ARTIFICIAL INTELLIGENCE: A POLITICAL SUBJECT

The Main World Powers and the Place for France among Them

April 2022

Based on the report by L. Dibiaggio, M. Keita & L. Nesta,
Artificial Intelligence: Key Technologies and Actors
2022 Edition

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INSIGHTS AND RECOMMENDATIONS

Paving the way for innovations that were once out of reach, artificial intelligence (AI) is expected to be a general-purpose technology, just like the steam engine, electricity and electronics in past industrial revolutions. In the space of just a few years, AI has extended into sectors as diverse as transport, telecommunications, healthcare, education, justice and safety.

Since 2010, there has been an interrupted rise in the number of AI patents filed each year. Over the past 30 years, **the top countries for AI patent production have been the United States (30%), China (26%), Japan (12%), South Korea (6%), Germany (5%), the United Kingdom (2.5%), France (2.4%) and Canada (1.9%).** The US and the Asian powers alone represent nearly three fourths of the AI innovation market. With more than half of global market shares, the United States and China have clearly asserted their dominance. What place is left for France and the rest of Europe in this strategic and ultra-competitive space? Have they achieved sufficient critical mass?

According to the Tortoise Global AI Index 2021[1], which evaluates nations based on their levels of investment, innovation and implementation of artificial intelligence, the US and China have held on to their leadership positions. Canada moved up to 4th place. It is ranked 1st for government strategy (ahead of China) and 6th for commercial strategy. As for France and Germany, they dropped to 10th and 9th place respectively, right after the Netherlands. **However, France rose to 5th place worldwide in terms of government strategy, above the US and Germany among others.**

In April 2021, the European Union released its new Coordinated Plan on Artificial Intelligence, built on collaboration between the Commission and Member States. It was based on the 2018 Coordinated Plan on AI. Its key objectives include accelerating investments and aligning AI policy to remove fragmentation[2]. That being said, in a field involving such colossal investment costs, French and European decision makers are subject to 'path dependence', meaning their future strategic choices are limited by previous long-term commitment choices. So, they must have a detailed understanding of the comparative advantages enjoyed by their own country and its competitors in AI-related fields in order to target specific investments that will allow them to make the necessary quantitative effort to expand their market share in key sectors.

This policy brief aims to give public and private decision makers some historical perspective on the strategic positions adopted by the leading AI countries over the past 30 years. This perspective is essential to making informed decisions about future investment, organisational and collaboration choices.

In the light of these insights, several recommendations are provided below.

- **Create the conditions for effective technology transfers between French actors in the public and private sectors, to make France competitive in AI beyond the borders of Europe**

In terms of AI specialisations and market share, France never finds itself in a situation of consolidating a dominant global position in any of the sectors along the value chain connecting the science to AI applications. It showed promise in neural networking techniques and in the field of transport but has not gained any market share since the 2010s.

Although ranked 7th for the number of AI patents produced, French private actors have struggled to compete with actors from the US, China and even Germany, as shown by the absence of any French private actors in the list of the top 20 biggest AI patent producers. Still, France is the leader in European public innovation, with six research institutions figuring among the top 10 public AI actors in Europe.

[1] This index examines seven factors: talent, infrastructure and operating environment (implementation), research and development (innovation), and government strategy and commercial (investment).
[2] Coordinated Plan on Artificial Intelligence 2021 Review, accessed 11 April 2022.

France is characterised by strong public sector research in the field of AI. This means that public sector decision makers have to rely on that research to create the conditions for transferring technology to actors closer to the markets.

- **Build national AI policies around the particularities of each country's specific national innovation systems**

Contrary to what might be expected, there does not appear to be a clear connection between States' specialisations and their achievements. Nonetheless, each country is working to specialise in at least one AI discipline. In France's case, there is a strong specialisation in the field of semantics. It is likely that this comparative advantage will be a real asset for the country when it comes to AI, because semantics is heavily dependent on computer science and expert systems, two areas (one scientific and the other technological) in which France displays an equally significant comparative advantage. The two other functional domains in which France specialises are character recognition and computer vision. However, those fields rely on learning techniques and sciences in which France has not demonstrated any especially strong skill sets.

Coordination between public and private actors in particular is specific to each region of the world and each country. A wide variety of models for interactions have been observed. This becomes all the more obvious when you look at the link between the dominant national companies and the countries' specialisations. That being said, the organisation of AI innovation is a crucial factor that should guide public policy decisions.

The diversity of national innovation systems calls for caution when it comes to writing policies in support of artificial intelligence that mimic the policies implemented in a benchmark country. In fact, this kind of diversity means that those policies cannot function in a vacuum, without relying on key national actors and tapping into synergies between the scientific, technological and functional domains that are most promising for the country.

- **Envision and build a European model for AI innovation that is in line with the diversity of its States, to improve Europe's position on a global scale**

Two findings led the authors to this recommendation. The first was that Europe is not at the forefront of global competition in the field of AI. In fact, only two European companies figure among the major actors in AI. Plus, European companies produce far fewer patents than the American and Asian giants. A quantitative effort is necessary at this point.

The second finding was that there are vast differences between national AI innovation systems. This can be seen in the radical divergences in the organisation of innovation in France and in Germany, particularly in terms of coordination between private and public actors and the opposite forms taken by their respective collaboration networks.

To build up its comparative advantages, Europe will need to consider establishing a European model for innovation in the field of AI. But the differences observed, especially between the German and French innovation systems, raise questions about the feasibility and coherence of a potential European model. Would that system be efficient? How would it fortify the specialisations of key European actors, both public and private? It will be up to public sector decision makers to answer these questions and devise more innovative organisational structures, as it is now recognised that being excluded from future developments in artificial intelligence would be synonymous with a loss of international influence and economic independence.

- **Anticipate the impact that AI might have on innovation activities and the job market**

The gains expected from AI, like in business productivity and the creation of new markets, have to be assessed in the light of the expected costs. It is important not to underestimate the challenges posed by the development of digital technologies in general, and AI in particular. The effects of reallocating capital and labour between

companies and sectors as a result of AI remain to be assessed, although it is certain that the process will engender substantial adjustment costs for companies and workers alike. The most significant impact of AI is expected to be felt in innovation activities and in companies' demand for labour.

Companies will need to revise their business models, make the necessary complementary investments and adapt their technical skill sets and human capital. For their part, public authorities will have to update current regulations, provide training to accompany the rise of AI and invest in scientific and technological infrastructure.

I. ORIGINAL INSIGHTS OF THE STUDY

This policy brief focusses on the institutional and political implications of the authors' original study, ***Artificial Intelligence: Key Technologies and Actors***. That study is part of a broader framework and addresses various aspects of artificial intelligence, particularly its technological aspects. One of its purposes was to **map AI activities and expertise in the eight leading countries in terms of patent applications filed between 1990 and 2017**[3], namely the United States, China, Japan, South Korea, Germany, the United Kingdom, France and Canada (in that order), differentiating between the positions of private and public actors within the complex technological field of AI.

That study features a number of important, original insights.

