ofce

Policy brief 118

2023

June 26

IDEAS WITHOUT SCALE IN FRENCH ARTIFICIAL INTELLIGENCE INNOVATIONS[1]

Johanna Deperi*, Ludovic Dibiaggio, Mohamed Keita, Lionel Nesta

Johanna Deperi, University of Brescia, Italy

Ludovic Dibiaggio, Mohamed Keita, SKEMA Business School

Lionel Nesta, OFCE Sciences Po, University Côte d'Azur CNRS-GREDEG, SKEMA Business School

* Johanna Deperi acknowledges the funding from the European Research Council (ERC) under the European Union's Research and Innovation program Horizon 2020 (ERCStG 2D4D "Disruptive Digitalization for Decarbonization", grant agreement n°853487).

Summary

Artificial intelligence (AI) is viewed as the next technological revolution. The aim of this Policy Brief is to identify France's strengths and weaknesses in this great race for AI innovation. We characterise France's positioning relative to other key players and make the following observations:

1. Without being a world leader in innovation incorporating artificial intelligence, France is showing moderate but significant activity in this field.
2. France specialises in machine learning, unsupervised learning and probabilistic graphical models, and in developing solutions for the medical sciences, transport and security.
3. The AI value chain in France is poorly integrated, mainly due to a lack of integration in the downstream phases of the innovation chain.
4. The limited presence of French private players in the global AI arena contrasts with the extensive involvement of French public institutions. French public research organisations produce patents with great economic value.
5. Public players are the key actors in French networks for collaboration in patent development, but are not open to international and institutional diversity.

In our opinion, France runs the risk of becoming a global AI laboratory located upstream in the AI innovation value chain. As such, it is likely to bear the sunk costs of AI invention, without enjoying the benefits of AI exploitation on a larger scale. In short, our fear is that French AI will be exported to other locations to prosper and grow.

1. This *Policy brief* is based on the annual report "Artificial Intelligence: key technologies and actors" (SKEMA Business School, 2022).

Artificial intelligence (AI) is viewed as the next major industrial revolution that will promote long-term economic growth worldwide. This policy brief aims to identify France's strengths and weaknesses in this great AI innovation race. AI can best be defined as a predictive technology that applies to a wide range of potential applications. As such, AI is seen as a *general purpose technology (*GPT, Bresnahan and Trajtenberg, 1995). In fact, the medium- and long-term competitiveness of countries is determined by the level of scientific and technological investments making possible the industrial exploitation of AI's potential. Many economists are currently contemplating both the qualitative and quantitative effects of AI on economic growth (Aghion *et al.*, 2019), the competitive process (Varian, 2018), innovation (Cockburn *et al.*, 2019; Babina, *et al.*, 2021) and, of course, employment (Acemoglu and Restrepo, 2019; Aghion, *et al.*, 2019; Agrawal *et al.*, 2019).

These challenges justify the establishment of national policies to support the development and application of AI algorithms. Following the United States' seminal series of initiatives, all industrialised countries, together with industrial players, have launched proactive investment strategies.[2] The cumulative net effect on global economic growth will exceed $15,000 billion by 2030 (McKinsey, 2018).[3] But this cumulated effect, although impressive, should be treated with caution. AI is neither a statistical category nor an accounting variable, so the mere quantification of AI investments is a challenge in itself. In turn, its measurement requires indirect empirical strategies, which, however diverse and innovative, are always imperfect.

This work relies on a unique and exhaustive patent database, PATSTAT (see Appendix), to reveal the investment strategies of countries and key players. Our use of patent data offers the advantage of providing a consistent representation of AI-related innovations. Nevertheless, the results provide only a partial picture of AI innovation. As an algorithm, AI cannot be patented. Only when it is integrated into a concrete artefact can it receive IP protection.[4]

We investigate five questions about France's position in the international AI arena:

1. Where does France rank in terms of patent-related AI innovation?
2. Which AI areas does France specialise in?
3. Is the French AI value chain integrated?
4. Who are the key French actors and how do they rank worldwide?
5. What is the division of labour between private and public organisations?

Our results indicate that:

1. Although not a world leader, France exhibits moderate but significant activity in AI-related innovation;
2. France specialises in machine learning, unsupervised learning and probabilistic graphical models, and in developing solutions for the medical sciences, transport and security;
3. The AI value chain of France is poorly integrated, mainly due to a lack of integration in the downstream phases of the innovation chain;
4. The limited presence of French private players on the world level contrasts with the extensive involvement of French public research organisations. French public research institutions produce numerous, high quality patents, as measured by the size of their patent families;

2. The 2020 OECD Report "Identifying and measuring developments in artificial intelligence: making the impossible possible" is an excellent illustration of this point.

3. By way of comparison, the US GDP was $21,000 billion in 2019, compared with $18,000 billion for the European Union and $14,000 billion for China.

4. Consequently, the proposed analysis cannot characterise pure algorithm development activities that are not integrated into a particular artefact. To do so, it would be necessary, for example, to consider scientific publications, identify the location of the institutions and researchers, and so on. The authors are currently developing a study along these lines.

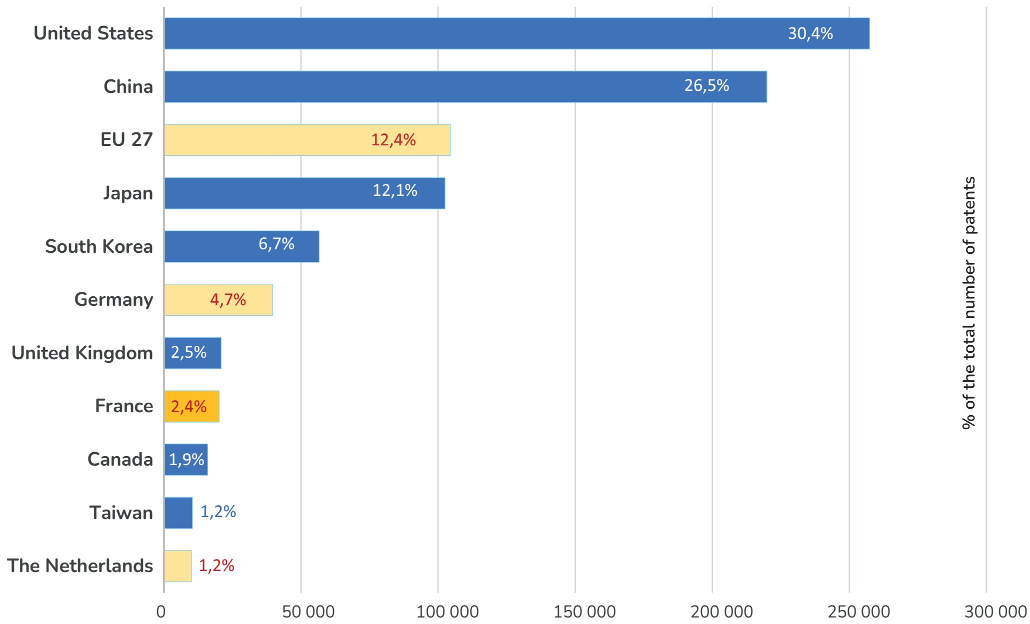
5. French collaboration networks involve mainly public research organisations, but they are not very open to international and institutional diversity.

In our opinion, France runs the risk of becoming an global AI laboratory located upstream in the AI innovation value chain. As such, it is likely to bear the sunk costs of AI invention, without enjoying the benefits of AI exploitation on a larger scale. In short, our fear is that French AI will be exported to other locations to prosper and grow.

Where does France rank in the production of patented innovations using artificial intelligence algorithms?

Figure 1 ranks the top 10 AI patenting countries. With 30% and 26% of AI patents respectively, the United States and China dominate the global production of innovation incorporating AI. The European Union and Japan both account for 12%. Four out of five AI patents come from these four leading geographical areas. South Korea accounts for 6% of AI patents. Within the European Union, Germany is the most active country in the field of AI. The United Kingdom, France, Canada and Taiwan form the first group of countries in the next category. France ranks seventh in the world, with 2.4% of AI patent production.[5] The top 10 countries account for 90%, and the top 20 for almost 97% of AI patents. [6]

Figure 1. **Ranking of the top 10 AI patent-producing countries (1990-2017)**



PATSTAT October 2020 edition. Authors' calculations.

