Les Notes de La Fabrique

Is Disruptive Innovation Only for Start-ups?

French Industry in the Face of Key Technologies

Sonia Bellit, Vincent Charlet

La Fabrique de l'industrie
laboratoire d'idées

A Think Tank for Industry

La Fabrique de l'industrie takes an in-depth, multi-disciplinary approach to the current situation and perspectives of industry in France and Europe. We work on relationships between the industry and the land, the attractiveness of industry-related jobs, opportunities and challenges brought by globalization and innovation as well as its competitiveness. Industry-related jobs, skills and energy transition are also at the forefront of our research work. By working in collaboration with a lot of other institutions, we encourage the confrontation of opinions and analyses, which is a necessary step towards shedding a light on a complex reality.
La Fabrique produces different kinds of books, briefing documents and multimedia tools, all available online for free. We share our expertise to fuel the public debate by answering questions from the media and by participating in various conference talks.

www.la-fabrique.fr www.linkedin.com/company/la-fabrique-de-l'industrie/ @LFI_LaFabrique

Is Disruptive Innovation Only for Start-ups?

Cover Picture:
La Roue de la Loi « Dharmacakra »
Provenance : temple of Phra Pathom
Art Môn de Dvaravati
Location : Paris, musée Guimet - musée national des Arts asiatiques
Photo © RMN-Grand Palais (MNAAG, Paris) / Thierry Ollivier

The original edition of this book has been published in French language with the title: Sonia Bellit et Vincent Charlet, *L'innovation de rupture, terrain de jeu exclusif des start-up ?,* Les Notes de La Fabrique, Paris, Presses des Mines, 2023.

ISBN : 978-2-38542-590-6
ISSN : 2495-1706

60, boulevard Saint-Michel – 75272 Paris Cedex 06 – France
presses@mines-paristech.fr
www.pressesdesmines.com

81, boulevard Saint-Michel – 75005 Paris – France
info@la-fabrique.fr
www.la-fabrique.fr

Design by Franck Blanchet
Cover and lay-out by Chloé Laforest

Is Disruptive Innovation Only for Start-ups?

French Industry in the Face of Key Technologies

Sonia Bellit, Vincent Charlet

La Fabrique de l'industrie
laboratoire d'idées

Foreword

I was delighted to accept, as president of the French Academy of Technologies but speaking in a personal capacity, to write the foreword to this study on disruptive innovation by the Fabrique de l'industrie.

Taking an original, highly pertinent approach, this publication employs patent applications to examine the position of global players and their corresponding countries on twelve key so-called disruptive technologies. After identifying the disruptive aspect, which may be technological or related to usage and markets, the study judiciously focuses on the industrial sector, which drives the deployment of these technologies in society.

Unsurprisingly, these disruptive innovations are centred on the two biggest challenges facing our businesses and our society: the ecological transition and the digital revolution. The dramatic changes taking place in the planet's environment make it clear that to deal with these transitions we need to regain control of our industrial and technological destiny. This is how we can make our economy and social system more resilient to the military, security, economic, sanitary and food-related threats that have become so numerous as to make crises and unexpected events a matter of course.

In this context, only a strong industry coupled with strong research will allow us to protect ourselves against the contingencies of history in the short, mid and long terms, and ensure the sustainability of the democratic and social model of our country and our Europe. The energy and digital revolutions generate both challenges and opportunities.

Clearly, the issue is not just about technologies and innovation; our academy, in line with its motto: "To promote reasoned, chosen and shared progress", pointed out in a recent opinion on energy sufficiency that although technologies are indispensable to tackle these challenges, they will not be enough, and will need to be accompanied by changes in behaviour and values.

Nevertheless, *gaining some control of key technologies, which are the driver of these transitions, is vital to ensure our future as a developed society.* What this publication does is to show where our country and our continent stand in relation to this challenge.

Of course, patent applications are not the only indicator of the performance of laboratories and companies. To observe the recent state of affairs, the authors opted to analyse patent applications because looking at accepted patents and their extensions would have delayed the observation by several years; obviously, these patent *applications* do not all have the same value and many will go on to be refused or circumvented. Moreover, an innovation's patent value is not the only criterion of its success: operational excellence and market access are also important indicators. However, faced with numerous situations and parameters, the choice made by the authors has a solid basis and is particularly instructive.

The resulting observation is very interesting, but rather worrying.

France, unlike the United States, China, Japan, Korea and Germany, *never features among the four leading countries* in each of the twelve areas studied. Our country comes in at fifth to ninth place, most often sixth or seventh.

This is obviously of concern, but can be put in perspective by pointing out that France is also the seventh global economy and the eight industrial power. This publication thus moves away from the popular image of a French industry shrunk beyond saving. But we can save it through action! As this study highlights, the performance of South Korea provides an instructive example.

Europe does a lot better, ranking in the top four for 11 technologies, only sliding down the scale for nanoelectronics. This second observation, while of some consolation, is not totally reassuring, since our Europe is not an integrated entity, and far from sovereign, meaning it cannot wield this strength in the same way as other powers can.

A particularly pertinent analysis relates to the *degree of specialization* of the different countries. While it is easy to understand why large countries like the United States and China are present in all sectors, it is more surprising to see that France, an average power, has not opted to specialize, unlike Korea and Japan, which have made specialization key to their performance. The reason is probably the historic heritage of France dating from the time of de Gaulle, wanting to depend on no one, but now flagging in the face of globalization and rapidly multiplying technologies: you cannot aim to be good at everything. Since European dependence is now much more acceptable, an effective, albeit simplistic, strategy would be to aim at a top ranking for our continent in all sectors, drawing from the specializations of different countries, and establishing France as the leader in a sufficient number of areas.

Throughout the world, the large majority of patent applications are filed by companies, rather than public laboratories. France is unusual in this area, since the share of laboratories, although in the minority, is much greater than in other countries. This is due to both the relatively good performance of French public laboratories compared to public research around the word, in terms of patent applications, and the under-performance of French industrialists… when they exist in that particular domain. This observation can be put down to the power of our large technological research bodies, and also perhaps their policy of maintaining ownership of their patents, even after transferring exploitation to a new or existing company.

Contrary to the widespread idea that start-ups have overtaken large companies in terms of disruptive innovations, this study shows that they in fact tend to spring from *established* companies, in particular the biggest ones, strongly supported by their home state. In fact, the development mechanisms of disruptive innovations are very different from one domain to the next (respective roles of large groups, start-ups, public research, etc.). The key is therefore to adapt tools to deal with this great diversity, and to encourage individual ecosystems to work as part of a network.

For each technology, the study presents an analysis of the global positions and categories of the dominant stakeholders, which is highly useful for *putting together a strategy to redevelop industry adapted to each domain.* Enriched by highly pertinent insights from experts, it shows how the roles of various stakeholders differ depending on the technological domain, and also mentions the instruments implemented to help these stakeholders (public laboratories, start-ups, SMEs, major groups) to work better together.

Based on observations made just before the launch of the France 2030 investment plan, which our academy advises, this publication provides valuable analyses to help public powers adapt the goals and action involved in the plan, for each domain. An awareness of France’s mediocre position and its relative dispersion should encourage us to focus this effort more on sectors where we are more likely to catch up our delay.

The French Academy of Technologies must attempt to contribute, and will be able to usefully draw from the analyses presented here.

One final remark: as the report suggests, targeting this (new) form of public action does not mean that we should abandon “horizontal” solutions like research tax credit and competitiveness clusters: they concern the existing fabric of industrial companies of all kinds, whose maintenance and development are just as necessary as breaking into new domains, which is the object of this publication.

Some of these sectors, beyond the scope of this study, are on the global frontline (aeronautics, space, defence, land transport, nuclear power, etc.). Their success encourages us to resolutely regain a foothold and to catch up in the new "disruptive" sectors, the subject of this remarkable publication.

Denis Ranque
President of the French Academy of Technologies

Acknowledgements

This study owes a great deal to the data of the Observatoire des Sciences et Techniques, and the painstaking patent bibliometrics carried out by its team that allowed us to exploit the data. Our sincere thanks go to Luis Miotti and Mounir Amdaoud, along with Frédérique Sachwald and Dominique Guellec for their contributions and quality advice.

This study also benefitted from the generous support of the Breakthrough Energy foundation, represented by Julia Reinaud and Pénélope Le Menestrel, to whom we extend our gratitude for their interest in our work and their support.

Other people helped us throughout our work, such as Cleantech for France, the company representatives whom we interviewed, and of course, the team at La Fabrique de l'industrie.

All studies are collective works and we thank you all for your numerous, decisive contributions.

Summary

This publication starts by defining disruptive innovations in the industrial sector, based on documentary research and interviews with experts. We consider these to be activities that stem from technological performance, including when it is incremental, combined with a radically new use on the market. Our scope of analysis therefore excludes reputedly disruptive companies like Doctolib, Facebook and BlaBlaCar, which do not belong to the industrial sector and, in particular, have transformed the market without being at the origin of an innovation in the technological sense of the term.

Starting from this definition, we identify twelve disruptive innovations, all of which are mentioned in reports by high-level experts, eight of them directly linked to preserving the environment and combatting climate change. In the industrial sector, myriad solutions exist for the problems raised by the energy transition, including decarbonized hydrogen, batteries for electric vehicles, and low-carbon steel.

Where do these disruptive innovations originate today, on which continents, and in which types of institution? This is the central question that we attempt to answer here, based on patent bibliometrics and interviews. The key issue for states is not only to respond to major societal challenges, but to avoid lagging behind their peers, some of which readily strongly support “their” companies in order to dominate key sectors. It clearly emerges that mastering technologies is necessary, if not sufficient, to defend national interests on the new global scene.

From this point of view, European countries lag far behind the global champions, according to our observations: apart from Germany, which ranks among the leading four patent applicants in half of the technological domains studied, the other European countries rarely feature among the leaders. France in fact never ranks among the most active countries in the twelve domains in our sample. Opposite Europe, a handful of four countries: the United States, China, Japan and South Korea, generally stand at the top of the podium. Their domination is all the more striking in that they systematically concentrate at least half of the patent applications filed in the world, and sometimes up to three-quarters of them (here we only consider patents filed in at least two national offices, in other words, patents that that have a recognized inventive scope and are not limited to a purely defensive role).

When looking at European Union scale, the results are more encouraging: in almost all of the technological domains studied, the global ranking of the European Union ranges from first to second place. The Union is particularly strong in the offshore wind power field, having filed almost two-thirds of patent applications during the decade studied. In the other domains, the European Union never holds more than half of patents, unlike the United States, which maintains a considerable advantage in the fields of quantum computing and messenger RNA. In addition, it is worth pointing out that the leadership of the European Union mainly relies on a small set of countries, dominated by Germany. France does not play a significant role. Interestingly, South Korea and Japan sometimes rank at the same level as the entire European Union.

This report also studies the respective contributions of public and private stakeholders. Every year, the vast majority of disruptive innovation patents are filed by companies. Public research very often plays a modest role, whatever the country. The most emblematic examples of this almost-exclusive domination of companies are batteries for electric vehicles and decarbonized hydrogen: firms are at the origin of over 90% of patent applications throughout the period studied, from 2010 to 2019. Conversely, public research is at times pioneering, such as in the domain of messenger RNA, where it was responsible for half of patent applications in 2010, dropping to one-third in 2019. It is also interesting to note that public research is relatively more represented among US and Chinese applicants, and even more so among French applicants.

This shows that public research can play a key role in initiating disruptive innovations. The French case is particularly striking insofar as public laboratories and universities rank much higher than companies. Among the seven technologies for which we dispose of detailed data, French laboratories represent from 9% to 14% of all patents resulting from public research in the world, which most often puts them in fourth place globally, third for photovoltaics, and fifth for spintronics. It is worth mentioning that French research relies on organizations like the CNRS and the CEA, which often rank among the top three French patent applicants, with the CEA being unusual in that it carries out fundamental research while developing close links with companies. Nevertheless, the problem is that the transmission of knowledge between public laboratories and companies is not enough. For example, in the domains of mRNA, nanoelectronics and spintronics, patent applications in France are almost exclusively made by public laboratories and universities. The objective of public powers is therefore to identify how best to boost private R&D efforts, such as by strengthening fundamental research, developing new instruments aimed at bringing labs and companies closer, and encouraging spin-offs.

Lastly, this publication takes a look at the respective roles of start-ups and large companies in the emergence of disruptive innovations. Since the global success of messenger RNA vaccines, no single sector of activity can avoid the prospect of being sooner or later “disintermediated” by champion start-ups. In fact, the bibliometric analysis shows that, from one technological domain to the next, innovation dynamics do not follow the same patterns, and cannot be boiled down to choosing between “Mark I” Schumpeterian archetypes (in which disruptive innovations are made by new, small players that accept to take big risks) and “Mark II” archetypes (in which established companies maintain their technological advantage by capitalizing on their previous knowledge). In France, as elsewhere in the world, start-ups rarely feature among the main patent applicants in the twelve domains studied. Without doubt, they do achieve high positions in other domains, but relatively rarely, and this is only observed in the United States, China and – at a much lower level – France, but never in Korea, Japan or Germany. Large companies therefore very often come across as leading providers of disruptive innovations, in all domains and in all countries… apart from France.

INTRODUCTION

For almost twenty years, from about 1990 to 2010, the term "European paradox" was used to describe the fact that while European economies were clearly struggling to catch up with the historical leader, the USA, on technological developments and innovation, European research laboratories were successfully advancing the progress of knowledge.

This idea, however controversial, that our technological performances fall short of the contributing capacities of our scientific teams, is an established pattern that has not only formed the keystone of Community R&D policies[1] since the early 1990s, but also features in French declarations from much further back (see for example the closing speech by François Mitterrand following debates on industrial policy in November 1982[2]).

That means that for at least fifty years, European policies, and particularly French policies, have been based on this idea of lagging behind the major global powers when it comes to innovation. Through a chain reaction, the more public research is seen to be excellent, the more the capacity of European companies to propose innovating solutions to the market is judged to be disappointing with respect to the economic influence of our countries.

It is worth noting that this inferiority complex was apparent well before China joined the WTO and gained the status of a new global superpower, and also before the fall of the Soviet block and the end of the Cold War, during which public R&D efforts were nevertheless largely determined by sovereignty objectives and, less than today, the search for economic opportunities. Clearly, this inferiority complex has only increased since. The chronic incapacity to establish a start-up ecosystem "at the right scale" and, even more so, the incapacity to spawn a "French Google" or "European GAFAM" remain the most common, best-known remarks.

1. Green Paper on innovation. Document drawn up on the basis of COM(95) 688 final. *Bulletin of the European Union Supplement* 5/95.
2. Mitterrand (1982).

In the months following the Covid-19 pandemic, the global triumph of Moderna thanks to its messenger RNA vaccine, coupled with the earlier, almost as rapid success of Tesla on low-carbon mobility, rekindled this questioning, in slightly different terms. Where do disruptive innovations spring from today? And what can we say about the respective capacities of large companies, start-ups and public research, particularly in France, to bring the market the disruptive innovations it needs, in the face of an urgent need to find industrial solutions to the problems raised by the energy and digital transitions?

These are the questions that this publication sets out to answer, based on detailed patent bibliometrics and interviews. The first chapter describes the constitution of a sample of twelve control technologies. Chapter 2 maps out the main countries in which disruptive technologies are developed, illustrating the manifest lagging behind of European countries. Chapter 3 looks at the discreet but decisive role played by public research in the emergence of these disruptive technologies. Lastly, Chapter 4 studies the respective roles of large companies and start-ups in this area.

CHAPTER 1

Disruptive Innovations: a Miscellaneous Assortment

Disruption can emerge in technologies or uses

Technology and innovation only partially overlap

The object of this study is to understand where the major technological breakthroughs of the decade emerge[3]. The first step involves putting together a pertinent, representative control sample of technologies that can then be analysed in more detail.

Technology is certainly not the same thing as innovation. "Disruptive technologies" are technologies or combinations of technologies that are radically different from existing technologies, often relying on considerable investments in still uncertain markets at the early stages of development[4]. Disruptive innovation covers a wider scope because it is not necessarily based on complex technologies: it includes product, process and organization innovations that transform uses and create new markets[5]. Thus, companies like Facebook and Twitter transformed the market without coming up with a technological innovation. In fact, they took advantage of available technologies, then intensified their R&D efforts. Reciprocally and by definition, inventions, whether technological or radically new, are only called "innovations" at the point when they find their market, which does not always happen. There is therefore no one-to-one relationship between these two terms.

3. Throughout this study, the terms "disruptive innovation", "radical innovation" and "technological disruption" are used indiscriminately.

4. Source: Conseil de l'innovation.

5. In his book published in 1997, *The Innovator's Dilemma,* Christensen differentiates two types of innovation: low-end disruptive innovation and new-market disruptive innovation. Here we concentrate on the latter. In a later publication dating from 2013, *The Innovator's Solution,* he considers that the disruption effect comes less from technology than from usage.

Nevertheless, it is undeniable that in the industrial sector, and even more so in heavy industry, technological performance is often a precondition for disruptive innovation. As a remIndiar, the French manufacturing sector is at the root of most corporate internal R&D expenditure (68% in 2020[6]), and half of this effort comes from only four areas: the automobile industry (12%), aeronautics and space (10%), pharmaceutics (8%), and the chemical industry (5%). In particular, the innovative industrial solutions that concern the ecological transition (green hydrogen, energy storage, low-carbon steel, etc.) often involve long research and development phases before entering the market – much longer than pure digital service solutions.

This is why studying the dynamics of disruptive innovations that come from the industrial sector involves combining technology-push and market-pull approaches. In other words, it involves looking at products that combine both technological performance, whether radical or not, and a new use on the market[7].

The fine line between disruptive innovations and other innovations

In all cases, so-called “disruptive” innovation is by definition the opposite of incremental innovation. Disruption can seem sudden, whereas incremental innovation tends to take place through the continuous improvement of existing technologies or products. However, as pointed out by Benjamin Cabanes, researcher in management science at Mines Paris PSL, *“there is a fine line between radical innovation and incremental innovation”*: an assembly of incremental innovations can result in a breakthrough and, conversely, disruptive innovation can go on to provoke a series of incremental innovations.

In industry more than in other sectors, innovation is often the fruit of a slow, gradual accumulation of knowledge and involves continuously improving products before they disrupt the market. For example, GPS (*Global Positioning System*), which is now a standard feature on smartphones and cars, is the result of the continuous improvement of satellite positioning initially employed in the first nuclear submarines the United States. Similarly, in the automobile sector, some driver assistance systems like automatic start and stop technology have totally changed driving practices and can therefore be considered as disruptive. However radical it is, innovation cannot therefore be reduced to a “stroke of genius”.

The radical character of an innovation can also stem from the coming together of several domains. According to the Génération Deeptech report by Bpifrance

6. Source: Ministère de l’Enseignement supérieur et de la Recherche, DGRI-DGESIP (2023).
7. Based on this definition, disruptive innovations in the digital sphere (Facebook, Doctolib, BlaBlaCar, etc.) are excluded from the scope of analysis because they are not at the origin of an innovation in the technological sense of the term.

(2019)[8], mastering interdisciplinarity is likely to bring about new products that break away from what is available on the market. As an example, according to Emmanuel Ladent, director of Carbios, the only company in the world to produce plastic from enzymatically reduced waste, his company results from, "*a marriage between two sciences that weren't destined to meet: biology and plastics processing*". As Ladent sees it, "*the two sciences had to come together for it to work*". Disruptive innovation therefore often emerges from cross-cutting projects organized within partnerships between research laboratories and companies.

Public policies increasingly guided by major human challenges

The second major question that came up when we put together our technology samples involved determining their object, their purposes. Since the 1940s, when public policies on research and innovation took on their present, institutionalized format, they have been split between the pursual of sovereignty objectives, support for the competitiveness of companies, and the resolution of major societal challenges (and more naturally the general advancement of knowledge and training through research)[9]. The list of these major societal challenges has evolved over the decades, but for the last few years it has featured the ecological and digital transitions, health, food security, and technological sovereignty.

The design of actual tools to securely or effectively reach these objectives has been the object of a large number of publications and numerous institutional setups: general organizations, dedicated agencies, major programmes financing industries or private operators directly, support for fundamental research of excellence, encouragement of start-up spin-offs from public laboratories, etc. Practically every possibility has been imagined and defended in all OECD countries, to accelerate the emergence of disruptive innovations.

These modulations have sprung from both endogenous considerations of the nature of knowledge and technical progress (see box), and from an external pressure of varying strength from legislative or regulatory authorities on public expenditure considered as acceptable[10]. They have also been the object of a debate that has continued to rage: who should receive the most support for their contribution to the development of new disruptive markets: big companies, start-ups or public laboratories?

---

8. Available online on the Bpifrance website.
9. Larédo and Mustar (1994).
10. See, for example, the periodic parliamentary debates on what limits to impose on research tax credit (CIR) to stimulate innovation while restricting windfall effects, or the pressure applied by the European Commission to very strictly regulate support from the Agence de l'innovation industrielle created in 2005 (Djelalian and Neale-Besson, 2006).

All those countries that, not so long ago, were competing to support their venture capitalism ecosystem in the hope that a national Google would eventually emerge, are now reviewing their range of tools to support research and innovation, faced with the urgency of reacting to climate change, or to draw lessons from the global Covid-19 pandemic. Not only are they dropping the promotion of neutral, transversal measures like research tax credit and competitiveness clusters; they are also gradually freeing themselves from the hitherto imperative constraint of confining their interventions to a precompetitive environment to avoid creating any market distortions. The same public agencies and ministries that were so careful to avoid being accused of cherry-picking[11] are now doing all they can to raise the ambitions of the programmes they subsidize, sometimes even helping the responsible parties organize themselves so that the expected transformations can "really" take place as fast as possible.

This is how acceleration strategies have recently been put in place in numerous countries, including at the scale of the European Union through Important Projects of Common European Interest (IPCEI). In France, the five major challenges launched in 2018 by the European Innovation Council (EIC) also illustrate this political direction: to foster new markets (market pull) by helping technologies – disruptive or otherwise – to respond to needs (technology push). Even more importantly, the latest version of the French investments for the future programme (PIA4) now includes "directed innovation" action that aims to accelerate innovation in sectors and technologies judged to be a priority (Larrue, 2023).

Sample of twelve disruptive innovations that represent this diversity

Twelve disruptive innovations identified in the literature

The focus of this study is therefore industrial disruptive innovations as defined above, and more particularly innovations aimed at resolving the energy and digital transitions. The aim is to understand where they emerge, and who develops and adopts them, in order to measure to what extent large French industrial companies still play a driving role.

11. The main criticism made of vertical, excessively proactive innovation policies (and also of industrial policies) is that they require the decision-maker to take the place of the "invisible hand of the market" and decide in advance which companies and technical solutions the market should opt for. This decision, necessarily based on imperfect information, leads to distortions. At best, according to opponents of these policies, the solution chosen by the authorities turns out to be sub-optimal (Concord, Minitel, etc.); at worst, it quickly ends in failure and a waste of public money (Landier and Thesmar, 2014).

The search for effective, customized innovation policies

In the late 1980s, in other words around the end of the Cold War and the start of the information technology revolution, Henry Ergas (1986) paved the way for promoting "diffusion-oriented" policy, which he observed to be more effective and likely to generate wealth than traditional "mission-oriented" policies aimed at sovereignty objectives. At the time, it was not unusual to read that countries like France or the United Kingdom were squandering their resources maintaining large military or aerospace programmes, with very uncertain economic returns, while Japan and Germany, whose history had deprived them of such political objectives, were taking full advantage of the diffusion-related benefits of transversal technologies like ICTs and unexpected revolutions in the biological field (Autret, 2001). In France, the development of intentionally non-targeted innovation policies like tax research credit (uncapped in 2008) and competitiveness clusters (2005) directly followed on from this reflection. Note that current debates on the need to re-establish our technological sovereignty and to mobilize innovation policies to deal with climate change more or less consist in making the same journey in the opposite direction.

With the intention of going beyond an over-simplistic formulation of this reflection, Dosi (1982) then Pavitt (1984) laid the foundations of sectorial taxonomies, which showed that technical change developed at different rates and in different specific formats in each activity sector, mostly due to institutional setups that conditioned the generation, circulation and appropriation of knowledge. Breschi, Malerba and Orsenigo (2000) supplemented this work by proposing the idea of "technological regimes". Each of these regimes, whose specific features result from the intrinsic characteristics of the sciences and industries that it encompasses, is supported through preferential institutional arrangements: spin-offs of start-ups for software and pharmaceuticals, major vertical programmes for space, etc. These technological regimes are initially differentiated by the main Schumpeterian archetype they come closest to: "Mark I" (where outsiders play a pioneering role in innovation through the creative destruction mechanism) or "Mark II" (where on the contrary established companies are the most innovative, through the mechanism of accumulating knowledge).

The first stage involved employing strategic documents[12] and interviews with experts to identify a sample of disruptive innovations that present strong societal and technological challenges. In the industrial sector, numerous solutions satisfy both criteria and have a well-documented, even proven, disruptive character. This study intentionally concentrates on twelve disruptive innovations, eight of which are directly related to the preservation of the environment and the energy transition. In terms of the low-carbon transition, some have a disruptive character – because they offer a totally new service – even though they are not based on cutting-edge technologies but rather on assembling or optimizing existing technologies. For example, the development of green hydrogen is highly dependent on the optimization of electrolysis, even though it constitutes a disruption in the energy and mobility sectors, and for this reason merits close attention.

Each of these twelve disruptive innovations was the object of an evaluation of the economic and societal issues, promising technologies, and potential applications (*cf*. figure 1.1).

12. Such as the so-called Potier Report published in February 2020 (*Faire de la France une économie de rupture technologique*) and the report by the Direction générale des Companies (DGE) (*Technologies clés 2020*).

Figure 1.1 – Presentation of the twelve disruptive innovations

Disruptive innovation	Economic and societal challenges	Promising technologies	Purposes, applications
Hydrogen for transport	Totalling 31% of domestic emissions in 2018, road transport represents the main generator of greenhouse gas emissions. Target of carbon neutrality by 2050.	Proton-exchange membrane fuel cells (PEMFCs); solid oxide electrolysis cells (SOECs or SOFCs)	Decarbonization of means of transport: private vehicles, heavy goods vehicles, trains, boats, aeroplanes.
Batteries for electric vehicles	Prohibition of the sale of internal combustion vehicles by 2035. Strong dependence on cobalt and nickel to produce batteries.	Sodium-ion, lithium-sulphur, "solid" batteries.	Electrification of the automobile fleet, battery storage and recycling.
Photo-voltaics	Commitment by France to increase the share of renewable energies in final consumption from 20% currently to 40% in 2030.	Perovskite, kesterite, organic solar cells.	Improvement of energy yield of solar panels and their lifespan.
Offshore wind power	Commitment by France to increase the share of renewable energies in final consumption from 20% currently to 40% in 2030.	Storage by compressed air, hybrid systems (coiled and permanent magnets).	Increased energy yield, storage of energy produced, reduced dependence on rare earths from China.
Recycling of strategic materials	Transition toward a circular economy, reduced environmental footprint. High dependence on foreign raw materials.	Hydrometallurgy, treatment with supercritical fluid.	Recuperation of metals contained in electronic products.
Sustainable aviation fuels	Air transportation contributes 2 to 3% of global CO_2 emissions.	Fuel produced from micro-organisms, electrofuels.	Reduction of the carbon footprint of the aviation sector, improved yield of SAFs (sustainable aviation fuels).

Disruptive innovation	Economic and societal challenges	Promising technologies	Purposes, applications
Low-carbon steel	Steel production represents from 7 to 9% of global CO_2 emissions. Accelerate environmental regulations aimed at decarbonizing highly polluting industrial processes.	Carbon capture, utilization and storage (CCUS), direct reduction of iron (DRI) with decarbonized hydrogen.	Production of low-carbon steel.
Biological plastic recycling	In 2019, over 350 million tonnes of plastic were produced, but only 10% were recycled. Accelerate the transition towards a more virtuous model that avoids using up environmental resources and reduces the environmental footprint. Law on climate and resilience, which prohibits non-recyclable plastic from 1 January 2025.	Marriage between plastics processing and the science of enzymology to develop an enzyme that can decompose polymers and reduce them to their original constituents.	Develop less-polluting procedures for recycling plastic. Endlessly recycle PET plastics (polyethylene terephthalate) without loss of quality.
Nanoelectronics	Strategic technology due to its omnipresence in numerous activity sectors. High dependence on foreign producers, in particular Taiwanese. Combine digital and environmental issues by developing more energy-efficient technologies.	Extreme UV3 technology, 3D integration, FD-SOI.	Increase the density of electronic chips, reduce their energy consumption, go beyond Moore's Law.
Messenger RNA	France has an ambition to become a leader in biotechnology-derived medicinal products. Reduce France's dependence on other countries for the production of biotherapies.	Messenger RNA.	Develop medical applications of mRNA, in particular for treating cancer and genetic and infectious diseases.

Disruptive innovation	Economic and societal challenges	Promising technologies	Purposes, applications
Spintronics	Combine digital and environmental issues. Increase sovereignty by removing technological barriers in little-explored fields.	Marriage of electronics and magnetism (spin).	Increase the performance of magnetic sensors used in numerous activity sectors, optimize MRAM memory, reduce energy consumption.
Quantum computing	Issue of digital transformation of industrial companies and sovereignty, residing in the capacity to protect sensitive information.	Quantum technology.	Improve computing power to resolve optimization problems in numerous domains (autonomous vehicles, probabilistic studies on safety of nuclear power stations, cybersecurity, industrial internet of things, etc.)

Initial identification of the different technological regimes

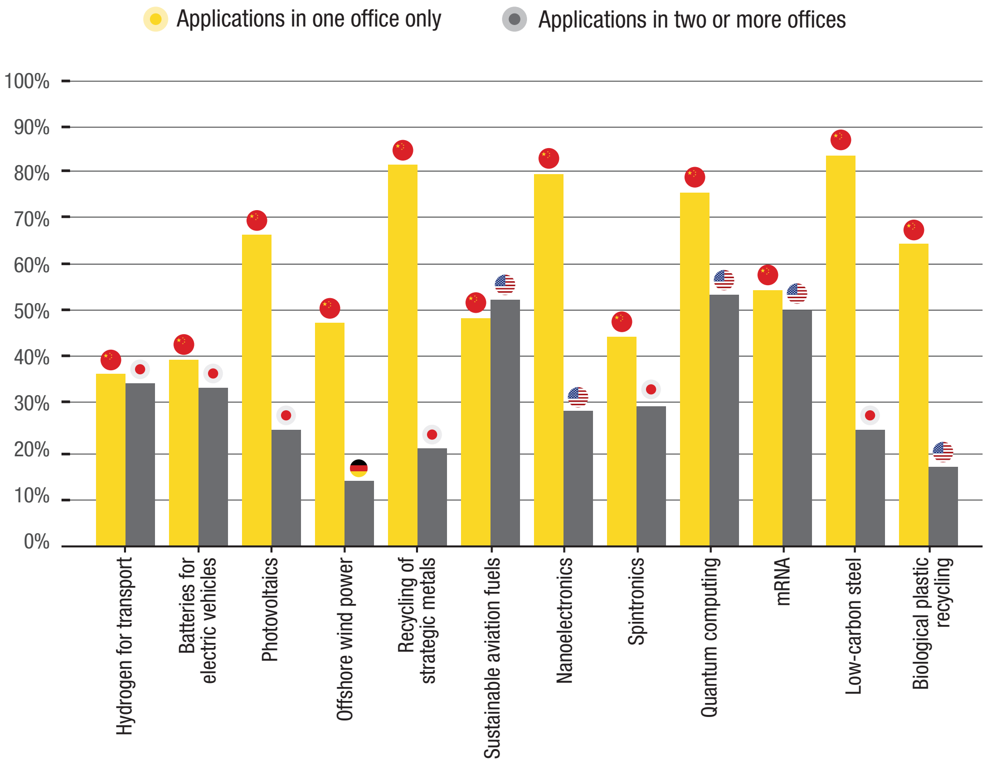
For each of these twelve disruptive innovations, patent bibliometrics were performed by the Observatoire des Sciences et Techniques (*cf.* detailed method in the appendix). In order to fully understand what follows, is important to note that we only include here patent families[13] filed with at least two national or international patent offices. The application of this filter eliminates essentially defensive patents (very abundant in China for example) – which mainly aim to set up a legal barrier to entering the market, even when the innovation has little value – and only considers offensive patents – which effectively set out to prepare the international diffusion of an important technology. This first precaution was adopted to process significant data. In practice, China, which largely dominates the global rankings for patent applications filed in one office only, whatever the technology studied, drops behind OECD countries when this qualitative filter is applied (*cf.* figure 1.2).

