La Fabrique de l'industrie
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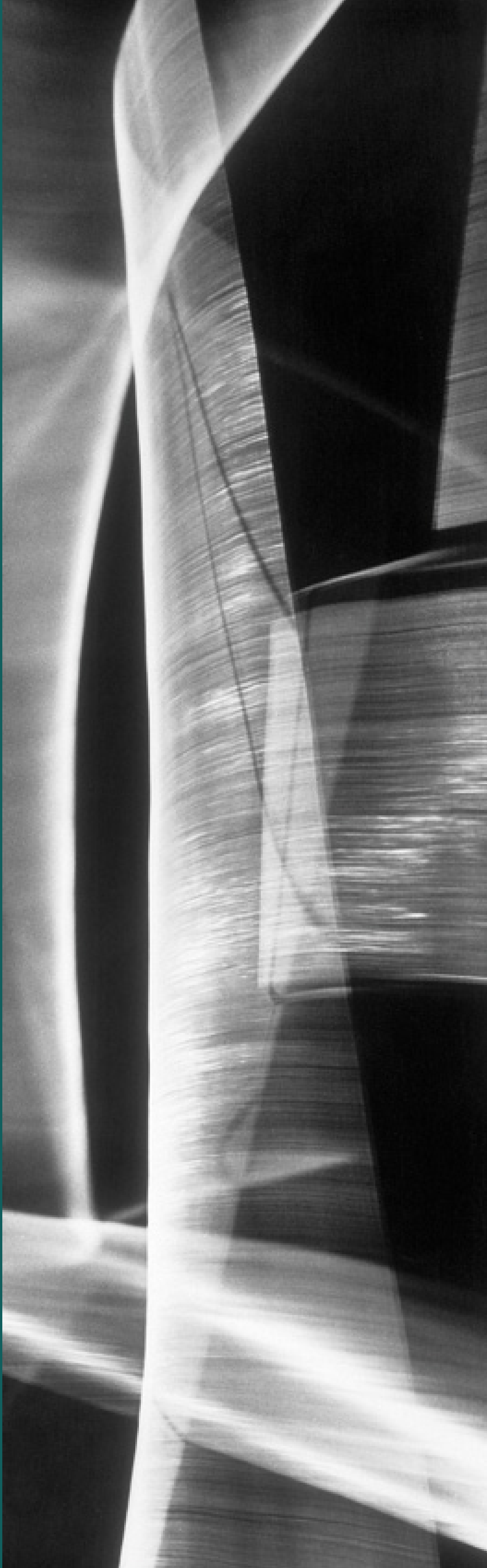
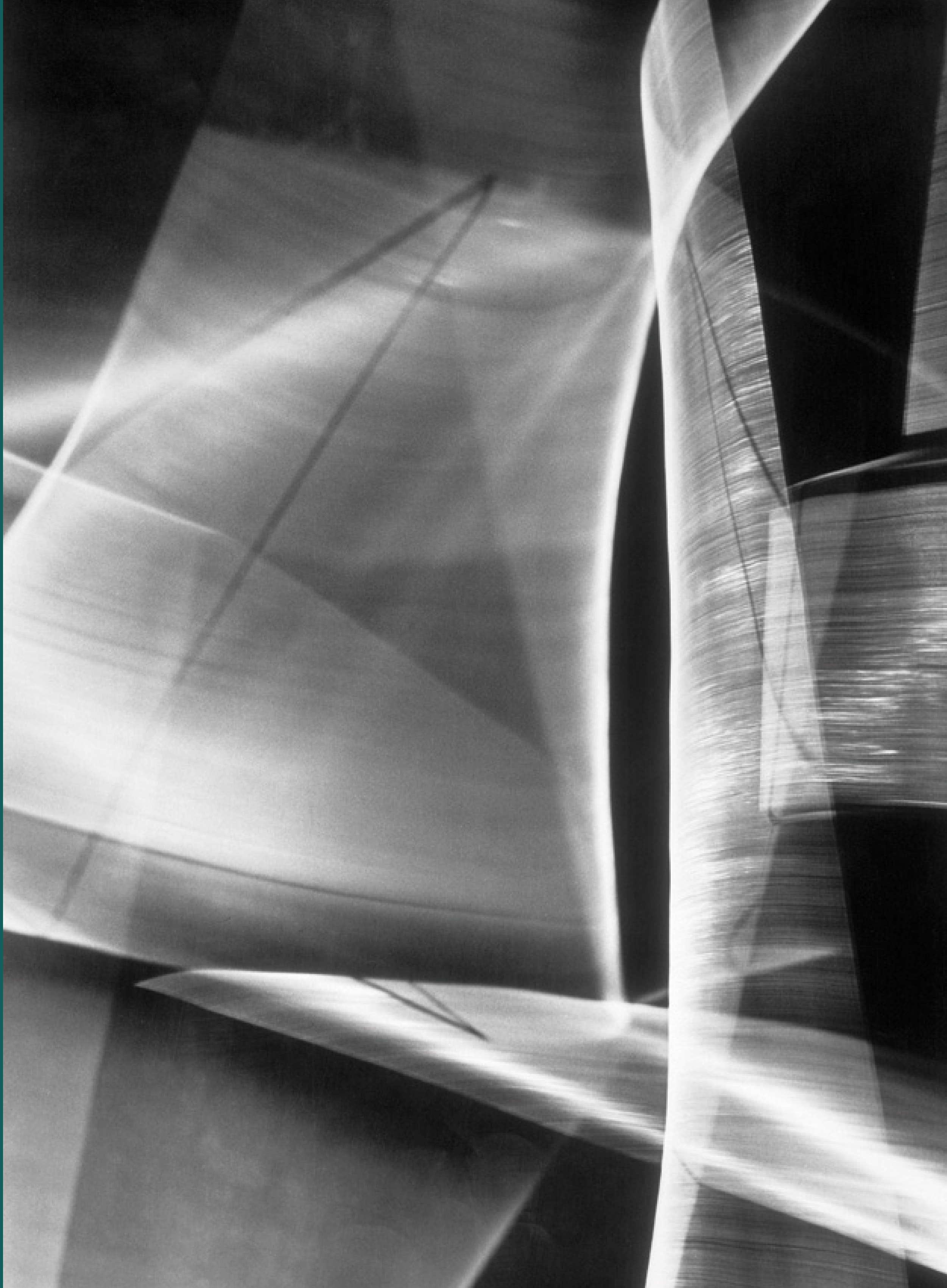
Les Notes *de La Fabrique*

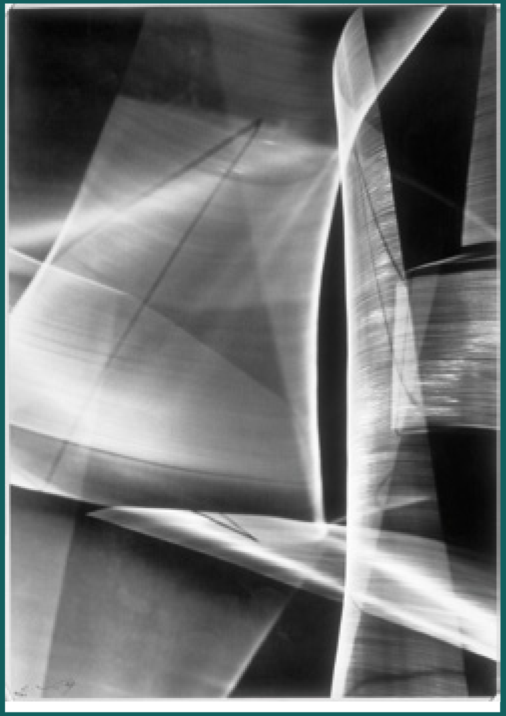
How do disruptive innovations start?

Industry drawing from global science

Vincent Charlet







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The “Notes de La Fabrique” form a collection which comprises contributions to the current economic debates: employment and social dialogue, competitiveness, international comparisons, etc. Written by observers and experts, sometimes with the help of partner organisations, these *Notes* are based either on a prior collective analysis (typically, a working group) or on an undeniable individual experience. They are subject to the control of the members of La Fabrique's Strategic Board.

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At first

Foreword

AT THE TIME OF WRITING IN WINTER 2025, Europe appears to be confronted by its own choices in a formidable face-off. The perspectives of competitively decarbonizing the European economy remain highly uncertain, while climate change continues apace, much faster than predicted by scenarios only recently viewed as pessimistic, and bringing with it a succession of massive, widespread disruptions. At the same time, the very competitiveness of European industry is being called into question. To overcome these historic challenges, we need to get back on track to attain sustained growth, robust technical progress, and a concerted approach from the main economic powers. Yet, indisputably, none of these key components can be counted on today.

Technical progress is scarce – or in fact, slow – in Europe. Productivity gains have never been so low, jeopardizing the prospect of growth. France has still not closed the gap dating from the Covid-19 pandemic. In reality, our continent is fast losing ground, as clearly pointed out by the Draghi Report, and is only likely to pick up the reins again if it can regain its former scientific and technological power.

More than elsewhere, France faces particular obstacles due to the persistent fragility of our industry and the bad state of public accounts, currently coupled with damaging political instability. None of which makes it easy for our country to fully play the socially responsible economic and political role that the EU requires from its Member States. Increasingly, it seems that Europe can only rely on its own strength, given the more openly unabashed behaviour of both China and the United States, whose economic and political rivalry has become exclusively predatory.

In this turbulent situation, it is indispensable to reinitiate a broad, deep discussion about how to pursue national and European research and innovation efforts. In a previous note, La Fabrique de l’industrie clearly demonstrated that European countries had lost technological control of disruptive innovations, in particular those required for the energy transition of our economies. This publication extends that diagnosis and sets out to understand to what extent this weakness concerns the scientific sources of these innovations. It is often said that EU states possess a highly effective research system, yet struggle to produce economic results that meet the expectations of new innovative markets. This publication reveals that this diagnosis needs some refining. In fact, European states suffer much more from a double deficiency: an industry insufficiently focused on innovation, and a weak research system, rather than an inefficient connection or lack of bridges between the two.

This note also shows that the main technological powers on the planet do not tackle the innovation process in the same way. Put simply, English-speaking states demonstrate an impressive capacity to roll out research conducive to excellence, in other words, capable of producing a large number of high-impact discoveries (here, scientific research papers). Japan and Korea have a remarkable talent for gaining ground on the road from research to innovation, increasing their market share at every stage. China, for now, is making great strides in its research output, which nevertheless struggles to inspire patent applicants both from China and elsewhere. In the midst of these proactive technological powers, the EU states seem to be weak right along the chain, from research up to the commercialization of innovations.

One of the important contributions of this note is the observation that knowledge circulates widely in the world, between research laboratories and patent applicants. This suggests that we can look separately at the questions of boosting research efforts and consolidating innovation efforts. On this point, it is often claimed that the reason that France has not achieved the ‘Lisbon’ target of spending 3% of GDP on R&D is because of a lack of private investments. The issue here is not the dynamism of companies, which make considerable R&D investments in their sectors (partly thanks to the French research tax credit). In reality, France is penalized by the modest size of its industry and the comparatively low weight of knowledge-intensive sectors. Which means that there is no point making demands on existing companies to increase private R&D efforts; rather, we should be thinking of ways to accelerate the development of productive activities in so-called ‘disruptive’ technology fields.