When standardised by population (Figure 2), South Korea stands out, producing more than 1,000 AI patents per million inhabitants.[7] With around 800 patents per million inhabitants, Japan and the United States also stand out for their extensive number of AI patents. With 234 patents per million inhabitants, Europe is not very active. However, this statistic conceals a wide disparity between countries. The Netherlands (574 patents per million inhabitants), Germany (475), Finland (748) and Sweden (701) are the most active. By contrast, Italy (72), Spain (69) and Portugal (39), as well as the

5. The surprise comes from the difference between this study and the World Intellectual Property Office (WIPO). More specifically, Figure 1 ranks the UK and France 6th and 7th respectively, whereas the WIPO report (2019) ranks them 12th and 13th. This difference can be explained by the fact that this study considers the location of patent inventors, whereas the WIPO study focuses on the country in which the patent is filed, i.e. the country in which the patent confers intellectual property rights on its owner. Thus, a patent filed in the United States but whose inventors are in France is counted in the United States in the WIPO studies, whereas we count it in France. In our view, the strategic challenge for countries is to develop the scientific and technical skills that will enable them to participate in the global effort to develop AI. The fact that a patent is developed by inventors from a particular country implies that the complementary investments, in terms of infrastructure, researchers, engineers, the national innovation system and the underlying training system, etc., have been made beforehand.

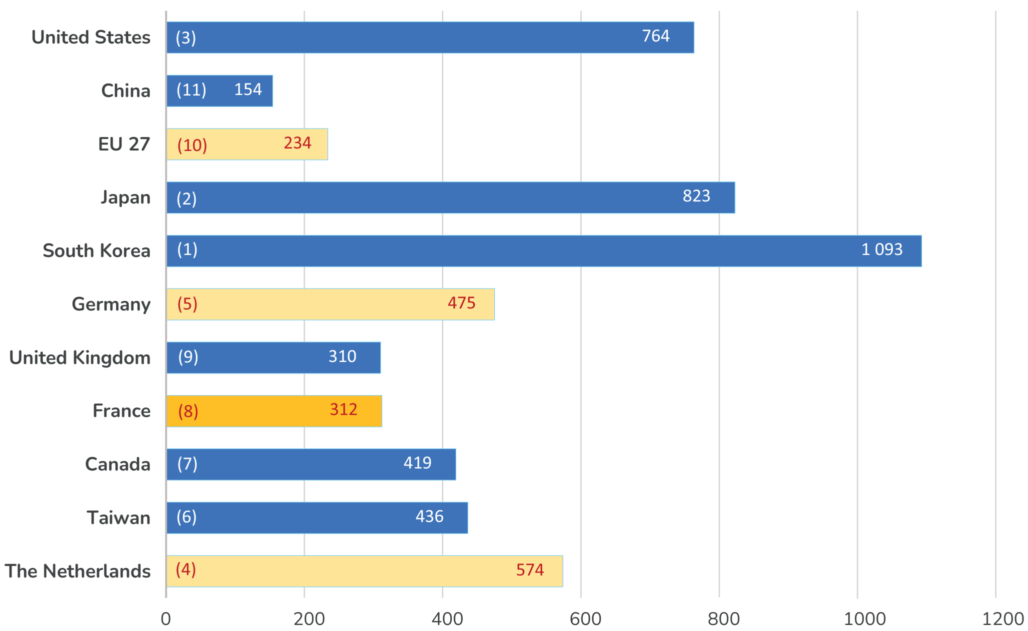
6. The next 10 countries are: Russia (1.1%); Israel (1.1%); Switzerland (1%); India (1%); Sweden (0.9%); Austria (0.7%); Italy (0.5%); Finland (0.5%); Spain (0.4%); Ireland (0.4%).

7. We could have chosen another normalisation, such as GDP, investment in R&D, or the total number of patents. Each of these variables engenders a particular normalisation, without any of them being the natural choice. For example, if we choose the country's R&D investment as the norm, the result is statistics that qualify the specialisation of the research system on AI, without taking into account the extensiveness of the country's research sector.

inhabitants, France ranks 15th in the world, and remains in the middle of the pack in Europe and the world.

First observation. *With a market share of 2.4% of AI patents, France ranks seventh in the world. Normalised by the number of inhabitants, France ranks 15th worldwide, with 312 patents per million inhabitants. Overall, without being a world leader, France shows moderate but significant activity in this field.*

Figure 2. **Number of AI patents per million inhabitants (1990-2017)**



PATSTAT October 2020 edition. Authors' calculations.

Country ranking is in brackets.

Which AI areas does France specialise in?

To characterise the positioning of countries, we qualify patents in terms of AI techniques, AI functions and AI applications.[8] Figures 3 to 5 show the strategic positioning in artificial intelligence of France, Germany, Europe, China and the United States over the period of 1990-2017 along these new dimensions. On the horizontal axis, each field (each AI technique, each AI function, each AI application) is characterised by the market share in patents of a given AI field in the world market. Common to all countries, this measure captures the economic importance of the particular field. For example, in Figure 3, machine learning accounts for more than 19% of all AI patented techniques, which makes it a major AI technique. The vertical axis indicates the relative NISR specialisation[9] of each country, and is therefore specific to each country. Thus, a country in the North-East quadrant exhibits a high degree of specialisation in a market that is a priori major. For example, when it comes to machine learning, the United States has the strongest specialisation, as opposed to China, which seems to be abandoning this AI technique. Therefore, a country in the North-West quadrant has a high level of specialisation in a market that would appear to be minor. A country in the lower part of the figure shows a lack of specialisation in the field in question.

8. Appendix details our methodology, drawing on – but extending it – the World Intellectual Property Organization's Artificial Intelligence Report (WIPO, 2019).

9. See Box.

Box. **Definition of strategic positioning and integration indicators**

The information contained in patents and their breakdown into AI techniques, functions and applications can be used to characterise the areas of specialisation of various countries and the degree of integration of the artificial intelligence innovation value chain. Based on the various fields (technical, functional or application, henceforth TFA), we use the following measure of specialisation by field / noting $B_{c,d}$ the number of patents developed in the inventor's country of residence c in the field d the relative specialisation index is defined by:

$$ISR_{c,d} = \frac{B_{c,d} \;/\; \Sigma_d B_{c,d}}{\Sigma_c B_{c,d} \;/\; \Sigma_c \Sigma_d B_{c,d}}$$

This index is the ratio of two proportions. The numerator represents the proportion of patents belonging to domain d in country c. The denominator is this same proportion (the share of patents belonging to domain d) in all countries. We then normalise this indicator so that it belongs to the interval [0 ; +2] as follows:

$$NISR_{c,d} = \frac{(ISR_{c,d} - 1)}{(ISR_{c,d} + 1)} + 1$$

The $NISR_{c,d}$ index retains unity as the pivot value. It can be applied to each of the TFA domains individually.

The fact that a country specialises in several AI techniques, functions and applications raises the question of the consistency of specialisations along the artificial intelligence value chain. For example, medical applications are essentially based on image and video segmentation and, to a lesser extent, control methods and computer vision (functions). However, image and video segmentation is largely based on unsupervised learning and fuzzy logic techniques. Therefore, a coherent value chain for a country specialising in medical applications suggests specialisation in the relevant functions and techniques. The degree of integration is an indicator of the complementarity of the innovation chain. It assesses a country's ability to create and benefit from the value produced from its areas of specialisation. We measure the degree of integration by the expression::

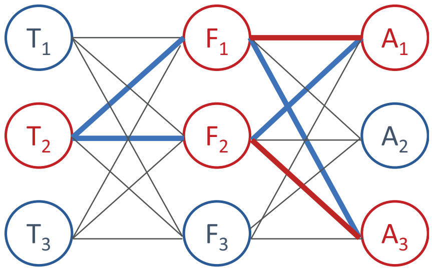
$$DI = \sum_T \sum_F \sum_A \left((\chi_{TF} + \chi_{FA}) \times (S_T \cdot S_F \cdot S_A) \right)$$

where χ_{TF} is a measure of the complementarity between techniques and functions, is a measure of complementarity between functions and S applications, and χ_{FA} is equal to 1 if the country has a relative specialisation index greater than 1, and 0 otherwise, in the technology t function f and application a. In addition, the complementarity measure χ is calculated as a Chi-2 distance. About the complementarity between techniques and functions for example, $\chi_{tf} = (O_{tf} - T_{tf})/T_{tf}$ compares the number of patents observed O_{tf} concerning both a technique t and a function f with theoretical numbers T_{tf} established under the hypothesis of independence between techniques and functions: $T_{tf} = P_{tf}/(P_t \times P_f)$ where P is the share of all patents.