The second precaution, which supplements the first one, consists in scrupulously selecting sets of patents that effectively relate to the twelve disruptive innovations chosen for our sample. This selection was carried out by combining filters on patent classes (see appendix) and by applying keywords. This laborious specialized work practically involves constituting sets of pertinent patents "by hand" so as to only effectively include technological patents. This is one of the scientific plus points of this contribution.

The fact remains that the choice of using patent bibliometrics to evaluate the development of a small number of technologies is a methodological bias that involves several hypotheses that should be borne in mind (*cf.* box). Following the initial development of this measurement tool (Narin *et al.*, 1984), patent bibliometrics have been significantly improved and refined, always accompanied by a discussion of their potential and limitations, as summed up by the bibliometric researcher Yoshiko Okubo (1997) in a synthesis report published by the OECD (see box).

13. A patent family is a collection of patent applications covering the same technical content or similar technical content. Within a family, applications are connected by the same priorities. Source: epo.org.

Figure 1.2 – Global share of the leader for each technology, according to number of applications



Source: Patstat. Processing: OST.

Bibliometric Indicators and Analysis of Research Systems (Okubo, 1997)

Uses

"Patent counts can be used to situate an invention and the role of each inventor in the development of new techniques; they are therefore a measure of innovation and technological capacity at the level of nations, industries or firms. Initial work on patent statistics as S&T indicators focused on clearly identified objects, such as molecules. Subsequently, competing technologies were measured, as was the level of inventiveness of countries in competition over a major invention."

Limitations

"The citations chosen by examiners raise questions about the reasons that lead them to cite references that differ from those cited by the applicants themselves. Examiners are not specialists, and they may cite patents more for their legal importance than for their innovative nature. Moreover, the citations proposed by patent applicants are not yet accepted as a truly significant measure of the importance of the patents cited, since the choice may have been motivated by factors other than scientific importance. The limitations of such measures need to be understood, since patents can be written in such a way as to conceal major inventions behind minor advances, in order to mislead the competition. Business enterprises, guided by their legal counsels, exhibit considerable diversity in the way they protect their research work."

In sum, this measurement tool would not have proved pertinent for some technical domains (such as software), but it is an appropriate choice for the twelve technologies in our sample. In addition, note that public research results do not necessarily lead to patent applications. Counting patents is therefore, by construction, a partial, biased tool that gives too much weight to companies in the emergence of innovations. Moreover, it is important to avoid making hasty comparisons between technologies, which each have specific characteristics, both concerning the general development of knowledge and the appropriation of some of it in the form of patents: the differences in patent volumes identified do not exclusively demonstrate their respective importance, or even their potential for transforming technologies; they also show the intrinsic differences in manifesting technical progress in these fields of activity.

Figure 1.3 – Cumulated and average annual growth of patent applications in the world, by technology (2010-2019)

	Cumulated	Average annual growth (%)
Hydrogen for transport	12 874	0.24
Batteries for electric vehicles	22 233	18.03
Photovoltaics	54 734	-6.02
Offshore wind power	1 440	-0.73
Recycling of strategic metals	7 216	0.56
Sustainable aviation fuels	320	-12.67
Nanoelectronics	7 907	2.84
Spintronics	4 970	0.89
Quantum computing	2 989	33.31
mRNA	2 865	9.72
Low-carbon steel	4 668	4.04
Biological plastic recycling	2 293	4.61

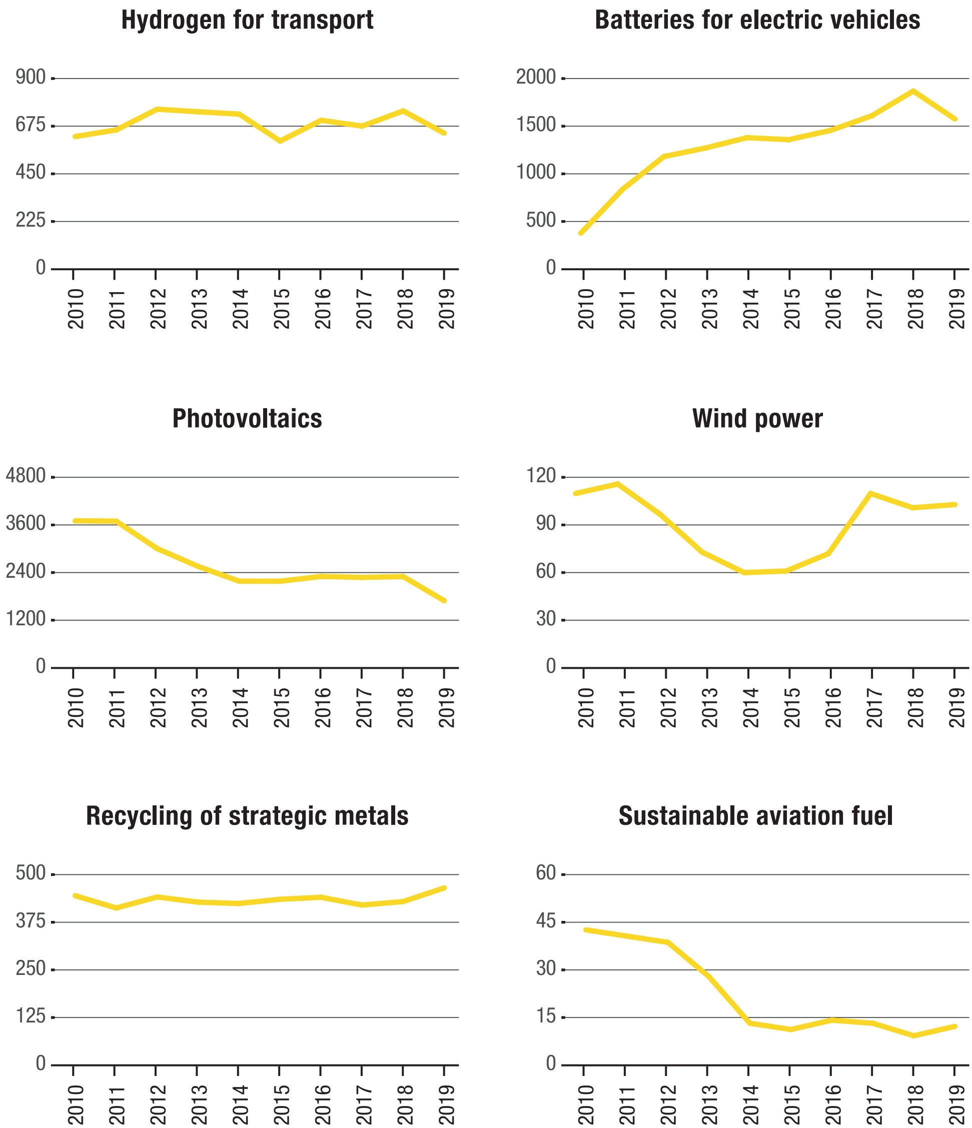
Source: Patstat. Processing: OST.

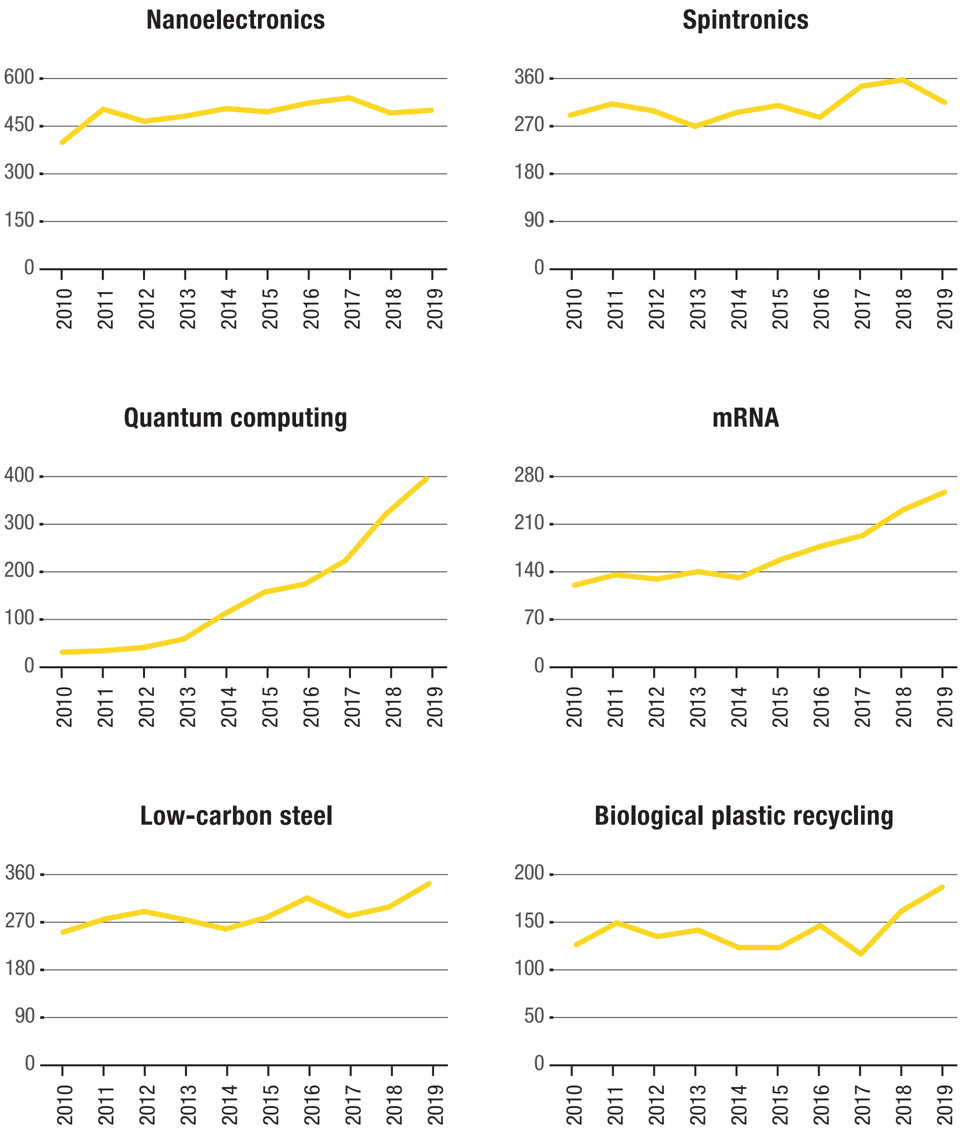
Precisely, and as a very first observation, the measurement of annual flows of patent applications[14] in the world confirms the existence of very different technological regimes. On the one hand, the number of patents filed by economic actors for each technology varies widely, ranging from 23 a year on average for sustainable aviation fuel to over 3,500 a year for solar panels, during the period 2010-2019 (*cf.* figure 1.3).

On the other hand, the kinetics of these application flows are also very variable (*cf.* figure 1.4). Some of these technologies grew considerably during the 2010-2019 decade; some increased more modestly at the limit of stability; others fluctuated more sharply; and others still saw a reduction, or even a near standstill in demand flows.

14. It can take from five to eight years for a patent application filed by an economic actor to be definitively issued by the office in question. To process data that are as recent as possible, bibliometrics usually considers statistics on requests and not patents granted.

Figure 1.4 – Annual demand for patents (2010-2019)





Source: Patstat. Processing: OST.

CHAPTER 2

Asia and the United States Overwhelmingly Dominate Patent Applications

France and other European countries rarely feature in the top rankings

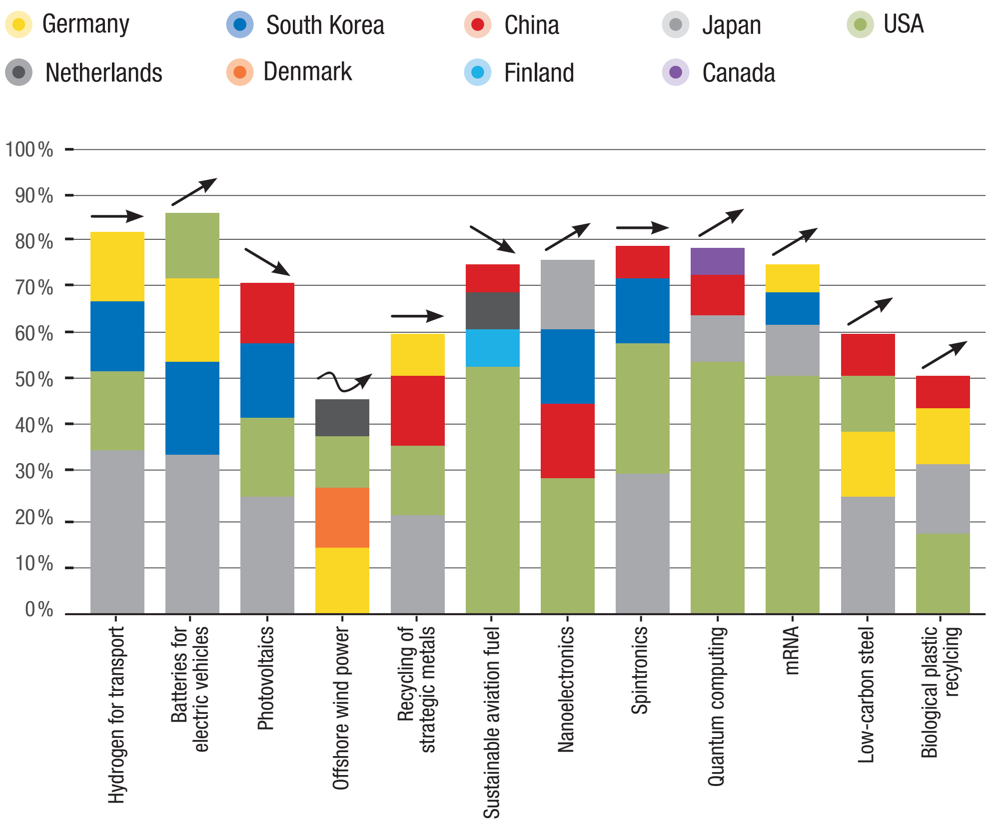
If there is one characteristic common to all of these technologies, it is that patent applications are highly concentrated in a very small number of countries. With the exception of offshore wind power (we shall see below that this sector stands apart from the rest of the sample for numerous reasons), the leading four applicants always hold at least half of the patents filed in the world. In six cases out of twelve, they even hold at least three-quarters (*cf.* figure 2.1).

It is even more striking to observe that the same countries often occupy the same position in the rankings. In three cases, more than half of global patents are held by one US applicant, putting the United States far ahead of all other countries: they are agrofuels for aviation, quantum computing and messenger RNA. In the latter two cases, US domination is all the more striking in that it concerns fast-growing sectors (insofar as the number of patents filed increases significantly from one year to the next).

For four other technologies, at least half of the global patents filed in the decade studied are held by applicants located in Asia, namely Japan, Korea and China (these three countries are in any case omnipresent in 11 of the 12 top rankings). These technologies are hydrogen for transport, batteries for electric vehicles, photovoltaics and spintronics. With a difference of only one percentage point, nanoelectronics could also be included.

While the United States, Japan, Korea and China are systematically among the four most represented countries for each of the twelve disruptive technologies, the same is not true for European countries, which are only among the top four in eight cases out

Figure 2.1 – Cumulated global shares of the leading four applicant countries, by technology (2010-2020*)



Source: Patstat. Processing: OST. The red arrows indicate the overall direction of the patent sets studied: increasing strongly, increasing moderately, stable, erratic or decreasing. Note (*): The year 2020 is incomplete.

of twelve, and for six of them, Germany represents Europe. Only in the domains of offshore wind power and sustainable aviation fuel, which are the "smallest" domains in our sample in terms of numbers of patent applications, do three other European countries feature among the top four applicants: Denmark, Finland, and the Netherlands.

France is totally absent from the table.

A complementary perspective through specialization indices

Clearly, not all countries can feature among the patent applicant global leaders for the simple reason that they are not all the same size and do not therefore have the same economic and human capacity to produce new knowledge. As a result, the quantitative approach described above is generally supplemented by a look through the lens of specialization.

The specialization Indiax (*cf.* figure 2.2) is the relationship between a country's global share in a given technology and its global share in all domains taken together. This ratio is the same, by arithmetic construction, as that of the national share of the technology considered in the global share of that same technology. For example, if we consider the first item at the top left of the table below, the global share of patents filed by South Korea is 1.7 times larger in the "hydrogen for transport" activity than it is in general, taking all domains together. This technology is also 1.7 times more present in all of the patents filed by South Korea than it is in the world.

This table is instructive in several ways. Firstly, it reveals the "small" countries that cannot play a leading position in a large number of domains but that may have strong specializations in some of them. This is the case of several European countries for offshore wind power, Chile for recycling of strategic metals, and Taiwan for nanoelectronics and spintronics.

The second interesting point is that several of the large leading countries identified previously also feature in this table of more specialized countries. For example, Korea and Japan confirm their dominating position in the sectors of hydrogen for transport, batteries for electric vehicles, and photovoltaics. This is also the case for the United States in the nanoelectronics and quantum computing sectors.

Is France trailing behind?

The third interesting point shown by the above table is that, apart from one exception (fourth place in the hydrogen for transport domain), France still does not feature among the most active countries in all or part of these technologies.

Figure 2.2 – Table of the four most specialized countries, by technology (2010-2020*)

	Rank 1		Rank 2		Rank 3		Rank 4	
Hydrogen for transport	Korea	1.7	Germany	1.5	Japan	1.5	France	1.1
Batteries for electric vehicles	Korea	2.3	Germany	1.8	Japan	1.5	Germany	1.0
Photovoltaics	Korea	1.8	Taiwan	1.2	Japan	1.1	Italy	1.0
Offshore wind power	Denmark	38.0	Norway	24.8	Spain	12.2	Netherlands	7.3
Recycling of strategic metals	Chile	8.0	Finland	6.4	Australia	5.5	Belgium	3.8
Sustainable fuel (aviation)	Finland	10.5	Netherlands	4.1	USA	2.2	Canada	2.1
Nanoelectronics	Taiwan	3.4	Korea	1.8	China	1.2	Korea	1.2
Spintronics	Belgium	1.7	Taiwan	1.7	Korea	1.6	Japan	1.3
Quantum computing	Canada	4.7	Australia	2.4	UK	2.2	Korea	2.2
Messenger RNA	Switzerland	2.6	USA	1.9	Netherlands	1.1	Canada	0.9
Low-carbon steel	Austria	5.6	Australia	3.1	Finland	2.4	Italy	1.8
Biological plastic recycling	Austria	7.8	Belgium	4.8	Netherlands	3.6	Italy	3.5

Source: Patstat. Processing: OST. Note (*): The year 2020 is incomplete.
Note for the reader: the global share of patents filed by France is 1.1 times larger in the hydrogen for transport domain than its global share, taking all domains together. This means that it is the fourth most specialized country in this domain.

A country that, like France, does not show a high specialization Indiax in any domain is a country whose research effort is very versatile, insofar as it corresponds to the global average in the thematic division of its production. This is not in itself a weakness. Another way of putting it is that, due to the way the indicators are constructed, any country that has strong points necessarily balances them out with weak points, since all countries by definition have an average specialization Indiax, taking all domains together, equal to one.

That said, it is however striking that, in a sample of twelve technologies intentionally identified as disruptive, two-thirds of which are related to the energy transition to tackle climate change, France never stands out as a leading or specialized country.

The following table shows the global rank and specialization Indiax of France in each of these twelve technologies (*cf.* figure 2.3). The country's global ranking ranges from fifth to eighth place.

Figure 2.3 – Global ranking and specialization Index of France, by technology (2010-2019)

	Global rank	Specialization Index
Hydrogen for transport	5	1.14
Batteries for electric vehicles	6	0.59
Photovoltaics	7	0.95
Offshore wind power	6	2.60
Recycling of strategic metals	6	1.34
Sustainable fuel (aviation)	6	1.31
Nanoelectronics	6	0.79
Spintronics	7	1.10
Quantum computing	8	0.94
Messenger RNZ	7	0.71
Low-carbon steel	8	0.69
Biological plastic recycling	5	2.14

Source: Patstat. Processing: OST.

For the sake of comparison, note that, taking all domains together, and without applying the qualitative filter of an application made in at least two countries, France comes eighth in the world for patent applications filed with the US Patent Office, according to National Science Foundation indicators (Robbins, 2022) and, according to INPI, ranks fifth for applications filed with the European Patent Office[15]. This geographic affinity with the nearest office is a phenomenon well documented by statisticians. Yet all things considered, it is nevertheless difficult to be as enthusiastic as this INPI press release at the idea that France is "the second-ranking European applicant and the fifth in the world". Put in a global context, the position of France in the world and that of Europe in general tend rather to indicate that they are trailing behind[16].

Another criterion for comparison points in the same direction. In 2022, France was Indiaed the seventh global economy in terms of GDP[17]. The United Kingdom and India, which come higher in this ranking, are just as absent as France from the above-mentioned list of patent application leaders. In contrast, Korea, undoubtedly one of the leaders of this sample of twelve disruptive technologies, only comes twelfth in the world in terms of GDP, with an economy 13 times smaller than that of the USA, and 1.6 times smaller than that of France (*cf.* figure 2.4).

France therefore appears, along with two other nations, as a country comparatively on the side lines of global technological competition, whereas Korea on the other hand comes across as strongly determined.

Of course, one of the explanations of this paradox is the more or less deindustrialized character of the different countries, but it does not fully explain this different level of involvement. While France Indiaed possesses the eighth global industry measured in value added, Korean industry, which comes in fifth, is much closer in terms of volume to Indian industry than to German industry, which is practically twice as big. Its place among the global patent applicants is therefore remarkable. More generally, all things being equal elsewhere, these various states are clearly involved at different levels when it comes to developing new technologies.

15. https://www.inpi.fr/barometre-oeb-2022-france-deuxieme-pays-innovant-europe
16. All of the data utilized and presented in this publication come from Patstat, a database produced by the European Patent Office (EPO), which contains exhaustive data on patents filed with the main national offices and the two large regional offices, the European Patent Office and the World Intellectual Property Organization (WIPO).
17. Source: World Bank (indicators).

Figure 2.4 – GDP and manufacturing value added of the main countries (2019)

	GDP (billions of current US$)	Rank	Manufacturing value added (billions of current US$)	Rank
USA	21 381	1	2 364	2
China	14 280	2	3 823	1
Japan	5 118	3	1 035	3
Germany	3 888	4	760	4
UK	2 857	5	249	9
India	2 836	6	382	6
France	2 729	7	273	8
Italy	2 011	8	299	7
Brazil	1 873	9	194	13
Canada	1 744	10	162	16
Russian Federation	1 693	11	220	11
South Korea	1 651	12	417	5
Spain	1 394	13	152	17
Australia	1 392	14	78	31

Source: World Bank. Processing: La Fabrique de l'industrie.

Stronger together?

Faced with two superpowers like the United States and China, it seems logical to rather compare the European Union as a single block. Considered separately, the European countries cannot compete with their Chinese and American opponents, which partly draw from their vast domestic markets.

It is interesting to observe that the European Union systematically figures among the four leading global applicants (*cf.* figure 2.5). It even ranks first in four domains: offshore wind power, recycling of strategic metals, low-carbon steel, and biological recycling of plastics. In the offshore wind domain, the European Union holds almost two-thirds of patents. Its leadership is nevertheless less marked elsewhere, since it never possesses more than half of patents.

In contrast, the United States clearly dominates the EU in the domains of quantum computing and messenger RNA, concentrating more than half of patents. Similarly, Japan remains the leader in the domains of hydrogen for transport and batteries for electric vehicles. The European Union comes in second here, ahead of the United States and Korea.

What are the lessons to be drawn from these results?

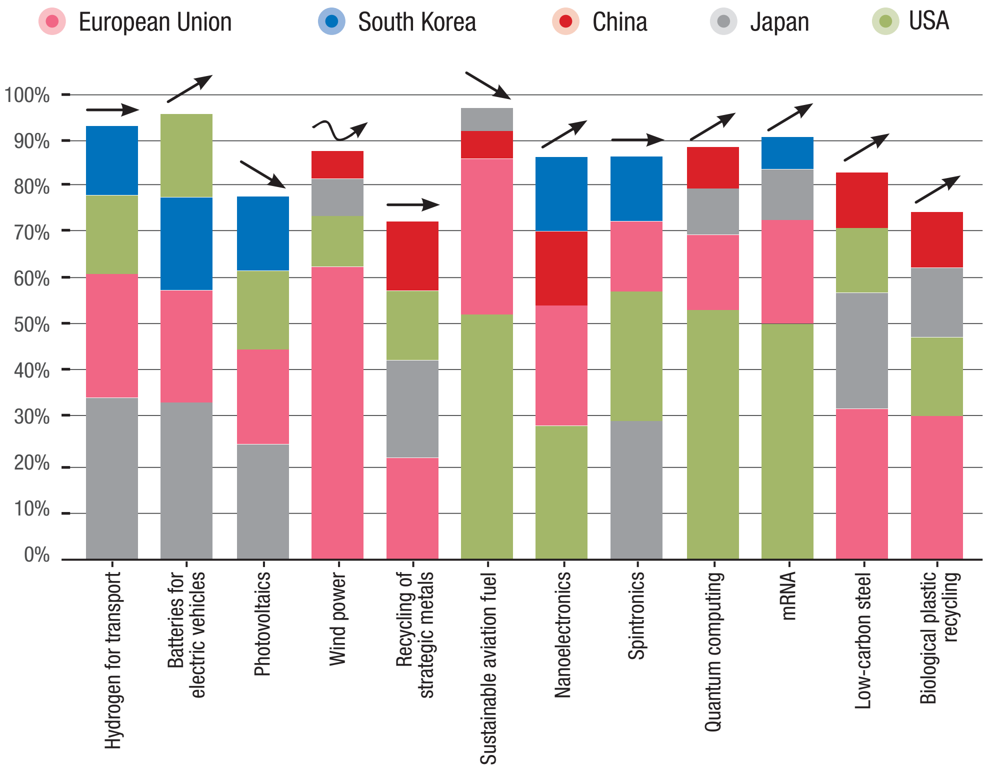
Firstly, Europe taken as a whole appears to be a serious competitor in the face of the major powers of the United States and China. Except for spintronics, its global ranking ranges from first to second place for patent applications. The European Union therefore undoubtedly has a part to play in the emergence of disruptive innovations, especially those related to combating climate change.

That said, when comparing these results with the disaggregated table shown in figure 2.1, we must express several reservations. Firstly, a handful of European countries, led by Germany, already figured among the leaders for eight technologies out of twelve. In other words, the leadership of the European Union can essentially be explained by Germany's top place and more marginally by the performances of other European countries like Denmark, Finland and the Netherlands. In contrast, France plays no significant role in this area, bringing a painful remIndiar of its unfavourable position in both global and European technological competitions. Moreover, apart from offshore wind power, the European Union dominates no technological domain sufficiently to easily maintain its advantage in the years to come. However, the United States clearly dominates the fast-growing domains of quantum computing and messenger RNA.

Next, a comparison between all European countries on the one side with "isolated" countries like Japan and Korea on the other seems imbalanced. Put differently, aggregating the scores of European countries into a single score only reinforces, by comparison, the impression that Japan and Korea are determined to be part of the technological race.

Lastly, it is difficult to celebrate European leadership insofar as the European Union remains undermined by internal dissensions that prevent it from establishing a true industrial policy coordinated between states. If individual countries prefer to defend their own interests rather than put together a common strategy, then the technological performances of the European Union as a whole resemble a mirage more than a reality.

Figure 2.5 – Cumulated global shares of the leading four applicants (European Union included) by technology (2010-2020*)



(*) The year 2020 is incomplete.
Source: Patstat. Processing: OST.

Individual technologies divided between the public and private sectors

Companies prevail among patent applicants

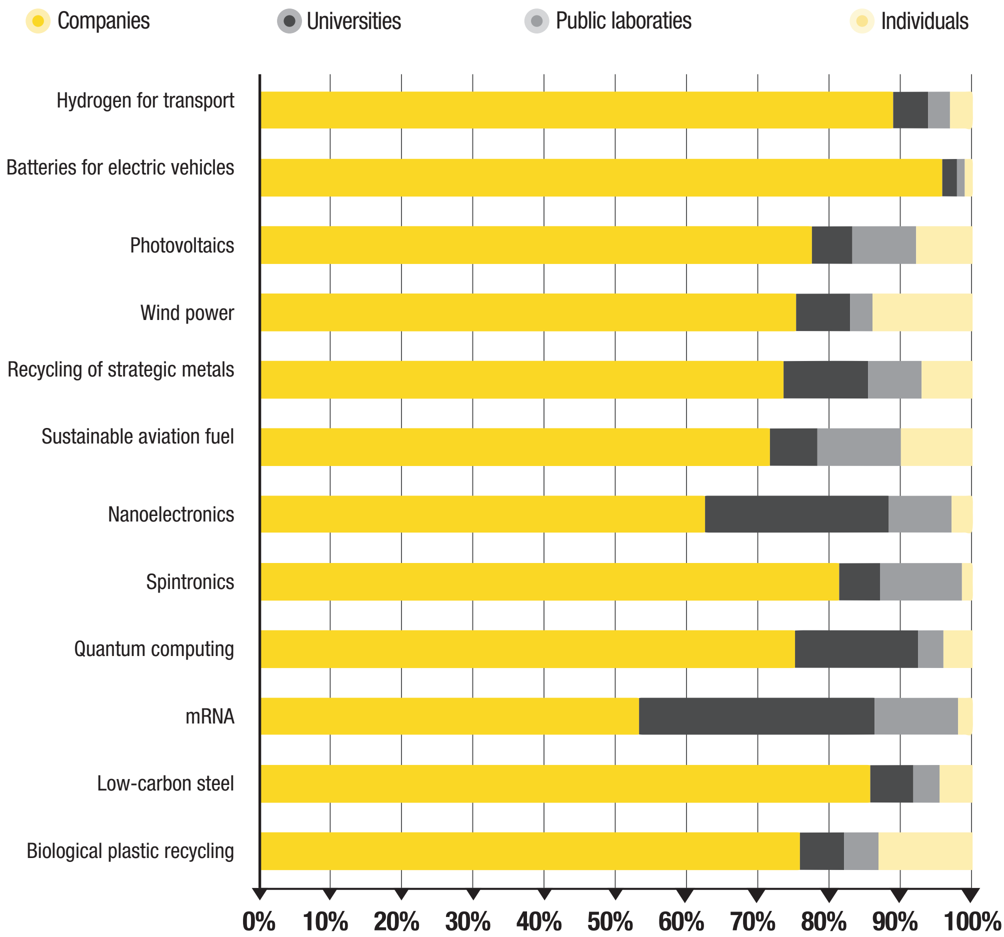
After examining the geographic origin of patents in the previous parts, here we study the respective contributions of public and private actors. On the whole (*cf.* figure 2.6), at first glance, patents from companies appear to largely dominate.