In addition, this note clearly establishes the fact that the state’s contribution to research is now insufficient in France (in particular since private contributions are limited for the reasons mentioned above): insufficient in terms of volume, certainly, but also perhaps insufficiently targeted on the teams and laboratories capable of producing high-impact results.

Without doubt, we need to react to this challenge relatively urgently. In the absence of clear intervention, not only will our economy pursue its upward trend in commercial and residential activities that bring low productivity gains and therefore weak growth perspectives, but in particular, we need to seriously envisage a probable near future in which our technological dependence on non-European states will come at a high cost.

Pierre-André de Chalendar and Louis Gallois
Co-chairs of La Fabrique de l’industrie

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The autor **thanks**

This note is the second to be published in two years by La Fabrique de l’industrie on the subject of disruptive innovations. The thinking process and data behind this work are indebted to the initial input of Sonia Bellit, until her departure from our team. We extend our warm thanks to her.

This study particularly draws from statistical processing and the comparison of a large number of data tables, for which the entire La Fabrique team provided invaluable assistance and contributions, ranging from the choice of statistical methods to the final presentation of the results. The clarity of the results that follow owes much to their work, and any errors or ambiguity are the responsibility of the author.

A number of external proofreaders accepted to give their time to improve the first versions of the manuscript, leading to this definitive text. I would like to thank them for their pertinent and generous contributions.

Lastly, this work is based on the interpretation of data that were organized, extracted and made legible by the French Science and Technology Observatory (OST). None of what follows would have seen the day without the interested, exacting involvement of its team and management, and primarily without the pioneering perseverance of Egidio Luis Miotti, to whose memory this publication is dedicated.

To sump up

Summary

THIS PUBLICATION follows on from a previous study by La Fabrique de l'industrie which indicated that France and our EU partners are losing ground on the disruptive innovations that we need to secure the digital and energy transitions of our economies. In this document, we look at the scientific sources of these innovations with the aim of feeding into reflections on the best ways to rectify the situation.

The common idea that research fuels innovation resisted post-Cold War controversies and still stands up as empirically robust. The road travelled between scientific papers and patents is without doubt long and tortuous, but step by step, or rather citation by citation, it includes 80% of the former and 60% of the latter. The meeting point between these two groups, comprising citations of articles by patents, approximately concerns one-tenth of articles and the same amount of patents. This makes it a relatively narrow passage between two vast words, like the neck between the two spheres of an hourglass, or a mountain pass between two valleys.

13% of patents
cite articles P. 38

The story is very different when it comes to disruptive technology patents, which by definition concern technologies capable of altering the course of economic activities. While they make up a small number of the total annual patents filed, they stand out for their propensity to directly refer to scientific articles, and in particular, articles with high academic impact. Among this group of patents, considerable differences can be observed from one technology to the next: some are very closely connected to science, others less so. US applicants appear to focus on the former, while a greater number of Asian applications concern technologies for which a large number of patents have been filed by companies – Europe tends to be relegated to technologies that have neither characteristic.

Specific patterns
by technology P. 44

When studying the global shares of the main countries in the successive stages of the innovation process, we can see that they participate in different ways. Firstly, Japan and Korea draw from a relatively limited national scientific base, but their global share steadily grows when moving closer to downstream markets, right up to disruptive patent applications. In contrast, the United States, which has a substantial scientific base that is however directed very little towards the technology core, produces research papers that are so attractive and of such high quality that they are absolute references for patent applicants (an average 37% of the global share). The country then loses some ground, but remains among the leaders downstream, in the patent application phases. European countries follow a similar pattern, with a higher global share of publications cited by patents than for their academic output in general, although at much lower levels than the US. In addition, the United Kingdom and France are a lot less involved downstream in the process, with the result that their global share of disruptive patents appears disappointing. Lastly, China carries out intense research in the scientific fields of the core technologies, but this does not yet translate into innovation, which can be judged by the quantity of patents that the country files and even more so by the number of Chinese articles cited by global patents, both of which are low.

Japan's global share
increases steadily P. 63

The upstream and downstream phases of the innovation process can therefore be studied separately, and even seem relatively disconnected in some Western countries. This is because knowledge circulates abundantly and very freely between the authors of research papers and patent applicants. Except for the United States, the research efforts of each country

US science
is unmissable. P. 66

feed into a lot more foreign disruptive patents than into patents filed by local companies, while the country's own patent applicants get more inspiration from foreign articles than from national articles. We should therefore drop the idea of 'naïve' countries that generously offer their science to industries around the world, while other 'predator' countries manage to protect themselves and glean the fruits of international research for their own industry. In reality, it is more about small countries and large countries: the former are more open to exchanges, in both directions, than the latter. This openness is not necessarily detrimental and can on the contrary lead to rewards, on the condition of excellence: the more a country publishes a large number of scientific papers that are picked up by patents, the more the useful share of 'its' industry grows. However, it is the proactiveness of patent applicants to go out and find the best science that results in large companies asserting their technological leadership. Once normalized, the 'return on investment' of the national research effort for the benefit of domestic industry and the 'national preference' of an industry for its domestic research are only really high for those countries that contribute the least to the global innovation effort. In contrast, the United States is without doubt the primary provider of 'patentable science' to the rest of the world, but it imports two or three times as much. This specific effort of US applicants to go and look in other countries for the scientific input they need makes them quite radically different from their competitors. Small countries that could seem protected or 'chauvinistic' are in reality net exporters of patentable science.

Small countries,
net exporters of science P. 83

The positioning of countries in the global disruptive technologies rankings is primarily correlated to the technological effort made by their productive base, which itself results from the volume of their industrial activity and technology-intensive character. It is also related to the extent of their national research effort and its level of excellence, in other words, their propensity to publish very high-impact scientific articles. English-speaking countries stand out in this second area, although Japan and Korea are not far behind. These two Asian powers, however, benefit from a decisive and distinctive advantage in the first area, in particular since their public and private R&D efforts seem to be better aligned here than elsewhere. France takes a back seat regarding all of these criteria. Our country does not suffer so much from an inefficient connection between its research and its industry, as postulated by the well-known 'paradox' theory, as from the fact that its research and industry are both too weak. These two subjects are linked but can be resolved separately, at least judging by a comparison with the other countries.

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No paradox,
either French or European P. 113

At stake

Introduction

IN A PREVIOUS NOTE (Bellit and Charlet, 2023), La Fabrique de l'industrie observed that the European Union was lagging behind in several disruptive technologies key to the energy and digital transitions of our economies.[1] This publication takes this analysis further by extending it to the scientific sources of technologies, to contribute to reflections on how to rectify this situation.

Our first study was based on the statistical analysis of patents, relating to a sample of twelve technologies.[2] These data indicated a significant gap between Europe and what we could call the four main technological powers of the planet in 2024: the United States, China, Japan and South Korea. Apart from Germany, European countries rarely rank among the top four global patent depositors in these technologies. France only does once, while the 'Big Four' always represent at least half of the patents filed in the world and sometimes as much as three-quarters. It is true that the results are more encouraging if we consider the European Union as a whole: it very often comes first or second. However, the EU almost never notches up half of global patents, whereas the United States remains a long way ahead in the fields of quantum computing and messenger RNA. And the European position is mostly thanks to Germany; France only plays a minor role, while Korea and Japan sometimes reach the same level as the entire European Union.

This French and European technological gap is backed up by other contemporary studies, starting with the Draghi Report produced in September 2024 for the European Commission (Draghi, 2024). The author indicates that Europe is lagging behind in terms of innovation in comparison with China and the United States, in a number of digital activities. In addition, the EU could be expected to lead the field in the clean-

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1— Here we consider 'disruptive innovations' as activities that relate to both technological performance, including when it is incremental, and a radically new use on the market, e.g. batteries for electric vehicles or offshore wind turbines, but not the invention of Facebook or Doctolib.

2— These technologies were identified based on strategic documents and interviews with experts. They involve the use of hydrogen for transport, batteries for electric vehicles, photovoltaics, offshore wind power, recycling of strategic metals, sustainable aviation fuel, nanoelectronics, spintronics, quantum computing, messenger RNA, low-carbon steel and biological plastic recycling. In both this and the previous publication, we only consider patents filed with at least two national offices (or with the EPO or WIPO), in other words, those with a recognized inventive scope and not limited to a purely defensive role.

tech domain, but suffers from a weakness downstream in the value chain due to its fragile industry and dependency on external supplies.[3] For the former president of the European Central Bank, this innovation handicap is one of the main reasons why the EU lags behind the United States in terms of productivity.[4]

Other contributions, following their own methods, converge to make the same observation, which can thus be considered an established fact. For example, Bergeaud (2024) points out that the EU makes a sustained innovation effort in middle tech companies (transport, energy production, carbon-free mobility), but that it has a very low profile in all of the digital technologies, responsible for the spurt of productivity observed in the United States, and in genetic technologies.[5] Evans (2024) makes a similar observation in the digital field: he points out that the EU only spawned 5 of the 69 tech companies that have passed the mark of 10 billion dollars of market capitalization and that their turnover represents less than 1% of the whole. Patricia Nouveau (2022) interprets this European lagging behind as the sign of a failure of EU innovation policies, which have never succeeded in overcoming rivalries between Member States, and the source of increasing economic and digital dependency on the United States and China. The Australian Strategic Policy Institute goes even further and rings the alarm bell with the observation that China is now the global leader for 37 of the 44 key technologies studied in its report (Gaida *et al.*, 2023) and that “only seven of the 44 analysed technologies are currently led by a democratic country, and that country in all instances is the US”.[6]

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[3] — See the graph on page 36 (part A of the report). The technologies studied are the internet of things, artificial intelligence, cryptography, cybersecurity, the cloud, quantum computing, hydropower, geothermal power, nuclear power, solar energy, batteries, biofuels, wind power, hydrogen, and carbon-free transport.

[4] — On this subject, see also (Desjeux, 2024).

[5] — Bergeaud analyses patents filed in the following technological fields: 3D printing, blockchain, visual recognition, genetic engineering, hydrogen storage, and autonomous vehicles.

[6] — The method used in the Aspi Report heavily weights scientific publications frequently cited by other publications. The rest of the present publication confirms that, measured in this way, the Chinese position comes out much better than when counting disruptive patents, for example. This methodological approach automatically favours large countries and linguistic proximity.

Evans (*op. cit.*) also points out, quite rightly, that this European handicap has been remarked on and documented for a long time, in particular by the European Commission, which has put forward a number of public policies to remedy it over the years. An article by Smith (1986) illustrates this point by observing in very similar terms to those used today the difficulty – already well-established at the time – of European economies to stop struggling to catch up and compete equally with the United States and Japan on the ‘new technologies’ of the time (information technologies and advanced weaponry).