First of all, it thinks of AI as a whole that incorporates the entire science-technology-industrial applications chain. Artificial intelligence is commonly seen through three lenses:

- techniques: advanced forms of statistical and mathematical models that enable the computation of tasks typically performed by humans
- functions: services carried out using one or several techniques
- industrial applications: defined as the joint product of a technique and a function, overlapping within a specific context.

The authors added a fourth lens, scientific fields, and took a close look at the ones cited by AI patent applications.

By revealing the interdependencies along the science-technology-applications chain, the study emphasises the notion that **AI is a system that is neither fluid nor easy to master**. **On the contrary, it a social construct in which actors are interlinked, appropriating technologies to make their choice of risky and unrecoverable local investments.**

The report's second original insight lies in its differentiation of the positions of private and public actors within this complex field. Special attention is given to **reliably determining the locations of AI activities, a strategic issue for States**. Most reports and rankings that use bibliometric data to compare technological advances in different countries break down when it comes to identifying data locations. **The authors utilise a simple and effective methodology that sheds new light on the expertise of the main countries identified.** The present study considers the locations of the patents' inventors in order to place each patent as close as possible to the place where the AI was developed and produced. So, it opts not to look at the country where the patent was filed, meaning the country of consumption, where the patent gives its holder intellectual property rights. This means that a patent application filed in the United States by inventors located in France is not counted for the United States, as is usually the case, but rather for France. This choice of methodology serves to locate AI expertise and reflects complementary investments in the underlying infrastructure, researchers, engineers, national innovation system and training system. This way, **the key countries can be characterised and compared on the basis of their relative specialisation by scientific, technological and functional domain, as well as by their potential applications of AI**.

[3] The database used to carry out this work was PATSTAT 2020, which contains a record of all patent applications filed through 2017.

Lastly, the report highlights **the particularities of how innovation systems are organised in the countries that contribute the most to evolutions in AI technology**. It identifies existing networks between key actors and shines a light on national trends in the leadership roles played by large multinational corporations and public research institutions. This diversity reveals **the historical and institutional importance of the organisation of innovation systems**, in spite of the fact that they are based on similar models and comparable public policies.

Methodology

The authors' work provides a partial, and therefore imperfect, overview of the field of artificial intelligence. AI is not an accounting value or a sector, and even less so a product. So, in order to measure, qualify, quantify and compare all the work that has been done on AI, paths must be followed which, though useful, are nonetheless incomplete.

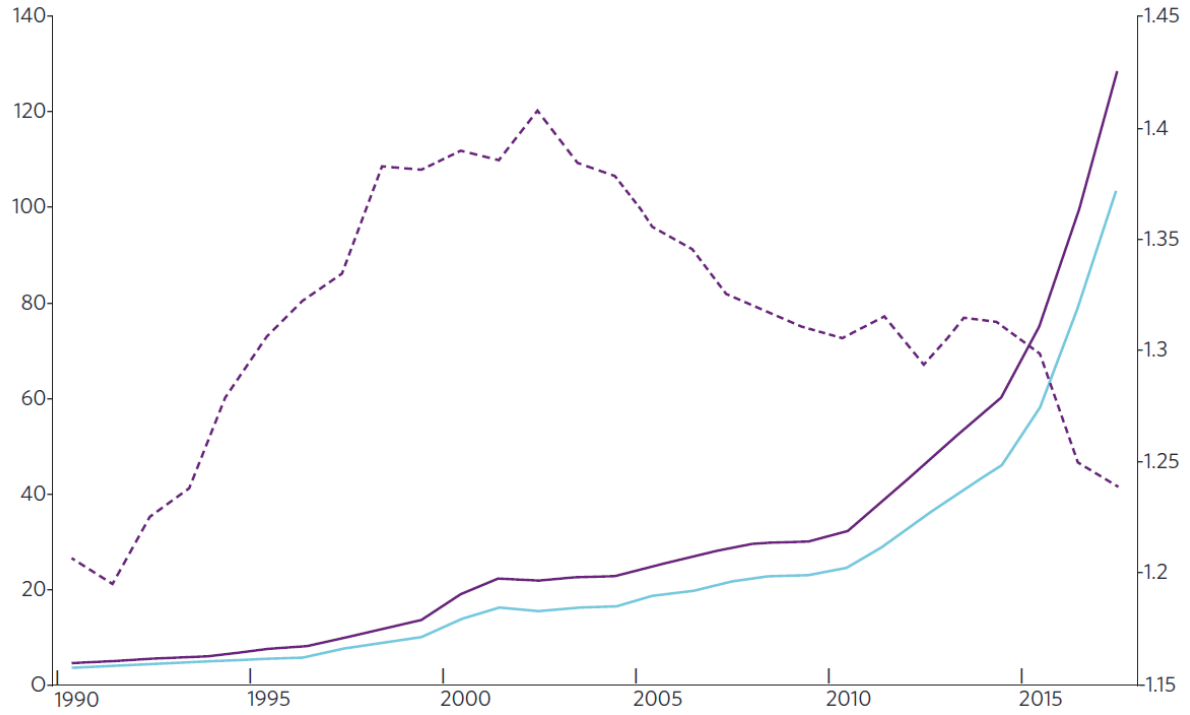
The report relies on a single source of patent data, PATSTAT, to reveal the investment strategies adopted by actors. PATSTAT has the advantage of being both global and exhaustive. However, in developing statistical patent indicators, this report offers a partial analysis of AI-related innovations. As a series of algorithms, AI does not readily lend itself to patenting. In fact, it can only be patented when embedded in physical technology. This report lays the foundations for thinking that will soon need to move beyond the use of patent statistics to incorporate a full review of artificial intelligence literature.

II. AI HAS FLOODED THE ENTIRE ECONOMIC SPHERE

Patent filings constitute a measurement instrument that is widely used to evaluate trends in innovation. **Between 1990 and 2017, more than 860,000 AI-related patents were filed around the world.** 1990 marked the first boom in the field, with some 5,000 patent applications. That number gradually increased to about 30,000 patent applications filed in 2010. The next major shift came in 2010, which was the beginning of an uninterrupted period of growth in the number of patents filed each year, reaching over 120,000 patents in 2017[4]. In other words, AI has enjoyed strong growth since the early 2010s, growth which is only likely to increase in the coming years.

Change in the number of AI patent applications between 1990 and 2017

Sources: PATSTAT, October 2020 edition; authors' calculations



Legend: — number of patents; — number of inventions (patent families[5]); --- average size of patent families. Right axis measured in units. Left axis measured in thousands.

The list of sectors concerned is already long and includes transport (self-driving vehicles), agriculture, financial services, legal services (especially the legal compliance of contracts), all scientific fields, healthcare, public policy, security (including corporate digital security management), etc.

AI not only drives product innovations but also gives rise to organisational and process innovations. The cumulative effects of AI, both positive effects like business productivity gains and the creation of new markets, and negative effects like the replacement of human labour by AI resources, are still poorly understood and

[4] Due to the time required to record patent applications, data from after 2017 is not available at the time of writing.