Two exceptions however exist: for nanoelectronics and mRNA, the share of patents filed by universities and public research bodies is much higher than for the ten other technologies. This observation raises an important question regarding the origins of these disruptive innovations and the respective roles of public research and companies in this area. Is it primarily a question of technology (hypothesis 1: depending on the domain, it sometimes requires more academic knowledge to produce a disruptive innovation, in particular in the health field), a question of kinetics (hypothesis 2: the "younger" a technology is, the more essential the role played by public research in its emergence), or rather a question of comparative advantage (hypothesis 3: the innovative power of universities in a particular country gives them an automatic advantage in the technologies they invest in)?

The four graphs above provide a first set of answers to these questions. First, figure 2.7.a dispels the idea of a possible correlation with the progression pattern of global patent applications: the proportion of companies among applicants can be very high, or on the contrary, relatively low for fast-expanding (considered as "young") innovations. Conversely, the proportion of companies varies very little, whether the innovations follow an increasing, decreasing, stable or even erratic trend. Figure 2.7.b confirms this observation, showing the evolution of the proportion of companies year on year, for the seven cases of technologies for which information is available: some feature a perfectly stable share of companies (e.g. batteries), others see this share grow suddenly at a precise moment (mRNA), while for others still it tends to decrease. We can therefore conclude that it is not the age of a technology that seems to determine, in the first instance, the division of roles between public and private applicants.

On the other hand, figure 2.7.c suggests that the share of companies is generally higher for innovations characterized by a domination of Asian countries (China, Japan, Korea) and that it is on the contrary close to 50% for innovations marked by US leadership. We might therefore expect the partial influence of comparative advantages. Figure 2.7.d confirms this hypothesis, showing to what point countries can be marked by preponderances of different degrees of one or other

Figure 2.6 – Institutional breakdown of applicants, for each technology (2010-2019)



Source: Patstat. Processing: OST. Here we use the categorization of owners recorded in the Patstat database. However, it should be noted that the data only document the last patent applicant, which creates three types of limitation. Firstly, former holders may have disappeared from the database. Secondly, new holders do not always register the transfer of the patent to their name because this registration is not obligatory (they generally do so in the case of litigation for counter-feiting or oppositions, because they have a very direct interest in claiming the ownership of intellectual property rights). Thirdly, mergers and acquisitions of companies are not taken into account by the database, nor are financial connections between companies, which need to be included "by hand".

Figure 2.7.a – Proportion of companies among applicants and type of progression (2010-2019)

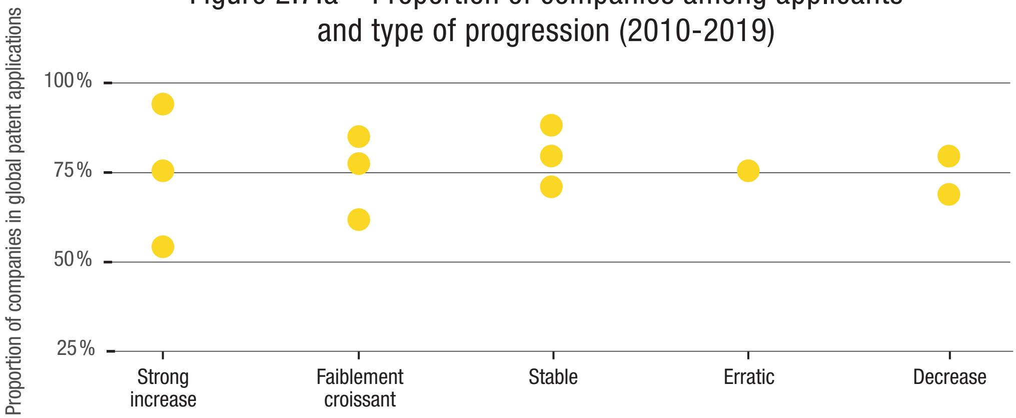


Figure 2.7.b – Evolution of proportion of companies among applicants (2010-2019)

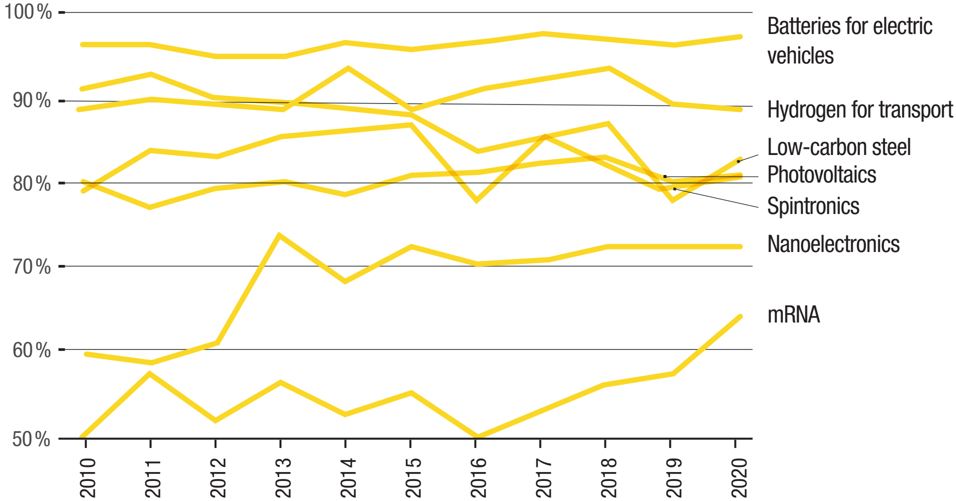


Figure 2.7.c – Proportion of companies among applicants and geographic distribution (2010-2019)

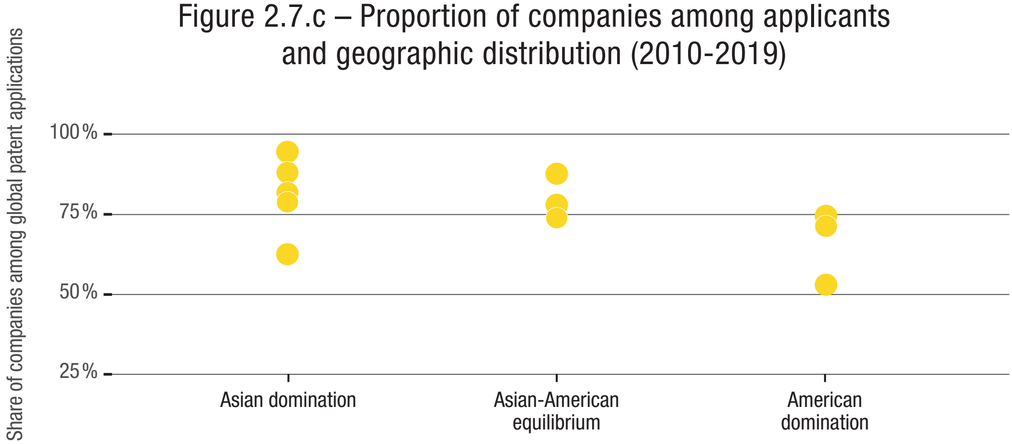
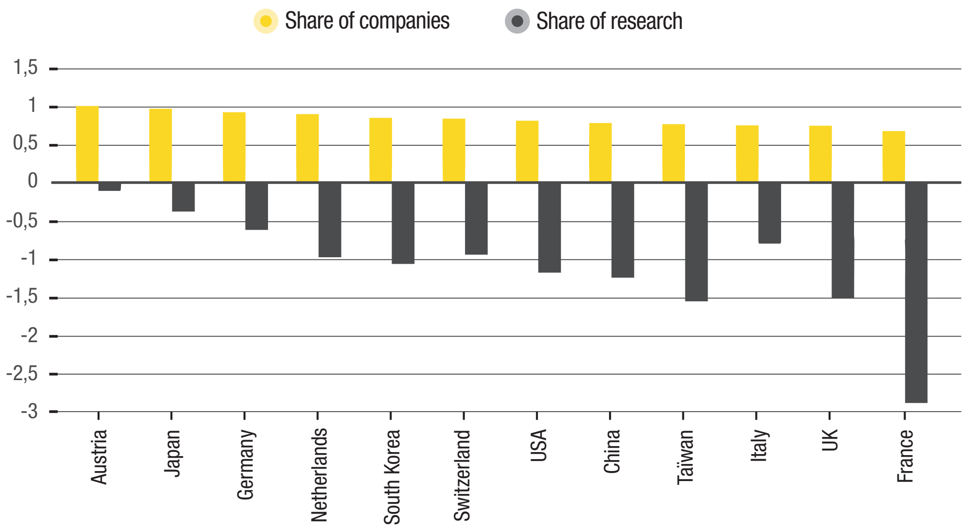


Figure 2.7.d – Preponderance of countries and public research for twelve countries (2010-2019)



Source: Patstat. Processing: OST and La Fabrique de l'industrie.

Note for the reader regarding graph d: here we call 'preponderance' the share respectively represented by companies and public research (indicated by negative indices) among the patent applicants of the country considered, compared to the average observed for the twelve main patent-holding countries, for a set of seven technologies (hydrogen applied to transport, batteries for electric vehicles, photovoltaics, nanoelectronics, spintronics, mRNA and low-carbon steel). For example, for this set of seven technologies, the share of companies among the Austrian applicants is 1.1 times bigger than the share of companies identified on average out of these twelve countries. Another example: the share of public research among French applicants is 2.9 times higher than on average for these twelve countries.

category of applicants. In Japan and Germany, for example, public applicants account for a relatively small proportion when taking the countries studied as a whole, but are comparatively more represented among US and Chinese applicants and, even more so, French applicants.

Kinetics therefore exist within each set and we need to look at these more closely to understand what is at play.

Batteries

As seen above, the domain of batteries for electric vehicles is one of the fast-growing technologies, with four leading countries (Japan, Korea, Germany and the United States) at the origin of almost 90% of patent applications filed in the decade studied. Figure 2.7.b also shows that the almost-exclusive domination of companies is confirmed, since they are at the origin of over 95% of patent applications.

Graph 2.8.a shows that public research, taking all countries together, only plays a minor role in this domain. Most of the technological battle is played out between Japanese companies (clearly dominant at the start but apparently having reached a glass ceiling and then possibly losing steam at the end of the period), German companies (late starters but with the strongest progression rate in the sample and the potential to take the lead fast), Korean companies (neck and neck with German companies), and US companies (also progressing fast, but not fast enough to out do the others, and perhaps soon to be overtaken by Chinese companies). The "other" category, which seems to have had a late kick-off in 2016, almost exclusively comprises European companies (French, British and Austrian).

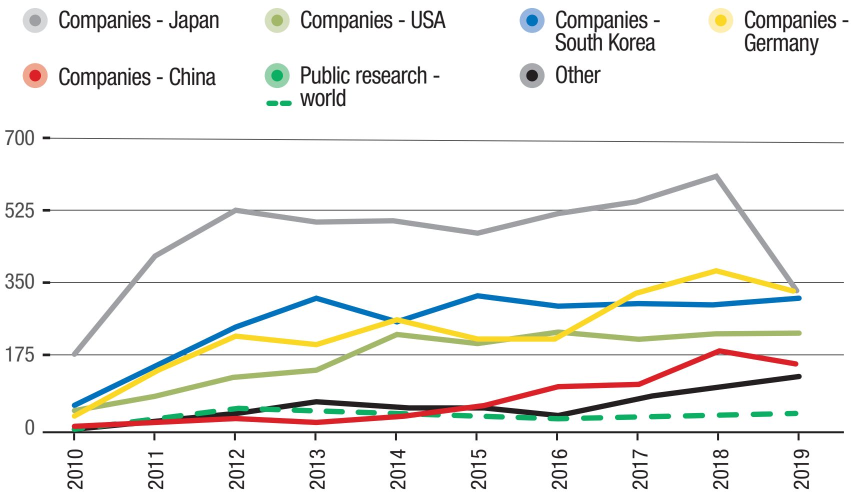
Low-carbon steel

The development of low-carbon steel is the object of a moderately increasing flow of patents, led by Japan, Germany, the United States and China. The share of companies appears to be on a downward trend, confirmed and explained by graph 2.8.b.

In fact, Japanese companies, which file between 60 and 85 patents a year, fairly clearly dominate this technology. Their German competitors were almost at the same level in 2010, but have followed a decreasing trend, and have since been caught up by the Americans and Koreans, which started at a lower level but have proved more dynamic over time.

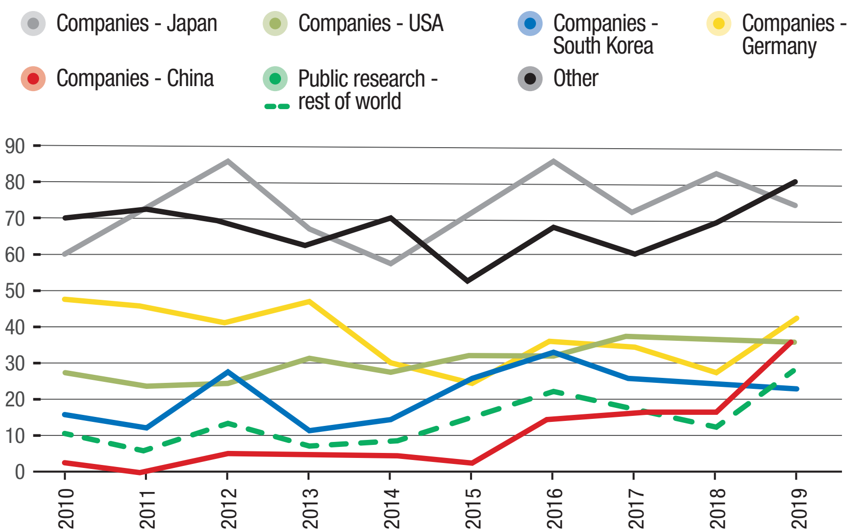
A doubly exceptional fact: not only has public research significantly increased its innovation efforts since 2014, but this effort is almost equally split between Chinese laboratories and those in the rest of the world, following very similar trends. Does this indicate that a new generation of technologies is about to emerge, led by the Chinese?

Figure 2.8.a – Batteries for electric vehicles – Patent applications (2010-2019)



Source: Patstat. Processing: OST.

Figure 2.8.b – Low-carbon steel – Patent applications (2010-2019)

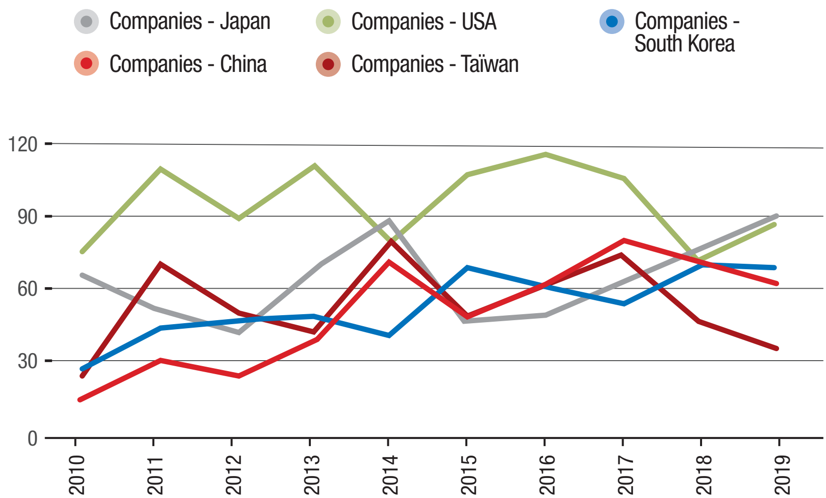


Source: Patstat. Processing: OST.

Nanoelectronics

Nanoelectronics is a domain that features moderate growth of patent applications, dominated by four countries: the United States, China, Korea and Japan. It is also one of the rare sectors where public research represents a high share of the patents filed. Concerning companies, which make up the majority, graph 2.8.c. shows that US companies have a stable hold on first place. Their leadership is however increasingly contested by their Japanese, Korean and Chinese opponents, which are on an upward trend. Taiwanese companies were also on a similar trend before dropping down at the end of the period.

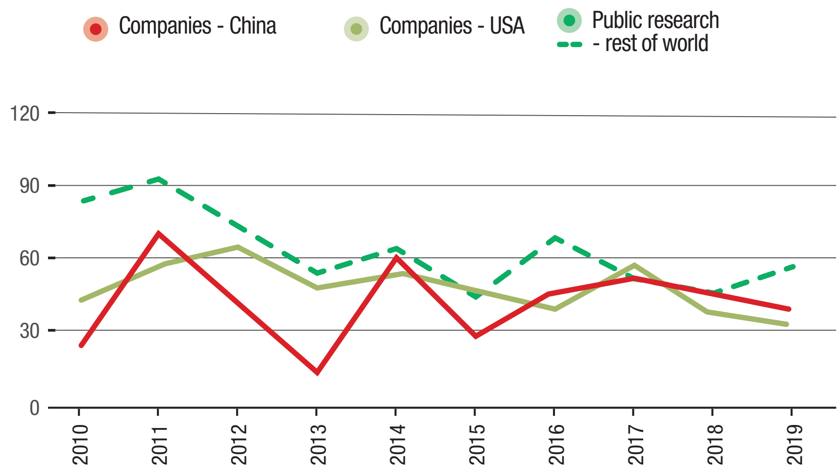
Figure 2.8.c – Nanoelectronics – Patent applications by companies (2010-2019)



Source: Patstat. Processing: OST.

In terms of public research (*cf.* graph 2.8.d), China, the United States and the rest of the world currently share patent applications in three equal parts, following a decade marked by the rise of Chinese research and a decrease for the two others. Overall, the flow of patents resulting from public research has almost halved in ten years, from nearly 200 patents a year to about 100. The share of public research in the total flow has therefore shrunk from more than one-third at the start of the period to one-quarter today.

Figure 2.8.d – Nanoelectronics – Patent applications by public laboratories (2010-2019)



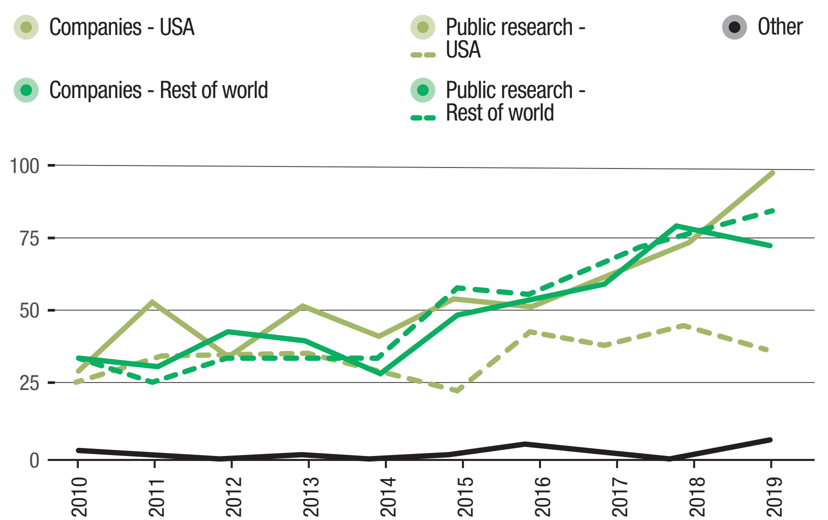
Source: Patstat. Processing: OST.

Messenger RNA

Messenger RNA technology stands apart from the rest of the sample for several reasons. Firstly, the global volume of patents follows a very strong rising trend, which has not yet slowed down. Secondly, US domination is particularly marked here. Thirdly, public research occupies a bigger place than for all other technologies in the sample.

Graph 2.8.e shows how these specific features come together. In fact, US public research is subject to a strong patent application activity that grew slightly over the decade. At the start of the period it represented half of global research patents but, following the "waking-up" of other laboratories around the world (mainly in Asia and France), it lost some of its foothold and decreased its share to only one-third. This slackening is likely to continue for several years, judging by the speed of the curves. Companies have followed the same very strong trend: initially US firms, then firms from the rest of the world, which pursue a similar upward trend but have not managed to close the gap. Lastly, public research, which was responsible for half of patents in 2010, only represented

Figure 2.8.e – Messenger RNA – Patent applications (2010-2019)



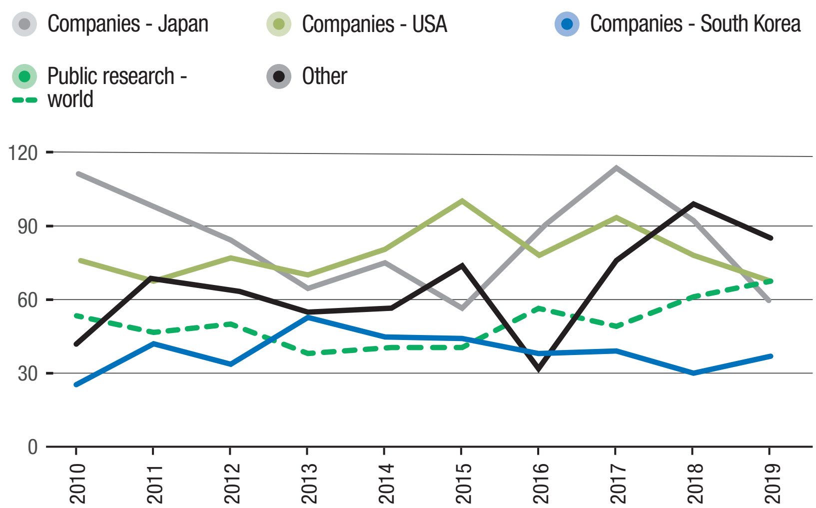
Source: Patstat. Processing: OST.

one-third in 2019; in addition, thanks to a public-private relay, the United States are still at the origin of 50%, even 60%, of patents each year.

Spintronics

The spintronics domain is has seen a slight rising trend in patent applications, almost reaching stability, led by the Japanese and Americans. Graph 2.8.f confirms that US and Japanese companies alternately take first and second place on the podium. Global public research, whatever its origin, initially played a secondary role but increased in proportion over the decade, which is relatively rare at the end of a period. Korean companies started off the decade with a very proactive approach, but then followed a downward trend from 2013.

Figure 2.8.f – Spintronics – Patent applications (2010-2019)

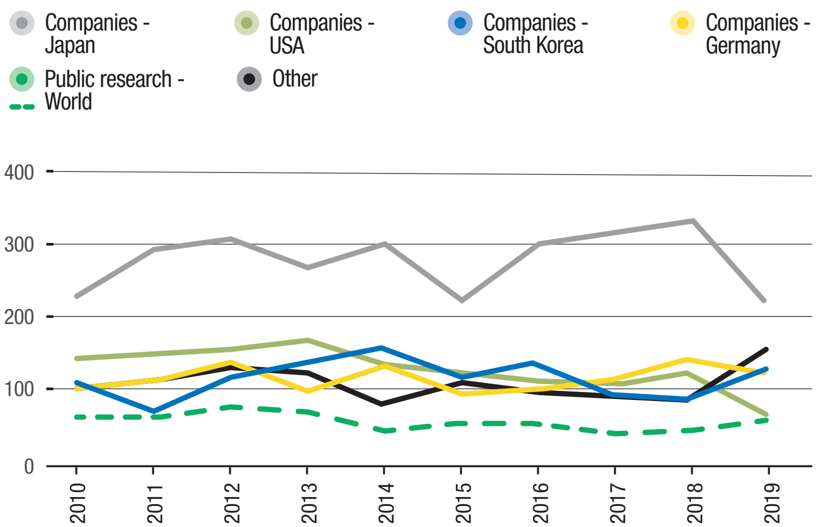


Source: Patstat. Processing: OST.

Hydrogen

As mentioned in the previous paragraph, technologies involving hydrogen for transport are characterized by very stable patent applications over time, in an established oligopolistic situation (Japan, USA, Korea and Germany are at the origin of 83% of global flows over the decade) and a very stable share for companies, at about 90% of global applicants. Graph 2.8.g confirms this stability: public research, all over the world, occupies the same modest position throughout the decade, with Korean, German and US companies respectively making between 100 and 150 patent applications per year (although with a downward trend in US applications) and Japanese companies clearly leading the race, with between 250 and 300 patent applications a year.

Figure 2.8.g – Hydrogen applied to transport – Patent applications (2010-2019)



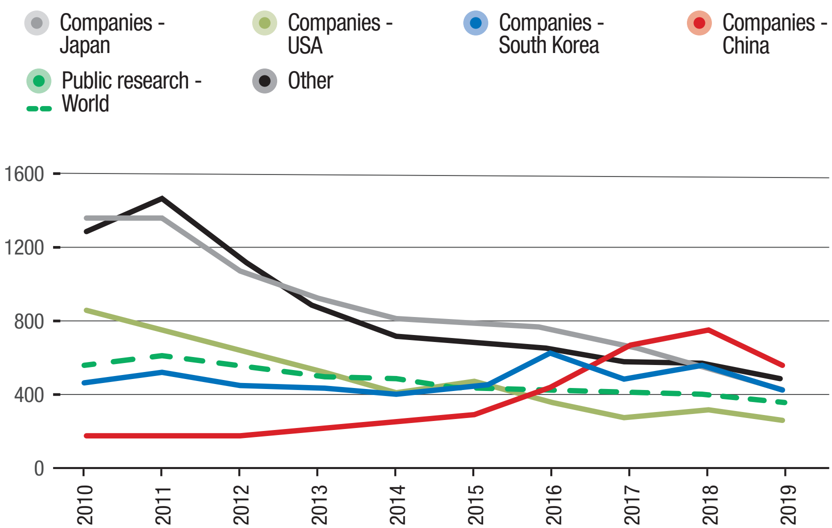
Source: Patstat. Processing: OST.

Photovoltaics

We have already seen that photovoltaics is a domain marked by a significant decline in annual patent applications, with a stable representation of around 80% companies. Graph 2.8.h confirms that Japanese and US companies, the former leaders, have drastically reduced their invention activity, similar to companies in other countries in the world involved in this domain (Germany, Taiwan, France, the United Kingdom, Switzerland and Italy) and public research laboratories.

Apart from the specific case of Korean companies, which maintain a stable activity, it seems that Western firms view the race to dominate this technology as a thing of the past. Only Chinese companies continued to increase their activity throughout the decade, rising to become the global leaders. The decline recorded in China in 2019 (partly due to the Covid-19 crisis) will need to be verified in a few years' time to ascertain whether Chinese companies also consider that this technological disruption episode is now over.

Figure 2.8.h – Photovoltaics – Patent applications (2010-2019)



Source: Patstat. Processing: OST.

Note: searches using keywords like "Perovskite" confirm that invention activity continues to focus on new-generation solar panels, but that related patent applications, although increasing, remain relatively few.

Consolidated proposal

In summary, patent applications concerning the disruptive innovations in our sample are made by companies in the immense majority of cases. Most technologies are characterized by a very stable share of patents filed by companies every year, whether the total volume of patents is increasing, stable, or decreasing. In other words, companies never collectively drop behind public research: when companies make fewer patent applications, such as for photovoltaics, public research does likewise.

> "In cases where the laboratories and universities in a country are so far ahead of their competitors that they are almost at the same levelas companies, they are either American or Chinese."

Nevertheless, public research can at times be pioneering – opening the way and then losing ground to companies that take over (nanoelectronics and mRNA) – or regain momentum just as companies seem to have established a steady rhythm of patent applications (spintronics and low-carbon steel).

Moreover, our sample features no cases in which Korean or Japanese public research takes on a form of leadership. In cases where the laboratories and universities in a country are so far ahead of their competitors that they are almost at the same level as companies, they are either American (nanoelectronics and mRNA) or Chinese (low-carbon steel and nanoelectronics). Conversely, the leadership of Korea and Japan, and more rarely Germany, exclusively involves the inventions of companies.

POINT OF VIEW

A researcher at the Centre for Science, Technology & Innovation Policy at the University of Cambridge, Martin Ho, studies the emergence of technologies over the long term. As such, he regularly contributes to national technology foresight exercises in the United Kingdom.

The study of technological trajectories

An important debate is currently taking place within industrialized countries over whether they should give more weight to "mission-oriented" policies, that is, policies that pursue government-decided objectives and focus on a small number of radical technologies – as opposed to "diffusion-oriented" policies, which finance research infrastructures and programmes initiated by researchers. The American DARPA has thus been widely hailed as the archetype of an agency capable of initiating new technological trajectories. However, before replicating this model in the United Kingdom, certain parliamentarians have requested that proof of its effectiveness be made. This is the question that my work attempts to answer.

My work consists in representing the deterministic sequence leading to the emergence of a given technology, from fundamental research to commercialization. In particular, I applied this method to eight vaccines, including two mRNA vaccines developed against COVID-19.

In practice, I work on multilayer citation networks, linking together academic publications, patents, clinical trials, and regulatory approvals, corresponding respectively to the various stages of innovation: research, development, production and commercialization. The longest path within a citation network is comparable to the critical path in operations research; I consider it to be the best representation of a technological trajectory, punctuated by events which constitute the "bottlenecks" of technical progress (in this case with a view to the development of a vaccine).

The networks contributing to a given innovation are extremely vast

For each of the eight vaccines – therefore the eight citation networks – that I study, a node represents a single innovation event (for example an applied research) and an arrow represents the diffusion of knowledge between two events. The median size of these eight networks corresponds to 62,793 nodes and 357,320 arrows. In the case of the Moderna Spikevax vaccine, it took 112,858 innovation events and 786,561 knowledge dissemination movements to succeed.

Naturally, this size of citation network depends directly on the method and depth of sampling. I use approval from the European and American drug agencies (EMA and FDA) as starting points, then search for clinical trials cited by these agencies, then search for articles cited by vaccine patents, etc. Your note takes a different approach, namely sampling by keywords and patent classification codes (CPC), for each of the twelve disruptive innovations. This naturally results in samples of very different sizes.

In the networks I study, I can additionally observe the funders associated with each node. Within the "Biontech/Pfizer Comirnaty" network, 49 countries appear. Entities based in the United States funds 67% of events related to this vaccine, the United Kingdom 10%, Canada 2.8%, Belgium 2.7%, Japan 2.5%, China 2.1%, Germany 1.6%, and France 1.4%. Similar results are obtained for the "Moderna Spikevax" network: 48 countries, including the United States (73%), the United Kingdom (5.6%), Japan (3.3%), Belgium (2.7%) and France (1.9%). The order of appearance of the countries generally agrees with your results, but I observe a greater bias than you towards the United States and the United Kingdom, because I consider academic publications and clinical trials and not just patents (note: I am talking here about the nationality of the funders, while you identify that of the performers of R&D work).

I note that companies only funded 4.6% and 2.7% of Comirnaty and Spikevax network events, respectively. Academic publications in fact represent the largest share of nodes within each innovation network.

I wish to add that, most often, the future applications of early innovations are unknown ex ante. In other words, most contributions to innovation are unintentional, motivated by other objectives than those which will justify them a posteriori, or by pure curiosity. Intentional interventions, particularly those by "mission-oriented" agencies, are significantly rarer.

Finally, the temporal spread of an innovation network depends on the number of iterations used in the sampling. If I take the longest chain of citations as a criterion, I observe that it took around 60 years between the first bottleneck (discovery of mRNA) and the last (first emergency authorization), in other words to bring the vaccine from basic science level to market entry. The growth of the network, more precisely of the number of events thus interrelated, follows a characteristic S-shaped curve: 20 years of initiation or pre-rupture, followed by 30 years of vigorous growth then 10 years of saturation.

What weight and what role for each institution?

Many people have been trying for a long time, but in vain, to attribute the emergence of a given innovation to political decision. It is difficult to describe the contribution of an agency or laboratory other than in an anecdotal and qualitative manner, whether during evaluation committees or more generally in case studies. On a quantitative level, the tools remain quite classic: large, "diffusion-oriented", organizations will tend to count measures of popularity or volume (citations of publications, number of patents, etc.), while "mission-oriented" agencies like DARPA rather measure financial leverage or the number of start-ups resulting from their programs.