In particular, this decades-old thinking process focuses on the idea of a ‘European paradox’.[7] This expression springs from the hypothesis that the atavistic difficulty of Europe to produce global champions in new technologies is counterintuitive since it is home to some of the best scientists in the world. The reason that Europe remains high in the research rankings but does not do well in converting results into solvent markets and competitive companies is a particular weakness, a kind of ‘drain’ that leaves the field free for companies outside Europe to exploit the discoveries made in our own labs. If this hypothesis were to prove valid, which would require long-term study,[8] then the remedy would involve creating a stronger, more fluid and effective link between the worlds of research and innovation.

This premise of a European paradox spurred a number of public policies launched over the last forty years at both European Community level and within its Member States (European Commission, 1995). Concerning Europe, it dates back at least to the launch of the Eureka Programme in 1984 – which was a reaction to the US offer, perceived as comminatory, to join Reagan’s Strategic Defense Initiative, as a subordinate supplier (Karsenty, 2006). However, similar reasons lie behind the establishment of the Lisbon Agenda in 2000,[9] and the creation of

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[7] — According to Soete (2002), the British identified a *British research paradox* in the 1960s. This phenomenon was the subject of numerous articles in the 1980s, and then went on to be applied to the whole of Europe in the early 1990s.

[8] — Tijssen and van Wijk (1999) for example propose a bibliometric demonstration in the information technologies field. See also Radicic and Pugh (2017), or Dedrick and Kraemer (2015).

[9] — Caracostas & Muldur (1998), Blanpied (1998).

programmes like Esprit, Brite and Euram, which were replaced by the framework programmes and now Horizon. Initiatives in France include the creation in 1981 of the Cifre scheme (grants to PhD students working in companies who receive a salary partially funded by the state), the promulgation of the Allègre Act[10] (which facilitates the mobility of researchers and in particular the creation of spin-offs), the research tax credit supplement to encourage companies to resort to public research, the launch of the Satt[11] in 2007 and then the PUI[12] in 2023, both of which are designed to encourage technological transfers from research laboratories.

All of these programmes, or 'bridges', devised and piled up over almost half a century, have constantly tried to facilitate scientific spin-offs in order to generate innovative products, growth sectors, and naturally, 'French Googles'.[13] The diagnosis underlying these proposals is always the same: European capitalism and management, reputedly more rigid than their US equivalents (in the face of failure, in the face of individual mobility, in the face of competition and entrepreneurship, in the face of public or private sectors depending on the point of view, in the face of progress per se), have always acted to hold back risk-taking and the circulation of ideas and people between the world of research and the business sphere, ranging from start-ups to major industries. Put simply, still based on this theory, the reason that Europe has not come up with a Google, Tesla or Silicon Valley is because of a missing link – for either cultural, capitalistic or institutional reasons – between otherwise excellent science and otherwise solidly based industry. A link that therefore needs to be urgently repaired.

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[10] — In 1999, the Allègre Act opened up the possibility for universities and researchers to create start-ups and file patents.

[11] — Thirteen *sociétés d'accélération du transfert de technologies* (technology transfer acceleration companies) were created in 2012 as part of the *Investissements d'avenir* (investments for the future) programme. See satt.fr

[12] — The France 2030 Plan established the creation of twenty-five *pôles universitaires d'innovation* (university innovation hubs - PUI), for a total budget of 166 million euros. "*By taking full advantage of the innovation mission of public higher education and research establishments, PUIs should foster the reflex for innovation behind each scientific discovery, encourage risk-taking, and generate more innovative projects from public research, for the benefit of society and the economy*" (extract from the press release of 11 July 2023).

[13] — For public opinions voiced on this recurring objective, see for example Néri (2018) and, in particular, the collective forum "*Un Google français n'est pas qu'une utopie*" (a French Google is not a utopia) by Barba *et al.* (2008).

Nevertheless, this idea of a European paradox has been refuted several times. In 2006, Dosi *et al.* pointed out that Europe suffered from both depleted science and a fragile industry, rather than an ineffective link between the two. A few years later, Conti and Gaulé (2010), then Herranz and Ruiz-Castillo (2013) observed that while the EU produced a few more scientific articles than the US, a close look at only those articles with a strong impact showed that "US domination is total".[14] Rodríguez-Navarro and Narin (2018) went on to drive the point home by stating that: "*Europe lags far behind the USA in the production of important, highly cited research. […] there is a consistent weakening of European science as one ascends the citation scale, […] while the USA is at least twice as effective in the production of very highly cited scientific papers, and garnering Nobel prizes. Only in the highly multinational, collaborative fields of Physics and Clinical Medicine does the EU seem to approach the USA in top scale impact.*"

These works did not close the discussion on a 'European paradox', periodically reignited by other observations that affirm or renew it. For example, Bergeaud (*op. cit.*) shows that the disruptive patents that he has studied, although mainly filed by owners outside the EU, cite research papers from 30%, and up to 40% of authors established in European universities. Bellit and Charlet (*op. cit.*) remark that France generally ranks sixth, and sometimes eighth globally for disruptive patent applications, but that it ranks third when looking only at patents filed by public research organizations. Which implies once again that laboratories and companies on our continent do not collaborate sufficiently to jointly exploit scientific results which happen to be of high quality, and which companies outside Europe can take advantage of.

The aim of this publication is to feed into this reflection by studying academic papers cited by patents, in other words, the links established each time that a scientific article is cited

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[14] — The interest of Conti and Gaulé's work is that it shows that, all things being equal elsewhere, Europe lags behind in terms of university technology licensing. Put differently, if Europe had the same level of scientific excellence as the United States, it would still underperform in commercializing its research results. The authors partly attribute this to the low number and inexperience of people responsible for technology transfer in European universities compared to the US. They do not therefore totally reject the thesis of an inefficient link between research and innovation.

by a patent applicant to support their request for protection. Each of these citation links is considered as the proof of an intellectual legacy for which the applicant recognizes that they are indebted to the author(s) cited (Narin, 1994). Since we can trace the address of the applicant of each patent and the affiliation of the author of each article, these patent citations should improve our understanding of the following question: does European research publish scientific articles of sufficient quality and quantity to serve the purposes of European disruptive patent applicants? And what is the situation regarding researchers and applicants elsewhere in the world? These questions are central to this publication.

The aim here is naturally to inform public policy. Fundamentally, the fact that this controversy is still alive illustrates our persistent inability to understand how science fuels innovation: by which paths, with which tools, on what scales, and thanks to whom. Consequently, we do not know which public policies can effectively foster the economic and industrial benefits of science.

At least three questions are key in this debate. First, it is still important to determine whether innovation is 'science-pushed' or 'demand-pulled'. According to defenders of the 'European paradox' idea, our problem lies half way between supply and demand, in the weakness of the link between research and industry.[15] To remedy the paradox therefore requires stronger policies to facilitate spin-offs (businesses created by researchers), technology transfer (patent applications or granting of licences to companies based on lab results), public-private research partnerships, mixed careers, and the attainment of major socio-economic objectives. However, as we have seen, others affirm that the European paradox does not exist, or in any case that it is more urgent to strengthen competitive funding for top-level research, not just in the hope of moving higher up the Shanghai ranking, but because better research produces higher economic impacts. Nagar *et al.* (2024) demonstrate this point concerning research financed by the European Research Council (ERC). Jonkers and Sachwald (2018) also confirm this

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15— In addition to the references already cited in note 7, see Santoprete and Berni (2010) or Conti and Gaule (2011).

double dividend of scientific excellence. Lastly, some industrials convincingly claim that the main obstacle is out on the field, in industries. They maintain that the reasons that disruptive innovations do not meet their market is because Europe particularly lacks industrialists capable of commercializing them, in other words, industrialists that are already competitive and have 'commercial clout': efficient production sites, top-level skills, networks of subcontractors, logistical partners, etc. This third hypothesis certainly does not rule out the second; however, as we can see, each has their own vision of which problem to grapple with, from the lowest levels of technological readiness to the highest ones.

This debate combines with another issue to determine how important it is to wager on local interactions to improve the link between research and innovation (e.g., through competitiveness clusters or SATTs) or whether public policies in this area should, on the contrary, avoid a territorial approach (which is the case for some Carnot Institutes, IPCEIs, ARPA-type agencies, etc.). Here, once again, opinions differ, since the modern conceptualization of agglomeration economies put forward by Krugman (1991) then Porter (1996), and the opening up of an intense reflection on open innovation mechanisms and the best ways to take advantage of them by organizing them all over the world, initiated by Chesbrough (2011). However, the controversy is not closed and scientific responses vary from one place to the next and one sector to another.[16] Niosi and Zhegu (2010) for example refute that knowledge spillovers of global aerospace clusters are essentially local. Globerman *et al.* (2005) show that the geographic range of these spillovers varies from one cluster to the next, even in the same sector (digital) and country (Canada).

Last but not least, the replicability of foreign examples itself is called into question, since two main explanatory patterns are alternately mobilized to guide these debates: the performance of countries, which emphasizes the effectiveness of public policies often reputed to be replicable, and technological paradigms, whereby innovation is rolled out in different formats

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16— See Wolfe and Gertler (2004), Fritsch and Franke (2004), Audretsch and Feldman (2004).

that themselves obey the intrinsic characteristics of the sectors and technologies concerned (Dosi *et al.*, 1994; Dosi and Nelson, 2010). In the latter case, we might typically hear that it is not worth envying the performance of US tech if Europe's priority is to put its technological efforts into decarbonizing industry, since start-ups are probably not the best way of accelerating innovation in this domain. Nelson (2016) goes as far as to affirm that we persist in trying to understand and measure all types of technical progress through the standardizing prism of Newtonian and post-Newtonian physics, which diverts us from both scientific discernment and political efficiency (Whitley, 2016).

The following chapters therefore bring successive insights to answer the following questions. Where and how does science turn into a patent? Who publishes and who patents? What role does geographic proximity play? And are variations in performance observed more in countries or in domains? The first chapter looks back on half a century of controversial analyses of the role played by science in the innovation process, and shows why academic citations in patent applications are still a pertinent measurement device in this area. The second chapter makes a first description of the one hundred thousand disruptive patents in our sample and the one hundred thousand scientific articles that they refer to, providing a good illustration of how disruptive technologies differ from 'ordinary' technologies, and differ from each other. The third chapter shows that the main countries that contribute to global research and innovation do not do so with the same effectiveness at the different stages of the process, from the production of scientific knowledge to its commercialization as a disruptive patent. The fourth chapter analyses the flows of citations between countries and shows to what extent knowledge circulates freely between the authors of research papers and patent applicants. The fifth chapter attempts to identify the key drivers of innovation by country and by technology, and then draws out the possible ways of improving the performance of European states. The reader can refer to the appendices (in French), the link to which is provided at the start of this note, for the source data and statistical processing employed for this analysis.