A positive value of χ_{TF} (respectively χ_{FA}) indicates mutual attraction between an AI technique and an AI function (respectively between an AI function and an AI application). A negative value suggests mutual exclusion. The complementarity index χ is calculated at the global level and applies to all countries in a uniform manner.

To better understand the spirit of the measure, Diagram represents the AI innovation value chain with three techniques, three functions and three AI applications. The result is 27 possible technique-function-application chains (in this work, with 10 techniques, 10 functions and 10 AI applications, the total number of possible chains is 1000). Imagine a country specialising in technique T_2, functions F_1 and F_2, and applications A_1 and A_3 (i.e. $NISR > 1$, implying the existence of four possible value chains (T_2-F_1-A_1 ; T_2-F_1-A_3 ; T_2-F_2-A_1 ; T_2-F_2-A_3). The lines between the vertices represent the degree of complementarity between techniques and functions (χ_{FA}), and then between functions and applications . Lines in bold

Diagram. **AI innovation value chain for a fictitious country**



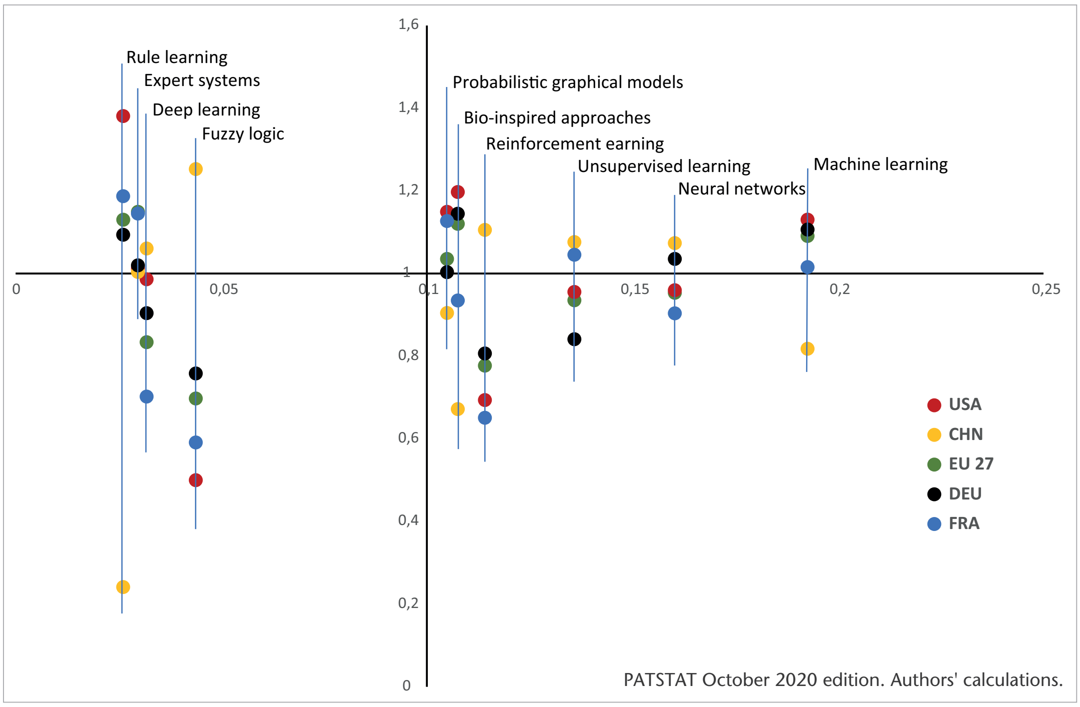
represent complementarities that are relevant for this country, i.e. complementarities linking proven areas of specialisation. In the Diagram, T_2 is positively associated with the functions F_1 and F_2 (blue lines). In addition, the function F_1 is negatively associated with the application A_1 (red line), but positively associated with the function A_3 (blue line), unlike function F_2. Overall, the degree of integration is the sum of all observed complementarities (the lines in bold) linking the vertices corresponding to the areas of specialisation. We interpret this measure as indicating the complementarity between TFA domains.

For example, France specialises in expert systems, machine learning, probabilistic graphical models, rule learning and unsupervised learning. It also specialises in computer vision, control methods, character recognition, image and video segmentation, and semantics. Finally, it specialises in applications relating to health (medical sciences), security and transport. For example, rule learning, a technique in which France has a strong comparative advantage, is highly complementary to computer vision, a function in which France has also developed a comparative advantage ($\chi_{ARE\text{-}VO}$ = 7,01). On the other hand, rule learning is negatively linked to character recognition ($\chi_{ARE\text{-}RC}$ = -0,68), and to image and video segmentation ($\chi_{ARE\text{-}SIV}$ = -0,98). In total, for France, there are 5 (techniques) × 5 (functions) × 3 (applications), or 75 possible value chains. The degree of integration is simply the sum of the degrees of complementarity observed (between techniques and functions, then between functions and applications) along these 75 possible chains.

As far as AI techniques are concerned, France has 2,242 patents in AI techniques, which represents around 1.9% of world production. France is present in three major markets (unsupervised learning, probabilistic graphical models and, to a lesser extent, machine learning), and in two minor markets (expert systems and rule learning). France is lagging behind in fuzzy learning, deep learning, neural networks and reinforcement learning, all of which are now at the heart of artificial intelligence. Germany and the United States have similar positions. China specialises in learning techniques (reinforcement learning, unsupervised learning, deep learning) and related fields (neural networks, fuzzy logic).

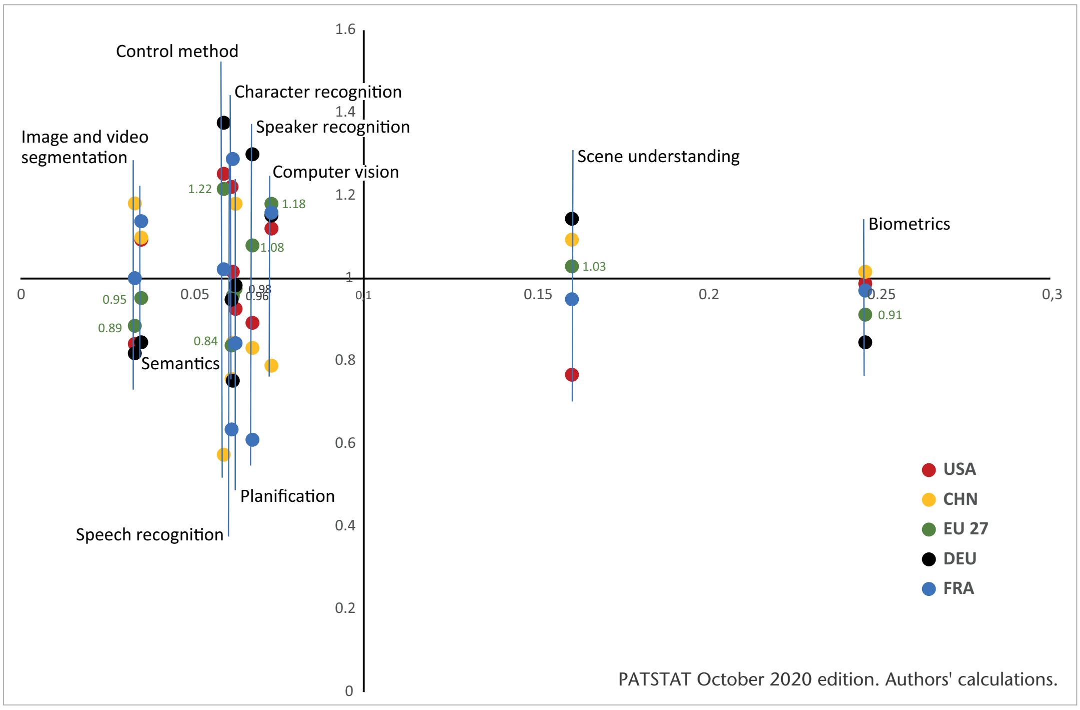
AI functions are dominated by biometrics and scene understanding. Focusing on the relative specialisations in the different functions (Figure 4), biometrics, a major source of applications linked to security, transport and medical sciences, shows relative positions close to unity for France, China and the United States, with a slight drop for Germany. Germany has a strong specialisation in scene understanding, a key function of AI in manufacturing in general, and in the transport sector in particular. France is highly specialised in character recognition (linked to document management), computer vision (linked to transport, security and medical sciences), and semantics (used extensively in business, education and office automation).