For my part, I try to appreciate the "criticality" of each contribution. Basically, it is its distance from the critical path, that is, from the longest citation network. The closer an event is to the critical path, the more likely it is to be an innovation bottleneck. This is how I highlight a difference, among donors, between the most generous and the most decisive. For example, for the Shingrix vaccine developed by GSK, the National Institutes for Health (NIH) dominates as the largest contributor, but it is DARPA, the Swedish Research Council and GSK that have funded the most critical innovations.

These networks generally follow a linear pattern, progressing from publications to patents, clinical trials, and finally regulatory approvals. Opposite movements are rarer but not negligible for example from patents to new publications. More precisely, 18% of the arrows go from upstream to downstream, while 7.5% do the opposite. The rest of the links, which are therefore the majority, are internal to each phase of the process.

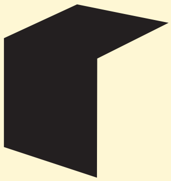
It is generally accepted that "diffusion-oriented" agencies indiscriminately support early-stage basic research, while "mission-oriented" entities (DARPA, BARDA and NCATS) bridge the gap between upstream and downstream innovation. In the case of the Novavax vaccine, the median NIH activity is 12 years ahead of FDA authorization, while "mission-oriented" agencies are between 2 and 8 years ahead. The data is less conclusive for large pharmaceutical companies, but they fall somewhere in between.

Final remarks

Disruptive innovation is defined in this report as a set of radical technologies driving new innovative activities and significant investment for an uncertain market. The report rightly invokes Christensen's (1997) original definition of "disruptive innovation". An important point made by Christensen is that entities seeking disruptive innovation initially underperform established products in the mainstream market and therefore target niche segments. This enables rapid performance improvement, ultimately meeting and exceeding the performance demanded by the consumer market. Christensen suggests that large incumbent companies can only focus on their traditional customers and therefore attack the market "from the top", due to their need to maintain significant cash flows. This offers start-ups the opportunity to attack it "from below", always targeting niche segments. For the twelve technologies analysed in this report (figure 4.3), this could imply that younger technologies could benefit from a greater presence of start-ups. However, your results underline that there are many possible configurations and that the maturity of a technology might not be the only determinants of relative participation by start-ups and large companies.

Regarding the geographical origin of disruptive patents and the dominance of large, industrialized countries such as the United States, China and Japan, it is worth noting the possible effects of the American Bayh Dole Act (and its Chinese equivalent), which encourages academics to spin out. Also worth noting are the large domestic markets enjoyed by the United States, China and Japan. China in particular has very complete domestic value and supply chains.

Concerning the institutional origin of patents, the report shows that the share of patents originating from the private sector is, over time, increasingly replacing those from the public sector, but that this, however, seems to saturate at around 90%. Again, this could be because patenting is the predominant activity for companies to protect their intellectual property, while public entities have less incentive to do so. Another plausible reason is that a certain amount of patenting commands the participation of non-private entities. It would be interesting therefore to characterize that remaining 10%.



CHAPTER 3

The Unobtrusive but Crucial Role Played by Public Research

Necessary public intervention

The fact that companies are at the origin of the large majority of patent applications (*cf.* chapter 2), including for disruptive innovations, still leaves the question of what role public laboratories play in their emergence. Our detailed analysis of the data even suggests that they are at times essential.

As far back as the 1960s, economists established – initially theoretically (Nelson, 1959; Arrow, 1962) then through numerous empirical confirmations (Levin et al., 1987; Mansfield et al., 1981; Hall, 2002) – that companies and other asset holders acting on a totally free market tend to under-invest in knowledge, despite the fact that it drives growth, and that this "market failure" requires public intervention. This arises from the fact that knowledge is a non-rival good (the fact of possessing knowledge does not prevent someone else from possessing it too) and that it generates positive externalities. For this reason, all economic actors need to protect themselves from potential stowaways that could easily appropriate the knowledge they are developing and use it to their own ends.

We could also say that, the more shareable knowledge is, the less likely it is to be appropriated, and the more necessary the role of public financing. This leads to a rather simplified division of roles, whereby companies preferably invest in applied technological development and innovation (both of which are easier to protect through secrecy or patents, and also happen to have shorter returns on investment), while public authorities take care of financing the general progress of knowledge.

By extension, we can rapidly see that, in the particular case of disruptive technologies, the impulsion and scientific risk-taking are very likely to initially fall on public research. In practice, in less capital-intensive activity sectors subject to a fast succession of technological generations (typically in the digital field), and also when talking about revolution of uses, disruptive innovations can sometimes be developed totally in-house by innovative companies, large or small. However, in the industrial world, this process requires a structurally longer maturation phase. This difference largely explains the role played by academic research in the emergence of the major technological domains studied here, like nanoelectronics, decarbonized hydrogen, quantum computing, new generations of photovoltaic cells, etc. We did however see in the previous chapter that empirical observation does not follow universal or unchanging patterns.

In any event, public research – fundamental or applied – offers a suitable environment for disruptive innovations. It draws from leading-edge skills and is less subject to time constraints or returns on investment than corporate R&D departments. Fundamental research itself, the objective of which is to build knowledge on a given subject, and not necessarily to lead to concrete or market-oriented applications, can serendipitously result in unexpected discoveries. As an example, Pascal Boulanger, founder of the deep tech NAWA technologies[18], explains that his company sprang from fundamental research carried out at the CEA[19] in the 2000s on carbon nanotubes[20]. This particular material has numerous applications: the challenge was to demonstrate the potential application of this research in the most attractive field. Among the domains identified by a market study, energy storage was selected[21].

In this area, one of the main challenges involved in pursuing disruptive innovations is therefore the level of public research financing and excellence – which is not always sufficient – coupled with a general slowing down in discoveries of disruptive knowledge all over the world and in all activity domains (see box).

18. NAWA technologies manufactures fast-charging, highly autonomous batteries. They contain super capacitators made from carbon nanotubes that considerably increase power and energy density compared to coal-based super capacitators.
19. French Alternative Energies and Atomic Energy Commission.
20. Carbon nanotubes were discovered in Japan in 1991 by Sumio Iijima. They were the outcome of long research triggered by the discovery of fullerenes in 1985 by Harold Kroto, Robert Curl and Richard Smalley. Source: CNRS Images (2008).
21. This choice was made in 2012, one year before the creation of NAWA technologies.

Research and technology are becoming less disruptive (article summary)

Park, Leahey and Funk (2023) start with a paradoxical observation. Following a century of observation, the hypothesis of the endogenous growth of knowledge is widely favoured: science and technology are seen as cumulative phenomena. The store of knowledge accumulated in the past promotes the production of new knowledge. Nevertheless, a number of recent empirical observations point to a slowdown in this production, which requires explanation.

The authors make a major contribution to this debate through their extensive analysis of 45 million scientific articles and almost four million patents, in all domains and all countries, over several decades. Their main tool is a statistical Indiax based on citations, which measures the capacity of a scientific publication or patent to disrupt, in other words to open up a new pathway. In practice, the greater the number of subsequent publications and patents that cite a particular patent and "forget" preceding contributions, the more a patent is considered to be disruptive (Indiax = 1). On the contrary, the more it is cited alongside former publications from which it also drew, the more it is considered to be cumulative (Indiax = -1).

The results of this highly remarked research are conclusive. In all domains of knowledge, the average disruption Indiax for scientific articles has plummeted from 0.3, even 0.5 just after the war, to almost 0 today. For patents, this decrease from 0.4 to 0 took place over an even shorter period, from the 1980s to today.

This slump in disruptive science and technology can also be measured using other criteria, such as the semantic impoverishment of articles and patents, which increasingly use the same restricted vocabulary.

In reality, the absolute number of disruptive contributions turns out to be stable over time, but more diluted in an increasing number of less interesting articles. However, while also observing that this flow of disruptive publications is subject to considerable transfers between scientific and technological domains, the authors esteem that humanity is a long way from having exhausting the list of new knowledge to be discovered and exploited, and that it moves more securely from one science to another depending on political trends and financing opportunities.

The authors point out that this decline should not be confused with a drop in the quality of science and technologies. In fact, this reduction in the number of pioneering or seminal articles can even be seen when looking only at the most prestigious reviews. We can therefore deduce that it is the way of fabricating science and technology that has intrinsically changed.

For these authors, it is precisely the nature of the relationship with previous knowledge that has changed. There is still a positive relationship between the volume of stored knowledge accumulated in a particular domain and the propensity of the publications of the moment to open up new pathways from this domain. However, this relationship is negative when it comes to patents.

The authors esteem that researchers and engineers who publish articles and patents are increasingly likely to focus on a narrow "slice" of previous knowledge: they increasingly cite a smaller number of very well-known articles, resort to self-citation, and find it difficult to remain up to date with new knowledge produced, referring more and more to the same old sources.

In conclusion, the authors affirm that, while science remains a cumulative process, the everyday practice of research and technology seems to be slowing down in this area. Making new discoveries requires remaining connected with global scientific production, which is increasingly complicated. On the contrary, remaining within an increasingly narrow, established field of knowledge is not necessarily a bad move for personal careers, even if the progress of global science suffers as a result.

Overall, these studies confirm the idea of a general slowdown in science and technology.

The search for efficient transmission channels

The broken link between laboratories and companies in France

At this stage of the analysis, the division of roles seems simple: companies accelerate the creation of wealth and the resolution of major societal challenges by proposing disruptive innovations to the market – all the more readily since they can appropriate them by filing patents – while public research very often plays a key role in their initiation.

This process involves finding effective ways to get the two to collaborate. And this is where the situation gets more complicated: how do you encourage public research laboratories to stay tuned into market needs, and how do you ensure that the appropriation of their results by companies is not only effective, but that it takes place as much as possible on the same territory, in other words, with public authorities financing the research?

The French case provides a good illustration of this issue. In the previous pages, we have shown that France only plays a small role in patent applications concerning the twelve disruptive technologies studied. However, as shown by table 3.1 below, public research laboratories rank much higher. For the seven technologies for which we possess detailed data, French laboratories represent from 9% to 14% of all of the patents resulting from public research in the world, often coming in at fourth place, third place for photovoltaics, and fifth for spintronics.

This position is undoubtedly more modest than that of Korean research, which ranks second in the world behind the United States and ahead of China, and holds 19% of patents resulting from public research in the world. However, it is much better than the contribution of German public research or that of Japan (not shown in the table).

Figure 3.1 – Global share and ranking for Germany, Korea and France(2010-2019)

	Germany				South Korea				France			
	Companies		Public research		Companies		Public research		Companies		Public research	
	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank	%	Rank
Hydrogen for transport	16	3	15	3	16	4	24	1	4	5	14	4
Batteries for electric vehicles	19	3	12	5	21	2	26	1	2	6	13	4
Photovoltaics	10	5	8	7	17	3	22	1	3	7	14	3
Nanoelectro-nics	3	6	3	7	15	3	15	3	2	9	9	4
Spintronics	5	6	5	8	14	3	17	2	4	7	12	5
mRNA	7	4	5	6	4	6	11	3	1	14	9	4
Low-carbon steel	17	2	5	6	9	4	16	2	3	9	0	4
Total	12	4	7	6	17	3	19	2	3	7	12	4

Source: Patstat. Processing: OST and La Fabrique de l'industrie.

From this comparison intentionally centred on similar countries, we can deduce that French public research could definitely progress further if it followed in the footsteps of Korea, but that overall it maintains its ranking in the global contest for disruptive technologies. The problem in France lies rather on the side of companies.

As we saw in Figure 2.7.d above, companies in France represent a much lower share of patent applications compared to the average figure for the other countries. We can see that they are only at the origin of an average 3% of patents filed by companies in the world for these seven disruptive technologies, compared to 12% for German companies and 17% for Korean companies. France's capacity to contribute to technical progress therefore seems particularly imbalanced, and French industry appears undersized to take advantage of the technological potential unleashed by public research in our country.

This diagnosis of France's insufficient industrial activity compared to its scientific offering has been made numerous times. As a remIndiar, in Germany and South Korea, companies represent from 8% to 12% of public research funding; in France, this figure never exceeded 5% over the last decade (Binois, 2022). This volume of research activity financed by companies only represents 713 million euros in France, compared to over 4.1 billion euros in Germany: a figure 5.8 times higher, whereas the industrial value added is only 2.8 times greater than in France.

Combining the concern for applied research with a culture of scientific excellence

Historically, the first institutional response to this need to bring companies and public research closer was to give some establishments an explicit mission to develop technologies and support companies, whether for cutting-edge technologies (e.g. the CEA in information technologies) or otherwise (for instance the support provided by the CETIM to the vast network of companies in mechanics).

Unlike academic research, the very essence of applied research is to respond to the problems raised by users, including civil society and companies. As mentioned above, the CEA is one of the organizations that in France combines a mission of serving public policies (initially in the nuclear energy domain and now in other strategic fields like electronics, medicine and renewable energies) with carrying out fundamental research (indispensable to the development of new discoveries) and maintaining close links with companies.

The CEA has the status of a public enterprise of an industrial and commercial nature (EPIC), like the other eleven EPICs that carry out research activities in their respective domains[22]. This has concrete impacts on their administrative aptitude to establish contracts with companies, and on their supervision of research personnel, who are employed on private-law contracts (Ottmann, 2021). In addition, in the civil domain, the CEA is funded 30% (in 2020) from external resources, over half of which from industrials[23]. The fact that the initial state endowment is insufficient to cover all of the establishment's fixed costs creates a natural incentive to develop contracts with public and private partners, and therefore to be attentive to their needs.

Public research, thus supported by regularly updated market knowledge, produces innovations more easily. This explains why the CEA is one of the five biggest patent applicants in France (for all technologies and not only disruptive technologies), after Safran, Stellantis and the Valeo group, according to the latest report by the French patent and trademark office (INPI, 2021). Consequently, it ranks first among public research organizations, ahead of the CNRS and IFP Énergies nouvelles.

Given the leading role that they play in private R&D expenditure in France, large companies are the most concerned by collaborations with public research. While they often have their own in-house research centres, they can also outsource some of their activities to public laboratories. More precisely, and as we have already seen in the statistics on patent applications, the respective roles of companies and laboratories vary depending on the theme. David Sadek, Vice President for Research, Technology and Innovation at Thales, puts it like this: *"The quantum physics field was born in the research lab, but today it's French start-ups like Pasqal, Quadela and Alice&Bob, and big digital companies like IBM and Google that are working on designing and manufacturing quantum computers. Similarly, although Artificial Intelligence was initiated in academic laboratories, processing power and the availability of massive volumes of data meant that companies like Facebook, Google and Microsoft could make real breakthroughs in machine learning, especially deep learning. Looking back at my own experience as an AI researcher in the industrial world, most of the PhD students I've supervised did more of their research in companies than in their associated academic labs."*

22. ANDRA (French National Radioactive Waste Management Agency), BRGM (Bureau de recherches géologiques et minières – French geological survey), CIRAD (Centre de coopération internationale en recherche agronomique pour le développement – French agricultural research and cooperation organization), CNES (French National Centre for Space Studies), CSTB (Centre scientifique et technique du bâtiment – scientific and technical centre for building), IFPEN (IFP Énergies nouvelles), IFREMER (Institut français de recherche pour l'exploitation de la mer – oceanographic institution), INERIS (French National Institute for Industrial Environment and Risks), IRSN (Institut de radioprotection et de sûreté nucléaire – institute for radioprotection and nuclear safety), LNE (Laboratoire national de métrologie et d'essais – national laboratory for metrology and testing), ONERA (French Aerospace Lab).
23. Source: CEA financial report (2020).

The situation is similar for STMicroelectronics, whose strong relationship with the CEA led to a model for the coproduction of knowledge, as pointed out by Benjamin Cabanes: *"Often, when people talk about fundamental research and applied research, they think that the public domain produces knowledge and then transfers it to companies. That knowledge transfer model does exist, but there is also another model, which is the coproduction of knowledge: both actors produce knowledge at the same time but taking slightly different approaches. Rather than transfer, it's about common production."*

This collaboration approach, according to Benjamin Cabanes, is particularly suitable for disruptive innovations, which require the production of fundamental knowledge, while demonstrating the potential for application. Cabanes has observed this phenomenon in his research work: *"Generally, a company has an intuition or a vision and then approaches a lab to work together to produce knowledge."* This "complicity" between large companies and research laboratories also translates into geographic proximity, which sometimes involves working at the same premises. For example, in the 1990s, some teams at the CEA moved to the premises of STMicroelectronics to get closer to the company's production sites and facilitate the transfer of technology. A recent survey carried out by researchers at Mines Paris - PSL questioning a sample of 373 companies (October 2022) about their vision of public research shows that on average large companies are more interested in collaborative research than intermediate-sized and smaller companies are.

Sometimes, this public research interest is split between different new entities created in public research specifically to foster partnerships. One example is Airbus, which collaborates with schools, institutes and research centres on all subjects in the exploration phase or peripheral to the company: *"IRTs[24] are 'good places': everyone makes a small contribution that creates a pool of solutions, skills, testing methods, etc. which ultimately turn out to be cheaper. It's a great system. For example, recently we had a discussion on 5G for aviation and space. It's a subject that we hadn't really considered because we didn't feel concerned. Yet, we discovered that it could interest us if low-altitude satellite fleets can relay 5G to be used by planes and helicopters,"* explained Alain De Zotti, Head of Aircraft Architecture and Integration at Airbus.

The search for new bridges: encouraging spin-offs

Nevertheless, in all cases, public research stops at the frontier of the market. The aim of public powers is thus to find ways to transmit innovating results obtained

24. Instituts de recherche technologique - Technological research institutes.

in the laboratory to companies in order to improve the social return on public expenditure without creating any market distortions. The potential instruments include creating a new company directly from a laboratory, known as a 'spin-off', in order to exploit, through a commercial activity, the knowledge and technologies that have been developed there.

The French Pacte Law (action plan for the growth and transformation of companies) of 22 May 2019 reinforced the status of research-entrepreneurs[25] by creating a number of provisions favourable to researchers wanting to create their own company. These include the maintenance of promotion status and the possibility to continue working part time in the research organization. According to François Breniaux, partner at Supernova Invest, a venture capital management company specializing in deeptech: *"technology needs to be well established to launch into the creation of a deeptech"*. Researchers have the advantage of a detailed vision of existing or promising technologies, which can avoid numerous setbacks, since *"the hardest part is identifying when to kick off the adventure. Sometimes, start-ups launch into a domain that's already full of foreign competitors. Researchers, who have detailed knowledge of existing technologies, tend to do better at avoiding that kind of pitfall"*, Breniaux points out.

Although indispensable, technical skills are not enough. Researchers' interest in entrepreneurship is in fact another decisive factor in the success of spin-offs. The career path of Pascal Boulanger, founder of NAWA technologies, provides a good illustration of this attraction to both research and business: *"After working in nuclear power then solar, I took a job as a technological consultant at Anvar[26], now Bpifrance, then as a manager back at CEA, on the Saclay site […]. I also took a course at HEC because I was interested in companies and more precisely business management. I wanted to understand how companies work and the specific features of start-ups compared to big companies. That's how I got to know how innovation financing works. When I returned to CEA in Saclay, I learned about an usual material […]. And then at some point, the puzzle fitted together."*

Thus, numerous entrepreneurship promotion programmes have been created in public bodies, like the CNRS, which had clocked up 1,500 spin-offs by the end of 2020 (CNRS, 2020). From a researcher's point of view, creating a company directly from a research laboratory has several advantages, the main ones being financial support and the possibility of returning to one's job if the company fails. Gilles Moreau, cofounder of Verkor, a start-up specializing in producing low-carbon

25. Status established by the Allègre Law on 12 July 1999 on innovation and research.
26. Agence nationale de valorisation de la recherche [national agency for promotion of research]. Founded in 1967, in 2005 this agency merged with other organizations supporting investment in SMEs, then integrated the Oséo group within Bpifrance.

batteries, did not have *"the opportunity to be supported by the CEA"*. He maintains that the risks that generally come up during the kick-off and launch phases of a start-up are considerably reduced: *"Leaders of projects that come from the CEA get support for at least a year and half, while maintaining their employee status. They can then return to their job at the laboratory for a period of two years, renewable once. In total, you can be protected for five or six years. So it's not really the same kind of entrepreneurship. When you don't have that opportunity, the prospect of unemployment looms much faster. The level of stress and commitment is not the same."*

Beyond spin-offs: collaborations between laboratories and deeptech

As well as established companies and spin-offs, the exploitation of public research results obviously concerns all young innovating companies. In fact, even when they do not directly spin off from a laboratory, start-ups[27] can draw from the skills, expertise, scientific discoveries and material resources made available to them by laboratories. This was the case for the start-up Carbios, whose director, Emmanuel Ladent, told us: *"No company would have had the means to carry out the initial research, and the academic sphere wouldn't have had the fund-raising means that Carbios had to move on to the industrial phase"* (*cf.* box).

That said, in the particular case of disruptive innovations with a high technological or industrial content, start-ups correspond to what is now known as deeptechs. A recent study (2019) by Bpifrance indicated that most of these spring from public research laboratories or are at least led by teams that have strong links with public research. This therefore more or less brings us back to the spin-offs mentioned in the previous section.

Bpifrance has even made this original proximity with research one of the four main criteria of its deeptech frame of reference. The other three are the existence of technological barriers that are difficult to overcome, a strongly differentiating advantage compared to competitors, and a long, complex go-to-market strategy.

According to Philippe Mutricy, Director of Studies at Bpifrance, it is now recognized that start-ups are an effective medium to exploit the results of public research, partly due to the existence of numerous specific funding packages, and partly because start-ups' Indiapendence makes them well placed to develop more mature technologies.

27. Although the term start-up is often associated with the digital technology sector, it is used in this study to qualify young innovative companies pertaining more to the industrial sector.

Carbios, an example of a start-up commercializing public research

Established in 2011 in Clermont-Ferrand, Carbios is a biotechnology company that develops and industrializes biological solutions to reinvent the lifecycle of plastics and textiles. More precisely, it uses natural organisms, i.e. enzymes, to break down all kinds of plastics made from PET (polyethylene terephthalate) and reduce them to their original constituents. The resulting materials, whose quality is equivalent to virgin, can then be recycled numerous times.

Carbios' main activity is the industrial exploitation of several years of academic research devoted to discovering and optimizing enzymes that break down polymers. From its creation, the company formed strategic partnerships, first with the University of Poitiers, then with the public laboratory TBI (Toulouse Biotechnology Institute), which emerged from the CNRS, Insa and Inrae. These public-private partnerships led to numerous scientific advances in the domain of enzymatic recycling, including patent applications and the publication in 2020 of an article in the science journal *Nature*. That same year, Carbios intensified its alliance with public research when it created, with Insa, an enzymatic engineering research centre dedicated to plastic recycling.

Today, Carbois is the only company in the world to have developed an enzymatic recycling process for PET at industrial scale. The process has been validated by an industrial demonstrator, in preparation for the future installation of industrial sites, initially in north-east France, then all over the world.

The difficult management of intellectual property

In all cases (established companies, spin-offs or deeptechs not directly stemming from a laboratory), technology transfer often includes exploiting some of the elements of intellectual property developed by the public research team. This point has inspired a great deal of literature on the best ways to manage intellectual property assets, as well as numerous debates and even new regulations, following the famous Bayh-Dole Act in the United States (see box below).

A first issue concerns the level of maturity of the technology concerned. If a company, and more particularly a start-up, can succeed in attracting investors to a mature technology, then it increases its chances of convincing them that exploiting the technology will create value and allow it to stand out from its competitors.

The Bayh-Dole Act

The *Bayh-Dole Act* or *Patent and Trademark Law Amendments Act* is a United States legislation dating from 1980, whose name comes from the two senators who sponsored the project. It concerns inventions resulting from federal government-funded research projects.

Prior to this law, government agencies owned inventions produced resulting from their support. The government therefore ended up possessing tens of thousands of patents that were only rarely commercialized. The aim of the Bayh-Dole Act was to stimulate innovation by automatically assigning intellectual property rights to small companies and non-profit organizations, including universities and other public laboratories. The underlying idea is that these non-administrative actors would be more able to use the patents to commercialize products.

N.B. The beneficiary of the financing can choose whether or not to conserve the property titles. If the government body also refuses them, they return to the original inventors. The beneficiaries of the financing must also abide by a number of requirements. In particular, the sponsor governmental organization must receive a non-exclusive, non-transferrable licence. In addition, all inventions used or sold in the United States must be substantially manufactured in the country as far as is reasonable. The non-respect of one of these requirements gives the government agency the right to take back the property title from the company, which loses all rights, including the right of application.

The government also has "intervention" rights in some situations (which have never been exercised). They can be triggered if a title-holding company does not apply the invention within reasonable time, if the health or safety of the nation are at risk, or if the resulting product is not mainly manufactured in the USA. In these cases, the government grants a licence to a trusted third party to carry out the necessary action.

This law is acclaimed for having facilitated the development of hundreds of new drugs, and thousands of new companies, along with the creation of hundreds of thousands of dollars in economic value.

Source: Canada Trade Commissioner Service.

On the contrary, a technology that remains at proof of concept (PoC) stage brings a high risk of compromising the start-up's development. To respond to this issue, in France, tech transfer acceleration companies (SATTs), are equipped with a significant budget to foster maturation and help technologies reach a sufficient level of advancement before being transferred to a company.

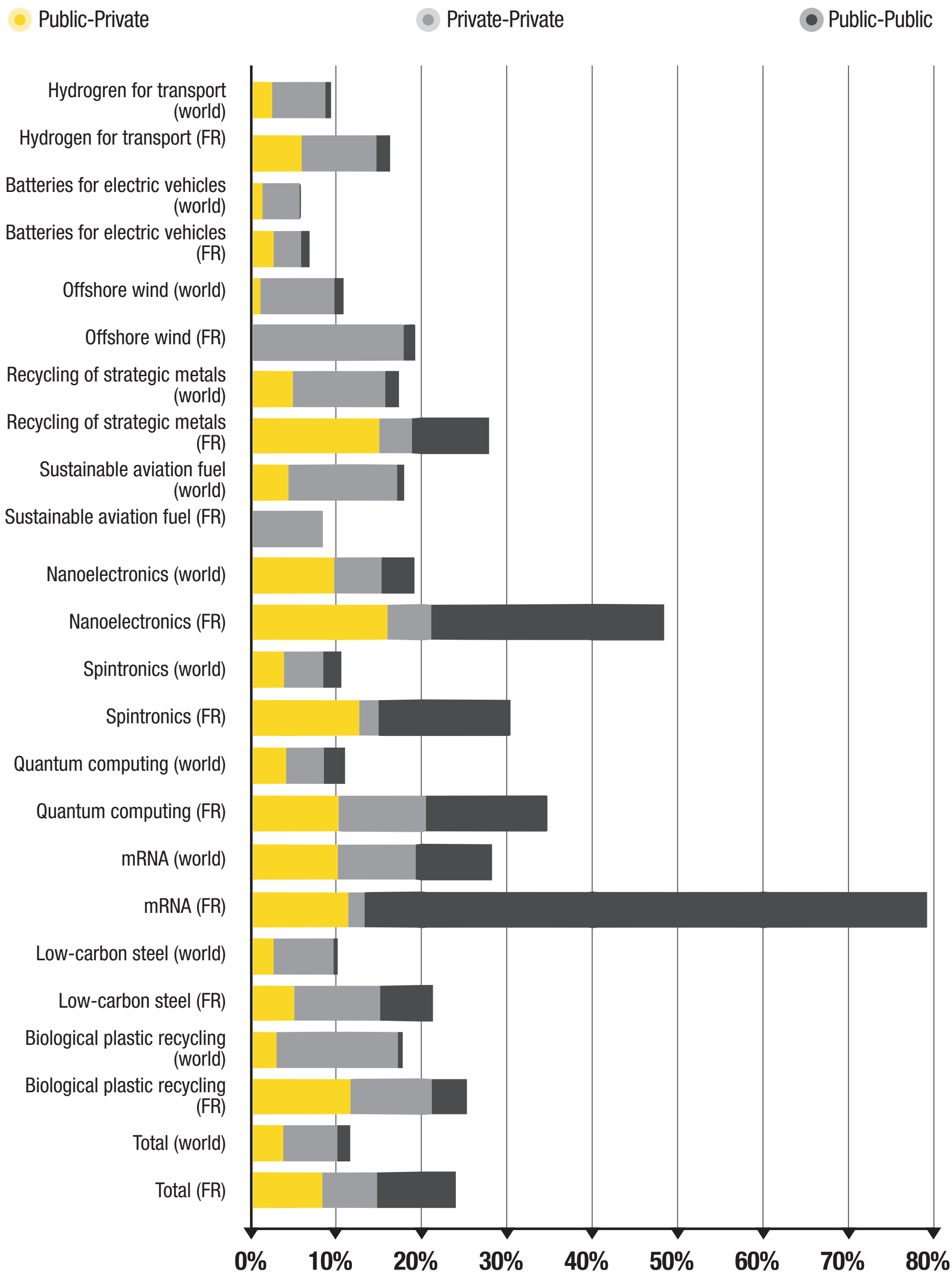
Paradoxically, a second issue for companies involves remaining Indiapendent from the public laboratory, or retrieving Indiapendence as quickly as possible. This is because commercializing patents resulting from public research rapidly becomes expensive for companies, and can put them in a servitude position that ends up diminishing the value for shareholders. The level of remuneration required by research laboratories is often judged to be excessive by start-up directors and investors, who need to keep down costs in order to foster strong growth for the activity.

According to the interviews carried out for this study, it is not unusual for companies to put a stop to collaborations or to attempt to develop their own patents in order to overcome this kind of constraint. Pascal Boulanger, a former employee of the CEA and founder of the start-up NAWA technologies, defends this strategy: *"From the start, my goal in terms of intellectual property was: how can I make myself as Indiapendent as possible from this CEA licence, which is going to cost the company a lot of money? We started out with four CEA patents in 2013. We signed a licence extension in 2019, when we dropped one patent that we didn't need any more. We have extended our technological portfolio with licences with MIT and the University of Dayton in the USA. Today, our technology is protected by 26 patents […]. And so we're no longer dependent on the CEA and the majority of our patent portfolio is owned 100% by NAWA technologies."*

The same observation applies to patents owned jointly by a company and a laboratory, a situation viewed as even more restricting for the company. Gilles Moreau, cofounder of Verkor, says that he viewed joint ownership as "troublesome" when raising funds because investors prefer companies to be totally in control of their intellectual property.

Figure 3.2 confirms this reluctance for joint patent ownership, including when public research plays a key role. On the whole, joint patent applications represent 11.6% of the total (24% for French applicants), fewer than 4% of which concern public-private joint applications (8% for France). This public-private joint application process is more marginal when the innovative activity is largely dominated by companies (batteries, hydrogen and low-carbon steel), whereas it exceeds 10% in technologies where public research still plays a large role (mRNA and nanotechnologies).