Note to the reader: This publication involved processing a large quantity of data. To avoid ending up with an unmanageably heavy document, the reader can refer to these data in the appendices, available (in French) using the following link and QR code.
All of the appendices named with a letter and all of the tables and graphs that feature one letter and two numbers (table X-00, graph X-00) can be consulted in this file.

1

Chapter

Science still feeds into technology

In 2024, research still plays a key role in shaping the technologies of the future, despite half a century of debates on the respective importance of science, market and capital in this area. Science's contribution to technology mainly involves long, sequential chains of interconnections.

THE PRIMARY ROLE OF SCIENCE PUT FORWARD AS SELF-EVIDENT

This publication aims to map the flows of knowledge circulating from the places where research is carried out to those where technologies are developed, employing citations between patents and scientific articles to do so. This approach assumes an important hypothesis: that science is (still) a primary source of technological innovation. It is only on this condition that academic citations referred to in patents can be accepted as an adequate measurement tool.

Yet this hypothesis has been the subject of much debate, on two different levels. The first and best-known one is economic: this consists in observing (or, for some, questioning) a measurable knock-on effect of R&D on innovation, and often more specifically of public R&D expenditure on private R&D expenditure (*cf.* box). In this area, we can consider it to be unanimously established that this knock-on effect is effective (Beck *et al.*, 2018).

The second level of this discussion is more sociological and political: it relates to the character, the meaning, and the kinetics of the connections between research and innovation. Are some innovations inappropriate for patent applications; are there patents that do not emanate from research results; are there not cases where it is bottom-up innovation that gives research a new kick start? These questions arise frequently. We have already responded to the first part of these objections in a previous note (Bellit and Charlet, *op. cit.*), by showing that, at least in the twelve technological domains studied here, the number of patents is clearly a

Off-screen

PUBLIC EXPENDITURE ON R&D, A CONTROVERSIAL DRIVER OF PRIVATE INNOVATION

IT HAS LONG BEEN RECOGNIZED that investment in R&D – both public and private – not only aims to advance knowledge but also, among other things, to encourage innovation in companies. An extensive body of literature therefore centres on determining what is known as 'private returns to public R&D investment'. The key question is the following: since knowledge is a public, non-rival good (Stiglitz, 1999), (Samuelson, 1954), and private investment therefore tends to be spontaneously sub-optimal, what is the right level of public investment to resolve this market failure (Guellec and van Pottelsberghe de la Potterie, 2010)?

This debate is by no means theoretical: French readers will be well aware of the fact that the level of state expenditure on R&D, in the form of research tax credit or the Investments for the Future Programme, is frequently the object of technical and budgetary debates on whether it is useful and justified (Harfi and Lallement, 2021) (European Economics, 2020).

Conversely, given the major climate, technical and social challenges facing Europe at the start of this 21st century, Mazzucato (2016) extends this question by suggesting that public intervention should also be mobilized to bring about solvent markets that will not emerge on their own, thus reviving a European reflection on 'mission-oriented' policies and more precisely the creation of ARPA-type agencies (Tagliapietra and Veugelers, Ed., 2023). Unsurprisingly, this debate is never purely arithmetic and inevitably becomes institutional. The question at the heart of the debate can therefore be reformulated as: How can investment in knowledge, whether private or public, produce spillovers that can be appropriated by private agents, and how should the ecosystem be institutionally organized to get the most efficient results in this area (Martin and Scott, 1998, 2000), (Mazzucato, 2018), (Aghion, 2023)?

pertinent measurement of the innovation efforts of companies and countries. Here, we take this question further, and now need to verify whether, in most cases, science and innovation are not only connected, but moreover connected in this order. If not, we would have opted for a non-significant measurement tool.

Several schools have clashed on the subject, even recently. According to Godin (2011), as far back as 1928, Maurice Holland, at the time director of the Engineering and Industrial Research Division at the US National Research Council, published an innovation 'model' that he called the 'research cycle'. He used it to describe the technical development of industry according to a linear, sequential process, from basic research to the commercialization of inventions. Still according to Godin, Holland's model features often heard but rarely demonstrated assertions, which he nevertheless turns into a theory with the aim of convincing manufacturers to accelerate their investment in R&D.

This archetype was the first incarnation of what is now called the 'linear model of innovation'. Some observers maintain that this linear model is obvious and has always existed in the minds of decision-makers. For others, it only really came into being in 1945, when Vannevar Bush published his report, *Science: The Endless Frontier*, which had an undeniable influence on the construction of post-war Western research policies. In this report, the author invites the US public authorities, and particularly the Department of Defense,[17] to distinguish basic research from applied research, in the first case leaving 'basic' researchers a large margin for manoeuvre, since they carry out their scientific work without being able to determine in advance which results will be usable or *a fortiori* commercializable. In the linear model, therefore, everything starts with basic research, driven by the quest for knowledge, and the impacts of which are unpredictable by nature, followed by applied research, then development, more and more resolutely oriented towards uses and applications, all of which feeds into the dissemination of knowledge further down the line, and then adoption by the market. This linear model clearly supports our choice of patent citations as a measurement and diagnosis tool.

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[17] An MIT engineer and scientific advisor to President Roosevelt, Bush also supervised the government mobilization of scientific research during the Second World War.

THE INTUITION OF A 'WORLD AFTERWARDS' IN THE 1980S

Godin (2006), and even more so Edgerton (2004), underline that this 'linear model' was never claimed or even conceived as such by either Holland or Bush. They maintain that the expression dates back to the 1980s, in fact coined by authors aiming to criticize the naivety, incompleteness or anachronism of this particular perception of the science-market connection – the true roots of which appear to, rather hazily, date back to the depths of the industrial era. In any case, what is clear is that starting from the 1980s, a great deal of the literature attempted to deconstruct this linear model, accumulating scientific proofs that the feeding line running from research to innovation was neither universal nor even intended to survive two major, independent upheavals: the fall of the Soviet Union – and the rapid demise of vast sectorial public R&D, civil and military programmes in Western countries – and the formidable dissemination of information technologies – in which the power of market forces amply matches that of technologies produced by laboratories.[18]

On the one hand, this criticism of the linear model can be described as politically motivated, or at least hostile towards the idea of unlimited public expenditure without accountability: contesting the linear model of innovation embodied by Bush means refusing the fact that the 'basic science' label might give researchers a blank cheque from public funds without reporting about its use to the state, users, or tax payers. It also means affirming that other forms of innovation, that come directly from the market and are possibly more efficient, warrant more attention and support from public authorities: stronger competition, unification of the capital market to constitute a capital-risk ecosystem, reduced taxes and regulations for innovative young enterprises, etc. For example, this criticism is implicit in the words of Nye (2006), for whom the "*fable*" of the linear model "*served particularly well*" scientists who benefited from "*large grants*" from the state by hiding behind the promise of pure science. In this area, Oliveira (2014) esteems that, in his point of view, the intentional and historically unfounded invention of this "*straw man*" of a so-called linear model has served as a weapon to those who promoted a certain "*commercialization*" of science and aimed to contest the validity of public funding for disinterested research.

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[18] Other technologies at the same time promised major disruptions, in particular those related to genetic engineering and nanotechnologies. However, the main role of research in the innovation process was questioned less in these two cases.

> Research also advances when it is questioned, shaken up, and even put under pressure by the political and social stakeholders.

Paradoxically, a second school exists that is critical of the linear model of innovation, with a much deeper social anchoring. This school of thought comprises sociologists and anthropologists of science (Latour *et al.*, 2010) who observe that research also advances when it is questioned, shaken up, and even put under pressure by the political and social stakeholders, or simply by empirical observations (Barthe *et al.*, 2014). This is what occurs, for example, when patients' associations, through their civic action, succeed not only in mobilizing researchers to pay attention to neglected diseases, but also to gather clinical information that is crucial for scientific progress (Rabeharisoa and Callon, 1998).[19]

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[19] Callon (1994) points out that public financing of R&D is justified in classic economic theory by the fact that knowledge is a public good. Yet, he observes, this hypothesis relies on the condition that hybrid collectives endowed with a degree of autonomy can continually appropriate science and call on research. If not, in other words, if knowledge only circulates between universities and companies, it is constantly privatized (notably at each patent application).

An even more iconic example is Louis Pasteur, who overturned the fundamental knowledge of his time *after* carrying out clinical observations – and precisely because he had carried them out – with the aim of responding to a public health problem. Interestingly, Bruno Latour, who was a pioneer in this school critical of modernity, started his long reflection with an anthropological immersion in a laboratory (Latour *et al.*, 2013) and a study of the life of Pasteur (Latour, 2011).[20]

Stokes (1997) drives the point home and immortalizes this observation by talking of *Pasteur's quadrant*. In this double entry table (see figure), he differentiates researchers who are mainly or even solely motivated by the advance of knowledge, epitomized by Niels Bohr, from those who are mostly concerned with the transformation of uses, like Thomas Edison, and lastly those who combine the two, such as Louis Pasteur. Stokes suggests that works falling into this final category have the maximum socio-economic impact and that consequently it is time to recognize the importance of 'use-inspired basic research'. Murray and Stern (2006) confirm this, and also esteem that researchers should be encouraged to file patents themselves, which, although it would slightly reduce the citation rate of their publications, would accelerate the market's adoption, and thus, the use of the fruits of their work.[21]

To sum up, at the turn of the 2000s, at the precise moment when the European Union formalized its Lisbon Agenda to accelerate the development of its industry by kick-starting R&D in order to catch up with the United States and Japan, it was paradoxically difficult, on the academic benches of science studies, to maintain that scientific research fuelled innovation without risking accusations of doctrinal blindness or social naivety. For many observers, supported by scientific articles, the main fuel of innovation should be found in networks of heterogeneous actors (therefore partly in civil society), in the market, large or small tech companies, or private equity, but in any case, not in research labs receiving public funds.

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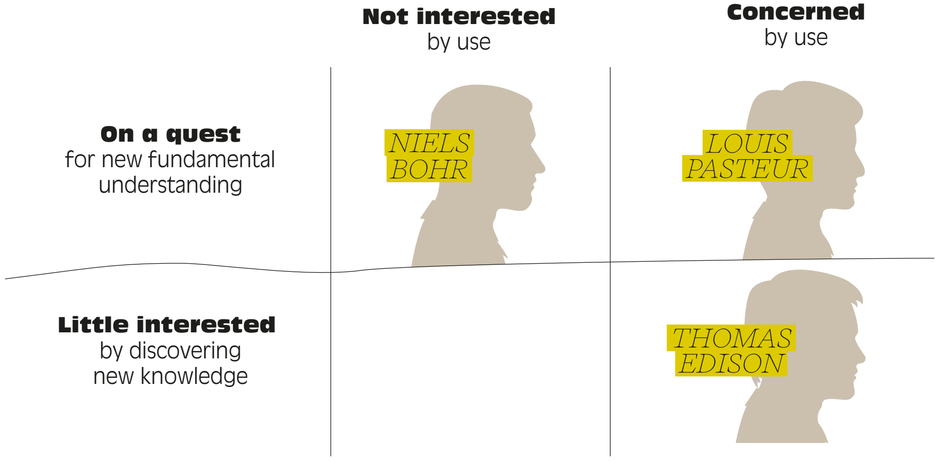
[20] All references to the works of Bruno Latour concern new editions. In reality, these publications date from the 1990s.