[5] The same invention can be patented in multiple countries. That invention then gives rise to as many patents as there are countries in which it is protected. The more patents protect the same invention (patent family), the higher the economic value that is expected or hoped for by the entity that owns it.

remain major issues for AI. **The effects of reallocating capital and labour between companies and sectors remain to be assessed, although it is certain that the process will engender substantial adjustment costs.** Those costs will be incurred by both companies and workers.

In the light of these significant costs, companies will need to revise their business models, make the necessary complementary investments, and adapt their technical skill sets and human capital. For their part, public authorities will have to update current regulations, provide training to accompany the rise of AI and invest in scientific and technological infrastructure.

What is artificial intelligence?

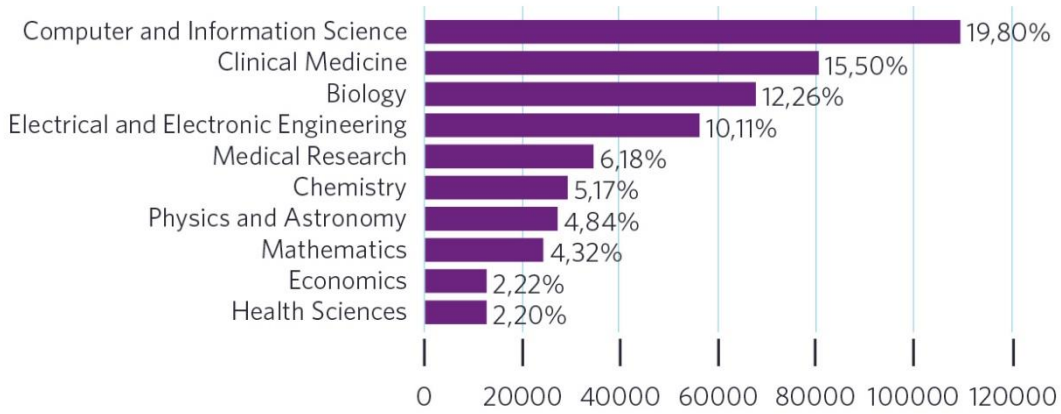
An AI system is 'a machine-based system that can, for a given set of human-defined objectives, make predictions, recommendations or decisions influencing real or virtual environments' (OECD, 2019).

At its core, AI is a set of prediction techniques that associate information with action in order to achieve a goal predefined by humans.

Since 2010, machine learning and deep learning have greatly improved the predictive performance of these algorithms. When we talk about artificial intelligence today, we mean a low-cost business intelligence tool or the development of automation (the ability of a device, process, or system to function autonomously).

Impact of AI by scientific field, technique, function and application, between 1990 and 2017
Sources: PATSTAT, October 2020 edition; authors' calculations

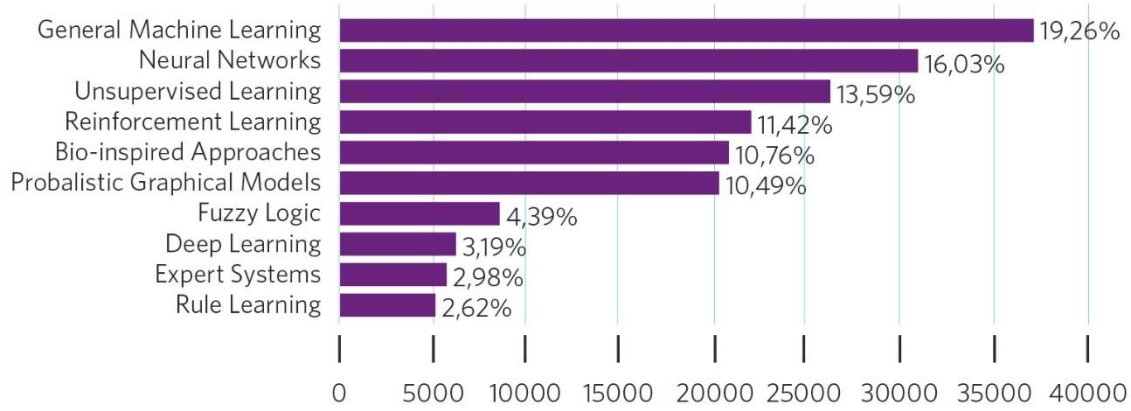
*Proportions of mentions of **scientific fields** in AI patents*



The top 10 scientific fields account for more than 80% of the scientific references in AI patents[6].

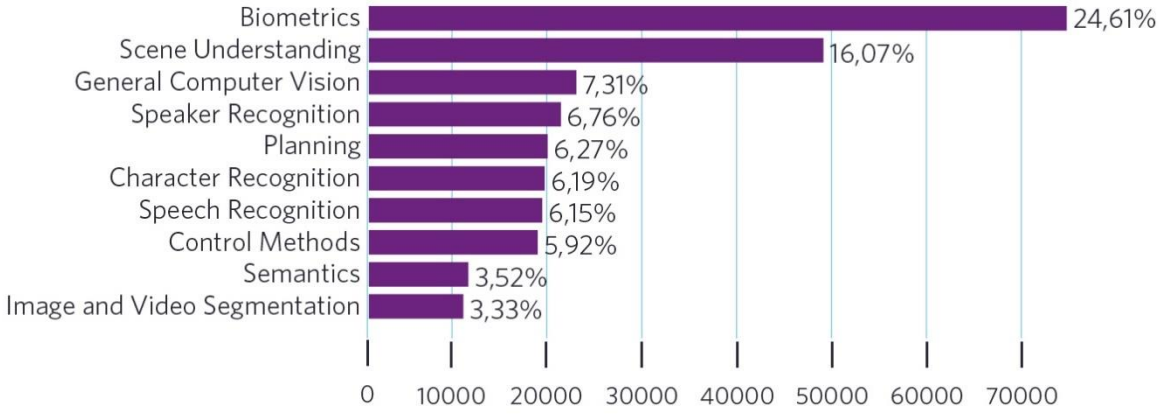
[6] The graphs provided here only show the top 10 scientific fields, techniques, functions and industrial applications. The full graphs are available in the report that formed the basis for this policy brief.

*Proportions of **AI techniques** presented in AI patents*



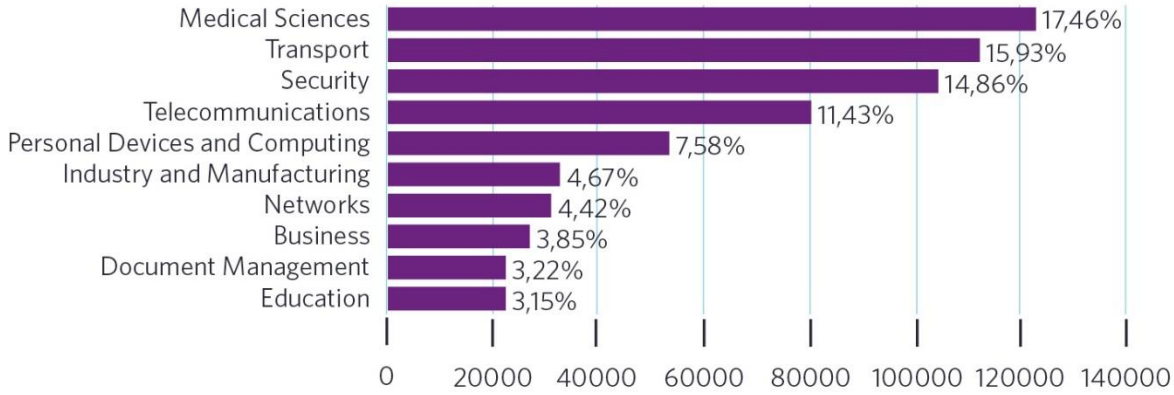
These top 10 techniques account for more than 95% of all occurrences of AI techniques.