Figure 3. **Strategic positioning of countries by AI technique**



Horizontal axis: Market share of AI techniques.
Vertical axis: Specialisation index *NISR* of AI techniques in the countries studied (see Box).
Interpretation: machine learning accounts for more than 19% of patents characterised by technique. With a specialisation index of less than one, China does not have a dominant position in this AI technique. The United States, Germany and Europe as a whole, and France to a lesser extent, are highly specialised in this field.

Figure 4. **Strategic positioning of countries by AI function**

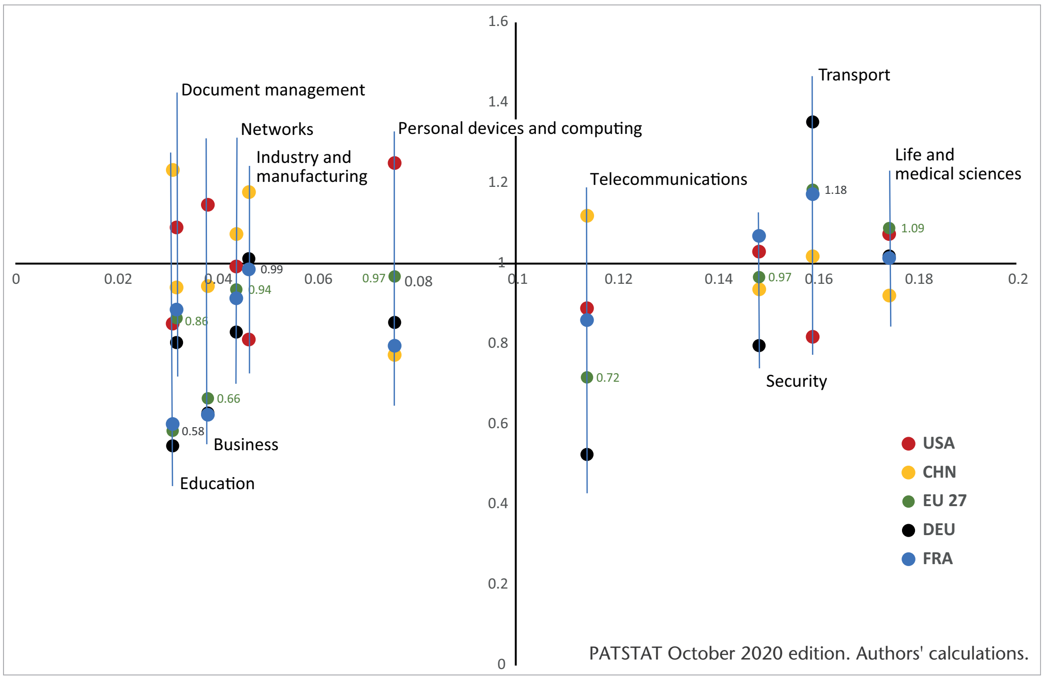


Horizontal axis: Market share of AI function.
Vertical axis: Specialisation index *NISR* of AI techniques in the countries studied (see Box). See Figure 3.

Figure 5 looks at applications. It shows that medical sciences, transport, security and telecommunications are major applications of AI. France is highly specialised in transport (like Germany) and security, and similar to China in telecommunications and the United States in medical sciences. In minor markets, China and the United States show strong domination, both in terms of the number of patents and relative specialisation. This is particularly the case in applications related to personal objects and computing, business, and document management, dominated essentially by the United States, and industry and handling and education for China. France and Germany remain marginal players in these minor markets.

Second observation. *France specialises in three major AI techniques (machine learning, unsupervised learning and probabilistic graphical models) and three major applications (medical sciences, transport and security). France has no comparative advantage in any major AI functions.*

Figure 5. **Strategic positioning of countries by AI application**



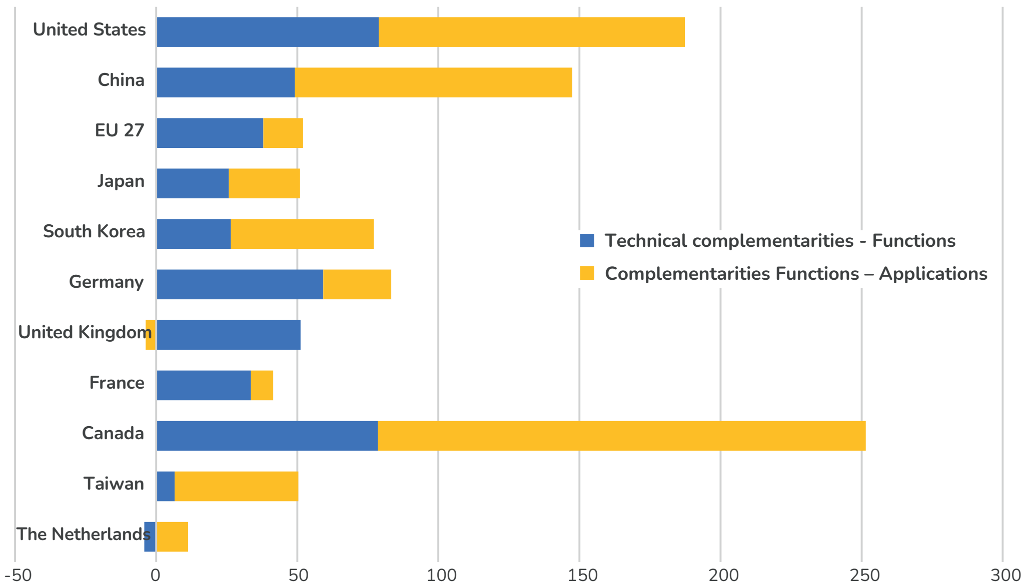
Horizontal axis: Market share of AI application.
Vertical axis: specialisation index *NISR* of AI application in the countries studied (see Box). See Figure 3.

Is the artificial intelligence value chain integrated?

The specialisation of countries in specific AI techniques, functions and applications raises the question of the coherence of specialisations along the artificial intelligence value chain. Coherence assesses the degree of complementarity between the different levels of the value chain and reveals the capacity for industrial development based on innovations designed, developed and exploited nationally. It thus provides an indication of the capacity to create and benefit from the value produced by domestic investment. Assuming a linear chain from techniques to functions, and then from functions to applications, we can characterise each country according to the degree of integration of the AI value chain. The more integrated a country is, the more it develops complementary TFA skills. In other words, (i) the techniques and functions in which the country has a comparative advantage are complementary; and (ii) the functions and applications in which the country has a comparative advantage are complementary. This is an indicator without any real dimensions. It is only by comparing countries that we can draw conclusions.[10]

Figure 6 shows the degree of integration of the main countries. The United States and Canada are highly integrated, followed by China. It is hardly surprising that the USA and China are highly integrated. Accounting for more than 50% of patents, it is these two countries that are essentially building and defining the complementarities between the TFA fields of AI. Canada's position reveals that its TFA profile is close to that of the United States. Other countries are less integrated. Germany and South Korea are more integrated than France and the Netherlands, which suffer from a lack of complementarity in their expertise in AI techniques, functions and applications.

Figure 6. **Degree of integration of the AI value chain, by country**



PATSTAT October 2020 edition. Authors' calculations.