[21] Akrich *et al.* (1998) even present a 'whirlwind model' of innovation. According to these authors, innovation can emerge anywhere, with no actor monopolizing the imagination, and an idea is only disseminated if it is taken up by groups that, in adopting it, adapt and modify it. In this whirlwind model, the focus is not centred on products but rather on the actors involved in the innovation process.

fig. **1.1**

Pasteur's quadrant, according to Stokes (1997)



THE END OF CONTROVERSY?

If these prophecies had come true, in 2024 we would be living in a world where academic citations in patents would no longer be useful for retracing the origins of disruptive innovations. However, the controversy finally blew over. Godin (*op. cit.*) observed that several scientific communities, precisely occupied with understanding how science has evolved, found that the linear model was particularly useful for their analyses, while new measures backed up this sequential description of the innovation process (Artz *et al.*, 2010). Godin even went so far as to declare the clinical death of alternative critiques – which was no doubt a step too far.[22]

Let us look here at the informative work of Ahmadpoor and Jones (2017): these authors retraced one by one the citations chains between 4.8 million US patents (filed from 1976 to 2015) and 32 million research papers (published from 1945 to

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[22] In any case, the link between science and technology cannot today be viewed as universal or immutable. As shown by Dominique Guellec, scientific advisor to the OST: "in artificial intelligence, scientific discoveries are almost always applied directly. It could almost be the definition of a 'frontier domain': the place where new applications coincide with new knowledge."

2013); they then attributed each element with a **'distance to frontier'**, which is the moment when the research paper was cited by a patent (see figure a). Their first result is that they link 80% of research articles with 61% of patents in their vast sample: most scientific and technological activities are therefore clearly connected with each other. This result is also supported by Gazni and Ghaseminik (2019), who show that the proportion of patents derived from scientific advances has in fact increased over the last 25 years. Ahmadpoor and Jones also show (figure b) that this connection is mainly indirect: the frontier area, where patents directly cite research articles, concerns respectively 8% of the total articles and 13% of the total patents.[23] *A contrario*, two-thirds (68%) of connected patents and three-quarters (79%) of connected articles are located at a distance of 2 to 4 from the frontier.[24]

In summary, the top-down linear model consequently always brings a sound explanation - which is partial but dominant - of the way that research and innovation operate and the contributions that the former makes to the latter. Following forty years of controversy on the respective roles of the state, market and society in the advancement of innovation, we can sum up by affirming that scientific research carried out in laboratories is clearly a key intellectual driver.

Distance to frontier

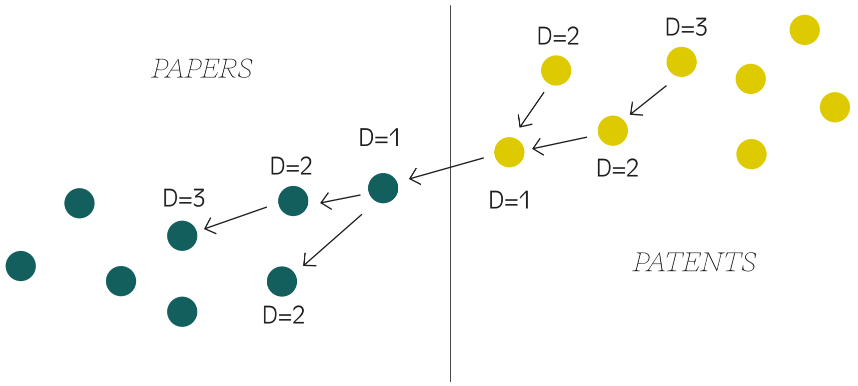
The 'frontier' corresponds to patents that cite research papers: these papers and patents are at a distance of 1. A patent with a distance of 2 cites another patent that itself cites a paper. And so on.

GLOSSARY

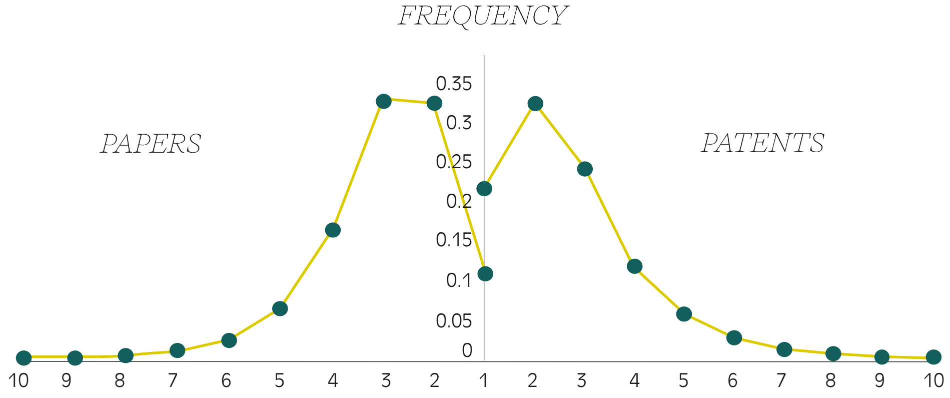
fig. **1.2**

Article citation-patent networks (a) and **Connectivity of articles and patents** (b)

(a) Article citation-patent networks according to Ahmadpoor and Jones



(b) Connectivity of articles and patents, according to Ahmadpoor and Jones



Source: Ahmadpoor and Jones (2017).

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[23] In other words, 10% of connected articles and 21% of connected patents. Van Raan (2017) calculates that about 3% to 4% of Web of Science articles are cited by patents, and that the proportion increases to around 15% when limiting it to papers based on a private-public partnership.

[24] A paper at a distance of 1 is directly cited by a patent, while a paper at a distance of 2 is cited by another paper, which is itself cited by a patent, etc.

2

Chapter

From research papers to disruptive patents

Disruptive technologies are a very specific type of innovation. These technologies, market changers by definition, concern a very low number of patents, yet are extremely closely connected to research and, in particular, excellence in research.

NARROW LINE BETWEEN TWO VAST WORLDS

This study is based on a panel of twelve disruptive technologies that were the object of 101,000 patent family applications from 2010 to 2021. Throughout this study, as in the previous one, we exclusively refer to patent families filed with at least two national offices (or with the WIPO or EPO), in order to eliminate essentially defensive patents, very numerous in China for example, which would give a distorted image of innovative activities.

On average, each of these disruptive patents cites 8 other patents to support its protection request, and 1.6 'non-patent literature' (NPL) references, including one scientific publication identifiable in Web of Science (see figure). This average figure of 1.6 NPL citations per patent disguises a heterogenous distribution: 30% of disruptive patents cite at least one NPL reference, meaning that the remaining two-thirds do not mention any. The citation of one or more research papers by a patent is therefore not systematic, including for technologies chosen for their disruptive nature.

Citing patent

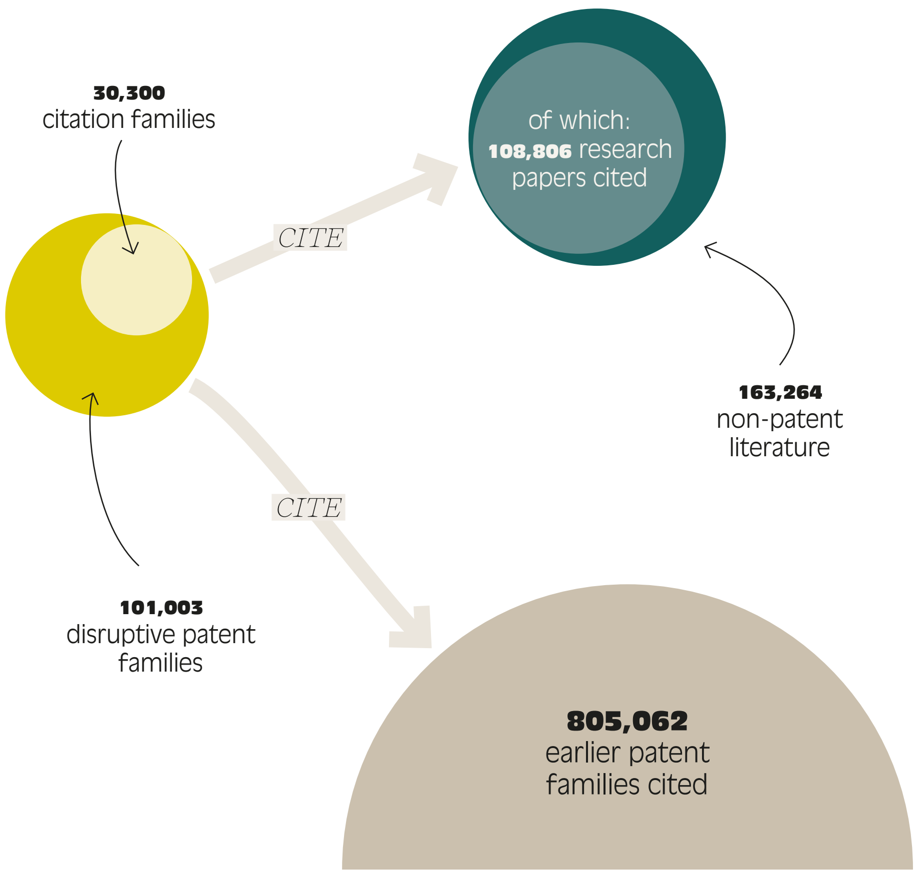
A 'citing' patent is a patent that cites scientific articles.

GLOSSARY

In what follows in this publication, we will therefore study the citation connections between about one hundred thousand disruptive patents corresponding to twelve technologies and the one hundred thousand scientific papers that they refer to. This first snapshot prompts three remarks. The first is that the rate of 30% of **'citing' patents** that we observe in our sample is commensurable, but significantly higher than the rate of 12.7% found by Ahmadpoor and

fig. **2.1**

Corpus of patents and papers cited as a reference



Sources: EPO-Patstat base spring 2024, ROS 2024 base, OpenAlex base 2024, OST-Web of Science base (year 2021, 95% complete), OST-Hcéres calculations.

NB: the source data can be found in Appendix B of this report. They include patent families filed with at least two national offices, with the EPO or the WIPO. We count about 163,000 non-patent citations (Non Patent Literature) indexed in the OpenAlex (OA) base, of which about 109,000 can also be identified in the OST-WoS base. This publications base features articles dating from 1999 to the present.

Jones (*op. cit.*).[25] We thus find a double confirmation in their work: both of the orders of magnitude at stake, and of the distinctive character of our sample centred on disruptive patents, which cite research papers almost three times more frequently than average.

The second remark is based on the table shown below, which shows that the citing patents in our sample represent scarcely 2% of the total citing patents filed in the world, taking all technologies together. Moreover, the scientific papers that they cite correspond to half a percent, at most, of the literature published in the same domains. In other words, our sample of twelve disruptive technologies, all of which have been identified by top-level panels for their capacity to strengthen or decarbonize industry, only make a moderate contribution to the research and innovation efforts being deployed in the world at the same time.