*Proportions of **AI functions** presented in AI patents*



These top 10 functions account for more than 86% of all occurrences of AI functions.

*Trends in **AI applications** presented in AI patents*



These top 10 application areas account for more than 85% of all AI applications.

As concerns the links between sciences and techniques, these were most frequently observed between computer science (as a scientific field) and machine learning, and then between computer science and neural networks. The strongest mutual attraction is between biology and bio-inspired approaches, followed by medical research and bio-inspired approaches.

As concerns the links between techniques and functions, these were most frequently observed between machine learning and computer vision, and then between neural networks and computer vision. The strongest mutual attraction is between rule learning and semantics, followed by fuzzy logic and control methods.

As concerns the links between functions and areas of application, these were most frequently observed between biometrics and security, and then between computer vision/scene understanding and the field of transport. The strongest mutual attraction is between character recognition and document management, followed by voice/speaker recognition and telecommunications.

III. THE POWER OF AI IS AND WILL BE A SOCIAL AND POLITICAL CONSTRUCT, FIRST AND FOREMOST

THE UNITED STATES, A LEADER RIVALLED BY THE ASIAN POWERS

Following on from the USA's 2016 National Artificial Intelligence Research and Development Strategic Plan, many countries have launched initiatives and established action plans followed by sizeable financial investments. This is the case with Canada for example which, in 2017, was the first country to earmark US$100 million in investments over the space of five years for AI research, as well as South Korea, which allocated a budget of $940 million to the field of AI. By way of comparison, in 2018 France announced the allocation of a budget totalling €1.5 billion to research and innovation in AI by 2022. By the year 2025, the plan is to devote a total of €2.22 billion to AI, including €1.5 billion in public funding and €506 million in private matching funds[7]. As for the European Union, it is dedicating €1.38 billion to digital investments, including AI, through the end of 2022[8]. These massive investments raise questions about countries' national strategic positions on AI prior to 2018.

Between 1990 and 2017, the United States and China were the two undisputed leaders in the production of patents incorporating AI systems, at 30% and 26% respectively. Together, they are responsible for more than half of all AI patents. Alongside them, the most active countries in this field are Japan (12%), South Korea (almost 6%) and Germany (almost 5%). These five countries alone account for 80% of the production of patents incorporating AI-related techniques. The first group of following countries comprise the United Kingdom (2.5%), France (2.4%) and Canada (1.9%), totalling almost 7% of AI patent production[9].

[7] French National Strategy on Artificial Intelligence, 10 November 2021 (in French), accessed 11 April 2022.

[8] In parallel, the Commission has published a cybersecurity work programme with a budget of €269 million through the end of 2022 and a support programme for the network of European Digital Innovation Hubs worth €329 million through the end of 2023. Source: Press release dated 10 November 2021, accessed 11 April 2022.

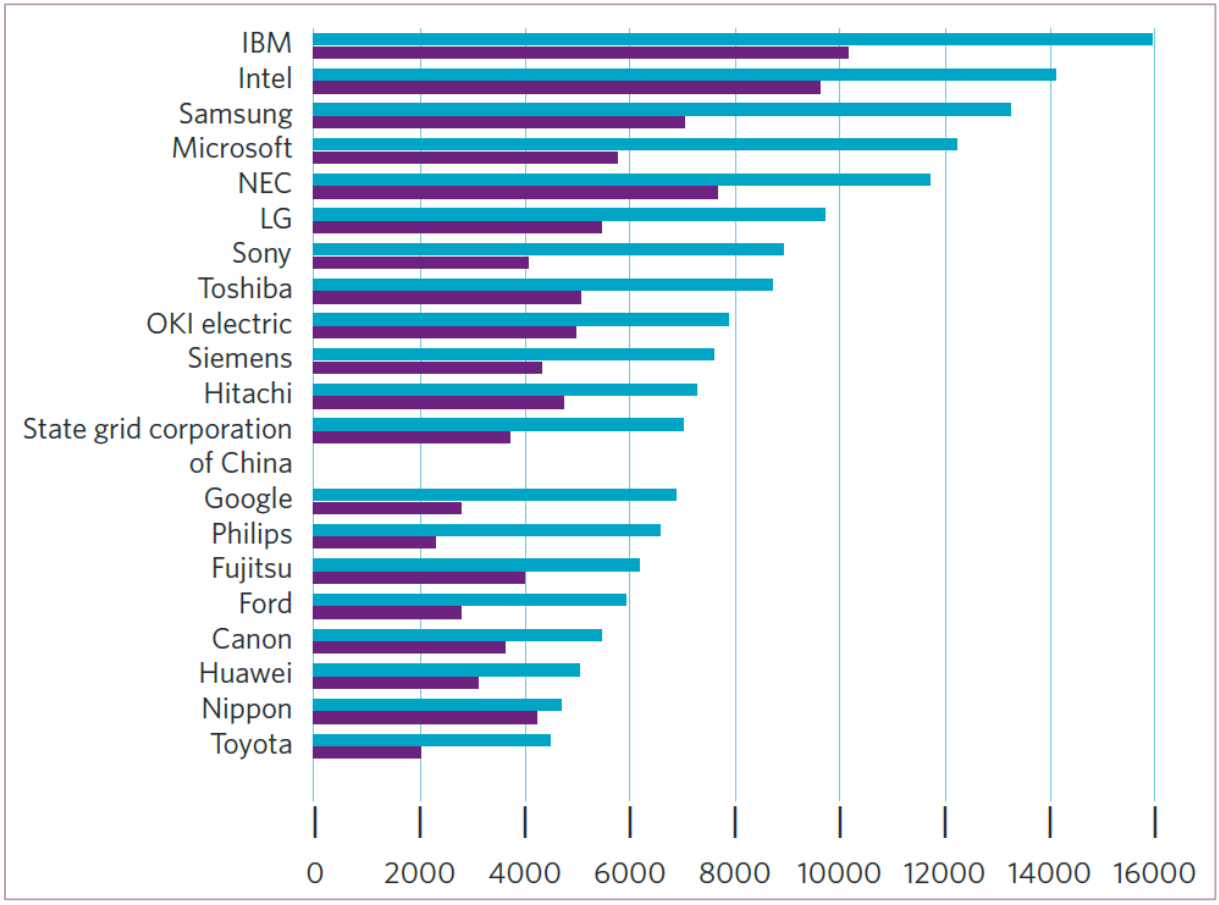
[9] The authors' rankings place the United Kingdom and France in the 6th and 7th positions worldwide, respectively, whereas the World Intellectual Property Organization ranked them 12th and 13th in 2019. This can be explained by a major difference in methodology. This study considers the locations of the patents' inventors, while the aforementioned ranking looks instead at the countries where the patents were filed.