Figure 3.2 – Breakdown of joint applications, as a percentage of the total (2010-2019)



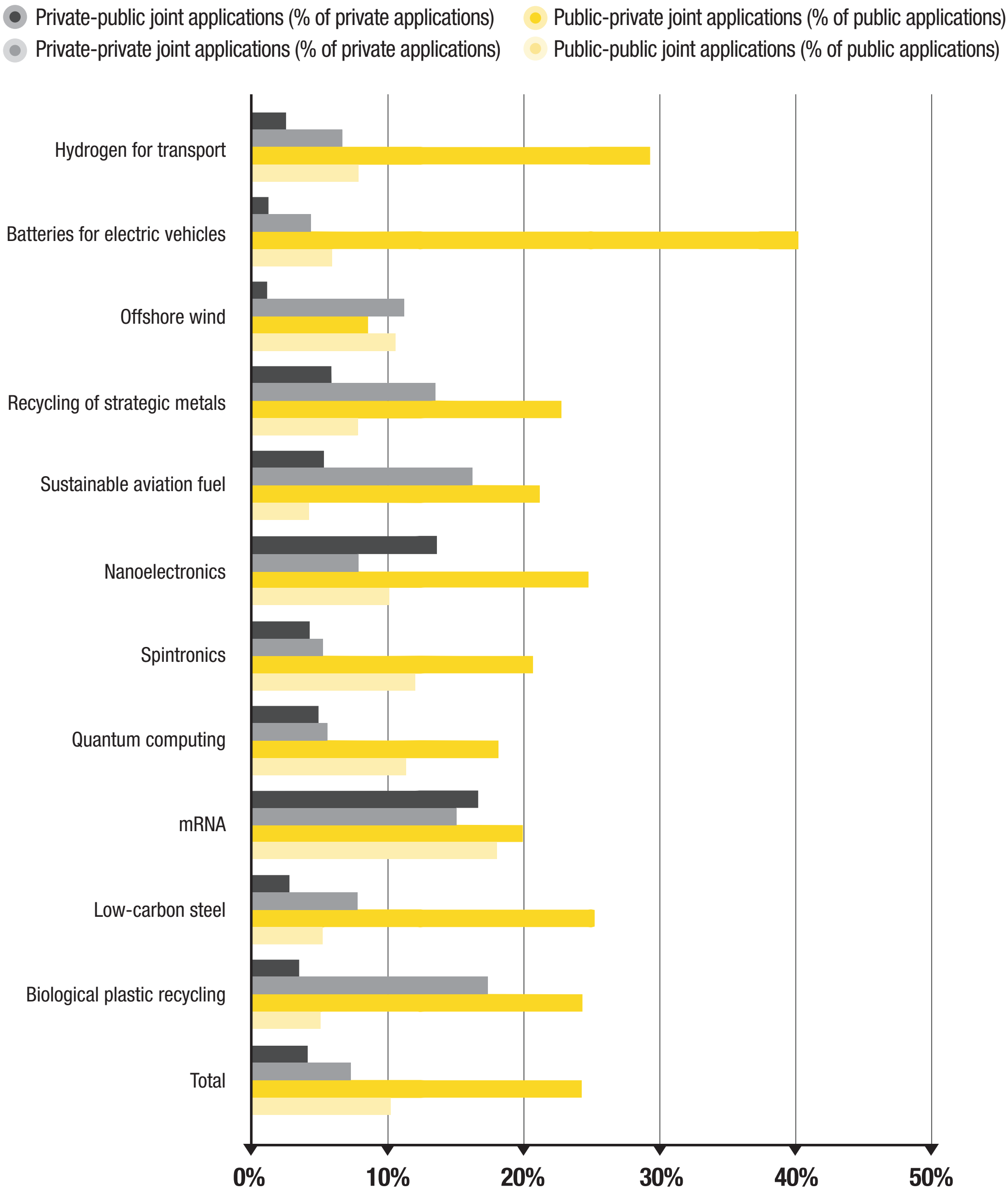
Source: Patstat. Processing: OST.

Understandably, when their technology stabilizes, companies want to break away from the public research that they needed at the start. It is harder to explain why they are more ready to establish joint patent applications with private partners than with public research (respectively 6% and 4% of the global total).

> "Companies more readily accept joint ownership with other companies than with public partners, whereas laboratories are more ready to share their patents with private partners than with their homologues."

Moreover, graph 3.3 shows an arithmetically intuitive fact given the disequilibrium between the volumes of patents respectively owned by public actors and private actors: while public-private joint applications only represent 4% of private patents, they make up 24% of public patents. Public research therefore appears less reticent than companies to share the same intellectual property title, even though the discomfort of jointly sharing a common asset is more or less the same for both parties. Oddly, companies more readily accept joint ownership with other companies than with public partners, whereas laboratories are more ready to share their patents with private partners than with their homologues.

Figure 3.3 – Respective shares of joint patent applications for public and private applicants (2010-2019)



Source: Patstat. Processing: OST.

POINT OF VIEW

Massis Sirapian was formerly deputy director of the "open innovation" department at the French defence innovation agency (Agence de l'innovation de défense - AID). He is currently director of the "new frontiers" department at the Secrétariat général pour l'investissement (SGPI).

Open innovation for the defence sector

Why is open innovation so crucial for exploring disruptive innovation?

The pace of technological development is accelerating, and the number of General Purpose Technologies (GPTs) is rocketing. From only two at the start of the 20th century, automobiles and electricity, today the long list of GPTs includes telephones then smartphones, IT, AI, renewable energy, biotechnologies, blockchain and additive manufacturing.

But the human mind is slow to adapt to exponential developments because it is linear. Similarly, institutions and organizations have trouble keeping up with this acceleration because of their inertia. To take an example, think of the difficulty in regulating the GAFAM in terms of disseminating information, or the different "uberization" waves.

This acceleration constitutes a fatal threat for large organizations. These organizations nevertheless have a way of attempting to survive, similar to what Clayton Christensen recommended when he described the disruption phenomenon: to avoid sinking, the organization itself has to surf the wave.

Why, then do so few major groups take that risk? That is the question that we asked ourselves at the creation of the French defence innovation agency (AID) in 2018.

What is the best way to work with start-ups?

When we created the defence innovation agency in 2018, we couldn't ignore the shortcomings identified since the explosion of the start-up phenomenon in France (let's say in 2013) regarding collaborations between them and major groups. Only 2% of the innovations detected by major companies are integrated into their processes. To explain this obvious failure, our analysis was that large groups treat start-ups like SMEs. Yet a start-up is an economic actor radically different from an SME or a midcap.

A start-up can be defined as a (possibly) temporary organization whose objective is to respond to a need by creating a product or service, and to find a coherent, repeatable, and if possible scalable economic model (increasing returns to scale). This difference with a company that knows its economic model may be small, but has major consequences for a start-up's development over time.

Initially, and up to a certain maturity level, a start-up is relatively indifferent in terms of market segment, as it works on developing its product or service. After this stage, the start-up starts to think about and explore potential market segments in which it could develop.

Once it has chosen its first market segment, a start-up's priority is to serve this target market to test out its hypothesis (remember that it does not yet know its economic model). When it gains in maturity, it once again considers another market segment to continue its development. This is the diversification phase.

Why has this problem persisted for over a decade?

This typical development mode of start-ups partly explains the difficulty encountered by most major organizations, whatever the sector, to move up a scale after a modelling phase. In fact, two major pitfalls can occur: identifying the start-up too early, or too late. If the start-up is approached when it is in the process of moving out of its non-differentiation phase, moving up a scale, for example into the defence segment, means that the start-up chooses defence as its first market segment.

To do so, it needs to move very fast and make a request to the ministry for rapid development and production, even though it is simply in a phase of evaluating or demonstrating the interest of the concept. No sizeable follow-up will occur within a reasonable time, and the start-up will therefore look for another segment. However, if the start-up is approached at the point where it has already dealt with one segment and is considering diversification, the effort required at this stage will probably be too great to choose defence as a second market segment, in particular if this sector has been ignored or eradicated during the first explorations made by the company. What are the consequences?

The first is the need to detect very early on and then follow those start-ups that do not signal a “national security” or “defence” market segment but that are nevertheless developing solutions of interest to the sector. The second is to consider that a start-up will only diversify towards defence if the effort involved is lower or if the expected profitability is much greater than for an alternative segment. In addition, the rapidity with which a start-up moves from this non-differentiation phase to one of diversification shows that making only periodic spot checks (e.g. calls for projects) is relatively inefficient.

What does this teach us about open innovation?

For the above reasons, the defence innovation agency is careful to consider three levels of maturity: technological maturity, the maturity of the economic actor vis-à-vis its initial and priority target, and the maturity of the final user (internal). An approach involving the acceleration of open innovation projects, promoted by the AID’s detection and capture unit, fits in with this vision: financing maturation on all of these axes, and not just the technical axis, to deploy the innovation detected as fast as possible. It was indispensable to develop a new tool at the AID when it was opened in order to identify, follow and even influence the development of new actors with little experience of the defence ecosystem.

More generally, to take into account the elements of context set out above, the mission of an (open) innovation agency should consist in the following: detect and follow innovations (including start-ups) that are not necessarily aimed at the sector, and launch joint development projects (maquettes, demonstrators and prototypes) at the right moment. The link between these two activities (watch and projects) is the acculturation of innovations within the organisation, in other words their permanent circulation. Through continued irrigation, the objective of this diffusion will be to influence internal road maps and those of the companies identified, in order to succeed in an unanticipated grafting.

CHAPTER 4

The Complementary Roles of Start-ups and Large Groups

Coexistence of two opposing innovation regimes

The old debate about the respective merits of young and established companies

The debate about the respective roles of start-ups and large companies in the emergence of disruptive innovations is an old controversy, and something of a thorny issue. The debate was recently reactivated in France when several apparently unrelated news stories highlighted the decisive role that some start-ups can play. These include not only the planetary success stories of companies like Tesla and Moderna – which stand in stark contrast to the difficulties of more established automobile and pharmaceutical groups in the face of challenges like the energy transition and the Covid-19 pandemic – but also the encouraging results of the new French unicorns, and the enthusiasm for the new deeptechs shared even by the government, etc.

To understand the complex reality of innovation dynamics nevertheless means moving away from making assumptions and arguing over which model of reference is better than the other. On the basis of research and interviews carried out for our study, it emerges that the disruptive capacity of a company of the same size and age depends largely on the sectorial and technological dynamics that it evolves in.

This result relates to the notion of technological regime, set out in the above chapters, and more simply to the two Schumpeterian paradigms known as “Mark I” and “Mark II”. These paradigms, which are based on the economist’s empirical observations, designate two different innovation regimes[28]. The first stems from an erosion of the competitive and technological advantages of established companies, favouring the arrival of more innovative, often small newcomers (Malerba and Orsenigo, 1995). The second is on the other hand characterized by the domination of a small number of large historical companies that, thanks to their accumulation of knowledge and expertise, are capable of effectively mastering a technological domain to the point that their technological advantage constitutes a genuine barrier to entry, all the more so since they devote significant sums to research and development.

While these two archetypes are not sufficient to represent all possible innovation patterns (see the point of view of Christophe Deshayes at the end of this chapter), they nevertheless provide an interesting starting point for understanding the respective roles of the different types of company and grasping what facilitates their development and what hIndiars it. It is vital to understand that these two regimes coexist, and that the empirical confirmation of one is in no way a refutation of the other.

There is therefore nothing contradictory about an "old" company maintaining a significant innovation activity, or even a role of technological leader in its market. An established group like Thales, for example, which has several research centres in the world, continuously explores new technological avenues. Every year, the group invests on average 3.5 billion euros in R&D, which is 20% of its turnover[29], because it is a condition of its continued existence. As pointed out by David Sadek, Vice President of Research, Technology and Innovation at the group, maintaining an innovation dynamic helps maintain sovereignty: "*It's vital for a strategic company like Thales to master quantum computing, which is going to be a real game changer in the coming years. Thales aims to be a pioneer in developing applications based on algorithms and quantum computing, in its activity sectors, both in the civil and defence fields.*" In highly technological domains, established companies that do not take part in disruptions are therefore bound to disappear or compromise the country's interests. They are aware that no position is ever definitively acquired, in particular in a globalized world where some states, like China, do not hesitate to massively subsidise national companies to hold back the competition.

They must also maintain and develop their capacity to look for and identify major breakthroughs and recognise the technological challenges that face them, or even

28. Other research studies (such as Crifo, 1999) highlight two types of innovation incentive that relate to very different market structures. The first incentive is competitive threat, which results in a monopolistic market. The second incentive is the search for profit, which involves a much more competitive market.
29. Source: "La R&D chez Thales", on thalesgroup.com.

that they have imagined. For example, Airbus's "zero emission" aviation project followed a letter written by the strategy managers asking teams to "imagine" a zero-emission aeroplane: "*The teams began in start-up mode, brainstorming, then progressively converging towards two technologies – SAF and hydrogen – going out to find skills and then institutional collaborations outside the company,*" according to Alain De Zotti, Head of Aircraft Architecture and Integration at Airbus. Some large companies constantly try to anticipate the next disruptive innovations and explore alternatives: "*We don't rest on our laurels […]. We're constantly on the watch,*" explains De Zotti.

A few cases of "creative accumulation" (Schumpeter Mark II)

Large established companies can therefore resolutely be leaders of all categories of innovation, including the most radical. In their publication, Marc Giget and Véronique Hillen (2021) observe this phenomenon in numerous sectors. The companies studied by the authors, such as Saint-Gobain, Schneider Electric and Veolia, have never stopped innovating and have even intensified their efforts over the last fifteen years. As evidence, according to a recurrent study by Derwent-Clarivate Analytics cited by the authors, most or all French companies that feature in the 100 most innovative global companies every year[30] are established large companies. The 2022 ranking featured the French companies Airbus, Alstom, Michelin, Safran, Thales, Valeo, etc. but no start-ups. This result shows to what point some major, well-established companies enjoy a solid position thanks to a sustained culture of innovation.

Start-ups therefore appear to be in a minority or sub-critical in domains where the constant accumulation of knowledge, massive investment in R&D, and industrial capacities are prerequisites to innovation. This in no way means that start-ups do not have a role to play here. In the aviation sphere, some interesting initiatives are led by emerging actors, such as the design of small electric planes. As an example, the Toulouse-based start-up Aura Aero has signed 330 intentions to purchase with several aviation companies for its future 19-seat electric regional transport aeroplane (Sommazi, 2022). However, making the step of competing with established manufacturers on large aeroplanes is much more difficult: "*Before someone arrives to upset the market, we'll have had time to see them coming. These new actors aren't a risk for Airbus. On the contrary, they invigorate the sector and develop the ecosystem,*" says Alain De Zotti. According to him, the risk is more threatening

30. The 100 most innovative global companies are ranked based on several criteria: the volume of patents filed with intellectual property organizations; the number of citations of patents by other companies and organizations; and whether or not the protection of inventions has been extended to patents in the main global markets.

on the Chinese side. Airbus is aware that China, through its China 2025 plan, is currently developing an aeronautical industry, and in particular its own aircraft manufacturer, Comac, destined to compete with the Airbus-Boeing duo. In late 2022, Comac's star aeroplane, the C919, reached a milestone when it obtained certification by the Chinese authorities. China's delay in this domain means that the C919 does not yet constitute a serious threat for Western players. Nevertheless, the "conquer the world" strategy in place since Xi Jinping's arrival in power in 2013 seems to have borne fruit in numerous domains (Mabille and Neveu, 2021), led by the digital sector; it would therefore be naïve not to anticipate the same type of market upheaval in aviation.

A few cases of creative destruction (Schumpeter Mark I)

While some innovation domains are characterized by the central role played by capitalizing on and transmitting knowledge, Mark I innovations see market newcomers as playing a dominant role. The literature has abundantly shown the reasons for this phenomenon. In his work, Christensen (1997) talks of the "innovator's dilemma" specific to established companies: if a disruption risks compromising the company's business plan, ignoring it might at best lead to a loss of leadership, at worst the demise of the activity. Much has been said about Nokia and Kodak, companies that collapsed because they left it too late to jump on the disruptive innovation bandwagon (Silberzahn, 2015), and Blackberry, victim of refusing to give up its cutting-edge system, not to mention Apple, reborn after introducing the right disruption at the right time.

The reticence of some large companies to launch into new or highly technological domains is rooted in what is commonly referred to as "legacy". In reality, breakthroughs involve overhauling everything that made the historic company a success: its organization, its culture, its production process, the skills of its employees, and its brand image.

In some areas, it is therefore not surprising that disruptive innovation has become the favourite playground of start-ups. Gilles Moreau, cofounder of Verkor, draws the following lesson from his experience: "*When you want to create a start-up and bring an innovation onto the market, the only possible and viable solution is to launch yourself into an activity that seems to be a bad idea for existing companies, but that is in fact a good idea. Why? Because they won't take the risk of doing it, which leaves the coast clear for start-ups. On the other hand, launching into an activity that everyone thinks is a good idea is suicide for start-ups, which have few resources compared to big groups.*"

Put another way, start-ups make up for the lack of initiatives in activities judged to be risky or not interesting by major groups. That is why numerous start-ups excel in new domains, such as cleantech – a term describing start-ups that aim to reduce negative environmental impacts in industry, buildings and transport. Based on a mapping produced in 2021, a study carried out by Bpifrance together with France Digitale (2021) lists 727 French impact start-ups[31], over half of them (53%) in the environment sector.

The electric vehicle sector provides an interesting case to understand why historic automobile constructors have been so late to get on the market. Tesla, a relative newcomer, had stratospheric market capitalization of 1,000 billion USD in late 2021, one hundred times higher than Renault (Dupont-Calbo, 2021). Yet Renault was a pioneer in the electric vehicle field, arriving on the market in 2009 and producing electric Kangoo cars in 2011 and Zoe cars in 2012. During this "pre-Tesla" period, Renault did not take great advantage of its leading position in the electric market. According to a manager from the company we interviewed: "*Renault didn't seem to believe in a full move over to electric, or in equipping all households with electric. A fringe group in the company didn't believe it and created resistance.*" In addition, at the time, there was a split between those promoting hybrid cars led by Stellantis (ex-PSA) and all-electric models supported by Renault, bearing in mind that the end of thermal combustion engines was in no way confirmed.

The first sales of Renault's Zoe missed their target by a long chalk: whereas the carmaker anticipated selling 50,000 units during 2013, the threshold of 10,000 registrations was only just reached at the end of December that year (Doche, 2013). At the same time, Tesla launched into a very specific segment of top-end electric cars with a very high pricing policy: the first model, the Tesla Roadster, was commercialized from 2008 to 2012 with a price tag of 128,000 USD (Martinage, 2022). While Renault had opted to produce a mass-market car using a barely emerging technology, Tesla made the choice of attacking the market from the top and then gradually entering into a more widespread market.

The particular strength of Tesla is its business culture driven by its director, Elon Musk. He has adopted a strategy of differentiation by innovation involving massive investment in R&D, right from the start: "*Where Renault had an administrative culture of ticking over, Tesla made its company culture about innovation and a questioning of all of its processes,*" recognizes a Renault manager. The result is that Tesla was a precursor not only in producing its own battery with unique features[32] but also in the widescale deployment of charging stations.

31. Impact start-ups carry out an activity specifically designed to respond to a social, societal or environmental issue.
32. Launched in September 2020 on Tesla Battery Day, the new battery cell, designed and manufactured by Tesla, has unique characteristics, including a so-called "tabless" design (no connector) and a bigger cell format. This new battery should allow Tesla to increase the autonomy of its vehicles and reduce production costs.

As pointed out by Jean-Louis Beffa, in his publication *Se transformer ou mourir* (2017), traditional businesses come up against difficulties in dealing with this new type of competition. These market newcomers, of which Tesla is a perfect example, are incessantly looking for creativity and innovation, even if it means taking reckless risks. Yet that is where their strength lies: putting disruption at the heart of their activity, often starting with a niche market and then gradually expanding.

“The market newcomers are incessantly looking for creativity and innovation, even if it means taking reckless risks. Yet that is where their strength lies: putting disruption at the heart of their activity.”

While Tesla’s success is a good illustration of the disruptive phenomenon described by Christensen (1997), the automobile sector does comprise numerous barriers to entry that still give some advantages to traditional carmakers.

From theory to practice: no big companies means no start-ups

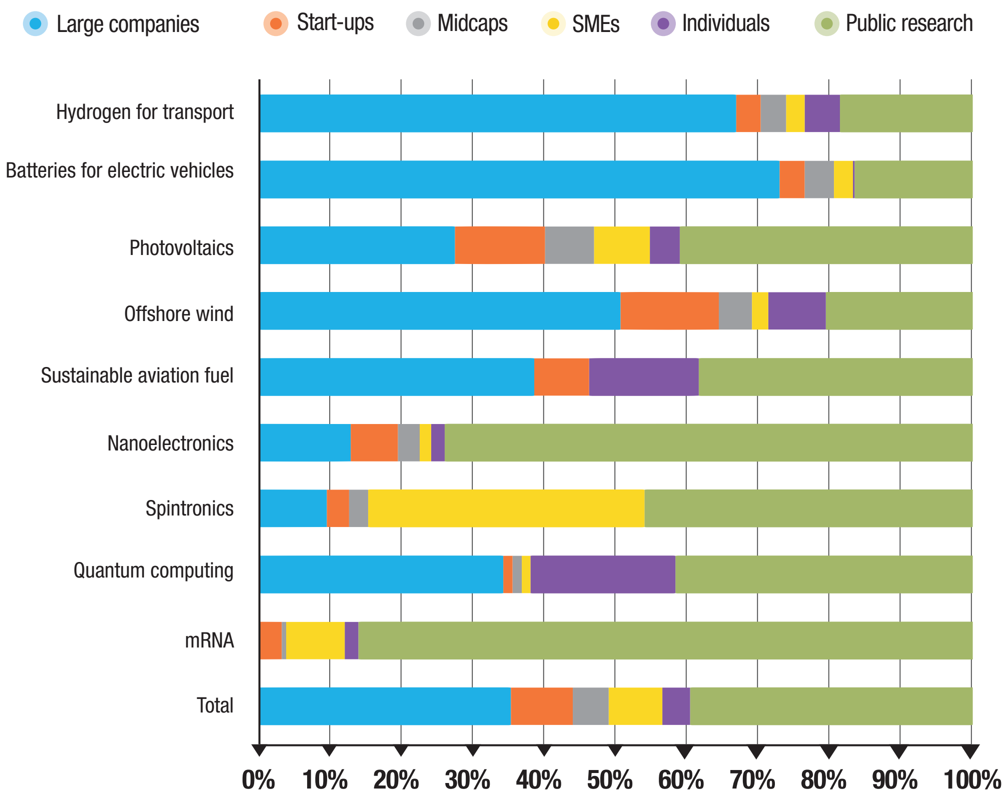
Looking for Mark I and Mark II regimes in the data

In this part, we propose to use data to study the respective places of start-ups and large companies for the twelve technologies in our sample. Note that we are confronted with a lack of precise definition of a start-up (see Appendix). For obvious data access reasons, French start-ups were easier to identify than their foreign equivalents. In addition, individual global-level data do not allow us to consider applicants from public research[33]. Therefore, we intentionally focus here on French applicants, and from time to time put the results into an international perspective.

Looking at figure 4.1, an observation can be made: the low proportion of start-ups among patent applicants in France. Conversely, patents filed by large companies make up the vast majority of those filed by French companies in most of the technologies studied. However, a few exceptions exist: messenger RNA, which features no large companies, nanoelectronics, spintronics, and to a lesser extent, photovoltaics. The relatively small number of large companies can mainly be put

33. Some research organizations can sometimes rank high among French patent applicants but not feature in graphs showing the global situation.

Figure 4.1 – Breakdown of French patents according to type of applicant



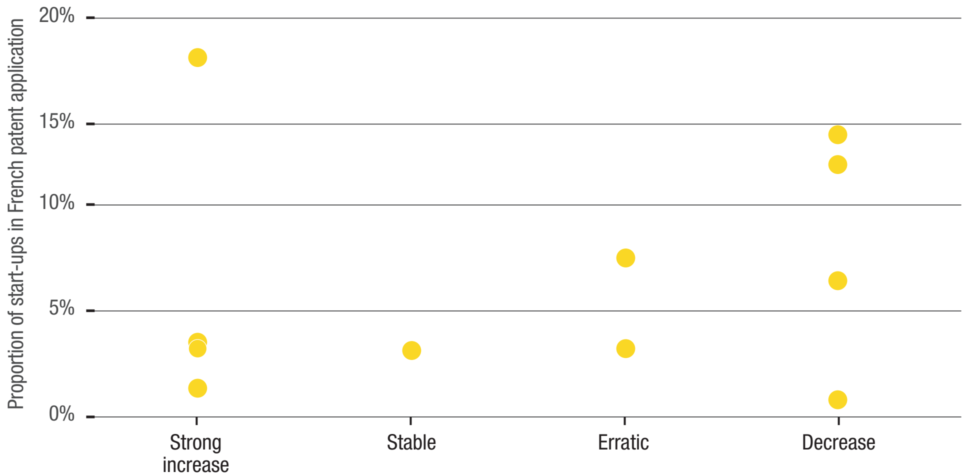
Source: Patstat. Processing: OST and La Fabrique de l'industrie. French applicants were identified from the Sirene database, which gathers numerous statistics on French organizations (number of employees, legal status, year of creation, etc.). Given that no precise definition of a start-up exists, they have been imperfectly defined as SMEs established less than 15 years ago.

down to the strong domination of public research which, as an illustration, owns almost 90% of French patents in the mRNA domain.

> "While the proportion of start-ups remains low overall among French applicants, it is comparatively higher in growing domains."

While the proportion of start-ups remains low overall among French applicants, it is comparatively higher in growing domains, such as biological plastic recycling, and more mature technologies – in the sense that the number of patents drops year on year (figure 4.2). In the photovoltaic and offshore wind power domains, start-ups represent respectively 13% and 14% of French patents.

Figure 4.2 – Proportion of start-ups among French applicants and type of growth



Source: Patstat. Processing: OST and La Fabrique de l'industrie. The kinetic flow of patent applications (strongly increasing, stable, erratic, decreasing) is here based only on French cases.

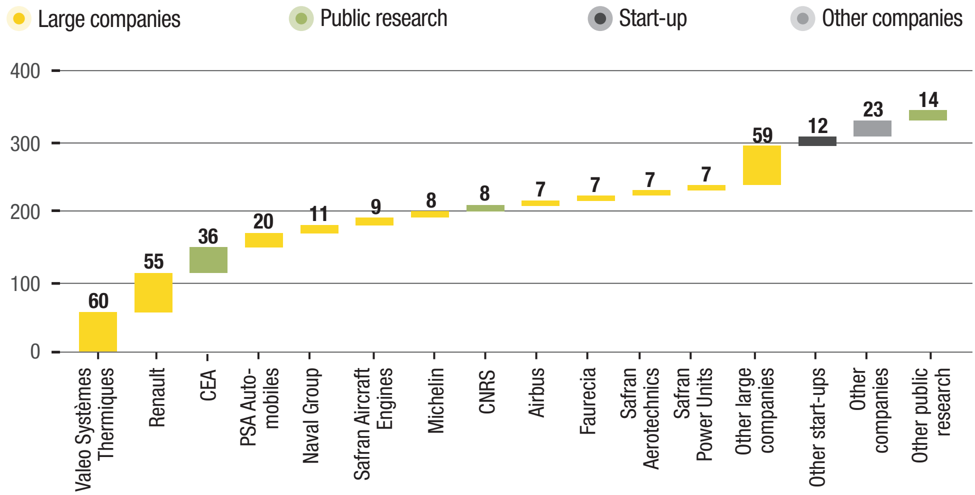
We now analyse in more detail the breakdown of roles between start-ups and companies within the different technological domains.

– When large established companies take the lion's share: hydrogen for transport and batteries for electric vehicles

In France, and more generally in the world, the domains of batteries for electric vehicles and hydrogen for transport are good illustrations of the Schumpeter Mark II regime: strong barriers to entry foster the maintenance of a small number of innovative companies that are large and stable over time. Figures 4.3 and 4.4 confirm the dominating role of large companies in these two areas. If we exclude public research, we can see that only large French companies take the top positions and that these few leaders hold over 50% of the patents filed for all companies (respectively 67% for electric batteries and 62% for hydrogen in transport). A similar picture exists at a global level: the large historic companies dominate the two rankings (figures 4.5 and 4.6), and in particular the dozen global leaders, which approximately concentrate half of the patents filed in the world. This absence of start-ups underlines how, faced with ecological urgencies and regulatory requirements, partly through climate policies established in Europe targeting a reduction in carbon emissions by 2050, established countries are getting organized to embark on the major technological shift of electrified vehicles. French start-ups are almost absent from this market, since they are at the origin of only 4% of French patent applications in each of the domains. Lastly, figures 4.3 and 4.5 also indicate that public research, through the CEA and the CNRS, plays a key innovation role in France in these two domains. In particular, the CEA always ranks among the top three and owns over 11% of all French patents.

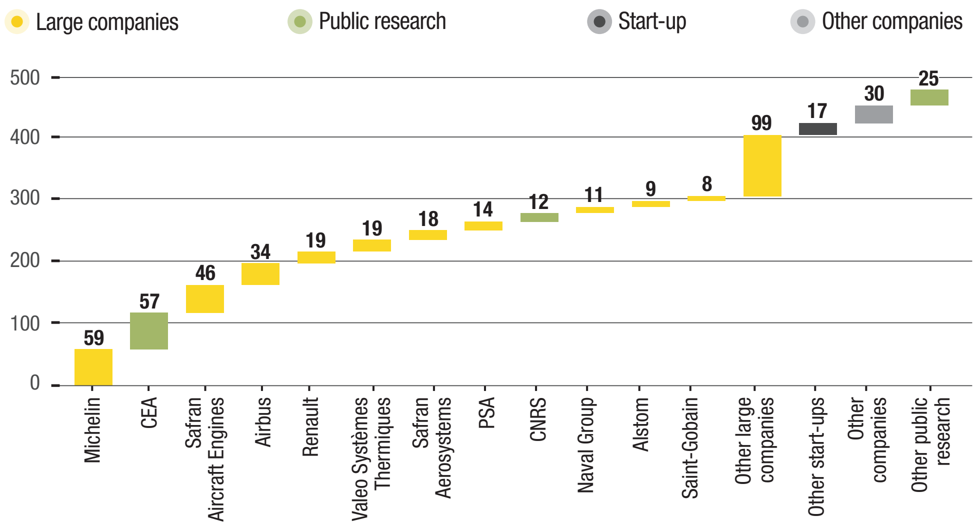
In the domain of low-carbon steel, the division of roles between the different stakeholders is not clear in France (figure 4.7). On the other hand, the global data (figure 4.8) clearly illustrate the power struggles typical of a Mark II regime. Large groups are by far the biggest patent providers in this area. Steel production requires colossal investments that necessarily give large companies an advantage. It is therefore hardly surprising that they are at the leading edge of steel decarbonization, in particular given that legislation requires them to increasingly reduce CO_2 emissions in the years to come.

Figure 4.3 – Breakdown of French patent families – Batteries for electric vehicles



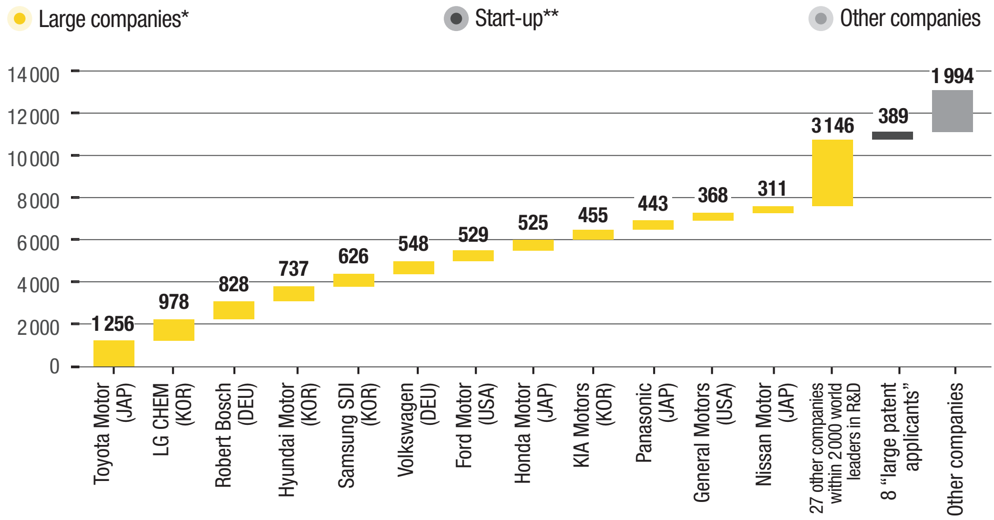
Source: Sirene. Processing: OST and La Fabrique de l'industrie.
NB: To illustrate the Mark II regime here we take the case of technologies in which large companies are over-represented among the leaders and alone own more than half of the patent families held in France.