The third remark refers to the third column of the table: the share of articles cited by patents featuring at least one author who works in a company ranges from 10% to 25% depending on the technology considered. Put differently, 75% to 90% of papers cited were produced solely by academic researchers.

> « The citation of one or more research papers by a patent is thereforenot systematic. »

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[25] They find a rate of 21% among connected patents, which represents 60.5% of total patents.

fig. **2.2**

Publications cited by patents and total publications, in the three most represented scientific domains (the 'core') 2010-2021

TECHNOLOGY	Articles cited by patents in the 3 leading domains (the scientific 'core' of each technology)	Papers featured in the WoS* in these 3 core domains (2010-2022)	Ratio	Patent families citing publications in the WoS*	Total number of patent families citing research papers	Ratio	Share of NPL where at least one author is with a company
Hydrogen for transport	3,796	6,034,645	0.06%	1,322			16.4%
Batteries for electric vehicles	4,036	4,957,865	0.08%	1,500			16.4%
Photovoltaics	21,156	4,701,714	0.45%	9,675			13.5%
Offshore wind power	48	4,477,118	0.00%	34			10.9%
Recycling of strategic metals	3,105	4,465,658	0.07%	1,761			13.6%
Sustainable aviation fuels	677	5,775,470	0.01%	134			14.0%
Nanoelectronics	11,384	4,529,162	0.25%	2,716			13.2%
Spintronics	2,717	4,529,162	0.06%	1,331			25.2%
Quantum computing	5,425	3,027,047	0.18%	1,859			18.5%
Messenger RNA	15,168	3,634,635	0.42%	2,348			16.7%
Low-carbon steel	1,565	4,957,865	0.03%	736			18.4%
Biological plastic recycling	1,086	4,222,516	0.03%	680			12.0%
Total				24,096	1,282,867	1.9%	

Sources: EPO-Patstat base spring 2024, ROS 2024 base, OpenAlex 2024 base, OST-Web of Science base (year 2021, 95% complete), OST-Hcéres calculations.

NB: details of some of these data are provided in Appendices B and F of this report. Only patent families filed with at least two national offices, with the EPO or WIPO are considered.

* The OST-Web of Science publications base features articles dating from 1999 to the present.

> «75% to 90% of papers cited were produced solely by academic researchers.»

TECHNOLOGY	Disruptive patent families	Citations of patent families*	Average number of citations of families	Share of families with patent citations	Non-patent literature**	WoS non-patent literature ***	Average number of citations identifiable in the WoS base	Share of families with non-patent literature
Hydrogen for transport	9,935	113,910	11.47	99%	8,871	5,438	0.55	18%
Batteries for electric vehicles	18,582	132,218	7.12	98%	7,150	4,721	0.25	11%
Photovoltaics	41,251	284,179	6.89	98%	47,306	30,741	0.75	30%
Offshore wind power	1,267	9,228	7.28	99%	193	55	0.04	8%
Recycling of strategic metals	6,600	58,678	8.89	39%	9,177	5,123	0.78	37%
Sustainable aviation fuels	307	5,063	16.49	99%	1,574	858	2.79	53%
Nanoelectronics	6,061	61,925	10.22	97%	22,586	17,044	2.81	50%
Spintronics	3,901	29,098	7.46	98%	4,743	3,307	0.85	40%
Quantum computing	2,942	14,096	4.79	90%	11,969	7,153	2.43	71%
Messenger RNA	2,763	26,271	9.51	97%	42,259	30,348	10.98	88%
Low-carbon steel	4,273	44,471	10.41	100%	4,087	2,105	0.49	27%
Biological plastic recycling	3,121	25,925	8.31	98%	3,349	1,913	0.61	30%
Total	101,003	805,062	7.97		163,264	108,806	1.08	30%

fig. 2.3

Citations per disruptive patent (patent and non-patent), 2010-2021

Sources: EPO-Patstat base spring 2024, ROS 2024 base, OpenAlex 2024 base, OST-Web of Science base (year 2021, 95% complete), OST-Hcéres calculations.

NB: only families of patents filed with at least two national offices, with the IPO or WIPO are considered.

* References to previous technologies that are pertinent, protected or described in other patent applications.
** Scientific papers, conference proceedings, publications, etc.
*** The OST-Web of Science publications base features articles dating from 1999 to present.

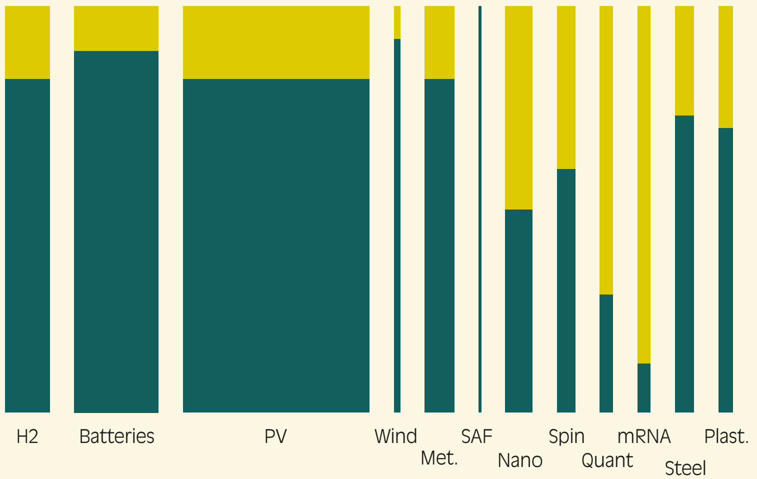
BIG DIFFERENCES FROM ONE TECHNOLOGY TO THE NEXT

The rates mentioned above are averages for a set of twelve technologies: as shown in the table below, both the total number of patents and the average number of citations per patent vary considerably from one technology to the next. Concerning citations of other patents, the variation is relatively moderate: from 4.8 to 16.5 patents cited per disruptive patent. For citations of scientific papers, the distribution is a lot more heterogenous and ranges from 11.0 articles cited per patent in the case of messenger RNA to 0.04 for offshore wind power. Similarly, the proportion of patents that cite scientific papers varies widely. For two technologies (batteries and offshore wind), about 10% of disruptive patents cite at least one NPL. The figure rises to almost 20% for hydrogen and close to 30% for low-carbon steel, biological plastic recycling and photovoltaics, then almost 40% for recycling of strategic materials and spintronics, 50% for nanoelectronics and sustainable aviation fuel, 70% for quantum computing and 90% for messenger RNA.

fig.
2.4

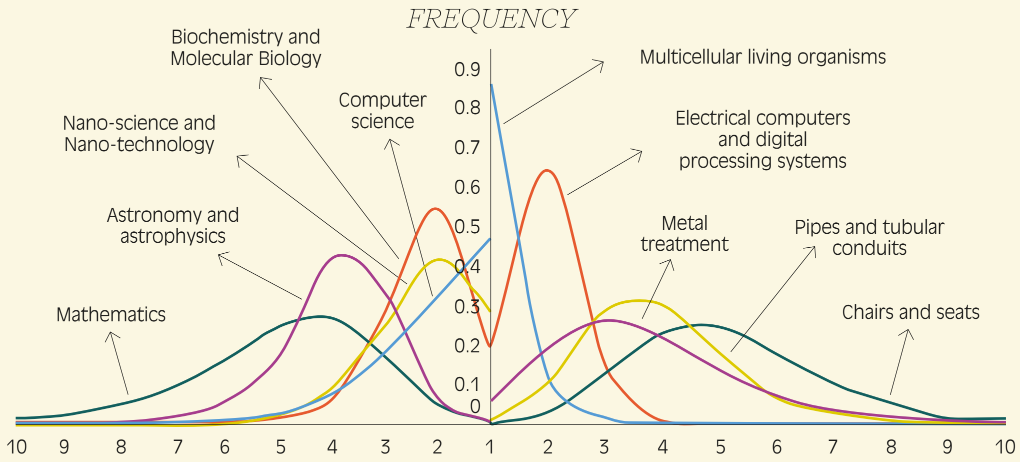
Big differences from one technology to the next

(a) The 12 disruptive patent corpuses



NB: the surface area of the rectangles is proportionate to the total number of patents. The yellow area represents the share that cites research papers.

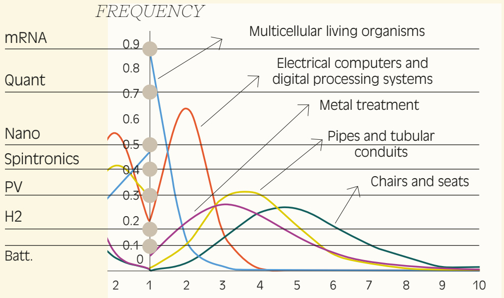
b) The distance to frontier of papers and patents for a few examples of scientific and technological fields, according to Ahmadpoor and Jones



Source: Ahmadpoor and Jones (2017).

Note for the reader: for mathematics, almost no articles are located at the frontier, in other words, cited by at least one patent. The modal distance of the distribution (i.e., the distance corresponding to the most frequent case) is slightly higher than 4. For computer science, 45% of scientific papers are at the frontier, giving a modal distribution distance of 1.

(c) The distance to the frontier of patents for a few examples of scientific and technological fields, according to Ahmadpoor and Jones, and comparison with the technologies in our corpus



Source: Ahmadpoor and Jones (2017).

Note for the reader: in the technology field relating to multicellular living organisms, 90% of patents cite at least one scientific paper, which corresponds exactly to the proportion of citing patents for messenger RNA in our panel.

In summary, as shown by figure (a) above, disruptive technologies vary considerably in terms of the number of patents that they generate, and the intensity of their relationship with academic output. The article by Ahmadpoor and Jones (*op. cit.*) once more confirms this heterogeneity, as seen in figure (b). This figure shows, for a series of typical examples of scientific and technological fields, the distribution of the distance to the frontier for publications and patents. Thus, for example, 20% of articles on biochemistry and molecular biology are at the frontier, in other words, cited by at least one patent (distance = 1), whereas over 50% are at a distance of 2. This set of curves shows that the proportion of citing patents varies considerably from one technological field to the next.

In figure (c), we reproduce the right side of this figure relating to technological fields, and include for comparison the proportion of citing patents in the technologies of our own sample. The correspondence is very close in the life sciences (messenger RNA in our sample, multicellular living organisms in theirs). Concerning ICT, the proportions of citing patents are often higher in our sample (quantum computing, nanoelectronics, spintronics, photovoltaics) than in theirs (computers and processing), which could be put down to differences in technological readiness or the disruptive character of the technologies that we have identified.

fig. **2.5**

Share of articles cited by disruptive patents ranking in the top 1% most cited articles

(in the three most represented fields)

TECHNOLOGY	*NUMBER OF ARTICLES CITED*	*NUMBER OF ARTICLES CITED IN THE TOP 1%*	*RATIO*
Hydrogen for transport	3,796	532	14.0%
Batteries for electric vehicles	4,036	545	13.5%
Photovoltaics	21,156	3,368	15.9%
Offshore wind power	48	4	8.3%
Recycling of strategic metals	3,105	263	8.5%
Sustainable aviation fuels	677	116	17.1%
Nanoelectronics	11,384	2,141	18.8%
Spintronics	2,717	395	14.5%
Quantum computing	5,425	971	17.9%
Messenger RNA	15,168	2,692	17.7%
Low-carbon steel	1,565	169	10.8%
Biological plastic recycling	1,086	121	11.1%
	70,163	11,317	16.1%

Sources: EPO-Patstat base spring 2024, ROS 2024 base, OpenAlex 2024 base, OST-Web of Science base (year 2021, 95% complete), OST-Hcéres calculations.