Looking at the actors that owned AI patents during this period, **the American computer hardware giant IBM was the undisputed leader in the field with nearly 16,000 AI-related patents representing just over 10,000 inventions (patent families)**. In second place is Intel, another American actor with more than 14,000 patents. Samsung, the Korean electronics giant, is ranked 3rd, with 13,243 patents, followed by the USA's Microsoft and Japan's NEC. Looking more generally at the top 20 biggest actors in AI, there are five American companies (the three mentioned above plus Google and Ford), two Korean companies (Samsung and LG Group), two Chinese firms (State Grid Corporation of China and Huawei), one German (Siemens) and one Dutch company (Philips). The nine other actors in that top 20 list are all Japanese.

This initial analysis of the top 20 actors clearly shows that Asian firms (especially from Japan) are positioned as very important actors in AI, going so far as to overshadow the GAFAM companies[10]. While it is true that Microsoft and Google appear in the top 20, you would have to look down to the 27th place to find Apple, and Amazon and Facebook came in respectively in the 42nd and 49th positions[11].

Top 20 Private AI Actors Worldwide

Sources: PATSTAT, October 2020 edition; authors' calculations



Legend: ● number of patents; ● number of inventions.

[10] GAFAM stands for Google (Alphabet), Apple, Facebook (Meta), Amazon, Microsoft.

[11] These results are partly dependent on the companies' intellectual property strategies. The fact is that, as indicators, patents have a limited ability to provide a vision of innovation activities in AI. Companies often use scientific publications to communicate about their advances without necessarily going down the patenting road. For example, Amazon and Facebook do not come in at the top of the list, despite the colossal investments they make in the field.

EUROPEANS STILL LAGGING BEHIND

The small number of European companies (two) among the major actors in AI is worthy of note. Although the ranking may be considered somewhat anecdotal, there is an enormous difference in the number of patents between European companies and the American and Asian giants. Siemens, the European AI leader with 7,628 patents (ranked 10th worldwide), has less than half the number of patents held by IBM (15,931). And that difference only increases as you go farther down the ranking of European companies.

CHINA ENJOYS A STRONG GLOBAL POSITION

All along the technology-industrial applications chain, China is largely dominating the innovation race, particularly as concerns unsupervised learning (technique) and biometrics (function). It also easily dominates the most prolific application areas (transport, medical and life sciences, security, and telecommunications). Its market share is only increasing in every domain, even if its level of specialisation is relatively low in several of them (machine learning, neural networking and reinforcement learning techniques; computer vision and speaker recognition functions), in spite of its continuously rising production numbers. South Korea is clear in its ambitions and is gaining market share in most sectors.

Conversely, Canada and Britain are not very active on the whole, with negative growth for both of them, although it is worth noting that the UK has solid expertise in certain sectors (machine learning and neural networking techniques, biometric and computer vision functions; security and medical and life sciences application areas). Japan is obviously struggling. It is losing momentum in most of the studied fields, resulting in South Korea and China ousting it from its position as challenger to the United Stated. As for the latter, it is clearly under threat from China mostly, and from South Korea to a lesser extent.

In Europe, Germany is by far the most productive country, with the most activity after the United States, China, Japan and South Korea, although its growth is often negative, even in its areas of specialisation (neural networking techniques, scene understanding and speaker recognition functions; transport and medical and life sciences application areas). **Lastly, France's position is something of a mixed bag. Sometimes up and sometimes down, it cannot claim to compete with countries like China and South Korea.**

Contrary to what might be expected, there does not appear to be a clear connection between States' specialisations and their achievements. For example, regardless of their degree of specialisation, China and South Korea are major producers and enjoy very high growth rates. Conversely, European countries produce little in terms of volume, despite specialising in certain areas of AI. Nonetheless, nearly all indicators show that each country is working to be a specialist in at least one AI discipline. This becomes all the more obvious when you look at the link between the dominant national companies and the countries' specialisations.

PRIVATE COMPANIES, THE WORLD'S TOP PRODUCERS OF AI

On a global scale, private companies produce far more patents than public institutions. For each public patent, 4.6 are filed by private actors, not counting lone inventors. **Moreover, there are major contrasts between countries, which are indicative of both different innovation systems and patenting tendencies that are specific to each country.** In Europe, the growth of AI has been achieved through a similar development of public and private research. In the case of Asia (South Korea and Japan), public actors are playing an expanding role in AI innovation, following initially sluggish public research in that field. Lastly, AI technology in the United States sits largely with private actors, built on the foundations of public research that, although still lively, is on the decline.

And finally, the global trend is moving towards the increased involvement of public research in the field of AI innovation, with exponential growth in the production of knowledge beginning in the 2010s. The start of that decade marked the appearance of a new facet of AI, with the advent of deep learning, a new statistical technique that gives algorithms a significant advantage in terms of computing times and the quality of their predictions. Among other points, deep learning revolutionised image recognition and allowed AI to become more effective

than human beings[12]. That radical innovation is receiving more and more interest from public authorities, more generous investments and, in the end, a larger number of patents produced by the public sphere.

Nationality and Organisational Status of Actors Involved in AI Patents

Sources: PATSTAT, October 2020 edition; authors' calculations

	Private	Public	Private / public
World	660 694	143 311	4.6
France	11 861	4 213	2.8
Germany	28 666	2 327	12.3
China	136 517	71 323	1.9
South of Korea	38 182	12 710	3.0
United States	204 931	23 262	8.8
Japon	101 747	4 982	20.4
United Kingdom	9 956	1 954	5.1

Interpretation notes: In China, there are 1.9 private patents for each patent produced by a public research institution.

[12] In 2012, Krizhevsky, Sutskever and Hinton, from the University of Toronto, published 'ImageNet Classification with Deep Convolutional Neural Networks' in *Advances in Neural Information Processing Systems.* That article proved the superiority of deep learning. As a result, it was cited more than 80,000 times in 2021. It is one of the most cited contributions to the field of visual recognition. In addition to image classification, deep learning has revolutionised fields like object detection, Q&A interactions, speech recognition and machine translation, among others.

IV. FRANCE'S PLACE IN THE INNOVATION RACE

A STRATEGIC POSITION FOR FRANCE THAT IS LOSING MOMENTUM

France never finds itself in a situation of consolidating a dominant global position in any of the sectors along the technology-applications chain. It showed promise in neural networks (technique) and the transport field (application) but has not gained any market share since the 2010s.