Figure 4.4 – Breakdown of French patent families – Hydrogen for transport



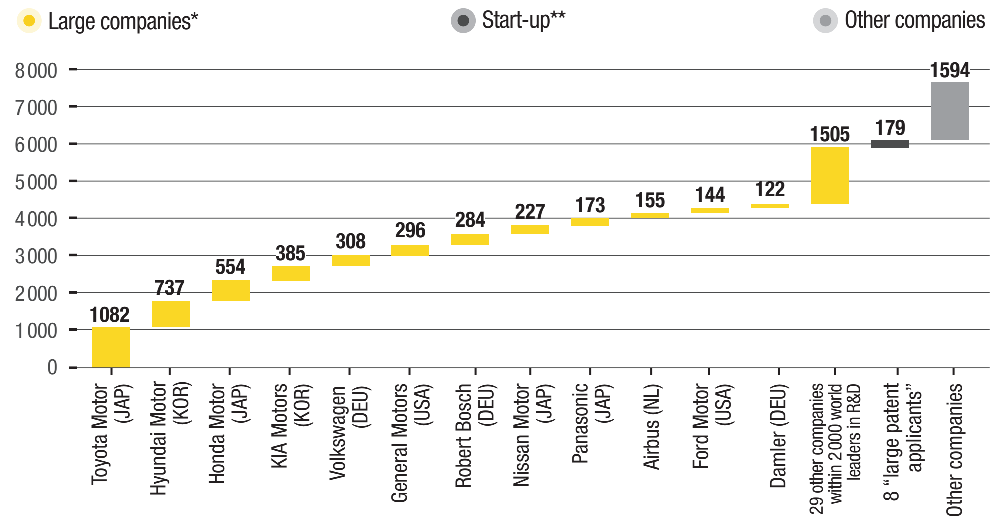
Source: Sirene. Processing: OST and La Fabrique de l'industrie.
NB: To illustrate the Mark II regime here we take the case of technologies in which large companies are over-represented among the leaders and alone own more than half of the patent families held in France.

Figure 4.5 – Breakdown of international patent families – Batteries for electric vehicles (exc. public research)



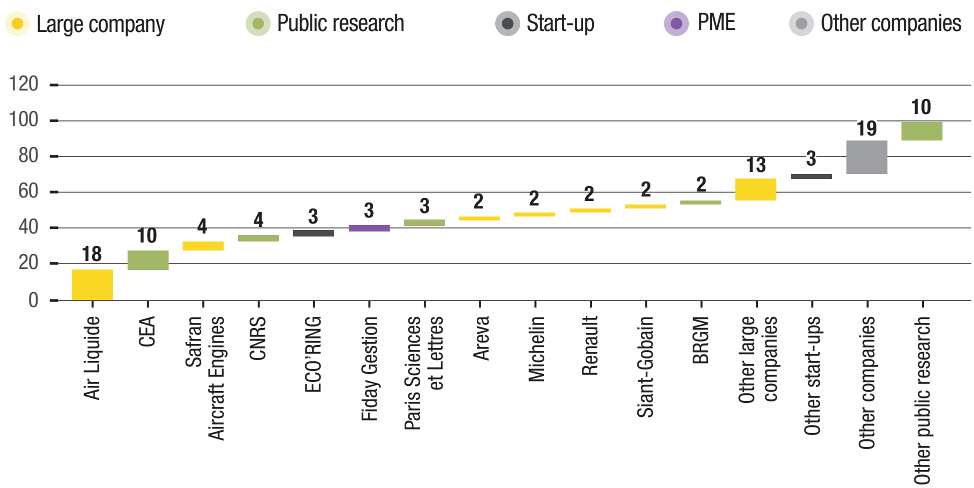
Source: Patstat et Cor&Dip (2021). Processing: OST and La Fabrique de l'industrie.
** Large companies correspond to "historical leaders", i.e. the 2 000 large companies leaders in R&D.*
***Start-ups correspond to "large patent applicants" (companies which file a lot of patents but are not the "historical leaders", therefore certainly start-ups or at least challengers).*

Figure 4.6 – Breakdown of international patent families – Hydrogen for transport (exc. public research)



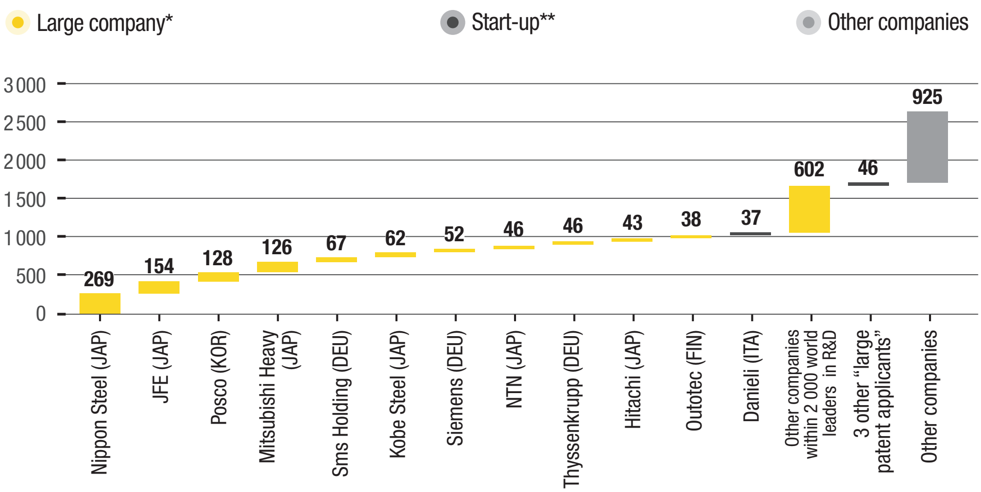
Source: Patstat et Cor&Dip (2021). Processing: OST and La Fabrique de l'industrie.
** Large companies correspond to "historical leaders", i.e. the 2 000 large companies leaders in R&D.*
***Start-ups correspond to "large patent applicants" (companies which file a lot of patents but are not the "historical leaders", therefore certainly start-ups or at least challengers).*

Figure 4.7 – Breakdown of French patent families – Low-carbon steel



Source: Sirene. Processing: OST and La Fabrique de l'industrie.
NB: To illustrate the Mark II regime here we take the case of technologies in which large companies are over-represented among the leaders and alone own more than half of the patent families held in France.

Figure 4.8 – Breakdown of international patent families – Low-carbon steel (exc. public research)



Source: Sirene. Processing: OST and La Fabrique de l'industrie.
NB: To illustrate the Mark II regime here we take the case of technologies in which large companies are over-represented among the leaders and alone own more than half of the patent families held in France.

– When small companies join the big players: photovoltaics, offshore wind power, biological plastic recycling

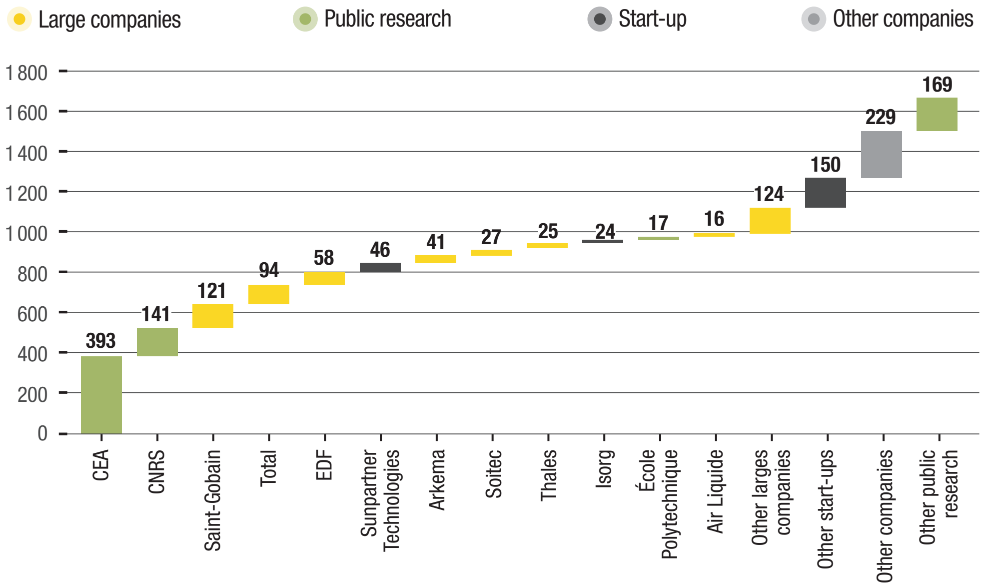
Graphs 4.9, 4.10 and 4.13 show that one domain can be dominated by a small number of companies that already include start-ups. Thus, in France, in the photovoltaic, offshore wind power and biological plastic recycling domains, several start-ups figure among the leaders alongside established large companies like Total, Naval Energies and the Suez group.

This result brings a slight difference to the Schumpeterian schematic representation by which Mark II-type markets are dominated by a small number of large companies that maintain strong barriers to entry. In France, the oligopolistic situation of patent applications in these domains has not prevented small innovative companies from taking a foothold. In total, start-ups represent respectively 23%, 19% and 18% of the patents filed by companies in photovoltaics, offshore wind power and biological plastic recycling.

In the latter fast-growing domain, Carbios is the only start up to count among the leaders, where it ranks number one (figure 4.13). The company's clout is confirmed at international scale since once again it features among the most active companies in the area (figure 4.14). This emerging domain required years of initial research in order to develop the enzymatic recycling process. It is therefore not surprising that Carbios was able to make its mark after a long, fruitful collaboration with the CNRS, Inrae and Insa. This scientific risk-taking probably dissuaded large companies from taking the plunge.

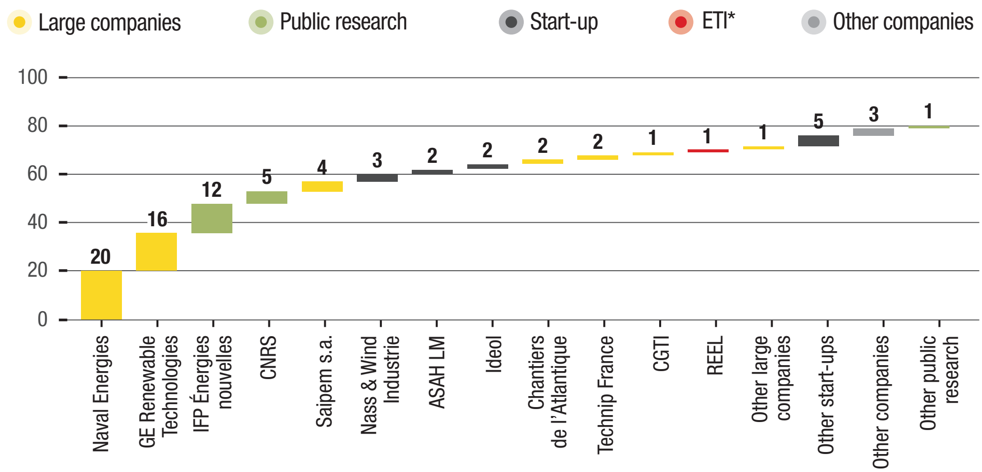
In the other two cases, however, French start-ups stand out for their inventive activity in domains neglected by large companies. As seen above, French companies and their foreign homologues have drastically reduced their innovative activity in the photovoltaics domain. They are also not very present in the offshore wind power domain. In addition, they do not feature at all among the main global applicants (figures 4.11 and 4.12) where large companies dominate (even though not with the same level of concentration of patents in the hands of a dozen leaders as in the two preceding examples). Here once again, we can presume that start-ups do not figure among the leaders because large US, Japanese and Chinese companies do not leave them room to do so.

Figure 4.9 – Breakdown of French patent families – Photovoltaics



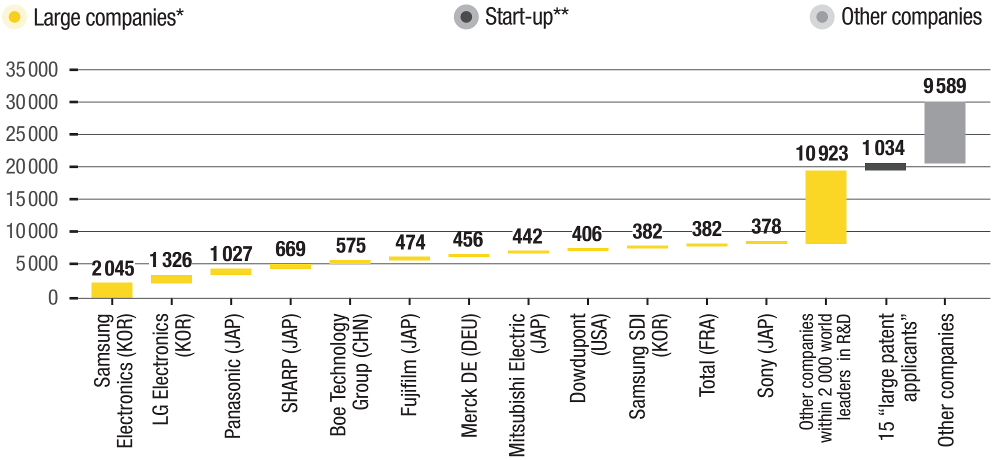
Source: Sirene. Processing: OST and La Fabrique de l'industrie.
NB: To illustrate the Mark II regime here we take the case of technologies in which large companies are over-represented among the leaders and alone own more than half of the patent families held in France.

Figure 4.10 – Breakdown of French patent families – Offshore wind power



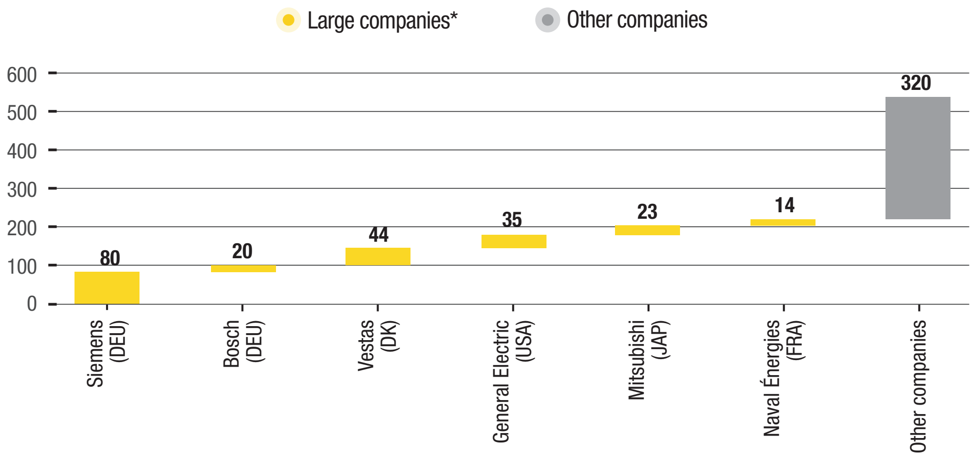
Source: Sirene. Processing: OST and La Fabrique de l'industrie.
** Mid-sized company*
NB: To illustrate the Mark II regime here we take the case of technologies in which large companies are over-represented among the leaders and alone own more than half of the patent families held in France.

Figure 4.11 – Breakdown of international patent families – Photovoltaics (exc. public research)



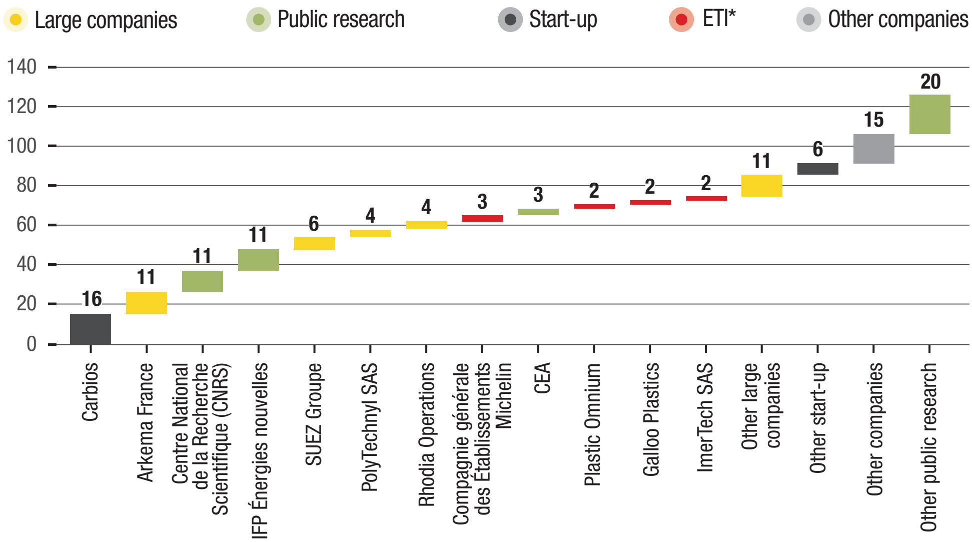
Source: Patstat et Cor&Dip (2021). Processing: OST and La Fabrique de l'industrie.
** Large companies correspond to "historical leaders", i.e. the 2 000 large companies leaders in R&D.*
***Start-ups correspond to "large patent applicants" (companies which file a lot of patents but are not the "historical leaders", therefore certainly start-ups or at least challengers).*

Figure 4.12 – Breakdown of international patent families – Offshore wind power (exc. public research)



Source: Patstat et Cor&Dip (2021). Processing: OST and La Fabrique de l'industrie.
** Large companies correspond to "historical leaders", i.e. the 2 000 large companies leaders in R&D.*

Figure 4.13 – Breakdown of French patent families – Biological plastic recycling

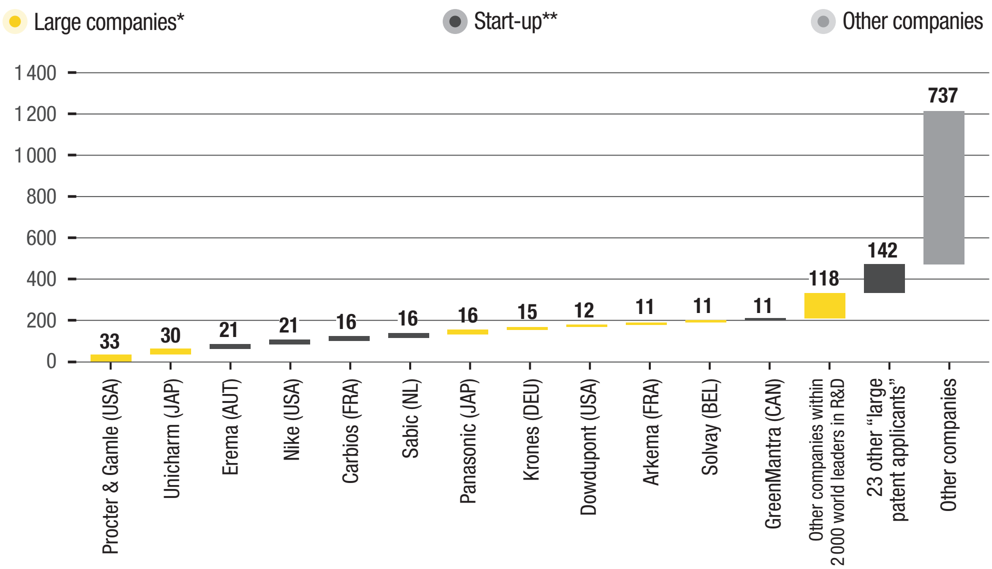


Source: Sirene. Processing: OST and La Fabrique de l'industrie.
** Mid-sized company*
NB: To illustrate the Mark II regime here we take the case of technologies in which large companies are over-represented among the leaders and alone own more than half of the patent families held in France.

– When a notable share of patents does not come from start-ups, or big historic leaders: mRNA, nanoelectronics

In France, more than elsewhere, public research takes a leading position in a number of domains. Its dominant position is particularly striking in the mRNA domain since it takes the first twelve places in the ranking of French applicants and generally owns over 90% of the patents filed in France (figure 4.15). This is therefore a second difference affecting the two Schumpeterian archetypes, since it cannot be qualified as either Mark I or Mark II. The low innovative activity of large companies does not necessarily indicate a massive presence of start-ups, far from it. The same can be said for the nanoelectronics domain, where the two leading applicants, the CEA an CNRS, are at the origin of almost half of the patent applications

Figure 4.14 – Breakdown of international patent families – Biological plastic recycling (exc. public research)

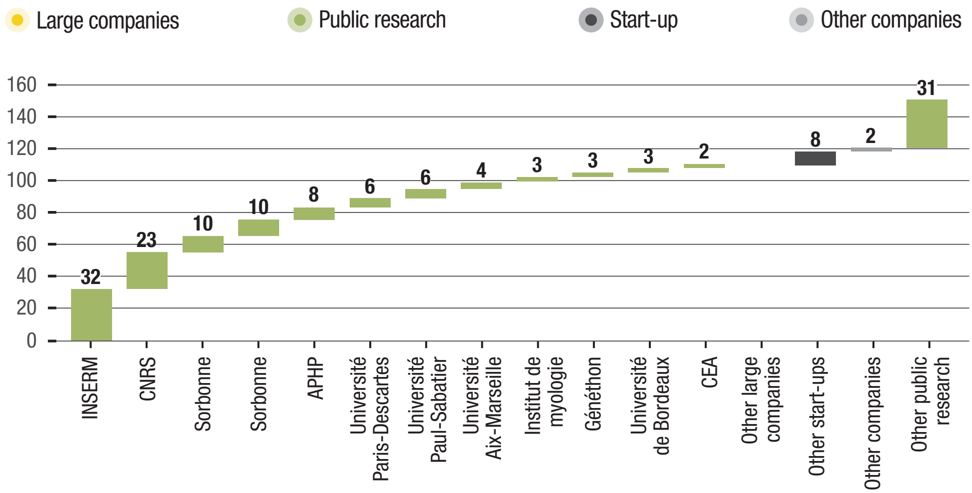


Source: Patstat et Cor&Dip (2021). Processing: OST and La Fabrique de l'industrie.
** Large companies correspond to "historical leaders", i.e. the 2 000 large companies leaders in R&D.*
***Start-ups correspond to "large patent applicants" (companies which file a lot of patents but are not the "historical leaders", therefore certainly start-ups or at least challengers).*

in France (figure 4.16). If we extend the analysis to include all French universities and laboratories, public research represents three-quarters of patent applications.

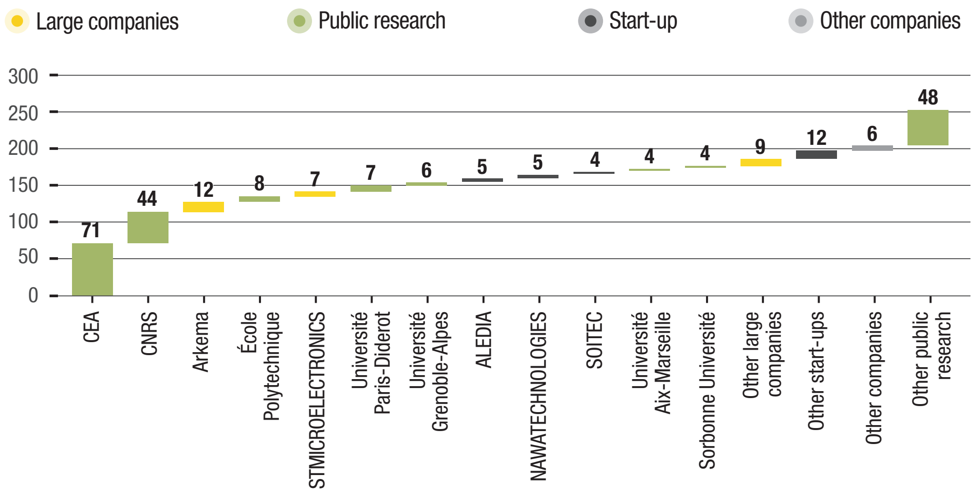
As we have seen above, the United States is the leader in these two domains and has also seen the proportion of its laboratories and universities decrease considerably to the benefit of companies over the last decade. The same is not at all true for France, where the specific inertia of French companies is particularly obvious. In the nanoelectronics domain, large companies appear very timid alongside the US and Asian giants whose domination was starkly obvious during the semi-conductor shortage in the first half of 2021. For the messenger RNA domain, the global ranking (figure 4.17) suggests that France is finding it difficult to help its start-ups grow.

Figure 4.15 – Breakdown of French patent families – mRNA



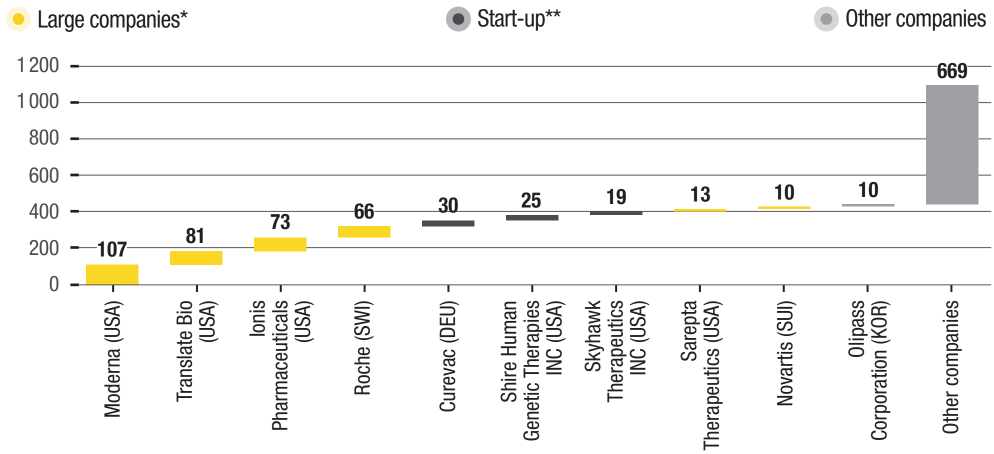
Source: Sirene. Processing: OST and La Fabrique de l'industrie.
NB: To illustrate the Mark II regime here we take the case of technologies in which large companies are over-represented among the leaders and alone own more than half of the patent families held in France.

Figure 4.16 – Breakdown of French patent families – Nanoelectronics



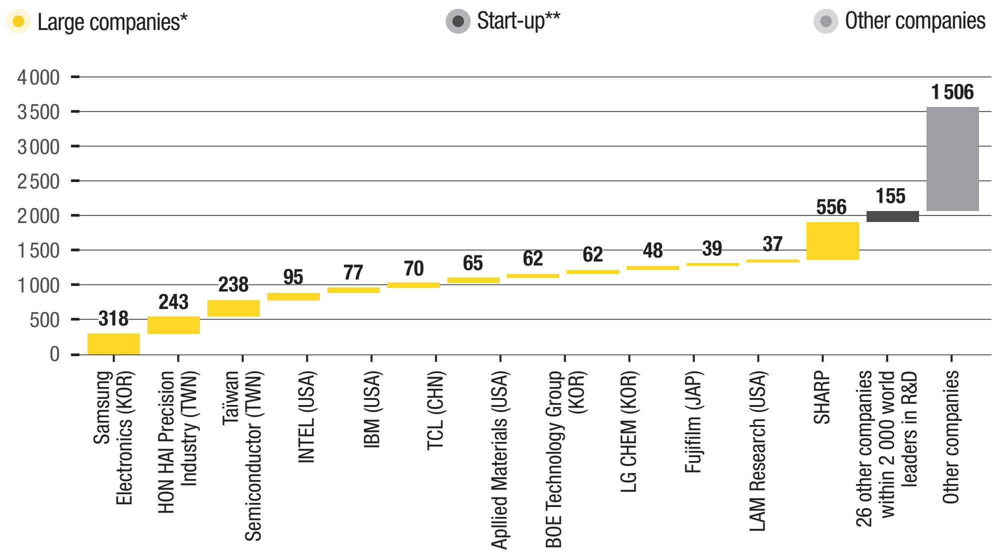
Source: Sirene. Processing: OST and La Fabrique de l'industrie.
NB: To illustrate the Mark II regime here we take the case of technologies in which large companies are over-represented among the leaders and alone own more than half of the patent families held in France.

Figure 4.17 – Breakdown of international patent families – mRNA (exc. public research)



Source: Patstat et Cor&Dip (2021). Processing: OST and La Fabrique de l'industrie.
** Large companies correspond to "historical leaders", i.e. the 2 000 large companies leaders in R&D.*
***Start-ups correspond to "large patent applicants" (companies which file a lot of patents but are not the "historical leaders", therefore certainly start-ups or at least challengers).*

Figure 4.18 – Breakdown of international patent families – Nanoelectronics (exc. public research)



Source: Patstat et Cor&Dip (2021). Processing: OST and La Fabrique de l'industrie.
** Large companies correspond to "historical leaders", i.e. the 2 000 large companies leaders in R&D.*
***Start-ups correspond to "large patent applicants" (companies which file a lot of patents but are not the "historical leaders", therefore certainly start-ups or at least challengers).*

– When start-ups and public research act together: spintronics

Graphs 4.19 and 4.20 show that, in the spintronics domain, the structure of patent applications in France is very different from what can be observed at global level. While major Japanese, Korean and US companies are at the top of the global rankings, in France the spintronics domain is dominated by a small number of start-ups, with large companies only representing a very small number of applications (9%). The French start-up Crocus Technology alone owns 35% of all of the French patents. French public research also plays a key role since, here once again, the CEA and CNRS are in the top three and are also at the origin of 35% of patent applications in the domain. In particular, when looking at the origin of the two leading start-ups in the ranking (Crocus Technology and Antaios), we can see that both of them were established as spin-offs of the French public laboratory Spintec. It is thus striking that public research not only owns a significant share of the patents, but that it is at the origin of the rare start-ups present in the domain. In other words, when it comes to spintronics in France, public research is pioneering, progressively making way for companies that directly spun from it. The global spintronics activity, however, tends to be dominated by large companies, featuring two start-ups.

Consolidated proposal

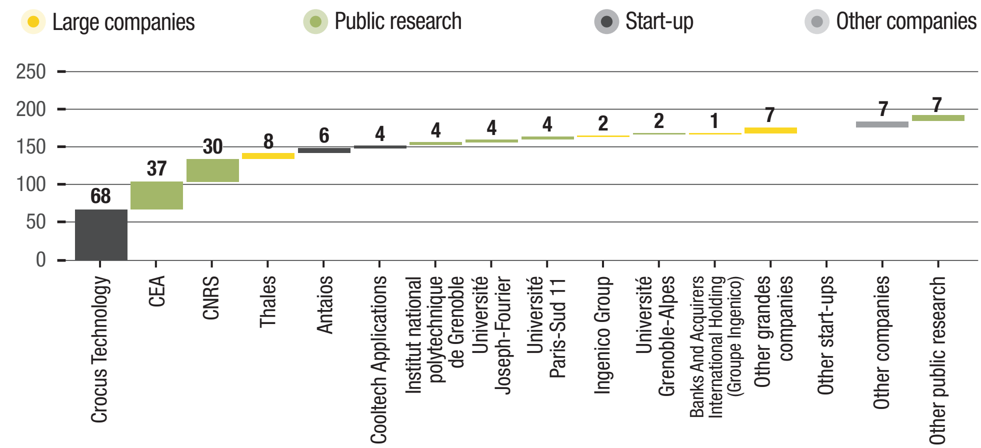
In France and internationally, start-ups rarely feature among the main patent applicants concerning disruptive innovations. When they are among the leaders, they rank alongside large companies or public research, from which they are sometimes spin-offs.