Figure 6 also shows the contribution of upstream complementarities between techniques and functions (in blue), and downstream complementarities between functions and applications (in orange). Once again, the United States, Canada and China show consistency across the entire AI innovation value chain. Europe in general, and France in particular, have a median position, while the Netherlands and Taiwan are not integrated. To a lesser extent, South Korea and Taiwan show substantial downstream complementarities. The low level of downstream integration is evident in Europe, and more particularly in France. The specialisations of the United Kingdom do not seem to be consistent with those of the Netherlands and the United Kingdom (in the downstream phases),[11] auguring future difficulties in terms of the economic value of the value chain.

Third observation. *The AI value chain in France is only moderately integrated, mainly due to a lack of integration in the downstream phases of the value chain. The United States, Canada and China are highly integrated, both upstream and downstream. Europe is more integrated in the upstream phases of the AI innovation chain, while Asia shows downstream integration. Germany is the most integrated country in Europe. In contrast, the Netherlands shows no integration at all, and therefore little coherence in its specialisation portfolio.*

10. See Box for a detailed presentation of the measure.

11. This implies three possible situations. Firstly, AI investments are made in areas that are completely independent of each other, leading to zero integration. Secondly, the country is involved in the construction of international complementarities, which the measure cannot capture. Thirdly, the country's position reflects a national desire to position itself in an original way in the AI landscape, and complementarities have yet to be built. These three explanations are not mutually exclusive.

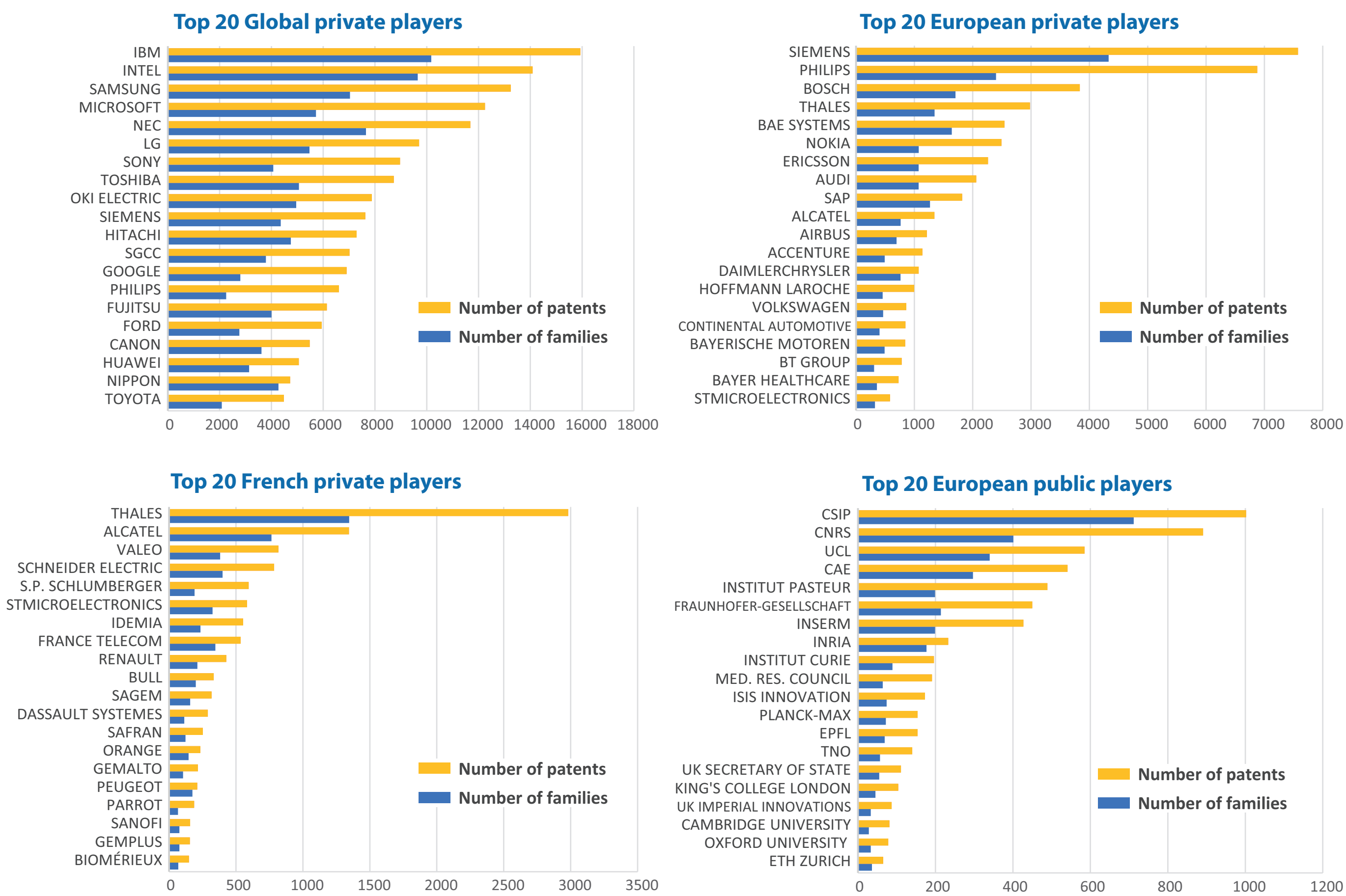
Who are the key French actors and how do they rank worldwide?

We now focus on the main public and private organisations that support AI innovation. Figure 7 depicts the main private and public organisations producing AI patents. The North-West quadrant shows the top 20 global private players, the North-East quadrant the top 20 European private players, the South-West quadrant the top 20 French private players, and the South-East quadrant the top 20 European public players.

Of the top 20 private global players (North-West quadrant), US hardware giant IBM leads with around 16,000 patents, corresponding to more than 10,000 patent families.[12] Intel (USA, 14,000 patents), Samsung (South Korea, 13,000 patents), Microsoft (USA, 12,000 patents) and NEC (Japan, 11,000 patents) are the major AI innovators. In terms of the nationality of the players, the top 20 include five American companies, two Korean (Samsung and LG Group), two Chinese (SGDC – State Grid Corporation of China – and Huawei), one German (Siemens) and one Dutch (Philips). The remaining nine players are Japanese. Not in the top 20, France's leading company Thales is ranked 37th, with around 3,000 patents.

12. The ratio between the number of patents and the number of patent families is an indirect indication of the economic value of inventions (see Appendix).

Figure 7. **Key players in the field of AI**



PATSTAT October 2020 edition. Authors' calculations.

Of the top 20 private players in Europe (North-East quadrant), Siemens (Germany, 7,500 patents), Philips (Netherlands, 6,900 patents) and Bosch (Germany, 4,000 patents) make up the top three. Thales is the fourth largest European player. A breakdown by nationality reveals Germany's dominant position, with nine companies in the top 20. There are also three French companies (Thales, Alcatel, acquired by Nokia in 2015, and ST Microelectronics) and two British (BT Group and BAE Systems). In terms of business sectors, there is a strong presence of car manufacturers (Audi, Volkswagen, DaimlerChrysler, Bayerische Motoren Werker BMW, Continental Automotive, Volkswagen). Also present are diversified groups such as Siemens (health, electronics and construction), Bosch, which specialises in construction and the automotive industry, SAP, which designs software, and Bayer Healthcare, a pharmaceutical and agrochemical company.

The bottom two quadrants focus on French and European players. The South-West quadrant lists the top 20 private French players. Behind Thalès are Alcatel with 1,300 patents, and Valeo with 800. Within Europe, the French leaders are lagging far behind. The South-East quadrant shows the top 20 public research organisations in Europe. With 1,000 patents, the Spanish CSIP (Consejo Superior de Investigaciones Cientificas) tops the ranking. French research bodies are strongly represented: the CNRS is 2nd with 891 patents, the Commissariat à l'Énergie Atomique (CEA) and the Institut Pasteur are 4th and 5th respectively, INSERM is 7th, INRIA is 8th and the Institut Curie is 9th. Thus, there are six French institutions in the top 10 European research organisations.