In terms of major areas of industrial applications, France specialises in transport and security. Its invention work and economic issues are particularly strong in the **field of transport**. The intensity of its inventions is most likely driven by Peugeot and Renault, which have demonstrated expertise with technological innovations in the field of AI. However, France is a long way behind in applications related to the business world, document management, word processing and education; personal and computer devices; and telecommunications.

In terms of AI techniques, France's strategic position focusses on innovations in expert systems, probabilistic graphical models and rule learning. It has significant weaknesses in deep learning, fuzzy logic and reinforcement learning. It is losing momentum compared to its competitors on the machine learning segment.

On the whole, French specialisations are more pronounced in terms of **functions** than techniques. **France is highly specialised in semantics, character recognition and computer vision.** In terms of biometrics and computer vision, France is thriving, with specialisation indices that are higher than the rest of the world, even though its volume of activity remains low. The country is notably absent from the functions of planning, speaker recognition and speech recognition. As concerns scene understanding, France is exposed to the possibility of a suspension of activity, due to its extremely low level of specialisation and number of patents.

DIFFICULTY FORGING A PLACE FOR ITSELF IN PRIVATE INNOVATION…

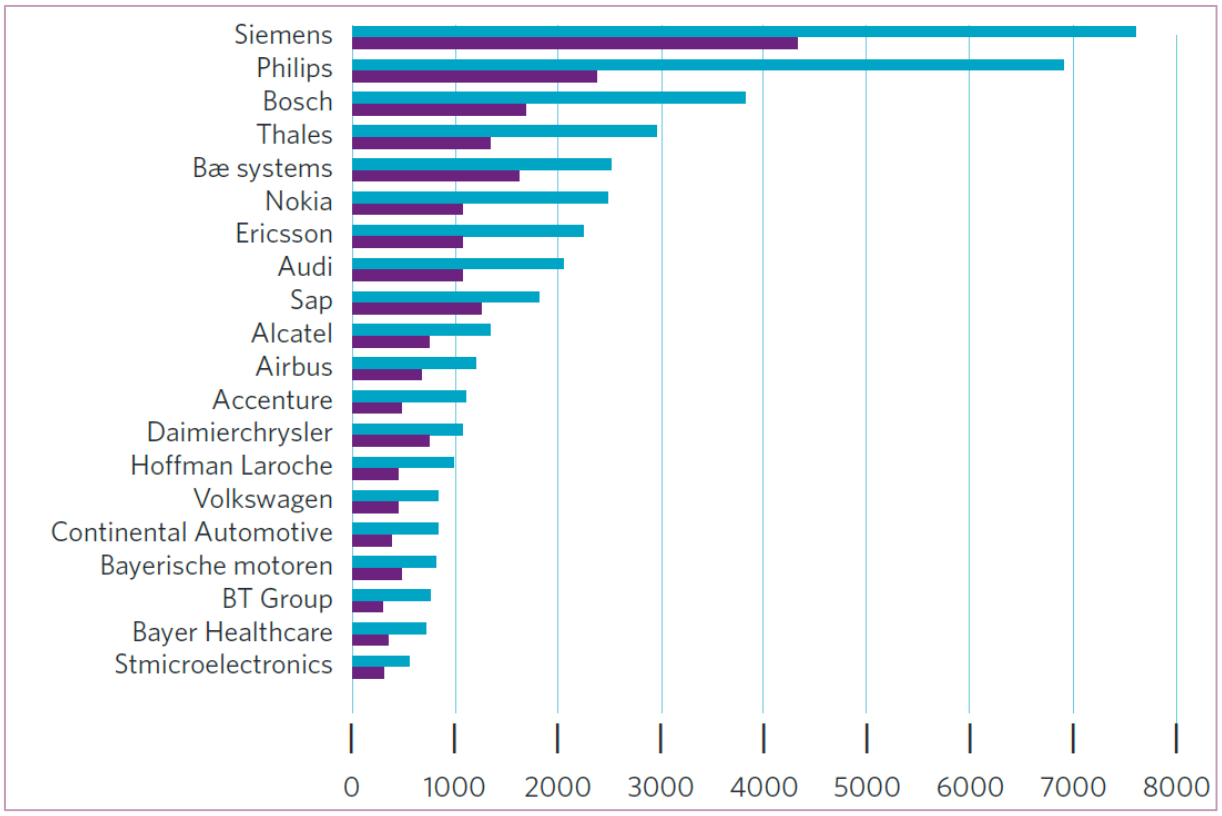
There are no French companies in the top 20 list of private actors in AI. Thales, the leading French company by number of patents, is ranked 37th worldwide, with close to 3,000 patents. However, it is the number four private actor in Europe, far behind the 7,576 patents filed by the frontrunner Siemens. It is even behind the 2nd German company (Bosch).

The top 20 most important AI actors in Europe includes two French firms, Thales and STMicroelectronics, and three historically if you count Alcatel (which was French up until 2006)[13], as well as two British companies, BAE Systems and BT Group. Germany clearly dominates this ranking, with no fewer than nine companies in a wide variety of business sectors: car manufacturing (Audi, DaimlerChrysler, Volkswagen and Continental Automotive), healthcare, electronics and building (Siemens), building and automotive (Bosch), software (SAP) and pharmaceuticals and agrochemicals (Bayer Healthcare). As a result, Germany stands out as the AI leader in each of those fields.

[13] Alcatel merged with the US-based Lucent Technologies in 2006 to become Alcatel-Lucent. Alcatel-Lucent was then acquired by the Finnish Nokia in 2015 and thus ceased to exist in 2016.

Top 20 Private AI Actors in Europe

Sources: PATSTAT, October 2020 edition; authors' calculations.



Legend: ● number of patents; ● number of inventions.

… BUT A EUROPEAN LEADER IN PUBLIC INNOVATION

The European ranking of public actors demonstrates the important role played by French public research institutions. With 891 patents corresponding to 401 inventions, the CNRS is the most prolific public actor in terms of AI patents. The CEA, Institut Pasteur, INSERM, INRIA and Institut Curie complete the list[14]. The quality of the AI patents held by French research organisations is impressive. French institutions produce patents with high economic value.

The CNRS is ranked number two among European public institutions. The CEA and Institut Pasteur come in respectively at 4th and 5th in that ranking. They are followed by INSERM (7th place), INRIA (8th) and Institut Curie (9th). In other words, of the top 20 most important European public actors, six are French institutions, all of them ranked in the top 10.