Messenger RNA appears to be the only exception to this “rule”, since US start-ups currently feature strongly among the first applicants. For the moment, this only concerns the United States: France, similar to other European and Asian countries, does not appear capable of propelling its start-ups to the top of the global innovation rankings.

Large French companies often take the top places in the French patent application rankings. However, their efforts are moderate on a global scale, and they often appear to be overtaken by much more active “giants”.

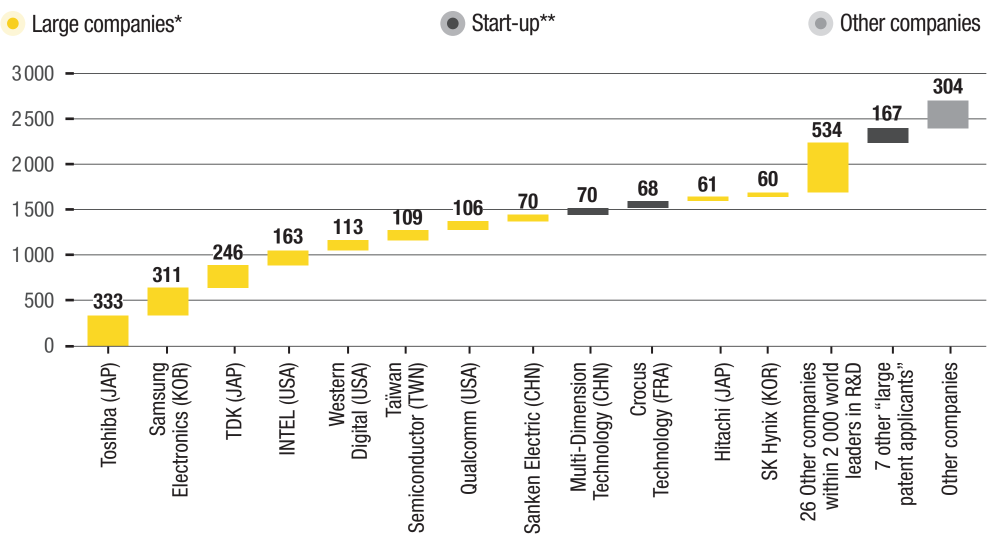
In addition, public research in France is at least as important as large companies in driving disruptive innovations. The CEA or CNRS (sometimes both of them) often feature among the top three French patent applicants. Public research is even sometimes the only master on board: in the domains of mRNA, nanoelectronics and spintronics, innovation is almost exclusively the fruit of research activity at public laboratories and universities.

Figure 4.19 – Breakdown of French patent families – Spintronics



Source: Sirene. Processing: OST and La Fabrique de l'industrie.
NB: To illustrate the Mark II regime here we take the case of technologies in which large companies are over-represented among the leaders and alone own more than half of the patent families held in France.

Figure 4.20 – Breakdown of international patent families – Spintronics (exc. public research)



Source: Patstat et Cor&Dip (2021). Processing: OST and La Fabrique de l'industrie.
** Large companies correspond to "historical leaders", i.e. the 2 000 large companies leaders in R&D.*
***Start-ups correspond to "large patent applicants" (companies which file a lot of patents but are not the "historical leaders", therefore certainly start-ups or at least challengers).*

Successfully coupling the “locomotives” with the “wagons”

Acquire or invest: two possible ways to bring start-ups and large companies closer

The division of roles between start-ups and large companies, in domains identified as disruptive innovations, is therefore not as schematic as the Mark I and Mark II theoretical models suggest. Between the first archetype, where impetuous challengers end up overthrowing ageing leaders, and the other, where they have no rightful place, numerous hybrid configurations in fact exist. Start-ups are not always the only way to bring disruptive innovations onto the market, or even to large companies, but they nearly always need large companies to play a significant role. Big firms also generally have everything to gain by collaborating.

The accepted form of this kind of association is no doubt the acquisition of a start-up by a large company. Large companies follow a pattern of observing young firms with the aim of buying out the most promising ones at the right moment. This opportunistic strategy is widely accepted in the pharmaceutical sector. In particular in the Medtech[34] domain, large firms put start-ups at the heart of their innovation strategy. These start-ups often sprang from public research in order to capitalize on results and put the next phases in place, such as clinical trials. They are ultimately bought out by large companies that have considerable financial means to roll out their solutions on a large scale. According to François Breniaux, partner at Supernova Invest, “*In the Medtech domain, large companies are in a position to buy out start-ups at a very high price because the product, already validated by clinical trials, offers near-fool-proof opportunities on markets that it is very familiar with.*”

The arrival of biotechnology profoundly changed the way that drugs and vaccines are now developed, compared to a time when pharmaceutical innovation was based on chemistry. While knowledge could at the time be easily internalized within large pharmaceutical groups, the much more complex development of molecules from biological processes led to the massive use of start-ups created on the base of public research results. For financial and availability reasons, large firms cannot explore the multitude of molecules that could potentially give birth to a future drug. They prefer to let start-ups specialize in this exploration and then select the most interesting ones.

Symmetrically, due the increasingly strict requirements of health authorities, start-ups cannot work alone to carry out clinical trials, which are extremely costly.

34. According to the Bpifrance definition, Medtech “groups all technologies aimed at the care environment and can designate an online appointment website, an artificial organ or a surgical robot”.

These start-ups therefore often try to be bought out when they are still in an upstream stage of development. According to Clotilde Jolivet, director of Government and Public Affairs at Sanofi, "*Biotech managers anticipate being bought out in their economic model. Some of them are serial entrepreneurs who create a new biotech as soon as the previous one has been purchased by a large group.*"

This state of mind is not restricted to the pharmaceutical sector. The interviews carried out for this study confirm that the aim of a start-up is either to enter the stock market, which is very rare, or to be bought out by a large company. Venture capital investment funds often themselves put pressure on the founders to encourage them to sell their business. In most cases, the purchaser is a big company (Revol and Piet, 2021).

Involving less commitment than a pure and simple acquisition, one way for large groups to directly participate in innovating start-ups is to increase their stake, in particular in the form of corporate venture capital (CVC) (Granier, 2021). A recent study by the Boston Consulting Group (2022) identifies three types of CVC: those relating to a long-term commercial relationship, similar to the commercial and operational synergies between Verkor and Renault; those relating to a pure capital investment; and more strategic CVCs that aim to follow major trends.

For start-ups, the presence of a large group in their capital brings some advantages, the main one being to be able to benefit from the force of its network in order to develop. This was the case for the start-up Carbios, a pioneer in enzymatic recycling of plastic. Thanks to the investment funds of large groups (including L'Oréal and L'Occitane), Carbios not only benefited from significant financial support to industrialize and commercialize its process, but also from commercial opportunities, such as responding to a growing call for sustainable packaging from large consumer goods companies. In June 2021, L'Oréal announced the development of its first fully recycled plastic bottle using Carbios technology, scheduled for production in 2025 (L'Oréal, 2021). The story is similar for the start-up Verkor, in which the Renault group holds a share of over 20%. Going further than a simple shareholder, Renault Group has signed a purchasing contract with Verkor that means it can produce sufficient volumes to build a Gigafactory in Dunkerque, including the creation of 1,200 direct jobs and 3,000 indirect jobs.

Difficulties can sometimes arise when large groups are not clear about their different strategies. According to the interviews we carried out, along with a return on their investment, some large companies expect the start-ups that they invest in to obey a kind of non-competition clause obliging them to keep some contracts with the group or deprive themselves

Sanofi's strategy to get back into the messenger RNA race

Specialized in recombinant proteins, the Sanofi group decided in 2018 to enter into an exclusive partnership with the US biotech Translate Bio, which specializes in messenger RNA technologies. Initially turned towards serious respiratory diseases such as cystic fibrosis, Translate Bio took advantage of a contract that could amount to as much as 805 million dollars in the case of total success, to develop mRNA vaccines to inoculate against different infectious diseases. According to the Sanofi group itself, the collaboration with Translate Bio aimed to pool both parties' knowhow and skills: Sanofi thanks to its experience as a leader in the vaccine domain, and Translate Bio for its research and development aimed at producing mRNA therapeutics.

When the coronavirus pandemic broke out in 2019, the scope of the agreement was extended, including a potential financial envelope of 1.9 dollars to develop a vaccine against Covid-19. Two clinical trials resulting from this partnership were underway, one for Covid and the other for seasonal influenza.

In order to accelerate the application of mRNA for developing vaccines, Sanofi finally bought out Translate Bio for 2.7 billion euros in late 2021. This purchase was in line with the company's wider strategy aimed at catching up with its competitors, and even becoming a leader in mRNA technologies, at a time when Pfizer and Moderna seemed to have gained an advantage during the health crisis. Sanofi has since created other synergies with the US biotech Tidal Therapeutics, specialized in research based on mRNA applied to cancer treatments, and in 2021 decided to finance a centre specialized in mRNA-based vaccines at two sites in Cambridge and Marcy-l'Etoile. This investment amounts to 400 million euros a year until 2025.

of business opportunities. Based on a survey of thirty people working at major groups, the BCG (Boston Consulting Group) study mentioned above shows that two-thirds of large groups questioned expect their collaboration with start-ups to bring them commercial synergies. A return on investment is also mentioned as one of the main expectations, but to a lesser extent (54%). These complementary expectations, combined with those of "classic" investors, can sometimes hold back the start-up's expected growth by preventing it from targeting new markets.

Large companies maintain cautious relationships with French start-ups

A report by the association Cleantech for France (2022) underlines the modest role played by French CVC funds in investments in innovative start-ups aiming to decarbonize industry (cleantechs). On the one side, the authors point out that no CVCs feature among the fifteen leading investors in French cleantechs, whatever the origin. On the other side, and in contrast, among the French CVCs, only the Via ID investment fund of Mobivia – which groups Norauto, Midas and ATU – stands out, with seventeen transactions made in France and twenty-three elsewhere in the world from 2017-2021 (figure 4.21). The other French CVCs made fewer than five operations over the same five years, and mostly invested abroad.

This reticence of large French groups to increase their investments in French start-ups is also apparent to Pascale Boulanger, founder of the start-up NAWA technologies, in his domain of energy storage. He points out that large French and European groups prefer to invest in US start-ups, even though firms like NAWA technologies "*do just as well terms of technology*". According to Boulanger, this preference can be put down to two factors. On the one hand, CVCs, which earn their money from the appreciation of their invested capital, are more likely to see the capital value of a US start-up increase thanks to easier access to the stock exchange. On the other hand, rigid dismissal laws in France and Europe, and in particular the difference in restructuring costs between France and the United States, appear to constitute a significant deterrent to investing in French start-ups. A recent note published by the Institut Montaigne (Babinet and Coste, 2022) supports this hypothesis with the observation that the factors that penalize Europe in terms of digital development include restructuring costs, which amount to €200 K per person for an R&D team in continental Europe compared to almost nothing in the United States, China and India. According to the authors, these costs do not encourage large groups to invest in Tech in Europe and thus prevent European start-ups from reaching a size comparable to that of the US and Chinese leaders.

Whatever the case, collaborations between large companies and start-ups are not always easy given the differences in organization, governance processes, culture and relationships of power (Deshayes, 2021). Nevertheless, it is in this area that progress needs to be made.

Figure 4.21 – Investments of French CVCs in numbers of operations from 2017 to 2021

Investor	France	World
Via ID de Mobivia	17	23
Suez Ventures	4	8
Total Carbon Neutrality Ventures	3	32
Renault	3	–
Safran	3	4
Schneider Electric	3	21
Air Liquide	3	5
Saint-Gobain	2	11
EDF Ventures	2	5
Engie New Ventures	1	21

Source: Cleantech for France (2022).

POINT OF VIEW

Christophe Deshayes is a researcher at the École de Paris du management where he runs a seminar on digital and entrepreneurial transformation. He is also co-director of the chair Phénix – Grandes entreprises d'avenir [major companies of the future] (Mines Paris – PSL).

Entrepreneurial innovation: a new frontier?

Everyone talks about innovation as if it is a given, yet it is one of the most ambiguous notions in the economic world. It is not enough to underline the difference between disruptive innovation and incremental innovation or technology and usage. In fact, there are dozens of different types of innovation. New types regularly emerge, sometimes with a power for change on a level with disruptive technology innovations. For example, in the 2010s, Orange, like two of its competitors present in Africa, successfully diverted the USSD norm to create a new industry: mobile money. As a result, Orange attracted 40 million African clients to its new service. It involved bringing together frugal innovation, twisted usage, and an innovative distribution network to produce a powerful disruption of the banking market.

Large companies are not only the uncontested champions of patent applications, they are also active in all kinds of innovation. Which means that innovation is not restricted to start-ups. In fact, the innovation intensity of some digital start-ups can be questionable when their presentation boils down to something like: "We are the Uber or Airbnb of such and such a domain…", or when investors make a priority of positioning themselves on the "last mile" of innovation when most of the road was financed by others.

However, there is one type of innovation that is inherent to start-ups and not to large companies, and that is entrepreneurial innovation, which requires a pilot with an entrepreneur's mindset and a specific legal structure to take off (spin-offs, start-ups, intrapreneurships, excubated subsidiaries, etc.).

When large companies go back to their original entrepreneurial roots

Numerous large companies have launched different actions in an attempt to adopt an entrepreneurial innovation culture, like hackathons, learning expeditions, fab labs, etc. They also invest in start-ups or buy them, which often leads them to put together financial teams with a risk capital background, a new area for them. Others, or the same ones, have launched intrapreneur programmes, in which selected, generally young volunteers work for a few months on an innovative project with an entrepreneurial spirit, without the personal financial risk. They develop their projects in incubators where they sometimes work alongside creators from start-ups supported by the company. In reality, large companies have launched so many initiatives that they have organized them to make them internally and externally visible. These gateways include for example ENGIE Fab (Engie), Gardens (Orange), NOVA (Saint-Gobain), Leonard (Vinci), VIA (Veolia), and Village by CA (Crédit agricole).

Large companies attempt in this way to adopt the methods and imagination of start-ups, but their issues and pace are very different. In start-up ecosystems, the idea is that you must succeed in nine months or die. This is totally illusory for large companies; moreover, the intrapreneur success stories put forward are all over three years old. A start-up has to find its place to justify its existence, whereas a large company has to reinvent itself to stay at the top; these are very different mindsets.

Whereas start-ups begin with an initial idea, the white page (type-1 method), corporate innovations often begin with knowledge of a market or the ambition to redesign existing assets to bring additional value to customers and therefore to the assets in question (type-2 method). This type of project does not involve growing a tree from a seed planted in the soil, as suggested by the Schumpeterian principle of creative destruction, but rather growing a second layer of trees on an existing tree, like in the ancient technique of Daisugi (pruning of cedars in Japan).

Almost all large companies can now showcase examples of viable intrapreneur start-ups that have often become part of their business units (type 1). However, they have difficulties upscaling them. These still-modest successes have significantly modified their managerial culture, but not yet their strategic situation. Yet some large companies have had bigger type-2 successes, like Danone, with its organic brand Les Deux Vaches. Another example is Casino, which in summer 2022 partially transferred its intrapreneur subsidiary GreenYellow, which installs and operates solar panels all over the world on the roofs of the group's stores and those of its competitors, while optimizing their energy consumption. The transfer price, amounting to 1.4 billion euros, to our knowledge makes this the first entrepreneurial start-up to attain unicorn status.

Therefore, to reinvent themselves through entrepreneurial innovation, large companies can use one of two methods: transpose the start-up method into their activity (type 1), or develop a specific method, based on an opportunity identified by the company itself, and developed by an intrapreneur selected for their capacities and capable of interconnecting existing assets in a different way (type 2). For these large innovative companies, the term "phoenix" is almost more appropriate than "unicorn" for start-ups with high potential.

CONCLUSION

In the last few years, much has been said about the idea of regaining our technological sovereignty and reindustrializing the country. These two objectives regularly feature in political speeches in France and Europe. Yet this ambition to make "*Europe a power in the world, totally sovereign and master of its destiny*"[35] seems more like a mantra given how far behind both France and Europe are in mastering major technological developments. Asia and the United States appear much more determined to win the technological battle.

This is in any case the first lesson that we draw from the analysis of patents that was part of this study. In the technological domains taking part in the energy and digital transition, France and Europe are at the bottom of the global competition rankings. Of course, some European countries do stand out, like Germany, which is among the leaders in half of the domains studied. Similarly, Denmark, Finland and the Netherlands are well positioned in the fields of sustainable aviation fuel and offshore wind power. Overall, though, this is little consolation, since the podium is systematically occupied by the same countries: the United States, China, Japan and South Korea.

It is also true that a statistical realignment tends to show the European Union as a global leader for these technologies. However, firstly, the EU almost never owns more than half of the patents for a given domain, unlike the United States. Secondly, we must not forget that the Union relies very little on the contribution made by French innovators, who never rank among the leaders. Thirdly, in some domains, Korea or Japan alone manage to compete with the entire European Union, showing that their technological strategy is much more combative than the strategies of the 27 European Member States. Lastly, this statistical aggregation only really makes sense if the associated public policies are also devised at Community level, which is not wholly the case.

While Europe puts forward its strong, even torch-bearing engagement in the fight against climate change, including a number of policies aimed at reducing carbon emissions

35. Speech made by Emmanuel Macron at the press conference for the French presidency of the European Union, 9 December 2021.

by 2050, it appears to have little involvement in developing new technologies, which are nevertheless the pillars of the low-carbon energy transition.

Another significant result of this study is the dominance of companies among patent applications when it comes to disruptive innovation. Consequently, the lagging behind of European countries, considered separately, seems initially to come from the difficulty of their companies to propose innovative solutions to the market. A more detailed analysis of French data in fact suggests that public research is sometimes the only patent applicant, and that companies have trouble taking the lead.

While much has been written about the incapacity of France to foster innovative start-ups, the idea of the decisive role that they could play in the emergence of disruptive innovations is negated by the data: they rarely figure among the main patent applicants. Without doubt, start-ups do stand out in some areas, such as photovoltaics, biological recycling of plastic and messenger RNA. Their success is in fact often the result of a fruitful collaboration with public research, which they often sprang from.

Some cases exist (in certain countries or domains) where companies maintain their innovation effort without being spurred on by competition from start-ups. In other cases, start-ups enter into direct competition with them. However, we cannot find a significant case where start-ups successfully dominate a technological race that large companies have decided not to pursue. When big companies give up the race, the ecosystem becomes more fragile and the start-ups are the first ones to suffer. Thus, their strategy sometimes boils down to mobilizing existing technologies in order to quickly (re)constitute an offer capable of rivalling Asian and US competitors, rather than developing their own technologies. Only public research can then easily survive, which is not necessarily an ideal situation.

Lastly, the observations made in this Note bring a remIndiar, if necessary, of the importance of ambitious innovation policies aimed at some domains judged to be strategic. In fact, if economies are to remain at or return to the technological frontier while tackling the planetary challenges of the moment, they must anticipate the most promising new technologies or products, and therefore supplement transversal measures to support innovation aimed at all sectors. The fourth Investment for the Future programme (PIA 4) fits in with this approach. Unlike previous versions of the PIA, it adopts a so-called “directed” innovation line, aimed at accelerating innovation in priority sectors and technologies thanks to “exceptional” financing amounting to 12.5 billion euros over five years (out of an anticipated 54 billion). It is difficult to predict today the outcomes of these efforts, in terms of market shares on new products for example, or even patent applications.

However, we cannot expect companies alone to invest the right amount at the right time in highly technological domains with considerable barriers to entry. In a world led by very powerful actors, where moving upmarket too slowly leads to an industrial and technological downgrade, the state plays centre stage.

Bibliography

Arrow, K. J. (1962). Economic welfare and the allocation of resources for invention. In *The Rate and Direction of Inventive Activity. Economic and Social Factors.* National Bureau of Economic Research. Princeton University Press (pp. 609-626). https://www.degruyter.com/document/doi/10.1515/9781400879762-024/html?lang=en

Autret, F. (2001). L'innovation technologique en Germany : performances et limites d'un système. *In* I. Bourgeois (dir.), *Germany 2001. Regards sur une économie en mutation* (pp. 39-58). CIRAC. http://books.openedition.org/cirac/845

Babinet, G., & Coste, O. (2022). *Technologies numériques : comprendre le retard croissant de l'Europe en huit graphiques.* Institut Montaigne.

Beffa, J.-L. (2017). *Se transformer ou mourir. Les grands groupes face aux start-up.* Éditions du Seuil.

Bellit, S. (2021). *Politique industrielle en réponse à la crise : Le retour de l'État pilote.* Les Synthèses de La Fabrique, Le Cube, vol. 11.

Binois, É. (2022). *Public research et entreprises : une coopération à renforcer.* Les Synthèses de La Fabrique, Le Cube, vol. 20.

Boston Consulting Group (2022). *Corporate Venture Capital et startups : comment prolonger le coup de foudre ? Les clés d'une association réussie.* BCG - RaiseLab.

Bpifrance (2019). *Génération Deeptech.* https://fr.slideshare.net/Bpifrance/generation-deeptech

Bpifrance & France Digitale (2021). *Mapping des start-up à impact* [Carte].

Breschi, S., Malerba, F., & Orsenigo, L. (2000). Technological regimes and schumpeterian patterns of innovation. *The Economic Journal*, vol. 110, n° 463, pp. 388-410.

CEA (2020). *Rapport financier 2020*. CEA.

Christensen, C. M. (1997). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail.* Boston: Harvard Business School Press.

Christensen, C. M., & Raynor, M. E. (2003). *The Innovator's Solution: Creating and Sustaining Successful Growth.* Boston: Harvard Business School Press.

Cleantech for France (2022). *Décarbonation, réindustrialisation et souveraineté verte en France. Zoom sur 13 domaines technologiques d'avenir.*

CNRS Images (2008). Nanotubes de carbone. Notice n° 1967. https://images.cnrs.fr/video/1967

CNRS (2020). « La création d'entreprises, au CNRS, ça fonctionne ». https://www.cnrs.fr/fr/cnrsinfo/la-creation-dentreprise-au-cnrs-ca-fonctionne

Crifo-Tillet, P. (1999). *L'analyse de l'innovation dans les modèles de croissance endogène. 14-2,* 189-221.

Deshayes, C. (2021). Réconcilier David et Goliath à l'heure de la start-up nation. *La Gazette de la société et des techniques,* vol. 112.

Djelalian, J.-C., & Neale-Besson, I. (2006). La Commission autorise le régime de soutien français en faveur des programmes mobilisateurs pour l'innovation industrielle géré par l'Agence de l'innovation industrielle. *Competition Policy Newsletter*, n° 3, pp. 77-79.

Doche, A. (2013). Renault : la Zoe très en dessous des objectifs de vente de 2013 ? *Caradisiac*. https://www.caradisiac.com/Renault-la-Zoe-tres-en-dessous-des-objectifs-de-vente-en-2013-90163.htm

Dosi, G. (1982). Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change. *Research Policy*, vol. 11, n° 3, pp. 147-162.

Dupont-Calbo, J. (2021). La capitalisation de Tesla passe le cap des 1 000 milliards de dollars. *Les Echos*. https://www.lesechos.fr/industrie-services/automobile/tesla-passe-le-cap-des-1000-milliards-de-dollars-a-wall-street-1358283

Ergas, H. (1986). *Does Technology Policy Matter?* (SSRN Scholarly Paper 1428246). https://doi.org/10.2139/ssrn.1428246

Francois, V. (2015). Les dynamiques entrepreneuriales d'une spin-off universitaire en phase d'émergence et lauréate du concours BPI. *Revue de l'entrepreneuriat*, vol. 14, pp. 41-72.

Giget, M., & Hillen, V. (2021). *Pérennité, innovation et résilience des entreprises. Panorama mondial des entreprises historiques innovantes*. EICSI. https://www.decitre.fr/livres/perennite-innovation-et-resilience-des-entreprises-9782956461135.html

Granier, C. (2021). *Industrie et start-up : des destins liés ?* Les Docs de La Fabrique, vol. 14. Presses des Mines.

Hall, B. H. (2002). The financing of research and development. *Oxford Review of Economic Policy*, vol. 18, n° 1, pp. 35-51. https://doi.org/10.1093/oxrep/18.1.35

Hamon-Beugin, V. (2022, février). Verkor choisit Dunkerque pour implanter sa méga-usine de batteries, 1 200 emplois à la clé. *L'Usine nouvelle*. https://www.usinenouvelle.com/editorial/verkor-choisit-dunkerque-pour-implanter-sa-mega-usine-de-batteries-1-200-emplois-a-la-cle.N1780032

INPI (2021). *Rapport annuel 2021*. INPI.

INPI (2023). *Baromètre OEB 2022 : la France reste le deuxième Country le plus innovant d'Europe.*

https://www.inpi.fr/barometre-oeb-2022-france-deuxieme-Country-innovant-europe#

Landier, A., & Thesmar, D. (2014). *10 idées qui coulent la France* (nouvelle édition augmentée). Flammarion.

Larédo, P., & Mustar, P. (1994). Les institutions face aux stratégies des laboratoires de recherche. *Politiques et Management Public*, vol. 12, n° 2, pp. 99-114.

Larrue, P. (2023). *Répondre aux défis sociétaux : le retour en grâce des politiques « orientées mission » ?* Les Docs de La Fabrique. Presses des Mines.

Levin, R. C., Klevorick, A. K., Nelson, R. R., Winter, S. G., Gilbert, R., & Griliches, Z. (1987). Appropriating the returns from industrial research and development. *Brookings Papers on Economic Activity*, vol. 1987, n° 3, pp. 783-831. The Johns Hopkins University Press. https://doi.org/10.2307/2534454

L'Oréal (2021). Le premier flacon cosmétique en plastique issu du recyclage enzymatique. *Loreal.com*. https://www.loreal.com/fr/news/commitments/loreal-launches-the-first-cosmetic-bottle-made-from-recycled-plastic-with-carbios/

Mabille, V., & Neveu, A. (2021). *Demain, la Chine ouverte?* Les Docs de La Fabrique. Presses des Mines.

Malerba, F., & Orsenigo, L. (1995). Schumpeterian patterns of innovation. *Cambridge Journal of Economics*, vol. 19, n° 1, pp. 47-65.

Mansfield, E., Schwartz, M., & Wagner, S. (1981). Imitation costs and patents: An empirical study. *The Economic Journal*, vol. 91, n° 364, pp. 907-918. https://doi.org/10.2307/2232499

Martinage, X. (2022). Les Roadster se vendent à des prix record. *Capital*. https://www.capital.fr/auto/tesla-les-roadster-se-vendent-a-des-prix-record-1425200

Mines Paris - PSL (2022, octobre). *Quelles relations entre Public research et entreprises ? Les résultats d'une enquête nationale.*

Ministère de l'Enseignement supérieur et de la recherche, DGRI-DGESIP (2023). *L'État de l'Enseignement supérieur, de la Recherche et de l'Innovation en France*, n° 16. Ministère de l'Enseignement supérieur et de la recherche, Direction générale de la recherche et de l'innovation, Direction générale de l'enseignement supérieur et de l'insertion professionnelle. https://www.enseignementsup-recherche.gouv.fr/fr/l-etat-de-l-enseignement-superieur-de-la-recherche-et-de-l-innovation-en-france-90566

Mitterrand, F. (1982). Discours de M. François Mitterrand, Président de la République, clôturant les journées de travail sur la politique industrielle de la France, Paris, Maison de la chimie, 16 novembre 1982. https://www.elysee.fr/francois-mitterrand/1982/11/16/discours-de-m-francois-mitterrand-president-de-la-republique-cloturant-les-journees-de-travail-sur-la-politique-industrielle-de-la-france-paris-maison-de-la-chimie-mardi-16-novembre-1982

Narin, F., Carpenter, M. P., & Woolf, P. (1984). Technological performance assessments based on patents and patent citations. *IEEE Transactions on Engineering Management*, vol. EM-31, n° 4, pp. 172-183. https://doi.org/10.1109/TEM.1984.6447534

Nelson, R. (1959). The Simple Economics of Basic Scientific Research. *Journal of Political Economy*, vol. 67. https://econpapers.repec.org/article/ucpjpolec/v_3a67_3ay_3a1959_3ap_3a297.htm

Okubo, Y. (1997). *Indicateurs bibliométriques et analyse des systèmes de recherche : méthodes et exemples*. OCDE, n° 1997/01. Éditions OCDE. https://doi.org/10.1787/233811774611

Organisation mondiale de la propriété intellectuelle (2021). *Propriété intellectuelle : faits et chiffres de l'OMPI 2021*. OMPI. https://www.wipo.int/edocs/pubdocs/fr/wipo-pub-943-2021-fr-wipo-ip-facts-and-figures-2021.pdf

Ottmann, J.-Y. (2021). Manager la Public research : défendre l'indépendance, assurer la pérennité. *Annales des Mines - Gérer et comprendre*, vol. 145, n° 3, pp. 13-25. Cairn.info. https://doi.org/10.3917/geco1.145.0013

Park, M., Leahey, E., & Funk, R. J. (2023). Papers and patents are becoming less disruptive over time. *Nature*, vol. 613, pp. 138-144. https://doi.org/10.1038/s41586-022-05543-x

Pavitt, K. (1984). Sectoral patterns of technical change: Towards a taxonomy and a theory. *Research Policy*, vol. 13, n° 6, pp. 343-373. https://doi.org/10.1016/0048-7333(84)90018-0

Potier, B. (2020). *Faire de la France une économie de rupture technologique. Soutenir les marchés émergents à forts enjeux de compétitivité*. Rapport aux ministre de l'Économie et des Finances et ministre de l'Enseignement supérieur, de la Recherche et de l'Innovation.

Revol, M., & Piet, J. (2021). *Rachat des start-up : des racines françaises, des ailes étrangères*. Les Docs de La Fabrique, vol. 15. Presses des Mines.

Robbins, C. (2022). *Invention, Knowledge Transfer, and Innovation*. National Science Foundation. https://ncses.nsf.gov/pubs/nsb20224

Silberzahn, P. (2015). *Relever le défi de l'innovation de rupture*. Pearson.

Sommazi, A. (2022). Pas encore né, l'avion régional 100 % électrique d'Aura Aero séduit déjà. *Le Monde*. https://www.lemonde.fr/economie/article/2022/10/16/pas-encore-ne-l-avion-regional-100-electrique-d-aura-aero-seduit-deja_6145988_3234.html

Appendix

Appendix 1: Method for analysing patents based on a sample of twelve disruptive innovations

Data used

The first stage of this analysis consisted in building a database listing patents filed from 2010 to 2019 by inventors in twelve European and non-European countries.

To do so, the Observatoire des sciences et techniques (OST) employed the Patstat database produced by the European Patent Office (EPO), which contains exhaustive data on patent applications made with the main national offices and two main regional offices, the European Patent Office and the World Intellectual Property Office (WIPO). In addition to its broad geographic scope, the advantage of the Patstat base is that it gathers patents into families that include patents filed by the same applicant regarding the same technology or invention. Patent applications are in fact often filed in several countries for the same invention. In addition, sometimes an initial patent application, known as a priority patent, is supplemented by extensions. Considering families of patents[36] rather than isolated patents therefore avoids duplications.

The next step involved removing patent families filed in a single office, in order to only retain families with extensions in at least two offices – including families only filed with the EPO or WIPO, which are gateways to a selection of offices. This distinction is based on the hypothesis that families of patents filed with more than one office are worth more, both in economic terms (a wider market) and technological terms (more expertise regarding innovativeness), than families that have only been filed in one office, the objective often being to protect a market with an ad *hoc* legal barrier.

