses

less on specific US achievements and rather concentrates on further developing AI. However, there is of course an intense focus in China on the United States' increased restrictions on access to pertinent technologies, with a strong mobilisation to develop these areas domestically to achieve technological independence.

Within this context it would be interesting if countries such as India, Canada, Sweden and the United Kingdom could offer a counterbalance to the US or Chinese models. While striking partnerships with the leading United States and China is the most attractive, smaller specialised labs in other countries can offer a complementary way forward. Smaller, less developed countries must invest with the aim of becoming valuable niche players in the global arena, as well as of developing strategies on the best ways to navigate the intense technology rivalry between the United States and China.

Observations

Research on AI is growing fast. AI research, as measured by the number of scientific publications, is growing rapidly in absolute as well as relative terms. In a comparison of several countries with substantial AI research, countries such as China, India, Singapore and Iran have a high share of AI publications in their portfolio whereas Sweden and Denmark have a relatively low share. Globally, about 57% of AI publications are within the Natural Sciences, followed by Engineering and Technologies (27%).

China and the United States are at the research frontier and are both the largest competitors and collaborators. At an institutional level, the top five Chinese universities have larger volumes of AI publications than all institutions in the other studied countries (Canada, Sweden, the United States). The largest corporate producers of AI publications are in the United States. China and the United States dominate as partners in the international collaboration for all four countries, but less so for Sweden, which has almost as high shares of international co-publications with the United Kingdom and Germany.

Dedicated national AI strategies are prevalent in most advanced economies. Over 60 countries have adopted some form of national AI policy, indicating the perceived policy importance of AI in society. Canada's long-term investments in AI have positioned the country as one of the leading national innovation systems in the area. Canada had, and still has, a choice between either building an ecosystem for AI or continue buying AI technology from the United States. The Canadian government promotes and funds the ecosystem approach and is building a critical mass of home-grown and recruited talent in the field. In China, the State Council has been driving a national strategy for AI with ambitious goals to become a worldleader both in research and industrial applications. Singapore's national AI strategy aims to develop and support an AI ecosystem, focusing on triple helix partnerships between the research community, industry, and government. In the United States, the White House sees AI as a prioritised strategic area and is set to increase funding in what resembles a new space or arms race, with both multinational corporations and governments striving for global leadership.

Sweden has strengthened research on AI, but international collaboration is still weak. Sweden produces AI research with a high citation impact in international comparison and the research volume exhibits strong growth. The five largest producers of AI publications in Sweden (KTH Royal Institute of Technology, Chalmers University of Technology, Luleå University of Technology, Linköping University and Uppsala University) exhibit different patterns of co-publications, with local/re-

gional partners dominating in three cases and international in two. Sweden's scientific profile is similar to the global one, but with a slightly higher share of AI publications in Medicine. The international collaboration pattern indicates that these institutions have so far not established strong international partnerships within the area of AI.

Sweden's national AI policy focuses on adoption rather than research excellence. The Swedish government has chosen to focus not so much on singling out AI as a separate policy field, but rather on including AI in policies to advance digitalisation in industry, academia, and government in general. Sweden has the ambition of maximising the potential of AI in areas such as education, research and innovation, as well as overall adoption in society. The emphasis is on the quick adoption of AI in society rather than on creating the capabilities to develop world-class AI systems. As neither a large producer of AI research nor a scientific leader, Sweden should have a strategy on how to best position itself to ensure access to and implementation of the leading edge of global AI advancements. This would include fostering an AI research and innovation ecosystem that is sufficiently strong to be able to attract leading scientists, innovators, and companies in the AI field to collaborate with, and/or work in Sweden. With rapidly increasing tensions and competition between the United States and China, Sweden needs to support its scientists interested in working with both countries in navigating that rivalry.

References

Interviews

Amiraux, Valérie, Vice-rectrice aux partenariats communautaires et internationaux, Universite de Montreal (May 6, 2021)

Ema, Arisa, Associate Professor, University of Tokyo, Japan (April 19, 2021)

Gianchandani, Erwin, Deputy Assistant Director, Computer and Information Science and Engineering, National Science Foundation, USA (August 11, 2021)

Joanette, Yves,Vice-recteur adjoint Recherche, découverte, création et innovation, Universite de Montreal, Canada (May 6, 2021)

Létourneau, Stéphane, Vice-président exécutif, MILA, Canada (May 17, 2021)

Lindsjö, Göran, Consultant, Governo, Sweden (May 17, 2021)

Meserole, Chris, Ph.D. Research and Policy Director, AI and Emerging Tech Initiative, Fellow, Foreign Policy Program, The Brookings Institution, USA (June 5, 2021)

Rentzhog, Magnus, Desk Officer, Government Offices of Sweden, Ministry of Enterprise and Innovation, Sweden (November 18, 2021)

Veerman, Alan, Chief Operations Officer, Vector Institute, Canada (April 22, 2021)

Wu, Fei, Professor; Vice Dean, College of Computer Science; and Director, Institute of Artificial Intelligence; Zhejiang University, China (April 4, 2021)

Reports

CSET (2019) Chinese Public AI R&D Spending: Provisional Findings, see https://cset.georgetown.edu/publication/chinese-public-ai-rd-spending-provisional-findings/

Deltek (2021) Federal Artificial Intelligence Landscape 2022, see https://info.deltek.com/federal-artificial-intelligence-2022

Elsevier (2020) Artificial Intelligence: How knowledge is created, transferred, and used Trends in China, Europe, and the United States, see https://www.elsevier.com/?a=823654

PWC (2019) Gaining Competitive Advantage through Artificial Intelligence (AI): Policy Making & National AI Strategies, see https://www.pwc.lu/en/advisory/digital-tech-impact/technology/gaining-national-competitive-advantage-through-ai.html

Radical Ventures (2021) 2021 Primer: Canada's AI Research Ecosystem, see https://radical.vc/2021-primer-canadas-ai-research-ecosystem/

Tillväxtanalys (2021) AI-politik för konkurrenskraft, see https://www.tillvaxtanalys.se/publikationer/pm/pm/2021-07-06-ai-politik-for-konkurrenskraft.html

Vinnova (2018) Artificiell intelligens i svenskt näringsliv och samhälle: Analys av utveckling och potential, Vinnova VR 2018:08

Appendix

Swedish institutions with AI publications according to Elsevier's method (2020).

Institution	AI publications 2016-2020	FWCI
KTH Royal Institute of Technology	489	2,42
Chalmers University of Technology	242	2,45
Luleå University of Technology	229	2,67
Linköping University	206	2,82
Uppsala University	184	2,38
Lund University	160	1,92
Karolinska Institutet	144	2,52
University of Gothenburg	127	1,81
Stockholm University	123	2,98
Umeå University	104	1,86
Mälardalens University	88	1,60
Örebro University	74	2,18

STINT, The Swedish Foundation for International Cooperation in Research and Higher Education, was set up by the Swedish Government in 1994 with the mission to internationalise Swedish higher education and research.

STINT promotes knowledge and competence development within internationalisation and invests in internationalisation projects proposed by researchers, educators and leaderships at Swedish universities.

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