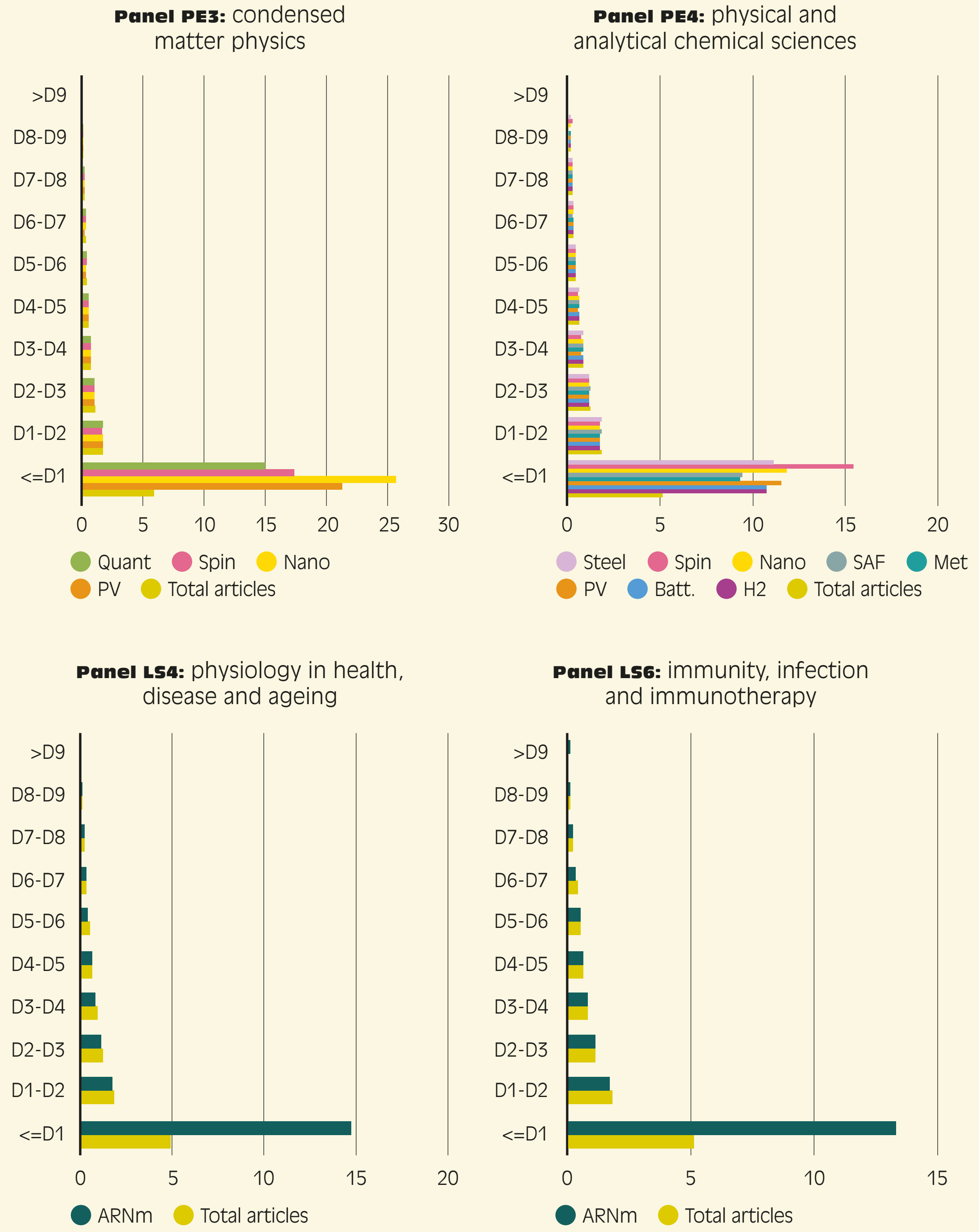
NB: details of these data are provided in Appendix G of this report. Only patent families filed with at least two national offices, with the EPO or WIPO are considered.

THE CRUCIAL INFLUENCE OF THE MOST CITED ARTICLES

As established by Tussen *et al.* (2000) in their analysis centred on the Netherlands, it is widely accepted that the best patents are inspired by the best science or, more precisely, that scientific articles frequently cited by other research papers are also more often picked up by patents. Ahmadpoor and Jones (*op. cit.*) confirm this with the following: when an article or patent features among the top 5% of the most cited in its field during a given year, they call it a 'home run'. The probability that a publication will achieve a home run is therefore on average 5%, by definition, but they measure a rate of over 18% for publications at the frontier, in other words, directly cited by patents.

This effect is even clearer in our sample, as we can see in the table below: the proportion of articles cited by patents that figure not in the top 5% but in the top 1% of the most cited articles is over 16%! Thus, it is clear that disruptive patents preferentially refer to scientific papers with the highest impact, in other words, those that are the most innovative on the scientific and technological levels simultaneously (Jonkers and Sachwald, *op. cit.*; 2018; Quemener *et al.*, 2024).

The figure below shows that this leaning towards excellence is perceptible in all of the technologies in our sample. The data can be interpreted as follows: for example, in the top left-hand box, which concerns 'condensed matter physics' (panel PE3 of the European Research Council), the top 10% of the most cited articles (those in the first decile) on average receive 5.8 citations per article. However, if we only look at articles in this same PE3 panel cited by the disruptive patents in our sample (in other words, concerning the four fields of photovoltaics, nanoelectronics, spintronics and quantum computing), this time the publications in the first decile have an average rate ranging from 15 to 25.6 citations per article. Disruptive patents therefore have a clear propensity to cite articles with a very high academic impact; put another way, they have a preference for scientific excellence.



Panel PE3: condensed matter physics

Panel PE4: physical and analytical chemical sciences

Panel LS4: physiology in health, disease and ageing

Panel LS6: immunity, infection and immunotherapy

fig.
2.6

Average number of citations per article, for all scientific publications and for those cited by disruptive patents, sorted into deciles, in four examples of ERC scientific panels.

Source: EPO-Patstat base spring 2024, ROS 2024 base, OpenAlex 2024 base, OST-Web of Science base (year 2021, 95% complete), OST-Hcéres calculations.

NB: details of these data are provided in Appendix E of this report. Only patent families filed with at least two national offices, with the EPO or WIPO are considered.

INITIAL CHARACTERIZATION OF THE TWELVE TECHNOLOGIES

The above data indicate that the twelve disruptive technologies in our sample possess bibliometric characteristics that both distinguish them from other 'regular' technologies (share of patents citing research papers, proportion citing very high-impact research papers), and from each other. This extends an observation already outlined in our previous note (Bellit and Charlet, *op. cit.*). The size of patent corpuses, their growth rate, the respective place of different countries in patent applications, etc. are all indicators which express that these twelve technologies, although treated equally in expert reports analysing the drivers of change in 21st century European industry, in reality have very different physiognomies, scientific roots and expansion kinetics.

As a result, we might be tempted to put forward a synthetic representation that reflects their level of 'disruptiveness'. The stated purpose of this investigation is to examine whether the weight of different countries, in Europe, Asia, and North America, in patent applications for each technology, has something to do with the readiness of the technology, or on the contrary, with the still exploratory nature of the scientific research that it stems from. An indicator of disruptiveness has been proposed by researchers, as mentioned in the previous note, but it is controversial due to its potential susceptibility to methodological bias (*cf.* box).

We therefore propose to make a simple principle component analysis of our sample of twelve disruptive technologies, each of which is characterized by fifteen variables.[26] The full process is developed in Appendix I of this note; here we concentrate on the presentation and interpretation of the results (the first two axes obtained represent 51% of the variance).

The first factor that distinguishes these disruptive technologies involves determining whether US applicants represent an over-proportional share, in which case joint public-private applications and the average number of citations of research papers also tend to be higher. On the contrary, when Japanese and Korean applicants play a key role, we observe a larger total volume of patents and a higher than average share of companies among the applicants. There is therefore clearly, from one technology to the next, a correlation between the relative weight of the main applicant countries and the kinetics of knowledge production. The remainder of this publication brings additional insights on this point. The second distinction consists in looking at whether the progression in the number of patents filed is positive or on the contrary nil, or even negative.

On this basis, twelve technologies can be classed into four groups. The first group features technologies where Asian applicants (and companies) dominate and where the increase in the number of patents is nil or moderate: hydrogen for transport, batteries for electric vehicles, photovoltaics, spintronics, low-carbon steel. The second 'group' relates to a single technology that is growing very fast and with a particularly high global share of US applicants: quantum computing. The third group concerns technologies with moderate, or even negative growth dominated by US applicants: SAF, nanoelectronics, and mRNA. The fourth group comprises the other technologies, for which European countries often represent a larger share: offshore wind, recycling of strategic metals, and biological plastic recycling.

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[26] These fifteen variables are: (i) the total number of applications of disruptive patent families, (ii) the annual growth rate of the number of patent applications, (iii-vi) the respective global shares of the United States, Japan, Korea and China, (vii) the share of citing patents in the total patents, (viii) the average number of patent citations, (ix) the average number of non-patent literature citations identified in OpenAlex, (x) the average number of academic citations identified in the Web of Science, (xi) the share of companies among the applicants, (xii) the share of public-private joint applications, (xiii) the cumulated share of the first twelve applicants out of the total patent applications, (xiv) the median age of the academic publications cited by patents, and (xv) the share of non-patent literature citations for which at least one author works in a company. *Cf.* Appendix I.

IS GLOBAL SCIENCE REALLY BECOMING LESS DISRUPTIVE?

IN A CELEBRATED ARTICLE PUBLISHED BY NATURE, Park *et al.* (2023) calculate the disruption index for each article and each patent. They deduct from their measurements that global research and technology follow an increasingly incremental pattern and make increasingly fewer major discoveries. Their analysis relies on the detection of continuous chains of citations in scientific papers: they call 'disruption' the moment when the publication of a new paper or patent succeeds in obscuring or overshadowing previous articles in the publications that follow.

However, Petersen *et al.* (2023) contest their interpretation of the results. According to these authors, the continuous decrease in the disruption index of contemporary papers and patents is primarily due to behavioural and endogenous factors: in practice, over time, authors are encouraged to present very long lists of bibliographic references in their articles, while also citing themselves. This constant evolution in the way of presenting scientific studies has the direct effect of artificially bringing down the disruption index of recent articles. At the end of their study, Petersen *et al.* affirm that the disruptiveness of scientific papers in fact increased from 2005 to 2015.