In terms of patent quality, French institutions produce patents with high economic value. The average size of patent families is 2.2 for the CNRS (compared with 1.9 for all of these institutions), 2.5 for the Institut Pasteur, 2.1 for INSERM and 2.2 for the Institut Curie. In contrast, British public research does little to patent its advances in AI. With the exception of UCL, the Medical Research Council and the universities of Oxford, Cambridge, Imperial College and King's College are less present in terms of the number of patents. However, a more detailed analysis shows that these institutions are filing patents with high economic value. The average patent family size is 3 for the Medical Research Council, 2.4 for Oxford, 2.9 for Cambridge, 2.6 for Imperial College and 2.3 for King's College.

Fourth observation. *The limited presence of French private players contrasts with the extensive involvement of French public research organisations. Besides the latter produce patents with high economic value.*

What is the division of labour between private and public players?

The rise of AI calls into question the usual distinction between science and technology. The distinction between fundamental and applied knowledge is becoming equivocal. Most of the fundamental knowledge associated with AI, such as Deep Learning-type association algorithms, can be used in numerous applied contexts. Conversely, the development of generic techniques is also driving a relationship in which the creation of applied knowledge is pushing back the frontiers of fundamental knowledge. This development calls into question the distinction between public players in charge of fundamental research and private players developing applied knowledge.

Table 1. **Nationality and institutional affiliation of the players involved in patents (1990-2017)**

	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 Korea	38 182	12 710	3.0
United States	204 931	23 262	8.8
Japan	101 747	4 982	20.4
United Kingdom	9 956	1 954	5.1

PATSTAT, October 2020 edition. Authors' calculations.

In China, for every patent issued by a public research institution, there are 1.9 private patents. The number of countries covered in this section is limited for reasons of data quality.

We compare the evolution of patents filed by public and private players. As Table 1 shows, the first observation is that private companies produce significantly more patents than public institutions. One public patent corresponds to 4.6 patents from private players, excluding individual inventors. In addition, there is considerable heterogeneity between countries. In Japan, for example, the ratio of private patents to public patents is over 20. In Germany, it is 12. These ratios contrast with those observed in China, France and South Korea, where public research bodies play a leading role in the generation of AI patents. Clearly, these figures reveal radically different national innovation systems.

Let's now look at collaboration networks, focusing on co-patents, meaning, patents belonging to several organisations.[13] Table 2 shows the main characteristics of the players involved in co-patents, according to their nationality and institutional affiliation. Those involved in a co-patent may be of the same or different nationalities, may work exclusively in private companies, exclusively in public institutions, or be involved in public-private collaborations. Table 2 provides a breakdown for all of the co-patents observed worldwide, and for each of the key countries (France, Germany, China, South Korea, the United States, Japan).

Overall, it is not surprising to find that co-patents mainly involve private players. While there are more than 7,000 co-patents between private players, there are fewer than 1,000 co-patents between public players, and around 2,000 mixed co-patents between public and private players. The vast majority of collaborations are intra-national (almost 90%), with only one co-patent in 10 bringing together players of different nationalities. It is interesting to note that overall (on a global level), companies favour intra-national collaborations, whereas collaborations involving at least one public player are more internationally oriented.

France is in a unique position. There is an absence of intra-national collaboration between private players. All private collaborations in France involve a foreign player. On the other hand, there is a high level of collaboration between the various French public research institutions (386 co-patents), and very few are international (only 38). The small number of French private sector players in co-patents contrasts with their high level of openness to international collaboration, because almost all of them involve international collaborations. Overall, in France, the main players in AI innovation collaborations formalised by a co-patent are public players. Germany's collaborative networks show the opposite trend to that of France. Patents between German players are held exclusively by private players. The public research institutions involved in German co-

13.
In the database of 860,000 AI patents, there are about 40,000 co-patents. In addition, we include only players with at least 50 co-patents in order to simplify the landscape of the players most involved in collaborations. This approach results in just over 10,000 co-patents for 166 players. These 166 actors establish 572 links between themselves, out of 13,695 potential links (166 × 165 ÷ 2). Each link can correspond to several co-patents. Each of these co-patents is then characterised by the nationality of the actors involved and by their public or private nature.

patents are located abroad. In terms of volume, German networks appear to be smaller than the volume of patents. However, when German players are involved in a co-patent, they show more openness to international collaboration.

Table 2. **Nationality and institutional affiliation of the players involved in co-patents**

	National collaborations			International collaborations				
Type of player	Private	Mixed	Public	Private	Mixed	Public	% I	% M
World	6 233	1 784	848	773	343	127	12.3	21.0
France	0	22	386	65	40	38	26.0	11.3
Germany	151	0	0	79	75	0	50.5	24.6
China	4 260	992	91	492	83	7	9.8	18.1
South Korea	553	391	42	35	34	32	9.3	39.1
United States	209	254	286	130	233	115	39.0	39.7
Japan	807	125	3	199	106	1	24.7	18.6

PATSTAT, October 2020 edition. Authors' calculations.

The observed number of co-patents between two private players of the same nationality worldwide is 6,233.
% I : *Percentage of international collaborations.*
% M : *Percentage of mixed collaborations between private and public players.*
The number of countries covered in this section is limited for reasons of data quality.

In terms of patent production, the USA engages in very little collaboration. However, as in the case of Germany, when American players are involved in a co-patent, it often involves a foreign player. In general, China, South Korea and Japan conform to the stylized facts observed at a global level. In these countries, private players drive collaborations, with intra-national collaborations predominating.

Fifth observation. *France stands out for the strong presence of its public research in the production of innovation incorporating AI. It differs from Japan and Germany, and is similar to China and South Korea. In terms of collaborations, public players drive French co-patent networks that are essentially intra-national, with little openness to the international arena or to a mix of public and private institutions.*

Conclusion

The key points are as follows:

1. With a market share of 2.4% of AI patents, France ranks seventh in the world. Normalised by the number of inhabitants, France ranks 15th worldwide, with 312 patents per million inhabitants. Overall, without being a world leader, France shows moderate but significant activity in this field.
2. France specialises in three major AI techniques (machine learning, unsupervised learning and probabilistic graphical models) and three major applications (medical sciences, transport and security). France has no comparative advantage in any major AI functions.
3. The AI value chain in France is only moderately integrated, mainly due to a lack of integration in the downstream phases of the value chain. The United States, Canada and China are highly integrated, both upstream and downstream. Europe is more integrated in the upstream phases of the AI innovation chain, while Asia shows downstream integration. Germany is the most integrated

country in Europe. In contrast, the Netherlands shows no integration at all, and therefore little coherence in its specialisation portfolio.

4. The limited presence of French private players contrasts with the extensive involvement of French public research organisations. Besides the latter produce patents with high economic value.
5. France stands out for the strong presence of its public research in the production of innovation incorporating AI. It differs from Japan and Germany, and is similar to China and South Korea. In terms of collaborations, public players drive French co-patent networks that are essentially intra-national, with little openness to the international arena or to a mix of public and private institutions.

Whether France will become a significant AI player in the future remains an open issue. Given the remarkable performance of French public research institutions, there is no reason to be pessimistic. The scientific basis stands firm, and given that AI is a science-based domain, this prerequisite can be considered as satisfied. Yet this condition cannot suffice. The absence of major French groups in the innovation networks combined with their lagging behind the major global players, raises scepticism. France runs the risk of becoming a global AI laboratory, situated upstream of the actual innovation activities, bearing the sunk costs associated with each micro-project, without enjoying their exploitation on a larger scale. In short, our fear is that artificial intelligence *made in France* will eventually be locked in upstream AI invention activities with no local capacities to capture their latent scale economies.

References

Acemoglu, D., & Restrepo, P. (2019). Automation and new tasks: How technology displaces and reinstates labor. *Journal of Economic Perspectives*, *33*(2), 3-30.

Aghion, P., Antonin, C., & Bunel, S. (2019). Artificial intelligence, growth and employment: The role of policy. *Economie et Statistique*, *510*(1), 149-164.

Agrawal, A., Gans, J. S., & Goldfarb, A. (2019). Artificial intelligence: the ambiguous labor market impact of automating prediction. *Journal of Economic Perspectives*, *33*(2), 31-50.