36. The OST employed *docdb* familes as a unit for analysing patents. These *docdb* families are built by experts at the European Patent Office for Patstat and are not reproducible.

Identification of applicants

In order to characterize the applicants of patent families (companies, public administration, universities, individuals), the OST employed the typology featured in the Patstat database. However, the data published by Patstat only record the last patent applicant. Thus, the exploitation of data comes up against three main limitations. Firstly, the original patent owners may have disappeared from the database. Secondly, new patent owners do not always register the purchase of a patent since it is not obligatory to do so (it is usually done in cases of infringement litigation)[37].

Company mergers and acquisitions are not taken into account by the database, nor are financial connections between companies[38]. In addition, a lack of consistent spelling means that the names of some applicants require standardization[39].

In order to identify the activity of large groups for each of the twelve technologies studied, OST started by adding together the families filed by each parent company and its subsidiaries. It is possible that some mergers and acquisitions not made public may have escaped this accounting process. The large groups detected were then compared with the database Cor&Dip (2021), which provides information on the R&D activity, patents and trademarks of the 2,000 highest-performing R&D companies in the world.

Lastly, to better characterize French applicants, the patent families associated with them were matched with the Sirene database[40], which lists a range of information on French organizations, such as their company name, size, legal status, year of creation and NAF (nomenclature of French activities) code. The main objective of this matching was to distinguish large companies from start-ups, the latter being imperfectly defined as companies established for less than 15 years[41].

37. Although rare, sometimes financial organizations can end up owning a patent following a company buy-out.

38. For example, in the case of France, some patents are owned by Alstom, even though General Electric took control of its energy and network activities in 2015.

39. For instance, DCSN and DCNS Energy patents can appear despite the fact that the firm has changed its name to Naval Energy. Consequently, we can identify patents owned by all name variants.

40. Computerized system of the national inventory of companies and organizations.

41. As pointed out in a previous document published by La Fabrique de l'industrie (Granier, 2021), no precise or statistical definition of the term "start-up" exists.

Construction of a set of patents associated with a disruptive innovation

For each of the disruptive innovations in the sample, the patent families were first identified on the basis of their CPC (Cooperative Patent Classification) codes. Each patent request is in fact associated with one or several technological domains, defined by patent office experts and structured into an arborescent classification including sections, classes, sub-classes, groups and sub-groups. This classification therefore represents a very detailed arborescence that currently includes over 250,000 categories.

Note: a new sub-class, Y02, has been created to identify technologies and applications concerning climate change mitigation or adaption. This facilitated the identification of patent families corresponding to disruptive innovations related to the ecological transition (offshore wind power, for example).

In all cases, the corpus was defined in a very strict manner: patent families were only selected if at least one of their members was designated by the code of the domain in question. In order to identify promising technologies, key words indicated by La Fabrique de l'industrie (*cf.* figure 1.1) were then searched for within the resulting defined corpus.

Specific case of Chinese patents

China's innovation strategy has for a long time featured technology transfer through joint ventures, obliging foreign companies that want to set up in China to work together with a Chinese partner (Mabille and Neveu, 2021). In this way, Chinese companies have built up a legal arsenal that allows them to copy the intellectual property of Western companies free of charge. This practice was the driver of the development of the Chinese economy in the 2000s.

In numerous sectors, Chinese companies have reached the same level of industrial maturity as their foreign competitors. As a result, the Chinese economy is now less based on the imitation of products as on innovation. In the space of a few years, it has therefore established a legal framework aimed at protecting intellectual property, which strongly encourages Chinese companies to file patent applications.

China now tops numerous statistical rankings for patent applications, like that of WIPO (World Intellectual Property Organization, 2021). Does that mean that the country has become the global innovation leader? Taking the example of offshore wind, we can see that China's place varies considerably depending on the ranking criteria (*cf.* figure below).

In fact, depending on whether the patent families have been filed with one office or at least two, the hierarchy of the owners changes. In the first case, Asian countries, headed by China, are overrepresented: Chinese, Korean and Japanese addresses make up over 82% of global patent applications in the domain. Chinese addresses alone represent 48% of applications. In the second case, German, Danish and US companies emerge as the technological leaders in the domain.

If we consider that patent applications filed with at least two offices have a bigger economic and technological value than those filed with a single office, we can conclude that Chinese applicants are more likely to be involved in a market protection strategy than to be genuine technological leaders, which tends to overestimate their inventive activity.

Figure A.1 – Number of patent families according to number of patent offices, by country of patent holder (e.g. offshore wind, 2010-2020*)

Address of holder or applicant	Volume of applications			Percentages		
	2 offices or more	1 office	TOTAL	2 offices or more	1 office	TOTAL
China	62	863	**925**	6.6%	48.0%	**33.8%**
South Korea	52	494	**546**	5.5%	27.5%	**19.9%**
Japan	75	120	**195**	8.0%	6.7%	**7.1%**
Germany	128	73	**201**	13.6%	4.1%	**7.3%**
United States	104	58	**162**	11.0%	3.2%	**5.9%**
France	73	39	**112**	7.7%	2.2%	**4.1%**
United Kingdom	43	23	**66**	4.6%	1.3%	**2.4%**
Taiwan. Province of China	5	19	**24**	0.5%	1.1%	**0.9%**
Netherlands	80	18	**98**	8.5%	1.0%	**3.6%**
Norway	44	17	**61**	4.7%	0.9%	**2.2%**
Spain	66	13	**79**	7.0%	0.7%	**2.9%**
Denmark	125	10	**135**	13.3%	0.6%	**4.9%**
Poland	3	8	**11**	0.3%	0.4%	**0.4%**
Belgium	25	6	**31**	2.7%	0.3%	**1.1%**
Brazil	6	3	**9**	0.6%	0.2%	**0.3%**
Australia	5	2	**7**	0.5%	0.1%	**0.3%**
Canada	2	2	**4**	0.2%	0.1%	**0.1%**
Chile	17	2	**19**	1.8%	0.1%	**0.7%**
Italy	9	2	**11**	1.0%	0.1%	**0.4%**
Singapore	14	2	**16**	1.5%	0.1%	**0.6%**
Other	4	24	**28**	0.4%	1.3%	**1.0%**
TOTAL	**942**	**1798**	**2740**	**100.0%**	**100.0%**	**100.0%**

(*): the year 2020 is incomplete.
Source: Patstat. Processing: OST.

Appendix 2: Number of patent families per year by patent holder's address

Figure A.2 – Number of patent families per year by patent holder's address (hydrogen for transport, 2010-2019)

Address of applicant/ holder	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Japan	240	298	310	275	305	228	305	317	334	228	**2840**
USA	156	168	176	185	147	137	128	122	133	76	**1428**
South Korea	124	80	118	152	169	141	154	102	94	137	**1271**
Germany	107	117	145	110	137	99	101	123	155	145	**1239**
France	24	40	61	54	31	32	23	28	25	42	**360**
China	11	18	24	15	17	26	36	29	38	74	**288**
UK	22	20	16	32	13	25	18	18	11	31	**206**
Switzerland	18	15	15	10	10	9	10	7	5	4	**103**
Canada	12	7	10	8	9	11	9	9	5	6	**86**
Italy	8	7	10	8	3	2	4	3	11	8	**64**
Austria	2	6	2	3	5	4	8	14	10	11	**65**
Taïwan	9	6	7	9	5	6	9	4	3	1	**59**
Sweden	3	3	9	3	5	2	3	8	7	4	**47**
Belgium	2	2	5	2	3	6	5	4	7	6	**42**
Denmark	2	3	3	3	2	3	8	2	7	7	**40**
Netherlands	6	3	7	4	0	4	6	2	4	5	**41**
India	3	3	4	2	1	8	4	3	5	2	**35**
Israel	3	2	4	4	8	1	4	4	4	1	**35**
Finland	6	3	2	3	7	1	3	1	4	3	**33**
Spain	8	1	0	2	4	3	2	3	0	2	**25**
Australia	3	3	4	3	3	1	2	3	1	2	**25**
Total EU 28	190	205	260	224	210	181	181	206	241	264	**2162**
Global total (without double counting*)	**747**	**778**	**875**	**863**	**852**	**726**	**823**	**796**	**867**	**763**	**8090**

(*): since some patents are owned by several holders, the total number of patents per country by far exceeds the global number of patents.

Source: Patstat. Processing: OST.

Figure A.3 – Number of patent families per year by patent holder's address (batteries for electric vehicles, 2010-2019)

Address of applicant/ holder	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Japan	188	424	532	498	500	471	521	543	610	336	4623
South Korea	64	158	261	326	264	331	308	315	311	326	2664
Germany	36	155	230	208	269	225	226	333	385	347	2414
United States	55	89	138	166	249	225	241	230	251	250	1894
China	8	27	35	30	39	66	119	120	202	171	817
France	6	12	32	38	30	23	17	35	43	55	291
UK	0	1	10	20	12	19	9	17	19	45	152
Austria	1	10	4	10	11	3	4	25	17	16	101
Taiwan	1	9	6	7	3	4	16	9	21	10	86
Sweden	1	4	6	6	6	5	6	6	17	14	71
Canada	5	2	5	5	6	7	13	7	13	11	74
Italy	0	1	3	5	7	3	1	4	17	14	55
Switzerland	2	1	5	5	7	4	7	3	7	7	48
Belgium	0	1	2	2	4	4	9	3	2	6	33
Israel	0	1	4	2	5	1	2	6	3	1	25
Netherlands	0	0	2	2	0	2	4	1	3	7	21
Finland	0	0	1	6	3	3	0	1	6	2	22
India	0	1	1	1	1	4	1	1	6	3	19
Singapore	0	3	3	2	2	0	2	2	3	3	20
Australia	0	2	1	1	1	2	1	4	2	3	17
Spain	3	2	1	4	1	1	1	1	1	2	17
Total EU 28	47	186	291	301	343	288	277	426	510	508	3177
Global total (without double counting*)	358	830	1186	1278	1390	1368	1467	1626	1894	1591	12988

(*): since some patents are owned by several holders, the total number of patents per country by far exceeds the global number of patents.

Source: Patstat. Processing: OST.

Figure A.4 – Number of patent families per year by patent holder's address (photovoltaics, 2010-2019)

Address of applicant/ holder	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Japan	1395	1384	1089	947	839	819	765	687	558	438	**8921**
United States	1 033	912	811	657	550	565	448	386	421	336	**6119**
South Korea	564	642	553	550	500	510	703	576	617	504	**5719**
China	220	208	217	257	286	344	551	756	855	651	**4345**
Germany	543	545	445	332	308	258	223	221	200	155	**3230**
Taiwan	222	279	241	194	156	111	98	102	79	81	**1563**
France	158	186	162	163	130	122	111	96	107	86	**1321**
UK	75	61	69	63	61	68	58	59	61	35	**610**
Switzerland	54	67	83	52	51	72	58	52	49	42	**580**
Italy	84	113	77	68	50	35	42	40	38	37	**584**
Netherlands	71	58	50	48	48	43	49	50	37	55	**509**
Spain	53	52	41	42	31	32	17	42	31	31	**372**
Canada	63	51	45	33	24	33	33	29	30	26	**367**
Australia	35	27	25	28	27	29	23	22	33	28	**277**
Singapore	24	35	37	29	30	11	19	22	23	10	**240**
Israel	28	23	30	22	11	19	28	28	26	25	**240**
Belgium	34	36	36	29	20	21	15	14	14	12	**231**
Austria	20	27	27	22	26	20	9	14	15	13	**193**
India	9	21	14	17	11	14	22	22	19	16	**165**
Russia	5	9	11	10	10	4	8	7	16	2	**82**
Poland	1	6	6	6	8	13	5	6	13	9	**73**
Total EU 28	1 039	1 084	913	773	682	612	529	542	516	433	**7123**
Global total (without double counting*)	**4 662**	**4 652**	**3967**	**3522**	**3154**	**3153**	**3273**	**3248**	**3269**	**2667**	**35567**

(*): since some patents are owned by several holders, the total number of patents per country by far exceeds the global number of patents.

Source: Patstat. Processing: OST.

Figure A.5 – Number of patent families per year by patent holder's address (offshore wind power, 2010-2019)

Country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Germany	23	18	24	17	5	11	8	6	8	8	**128**
Denmark	9	10	12	10	6	5	9	11	18	26	**116**
United States	19	12	5	6	8	6	12	12	14	8	**102**
Netherlands	10	5	7	6	4	4	5	18	12	7	**78**
Japan	9	12	6	9	8	6	8	4	3	8	**73**
France	6	9	14	8	5	6	7	9	7	0	**71**
Spain	3	7	16	4	5	2	10	9	3	6	**65**
China	4	6	3	1	3	1	4	13	6	14	**55**
South Korea	3	6	6	6	6	4	3	10	1	6	**51**
Norway	4	7	4	2	0	3	3	2	4	12	**41**
UK	7	11	4	2	2	2	2	6	4	1	**41**
Belgium	4	1	2	0	1	1	0	4	10	0	**23**
Other EU 28 Member States	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	**12**
Other States	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	**53**
Total UE 28*	62	61	79	47	28	31	41	63	62	48	**534**
Global total (without double counting*)	**110**	**116**	**97**	**73**	**60**	**61**	**72**	**110**	**101**	**103**	**942**

(*): since some patents are owned by several holders, the total number of patents per country by far exceeds the global number of patents.

Source: Patstat. Processing: OST.

Figure A.6 – Number of patent families per year by patent holder's address (recycling of strategic metals, 2010-2019)

Address of applicant/ holder	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Japan	100	118	105	89	85	92	89	89	69	92	**928**
United States	83	68	65	69	68	80	51	71	58	48	**661**
China	34	29	45	36	45	50	87	79	99	121	**625**
Germany	52	53	48	44	39	39	44	37	40	35	**431**
South Korea	20	16	32	26	24	34	28	34	26	31	**271**
France	20	20	20	16	29	23	14	16	13	12	**183**
Canada	17	15	18	15	20	13	15	18	16	21	**168**
Australia	30	12	20	13	13	14	13	17	23	13	**168**
Finland	13	15	19	29	15	18	16	7	9	7	**148**
UK	13	7	10	18	13	11	9	8	12	9	**110**
Italy	11	6	9	11	7	11	11	4	15	11	**96**
Chile	4	5	7	7	11	11	5	7	9	13	**79**
Russia	12	10	6	13	10	7	6	4	2	6	**76**
Belgium	9	2	2	7	9	8	8	8	7	13	**73**
Austria	9	8	8	11	10	2	6	5	3	6	**68**
Switzerland	11	8	8	7	8	6	6	7	8		**69**
Netherlands	8	7	3	2	4	7	4	8	2	6	**51**
Total EU 28	135	118	119	138	126	119	112	93	101	99	**1160**
Global total (without double counting*)	**462**	**424**	**458**	**442**	**438**	**451**	**457**	**433**	**444**	**486**	**4495**

(*): since some patents are owned by several holders, the total number of patents per country by far exceeds the global number of patents.

Source: Patstat. Processing: OST.

Figure A.7 – Number of patent families per year by patent holder's address (sustainable aviation fuel, 2010-2019)

Address of applicant/ holder	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
United States	31	25	32	15	4	1	4	4	4	3	**123**
Finland	5	0	0	1	1	2	2	2	3	3	**19**
Netherlands	6	4	7	0	0	0	0	1	0	0	**18**
China	1	0	1	2	2	2	2	2	0	0	**12**
UK	2	2	2	1	0	1	1	0	0	3	**12**
France	1	5	0	0	1	3	1	0	0	1	**12**
Japan	1	3	0	2	2	0	1	1	1	0	**11**
Germany	1	1	0	2	3	1	1	0	0	1	**10**
Canada	1	3	1	0	1	0	2	0	0	0	**8**
South Korea	0	1	1	0	1	0	0	2	0	0	**5**
Brazil	3	0	0	0	0	1	0	0	0	0	**4**
Romania	0	0	1	3	0	0	0	0	0	0	**4**
India	0	1	1	0	0	0	0	0	0	1	**3**
Italy	0	0	0	1	0	0	0	0	1	1	**3**
United Arab Emirates	0	2	0	0	0	0	0	0	0	0	**2**
Argentina	0	0	1	0	0	0	0	0	0	0	**1**
Australia	1	0	0	0	0	0	0	0	0	0	**1**
Switzerland	0	0	0	1	0	0	0	0	0	0	**1**
Costa Rica	0	0	0	0	0	0	0	1	0	0	**1**
Greece	0	0	0	1	0	0	0	0	0	0	**1**
Liechtenstein	0	0	1	0	0	0	0	0	0	0	**1**
Total EU 28	15	12	10	9	5	7	5	3	4	9	**79**
Global total (without double counting*)	**44**	**42**	**40**	**29**	**14**	**12**	**15**	**14**	**10**	**13**	**233**

(*): since some patents are owned by several holders, the total number of patents per country by far exceeds the global number of patents.
Source: Patstat. Processing: OST.

Figure A.8 – Number of patent families per year by patent holder's address (nanoelectronics, 2010-2019)

Address of applicant/ holder	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
United States	122	168	155	163	127	155	152	165	110	118	**1435**
China	32	79	60	51	104	72	94	107	102	96	**797**
South Korea	57	76	70	68	65	92	88	74	82	88	**760**
Japan	76	58	48	71	94	49	59	70	80	101	**706**
Taiwan	31	78	61	51	85	53	66	79	53	42	**599**
France	25	25	23	16	9	14	10	14	13	4	**153**
Germany	21	21	13	11	19	15	10	13	13	9	**145**
UK	7	12	9	11	9	12	12	19	9	10	**110**
Netherlands	5	6	14	8	8	8	7	11	9	8	**84**
Sweden	5	7	6	9	9	2	6	2	1	2	**49**
Canada	7	7	3	5	5	4	4	4	11	1	**51**
Belgium	2	2	0	7	4	9	6	5	2	4	**41**
Singapore	3	8	5	5	4	1	4	4	1	4	**39**
Finland	3	3	6	3	5	4	8	2	1	5	**40**
Switzerland	1	1	1	5	1	8	4	4	5	3	**33**
Spain	3	0	5	3	2	1	2	1	10	4	**31**
Israel	4	6	4	2	0	3	2	2	4	4	**31**
Italy	2	3	2	3	7	6	2	4	0	3	**32**
Cayman Islands	0	1	3	7	3	3	7	2	4	1	**31**
India	2	1	3	1	3	0	1	5	2	1	**19**
Saudi Arabia	0	1	1	2	2	3	4	2	3	1	**19**
Total EU 28	73	79	78	71	72	71	63	71	58	49	**685**
Global total (without double counting*)	**387**	**502**	**460**	**478**	**504**	**493**	**523**	**541**	**489**	**498**	**4875**

(*): since some patents are owned by several holders, the total number of patents per country by far exceeds the global number of patents.
Source: Patstat. Processing: OST.

Figure A.9 – Number of patent families per year by patent holder's address (spintronics, 2010-2019)

Address of applicant/ holder	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Japan	119	103	91	71	79	69	99	123	108	67	**929**
United States	83	77	88	77	87	104	86	100	82	75	**859**
South Korea	26	44	42	58	54	46	50	46	35	51	**452**
China	9	25	11	15	20	16	14	24	29	50	**213**
Taiwan	5	11	21	9	5	15	6	25	50	32	**179**
Germany	17	17	18	13	13	20	7	16	14	12	**147**
France	16	21	17	10	16	12	5	5	19	5	**126**
Netherlands	4	9	8	9	8	18	1	6	5	4	**72**
Belgium	0	0	1	4	3	6	4	5	3	9	**35**
UK	1	1	4	0	1	3	3	6	3	6	**28**
Singapore	2	0	1	3	5	4	2	1	4	5	**27**
Switzerland	5	0	3	1	2	3	3	2	2	2	**23**
Italy	5	1	1	0	1	0	0	1	1	2	**12**
Israel	0	2	0	1	2	0	1	0	2	0	**8**
Bermudes	0	0	0	0	1	1	2	2	1	0	**7**
Russia	1	1	0	0	0	0	1	2	2	0	**7**
Austria	1	0	0	1	0	0	1	2	1	0	**6**
Spain	1	0	1	1	0	0	0	1	0	2	**6**
Cayman Islands	0	1	0	0	0	2	0	0	2	1	**6**
Sweden	0	1	0	1	1	1	1	0	0	1	**6**
Irlande	0	1	0	0	0	1	1	0	0	1	**4**
Total EU 28	45	51	50	39	43	61	23	42	46	42	**442**
Global total (without double counting*)	**289**	**310**	**297**	**268**	**294**	**307**	**285**	**343**	**355**	**313**	**3061**

(*): since some patents are owned by several holders, the total number of patents per country by far exceeds the global number of patents.
Source: Patstat. Processing: OST.

Figure A.10 – Number of patent families per year by patent holder's address (quantum computing, 2010-2019)

Address of applicant/ holder	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
United States	11	10	13	26	39	82	96	145	210	228	**860**
Japan	7	9	8	4	27	12	15	17	21	43	**163**
China + Cayman Islands*	1	4	3	10	10	11	13	14	22	32	**120**
Canada	2	1	3	9	5	12	22	7	18	23	**102**
UK	3	6	3	0	8	10	5	9	10	9	**63**
South Korea	1	4	6	3	6	8	8	6	9	10	**61**
Germany	2	0	2	3	3	5	2	3	7	13	**40**
France	2	1	0	4	3	2	0	8	14	8	**42**
Australia	0	1	3	3	3	3	1	0	10	3	**27**
Switzerland	0	0	0	1	5	4	3	1	1	5	**20**
Netherlands	0	1	0	0	1	2	4	6	1	6	**21**
Total EU 28	7	8	5	7	15	19	11	26	32	36	**166**
Global total (without double counting)**	**30**	**33**	**40**	**58**	**111**	**158**	**175**	**225**	**324**	**399**	**1553**

(*): the holding of the Chinese group Alibaba is located in the Caiman Islands. The patent families held by this holding have been added on to those identified in China.
(**): since some patents are owned by several holders, the total number of patents per country by far exceeds the global number of patents.
Source: Patstat. Processing: OST.

Figure A.11 – Number of patent families per year by patent holder's address (mRNA, 2010-2019)

Address of applicant/ holder	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
United States	49	83	63	80	67	75	90	90	110	130	**837**
Japan	15	17	22	15	18	24	20	20	12	25	**188**
South Korea	12	4	6	7	7	12	19	18	18	21	**124**
Germany	4	5	12	15	10	11	13	9	13	12	**104**
China	3	5	5	4	6	7	8	20	18	21	**97**
Switzerland	7	6	3	5	3	6	6	9	32	16	**93**
France	3	2	0	1	3	4	5	9	11	9	**47**
Netherlands	4	1	3	1	3	7	4	2	3	5	**33**
UK	2	4	6	3	3	3	1	5	4	1	**32**
Canada	2	1	1	2	2	1	5	3	5	5	**27**
Other EU 28 Member States	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	**71**
Other States	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	**50**
Total EU 28	13	12	21	20	19	25	23	25	31	27	**287**
Global total (without double counting*)	**115**	**132**	**125**	**137**	**127**	**156**	**178**	**195**	**237**	**265**	**1788**

(*): since some patents are owned by several holders, the total number of patents per country by far exceeds the global number of patents.
Source: Patstat. Processing: OST.

Figure A.12 – Number of patent families per year by patent holder's address (low-carbon steel, 2010-2019)

Address of applicant/ holder	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Japan	59	71	85	67	57	70	85	72	84	75	**725**
Germany	47	47	43	47	32	26	40	35	29	43	**389**
United States	31	28	30	34	33	39	38	44	38	35	**350**
China	10	9	13	10	11	15	36	33	41	68	**246**
South Korea	17	15	34	14	18	33	37	28	25	26	**247**
Austria	13	16	17	14	17	6	8	12	11	11	**125**
Italy	13	8	8	8	6	8	8	6	10	11	**86**
France	9	11	12	8	5	5	6	7	5	10	**78**
Canada	4	9	6	8	13	8	3	7	1	8	**67**
Australia	7	8	5	7	3	0	6	4	10	8	**58**
UK	8	6	5	4	9	5	6	5	3	7	**58**
Sweden	5	7	7	5	5	5	1	8	2	9	**54**
Finland	3	9	7	9	4	8	6	3	4	4	**57**
Switzerland	7	5	7	5	8	7	9	2	3	2	**55**
Other EU 28 Member States	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	**99**
Other States	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	**345**
Somme UE 28	98	104	99	95	78	63	75	76	64	95	**946**
Global total (without double counting*)	**245**	**273**	**290**	**272**	**252**	**277**	**319**	**280**	**299**	**350**	**3301**

(*): since some patents are owned by several holders, the total number of patents per country by far exceeds the global number of patents.

Source: Patstat. Processing: OST.

Figure A.13 – Number of patent families per year by patent holder's address (biological recycling of plastic, 2010-2019)

Address of applicant/ holder	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
United States	27	28	23	25	20	29	26	15	30	30	**253**
Japan	15	28	22	25	20	20	24	21	27	21	**223**
Germany	18	21	15	24	17	15	20	3	14	18	**165**
China	8	7	6	12	5	3	8	12	10	26	**97**
France	4	5	10	11	9	8	7	4	13	12	**83**
South Korea	6	7	5	6	6	9	6	7	6	13	**71**
Netherlands	4	8	6	7	5	5	10	4	5	8	**62**
Austria	7	14	3	0	3	8	4	4	11	5	**59**
Italy	6	4	6	6	1	4	13	6	3	7	**56**
UK	6	8	8	5	3	2	3	2	7	8	**52**
Canada	4	3	2	4	3	3	5	6	9	5	**44**
Taïwan	3	3	0	1	2	1	5	6	7	7	**35**
Belgium	4	3	2	1	2	4	2	2	5	3	**28**
Spain	4	4	2	2	3	2	2	2	3	3	**27**
Brazil	0	1	0	1	4	3	4	2	7	5	**27**
Other EU 28 Member States	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	**28**
Other States	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	**322**
Total EU 28	53	67	52	56	43	48	61	27	61	64	**560**
Global total (without double counting*)	**126**	**150**	**135**	**142**	**123**	**123**	**147**	**116**	**163**	**189**	**1764**

(*): since some patents are owned by several holders, the total number of patents per country by far exceeds the global number of patents.
Source: Patstat. Processing: OST.

La Fabrique Advisory Board Members

La Fabrique de l'industrie includes an Advisory Board that monitors the scientific quality, pertinence and originality of the work carried out, and ensures diverse, balanced points of view. Board members participate in a personal capacity that does not concern the companies or institutions that they belong to. Their participation does not mean that they adhere to all of the messages, results and conclusions put forward by La Fabrique de l'industrie.

On 15 September 2023, the board comprised:

Gabriel ARTERO, honorary president of the CFE-CGC metallurgy foundation,

Vincent AUSSILLOUX, head of the economics-finance department at France Stratégie,

Hervé BAUDUIN, president of UIMM Lorraine,

Michel BERRY, founder and director of the Ecole de Paris du management,

Jean Michel BEZAT, journalist at the newspaper Le Monde,

Augustin BOURGUIGNAT, task officer at Crédit Mutuel Alliance Fédérale,

Pierre-André de CHALENDAR, president of Saint-Gobain group, co-president of La Fabrique de l'industrie,

Marc CHEVALLIER, editor-in-chief of the magazine Alternatives Économiques,

Carole CHRÉTIEN, director of corporate relations at the CNRS,

Patricia CRIFO, professor at École Polytechnique and researcher at CREST (CNRS),

Philippe DARMAYAN, former president of ArcelorMittal France,

Stéphane DISTINGUIN, founder and president of Fabernovel, president of the competitiveness cluster Cap Digital,

Flora DONSIMONI, general manager of Institut de l'Entreprise,

Elizabeth DUCOTTET, CEO of Thuasne,

Pierre DUQUESNE, former ambassador in charge of coordinating international support to Lebanon,

Olivier FAVEREAU, professor emeritus of economic science at Paris X University,

Denis FERRAND, managing director of Rexecode,

Jean-Pierre FINE, secretary general of UIMM,

Louis GALLOIS, former president of the supervisory board at PSA Group, co-president of La Fabrique de l'industrie,

François GEEROLF, economist at OFCE and professor of economics at Sciences Po,

Frédéric GONAND, economic advisor to UIMM, associate professor of economic science at Paris-Dauphine University,

Guillaume de GOŸS, president of Aluminium France,

Bruno JAQUEMIN, general manager of A3M,

Sébastien JEAN, professor at the Conservatoire national des arts et métiers (CNAM),

Éric KELLER, federal secretary of the FO Métaux federation,

Élisabeth KLEIN, director of CFT Industrie,

Dorothée KOHLER, managing director of KOHLER C&C,

Éric LABAYE, former president of École Polytechnique,

Emmanuel LECHYPRE, editorial writer at BFM TV and BFM Business,

Xavier LECOQ, president of the steelworkers' union CFE-CGC,

Olivier LLUANSI, partner at Strategy&PWC,

Philippe MUTRICY, director of evaluation, studies and prospective at Bpifrance,

Hélène PESKINE, permanent secretary at the urban planning, construction and architecture department of the French ministry for the ecological transition,

Philippe PORTIER, national secretary of the CFDT union,

Grégoire POSTEL-VINAY, former strategy director at the directorate general for enterprise, and editor-in-chief of the Annales des Mines,

Joseph PUZO, president of AXON'CABLE SAS and the Matéralia competitiveness cluster,

Xavier RAGOT, president of OFCE,

Robin RIVATON, investment director – Venture Smart City at Eurazeo,

Alexandra ROULET, economics professor at Insead,

Frédéric SAINT-GEOURS, vice-president of the board of directors at SNCF,

Ulrike STEINHORST, president of Nuria Conseil,

Mickaël VALENTIN, founding partner of OPEO,

Pierre VELTZ, former CEO of the public establishment Paris-Saclay,

Alain VERNA, managing director of Toshiba Tec Europe,

Dominique VERNAY, president of the industry department at the French Academy of Technologies,

Jean-Marc VITTORI, editorial writer at the newspaper Les Echos.

Sonia Bellit is a Doctor of economic science and a project manager at La Fabrique de l'industrie. Her work focuses on industrial policies, the challenges of reindustrialization, and Industry 4.0.

Vincent Charlet is executive director of La Fabrique de l'industrie. Following studies in engineering, he moved on to analysing public systems and change management. He has taken part in various initiatives aimed at renovating the research and innovation system in France, including the FutuRIS project, which he directed from 2006 to 2011, before participating in the creation of La Fabrique de l'industrie.

Is Disruptive Innovation Only for Start-ups?

French Industry in the Face of Key Technologies

Since the global success of messenger RNA vaccines, no single sector of activity can avoid the prospect of sooner or later being “disintermediated” by digital giants or shattered by triumphant start-ups: the issue of technological disruption is the subject of a new focus. Because it is through disruptive innovations that an economy anticipates and promotes the major transitions that shape tomorrow’s society. It is also how companies stand out in a changing, highly competitive environment. The challenge involves not just inventing, but in particular getting ahead of foreign countries that do not hesitate to staunchly support certain companies in order to dominate key sectors.

Start-ups have been put forward as a reference model for years, but are large French companies still capable of creating the technological disruptions that markets expect from them? Based on testimonials and an original analysis of patent data covering twelve technological areas, eight of which concern the ecological transition, this publication looks closely at the innovation movement in France, its technological positioning, and the type of companies involved.

This note is aimed at business leaders, public decision-makers, researchers, students, and all readers interested in innovation issues in France.

La Fabrique de l’industrie
laboratoire d’idées
www.la-fabrique.fr

MINES PARIS | PSL
Presses des Mines

ISBN : 978-2-38542-590-6
ISSN : 2495-1706