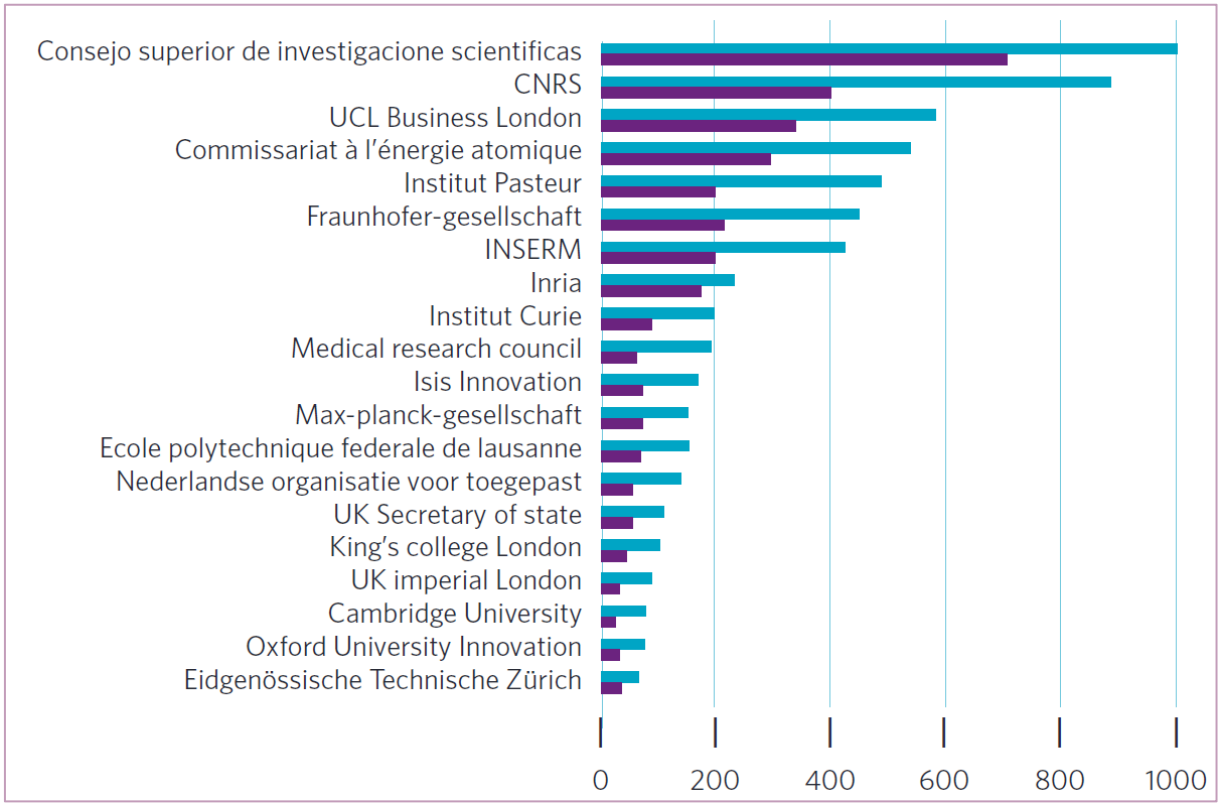
The CNRS protects its inventions in more than two geographic areas on average, which is considerable. The same can be said of the other most prolific French institutions, with the exception of INRIA (which averages 1.31 geographic areas per invention). It should be noted that this is also true of certain private French companies like Thales, which protects its inventions in an average of 2.21 geographic areas, Valeo in 2.13 geographic areas, and IDEMIA in 2.35.

[14] CNRS: French Centre for Scientific Research; CEA: French Alternative Energies and Atomic Energy Commission; INSERM: French Institute of Health and Medical Research; INRIA: French Institute for Research in Digital Science and Technology.

The strength of French public research means that public decision makers cannot help but rely on public sector researchers, working with them to create the conditions for transferring technology to actors that are closer to the markets.

Top 20 public AI actors in Europe

Sources: PATSTAT, October 2020 edition; authors' calculations



Legend: ● number of patents; ● number of inventions.

A FORMATIVE ROLE FOR FRENCH PUBLIC RESEARCH INSTITUTIONS IN THE ORGANISATION OF INNOVATION

Public research is an essential actor in the development of AI in France. Although patent production displayed similar linear growth in the public and private sectors between 1990 and 2015, production by public actors began to accelerate in 2009, catching up with the private sector in 2010. The trend has been similar in Germany (and the rest of the world), in spite of the fact that public research is much less involved in Germany than in France (see the table, 'Nationality and organisational status of actors involved in AI patents').

FRENCH ORGANISATIONS ARE ALSO DRIVING COLLABORATION NETWORKS

Some 551 French co-patents were recorded during the studied period of time. The collaboration networks used by French actors are particularly unusual. In France, **the main parties involved in collaborating on AI innovations that went on to be formalised by co-patents are public actors**, unlike the global trend in which co-patents primarily concern private actors. Those private actors participate in 90% of co-patents, while just 30% involve one or several public actors.

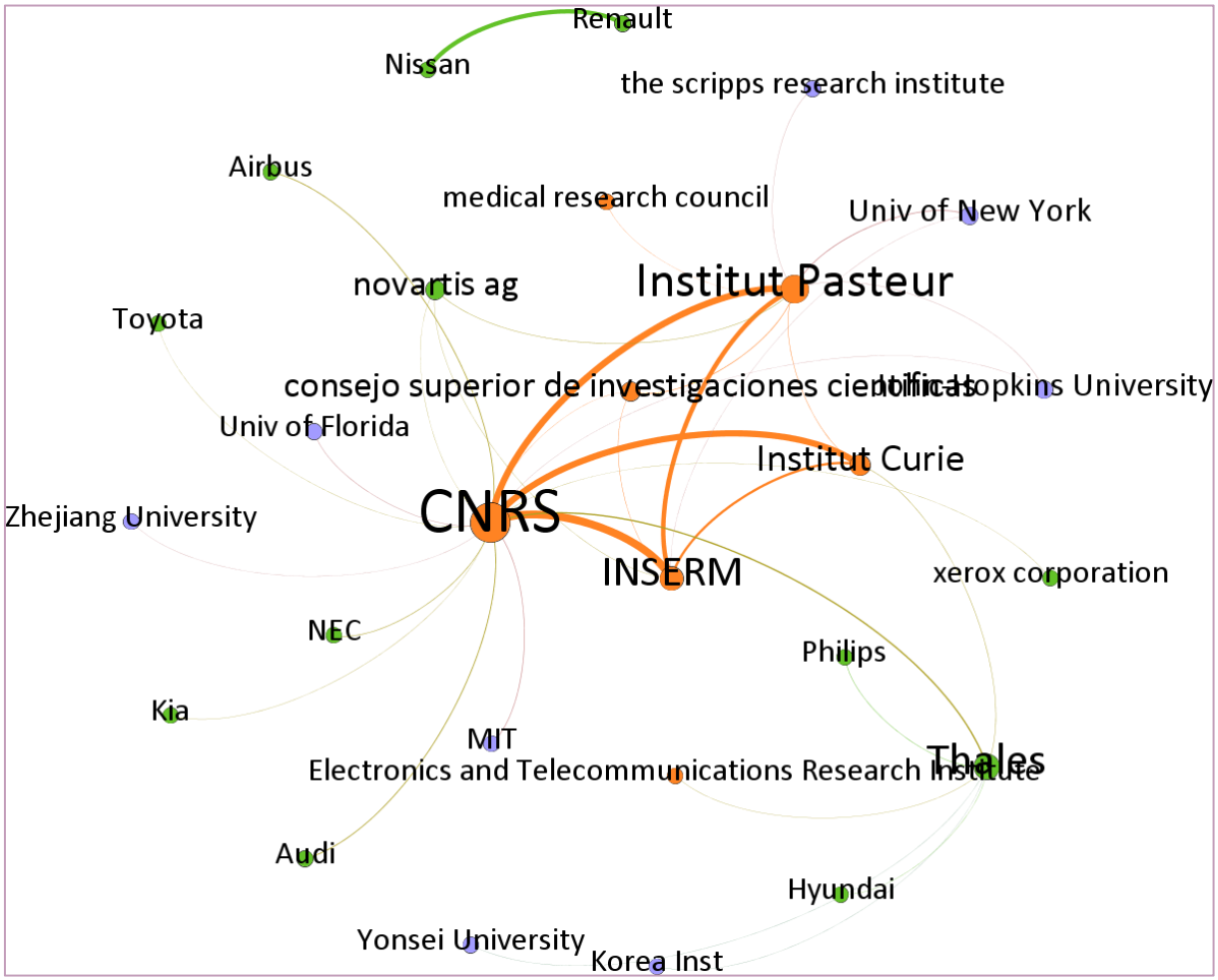
10,000 co-patents have been recorded worldwide. Almost 90% of collaborations are intra-national, while only one co-patent in 10 includes actors of different nationalities. One major difference between public and private