Babina, T., Fedyk, A., He, A. X., & Hodson, J. (2021). Artificial Intelligence, Firm Growth, and Product Innovation. *Firm Growth, and Product Innovation November 2021.*

Bresnahan, T. F., & Trajtenberg, M. (1995). General purpose technologies 'Engines of growth?' *Journal of Econometrics*, *65*(1), 83-108.

Cockburn, I. M., Henderson, R., & Stern, S. (2019). 4. The Impact of Artificial Intelligence on Innovation: An Exploratory analysis. In *The Economics of Artificial Intelligence*. pp. 115-148. University of Chicago Press.

McKinsey Global Institute, (2018). Notes from the AI frontier: Modeling the impact of AI on the world economy. *McKinsey Global Institute*, *4*.

OECD (2019). *Artificial intelligence in society.* OECD, Paris.

OECD (2020). *Identifying and measuring developments in artificial intelligence: Making the impossible possible*. OECD, Paris.

SKEMA Business School (2022), *Intelligence artificielle: technologies et acteurs clés.* Rapport annuel. Edition 2022, SKEMA Business School, OTESIA-Université Côte d'Azur.

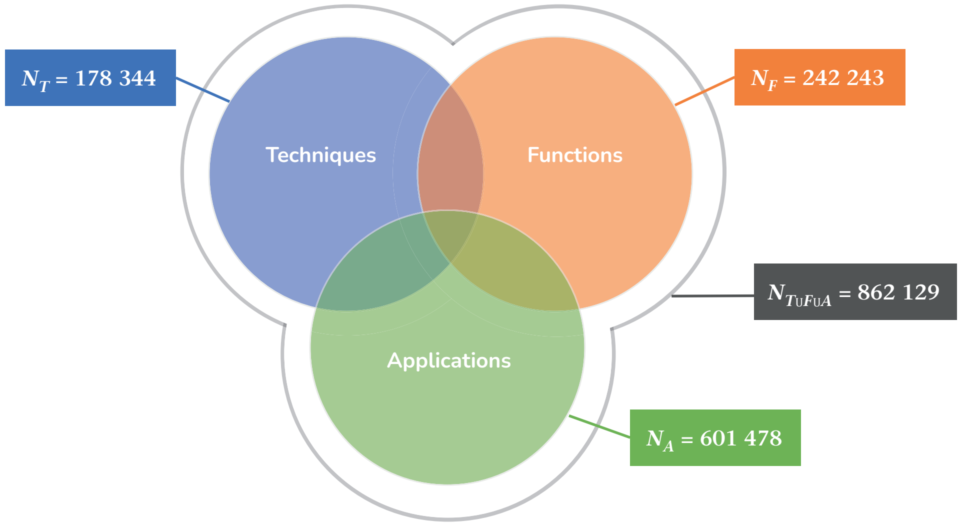
Varian, H. (2018). Artificial intelligence, economics, and industrial organization. In *The economics of artificial intelligence: an agenda* (pp. 399-419). University of Chicago Press.

WIPO (2019). Technology Trends: Artificial Intelligence. WIPO Annual Report, 2019.

APPENDIX. AI patents as basic material

We use patent data to describe the dynamics of AI. By developing statistical indicators for patents, this report provides a partial picture of AI innovation. As an algorithm, AI does not lend itself to patenting (Article 52 of the European Patent Convention, 16th edition, 2020). Only when integrated into a tangible technology can it can be patented. However, the use of patents has two essential advantages. Firstly, the patent is a rare, unique and systematic source of data in terms of the wealth of information it contains: its technological content; the name and location of the inventor and owner; the year of filing; the title of the patent and its summary. Information relating to the scientific publications mentioned in patents provides an opportunity to establish a link between the technological world represented in patents and the scientific world. Secondly, patents enable us to understand the innovation activities that involve artificial intelligence and associate it with markets that are seen as promising. In so doing, we focus on the market development of AI, meaning its incorporation into products to add value to them, rather than on the scientific and technical development of AI (Figure A1).

Figure A1. **Number of AI patents identified, according to the TFA model**



PATSTAT October 2020 edition. Authors' calculations.

The letter N stands for the number of AI patents identified. The intersections of the sets are as follows: $N_{T \cap F}$ = *40 973 ;* $N_{T \cap A}$ *=45 679 ;* $N_{F \cap A}$ *=92 989 ;* $N_{T \cap F \cap A}$ *=19 705.*

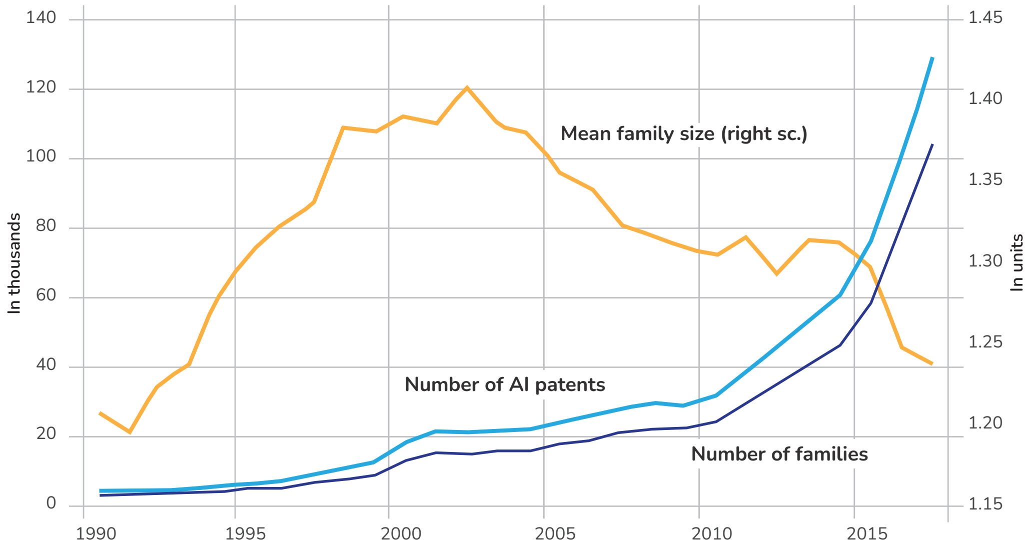
Our source of information is PATSTAT, a database listing patent applications and thus containing bibliographic data on more than 100 million patent documents from major industrialised and developing countries. The systematic nature of the database makes it very attractive, although it is not exhaustive, either geographically or temporally. However, the main intellectual property offices form the structural part of the database. A very useful feature of PATSTAT is the organisation of the information in relational tables, which makes it very intuitive to use. We are inspired by the method used by the International Patent Office (WIPO) and their report "WIPO Technological Trends 2019 - Artificial Intelligence".[14] This classification is based on the three main categories of AI in the techniques, functions and applications triptych:

14. World Intellectual Property Organization: https://www.wipo. int/ publications/en/details.jsp?id =4386

1. Techniques: these are advanced forms of statistical and mathematical models used to calculate tasks that are generally carried out by humans;
2. Functions: these are functions that can be performed using one or more AI techniques;
3. Application domains: these are the different fields in which AI is applied, such as transport, agriculture or medical sciences.

The identification of an AI patent, and its classification into techniques, functions and fields of application, is carried out by searching the database using keywords and technological classes. A patent can be a technique, a function and an application at the same time, just as it can be limited to being a technique, a function or an application.

Graph A1. **Change in the number of patent applications in artificial intelligence, patent families and average family size, between 1990 and 2017**



PATSTAT October 2020 edition. Authors' calculations.

Graph A1 shows the trend in the number of patents identified as relating to AI and filed between 1990 and 2017 (dark blue curve, left vertical axis). The number of patents increases significantly over the period, with the exception of the early 2000s. After 2010, we see an impressive acceleration in the number of patent applications over the period, reaching 140,000 in 2017. We might be tempted to attribute this strong growth to the advent of Deep Learning in the early 2010s, which represented a real breakthrough in the development of AI. However, we remain cautious about this explanation, as we observe this non-linearity across all patent applications. Finally, the dashed line shows changes in average patent family size. We observe a large cycle in line with the general cycle. We posit, however, that this cycle will turn around with the development of AI.

Overall, our method of identifying AI patents yields a set that we can consider our base of AI-related patents from 1990 to 2017. In total, between 1990 and 2017, there are more than 860,000 AI-related patents. Of these, around 178,000 patents relate to AI techniques, around 242,000 to AI functions and over 600,000 to AI applications.