actors is that, on a global level, companies tend to prefer intra-national collaboration, while collaborations involving at least one public actor are generally more internationally oriented. **The opposite is true in France, where intra-national collaboration between private actors is nonexistent**: all private collaborations on co-patents in France involve a foreign actor.

By contrast, **there is a high level of intra-national collaboration between the various French public research institutions** (386 co-patents). And few of them choose to open up to international partners (a mere 38 co-patents).

Collaboration Networks Used by Leading French AI Actors

Sources: PATSTAT, October 2020 edition; authors' calculations

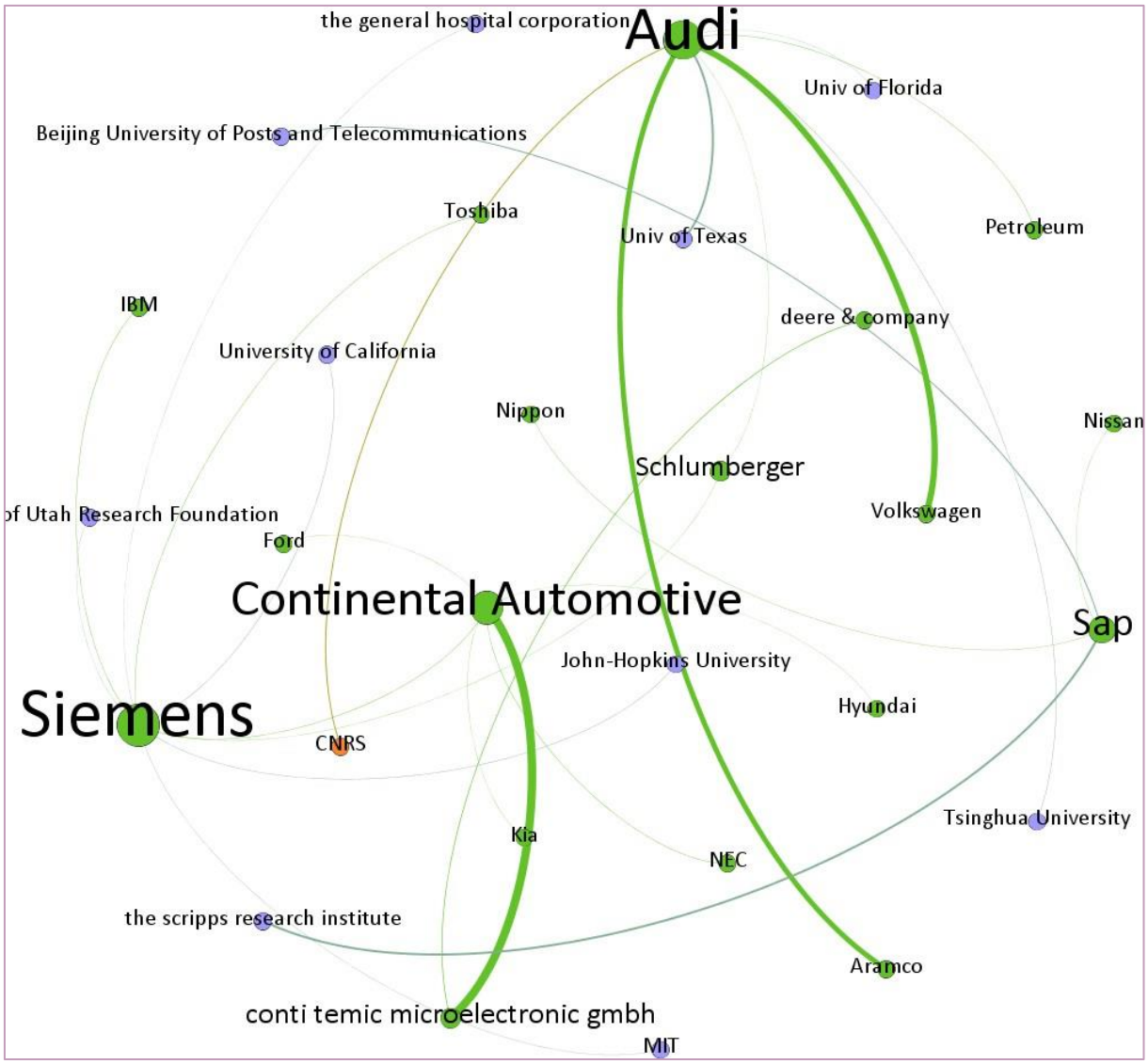


Legend: ● private actor; ● university; ● public research institute.

As for Germany, it follows global trends, displaying the opposite dynamic to the one observed in France. Patents between German actors exist exclusively in the private sector. Public research institutions involved in German co-patents are located overseas. By volume, German networks are well below the rest in terms of patent numbers. Still, Germany is the most open to international partners, with more than 50% of its private co-patents involving a foreign actor.

Collaboration Networks Used by Leading German AI Actors

Sources: PATSTAT, October 2020 edition; authors' calculations



Legend: ● private actor; ● university; ● public research institute.

The diversity of national innovation systems calls for caution when it comes to writing policies in support of artificial intelligence that mimic the policies implemented in a benchmark country. On the contrary, this kind of diversity suggests that those policies cannot function in a vacuum, without referring to key national actors. Those strategies should instead be based on those key national actors.

Since Europe's numbers are down, it would be helpful to consider building a European model for innovation in the field of AI. However, the differences observed between the German and French innovation systems raise questions about their complementarity or, conversely, their usefulness as replacements. Can they 'meld' into one another? How can they be coordinated in a way that reinforces the positions of key actors in both countries? It is up to public sector decision makers to devise more innovative organisational structures, as it is now recognised that being excluded from future developments in artificial intelligence would be synonymous with a loss of international influence.

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