There are two ways of counting invention activity giving rise to intellectual property applications. Firstly, the number of patent families can be counted. The patent family is a generic term in PATSTAT that identifies the invention. For example, a fictitious French company decides to protect its invention with the *Institut National de la Propriété Intellectuelle* (INPI), and then decides to extend its protection to Brazil, the United States, South Africa and China. In PATSTAT, this decision would translate into four new patents. However, these patents refer to one and the same invention, in other words, one and the same *family*. Secondly, we can count the number of patents. Another interpretation of the patent count is that it is the number of families, each family being weighted by the number of patents. Knowing that an invention is all the more important if it is protected in a large number of countries, we can interpret the number of patents per family as defining the economic value of an invention. In this work, the average size of an AI patent family is 1.3 patents.

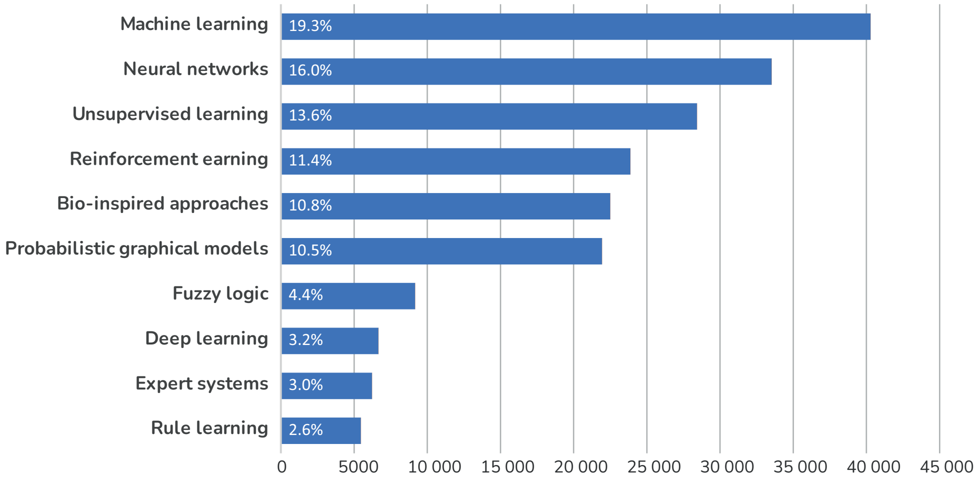
Of the 860,000 AI patents, 178,344 are associated with at least one AI technique belonging to 124,675 patent families between 1990 and 2017. The top 10 techniques are (by decreasing frequency, see Graph A2): machine learning (19.3%); neural networks (16%); unsupervised learning (13.6%); reinforced learning (11.4%); bio-inspired approaches (10.8%); graphical probabilistic models (10.5%); fuzzy logic (4.4%); deep learning (3.2%); expert systems (3.0%); rule learning (2.6%). These top 10 AI techniques thus cover more than 95% of the occurrences of AI techniques.

There are 242,243 patents belonging to 154,856 patent families associated with AI functions. The top 10 functions are (by decreasing frequency, see Graph A3): biometrics (24.6%); scene understanding (16.1%); computer vision (7.4%); speaker recognition (6.8%); planning (6.3%); character recognition (6.2%); voice recognition (6.2%); control methods (5.9%); semantics (3.5%); image and video segmentation (3.3%). These top 10 AI functions thus cover more than 86% of the occurrences of AI functions.

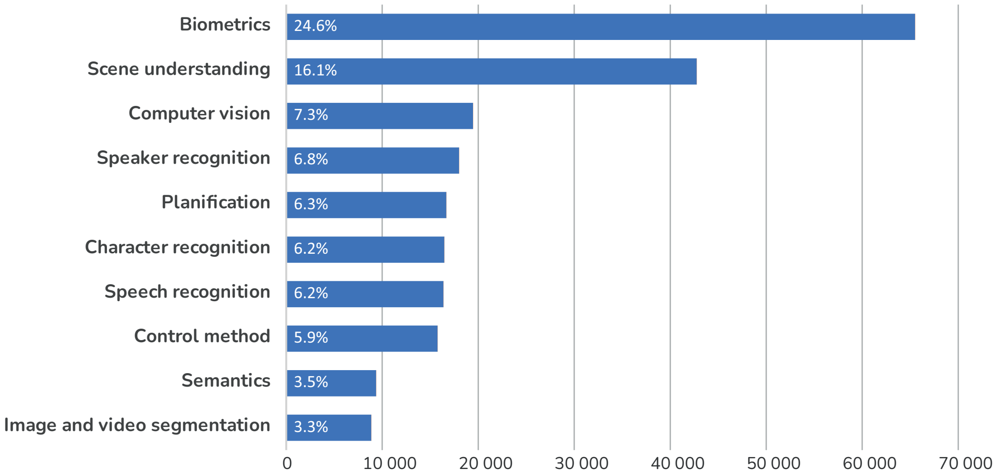
The number of application patents far exceeds the number of patents associated with techniques or functions. This finding seems consistent with the hypothesis that AI is a GPT: a limited number of techniques and functions contribute to the development of a large (and growing) number of applications. Between 1990 and 2017, there were 601,478 unique patents referring to one or more application domains. The top 10 fields of application are (by decreasing frequency, see Graph A4): medical sciences (17.5%); transport (15.9%); security (14.9%); telecommunications (11.4%); personal objects and computing (7.8%); industry and handling (4.8%); network industries (4.4%); business (3.8%); document management (3.2%); education (3.1%). These top 10 application areas thus cover more than 85% of occurrences in AI applications.

Johanna Deperi, Ludovic Dibiaggio, Mohamed Keita, Lionel Nesta, 2023, « Ideas Without Scale in French Artificial Intelligence Innovations », *OFCE Policy brief* 118, June 26.

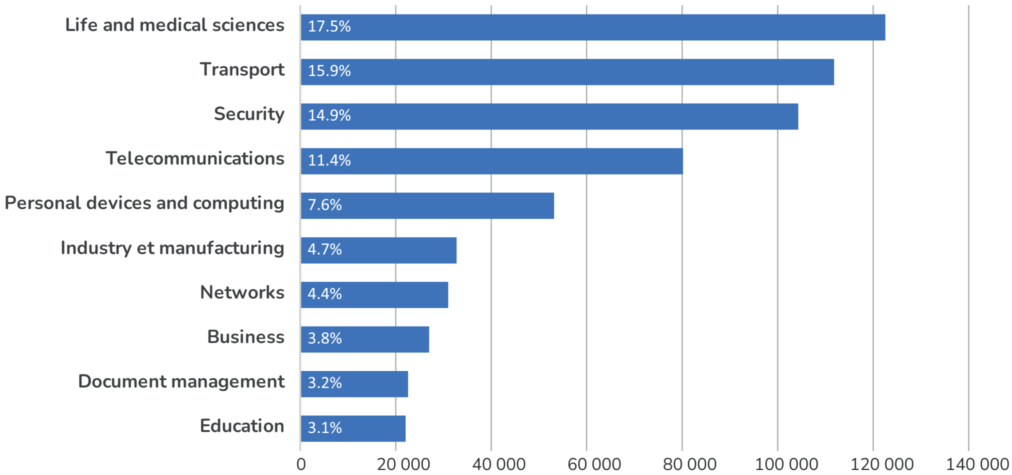
Graph A2. **Relative Frequencies of Top Ten AI Techniques Revealed in AI Patents**



Graph A3. **Relative Frequencies of Top Ten AI Functions Revealed in AI Patents**



Graph A4. **Relative frequencies of top ten AI applications revealed in AI patents**



PATSTAT October 2020 edition. Authors' calculations.

Directeur de la publication Xavier Ragot
Rédactrice en chef du blog et des *Policy briefs* Christine Rifflart
Réalisation Najette Moummi (OFCE).

www.ofce.sciences-po.fr @ofceparis

Observatoire français des conjonctures économiques I Centre de recherche en économie de Sciences Po
10, place de Catalogne I 75014 Paris I Tél/ 01 44 18 54 00