Point of view

by **Arnoud de Meyer**

How do disruptive innovations come about?

Arnoud de Meyer
Professor Emeritus, Singapore Management University.

THIS EMPIRICAL ANALYSIS represents an impressive and unprecedented effort to examine the relationship between science and innovation across 12 industrial sectors disrupted by technological change. As a scientist with experience consulting for industry, I have some observations on this analysis.

Key Observations

The Good News

Charlet's research highlights a clear link between high-quality scientific endeavours and industrial innovation. From his analysis it is clear that technological disruption often has roots in scientific outcomes. However, I remain unconvinced that this relationship follows a straightforward, linear model. In high-tech fields—which I acknowledge differ somewhat from disruptive technologies—the essence lies in the close collaboration between academic and industrial scientists working on shared problems. For me this almost the definition of what high tech is. This contrasts with more conventional technologies, where the interests of industry and academia often diverge, and where the problems academics work on often seem irrelevant or marginal to industrialists.

In high-tech sectors, academic researchers and industrial technologists frequently interact, pushing the boundaries of technology together. I found Table 2.2 in Chapter 2 particularly intriguing. It shows that the proportion of academic articles cited by patents with at least one company-affiliated author varies between 10% and 25%, depending on the technology. This underscores the importance of academic-industrial collaboration in high-tech fields. Notably, offshore wind turbines, which I personally would not classify as high tech, show the lowest collaborative citation rate (10.9%), while quantum computing—a quintessential high-tech domain—has the highest (18.5%). The 2024 Nobel Prize in Chemistry, awarded to one academic and two industrial scientists, further supports the hypothesis of productive academic-industrial collaboration and interaction.

The Bad News

For scientists like me, a concerning finding is the limited citation of academic work in patents compared to the vast volume of research publications. Charlet's analysis reveals that scientific articles cited by patents represent a mere 0.5% of the total literature published in the same fields. Moreover, his analysis relies on Web of Science data, which already narrows the pool to higher-quality publications. Among the cited articles, the most impactful ones dominate: over 16% of articles cited by patents are from the top 1% of the most-cited articles. Again, there is variation by technology, ranging from 8.3% for offshore wind turbines and 8.5% for strategic metals recycling to 18.8% and 17.9% for quantum computing. This suggests that closer interaction between top academic scientists and advanced industrial researchers is more prevalent in high-tech fields. And one cannot escape the conclusion that only a limited output of scientific research has a real impact on economic disruption.

Reflections on the Findings

The Volume of Low-Impact Research

Why is there such a vast quantity of research publications with probably minimal or no impact on patents and, by extension, industrial innovation? I consciously say "probably" because academic research may influence innovation through other pathways, such as consulting, executive education, conferences, and networking. This is well-documented in the social sciences and it could apply to STEM fields as well – I do hope that 'La Fabrique de l'industrie' finds a methodology to measure these other impacts in a future monograph.

Even when considering patent citations alone, I wonder why so much research output lacks tangible impact. Is it due to a Darwinian process in science, where a large volume of publications is necessary to produce a few breakthrough studies? Or is it a sign of inefficiency in research productivity?

Doctoral education, often an apprenticeship in research, frequently requires students to publish one or more papers, many of which are marginal in contribution. We should find a way to discount for these exercises for PhD students. Furthermore, the "publish or perish" culture in academia exacerbates this issue, leading to a proliferation of narrowly focused, often quasi-irrelevant papers (the rise of predatory journals has only worsened the problem). Charlet's detailed analysis reinforces my conviction that academic institutions and their funders must critically evaluate how to improve research productivity and support top-quality research. Effective dissemination of such high-quality results is equally important, and it is not obvious to me that publication of research results in specialized peer-reviewed journals is the best way for efficient and fast dissemination.

Academic-Industrial Collaboration

As mentioned earlier I strongly believe in the interactive model of collaboration between academic and industrial scientists. Interactive collaboration between academia and industry is vital but not without challenges. From my experience, top laboratories and companies leading in disruptive technologies do collaborate, but such partnerships face many significant obstacles. Differences in organizational structures and communication methods are key barriers. In academia, doctoral students and post-docs report directly to their principal investigator (PI), while industrial researchers often operate within hierarchical layers. These differences complicate communication, in particular when there are conflicts, and collaboration.

Additionally, academic and industrial goals can diverge. Top researchers often seek peer recognition among their worldwide colleagues, even striving for eponymy or Nobel prizes and their equivalents, while companies prioritize economic success. Although these objectives are not mutually exclusive, misalignment can erode the trust necessary for successful collaboration. Academic leaders and government agencies can and must create frameworks and resources to foster trust and facilitate collaboration between top researchers and technologists.

The Role of National Absorptive Capacity

The success of translating academic outcomes into industrial innovation is in my opinion closely tied to a country's industrial absorptive capacity. This is particularly critical for smaller and mid-sized nations. I have often observed that governmental funding agencies make substantial investments in exciting new research disciplines, yielding excellent outcomes, only for these results to be underutilized due to insufficient absorptive capacity of the local industry. Consequently, the benefits are either lost or exploited elsewhere.

My advice to research funders: while some resources should be allocated to exploring white spaces for new technologies and industries, the majority of your research spending should focus on areas where industrial absorptive capacity already exists. This approach ensures that research investments yield tangible benefits for the local economy and translates in growth in the GDP. It is my observation that the East Asian economies that Charlet describes have well understood this.

Conclusion

Charlet’s analysis offers valuable insights into the intersection of science, innovation, and industrial disruption. It underscores my call for the need for better-targeted research funding, stronger academic-industrial collaboration, and a strategic focus on leveraging a country’s absorptive capacity. By addressing these challenges, we can maximize the impact of scientific research on innovation and economic growth.

3

Chapter

Very different national profiles

Japan, China, Korea, the United States and European states do not get involved in the innovation process at the same stages or produce the same output. These clear differences between countries are consistent for all of the technologies studied – which implies that the real issue is the effectiveness of public policies and private ecosystems, whatever the field.

COUNTRIES' WEIGHT AT FIVE SUCCESSIVE STAGES

The first two chapters of this publication showed that it was possible to consider the innovation process following a linear, sequential pattern, from the research that produces scientific papers to patent applications. We can therefore split this top-down flow into different stages where we measure the respective shares of the main countries studied (*cf.* figure below): first, in international scientific publications covering all fields; second, in academic output in the **scientific core** of each technology (i.e. in the three fields most frequently cited by the corresponding patents); thirdly, among the articles actually cited by patents for each technology (in other words, among the NPL citations of disruptive patents); fourth, in the citing disruptive patents; and fifth, in all disruptive patents.

Scientific core

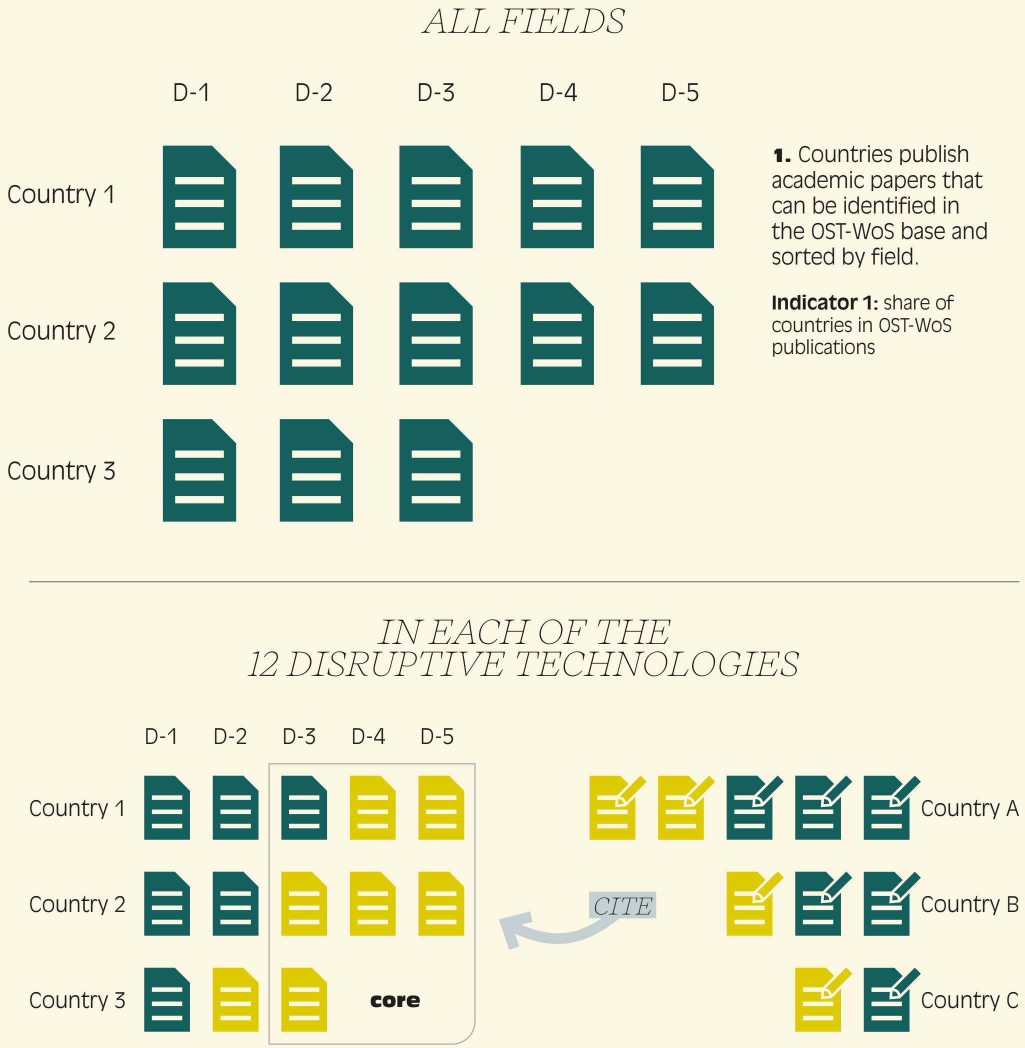
Each research paper can be related to an academic discipline of one of the 27 European Research Council panels. The 'scientific core' of a technology refers to the 3 panels, of these 27, that are the most frequently represented by the scientific papers cited by patents.

GLOSSARY

> These countries are not uniformly involved in disruptive technologies

fig. 3.1

From publications to patents



1. Countries publish academic papers that can be identified in the OST-WoS base and sorted by field.

Indicator 1: share of countries in OST-WoS publications

2. Some of these articles are cited by disruptive patents. The three fields most frequently cited form the 'core' of each technology. This core features both cited and non-cited articles.

Indicator 2: share of countries in the academic core of each technology

Indicator 3: share of countries among the articles actually cited as a reference by disruptive patents, in each technology

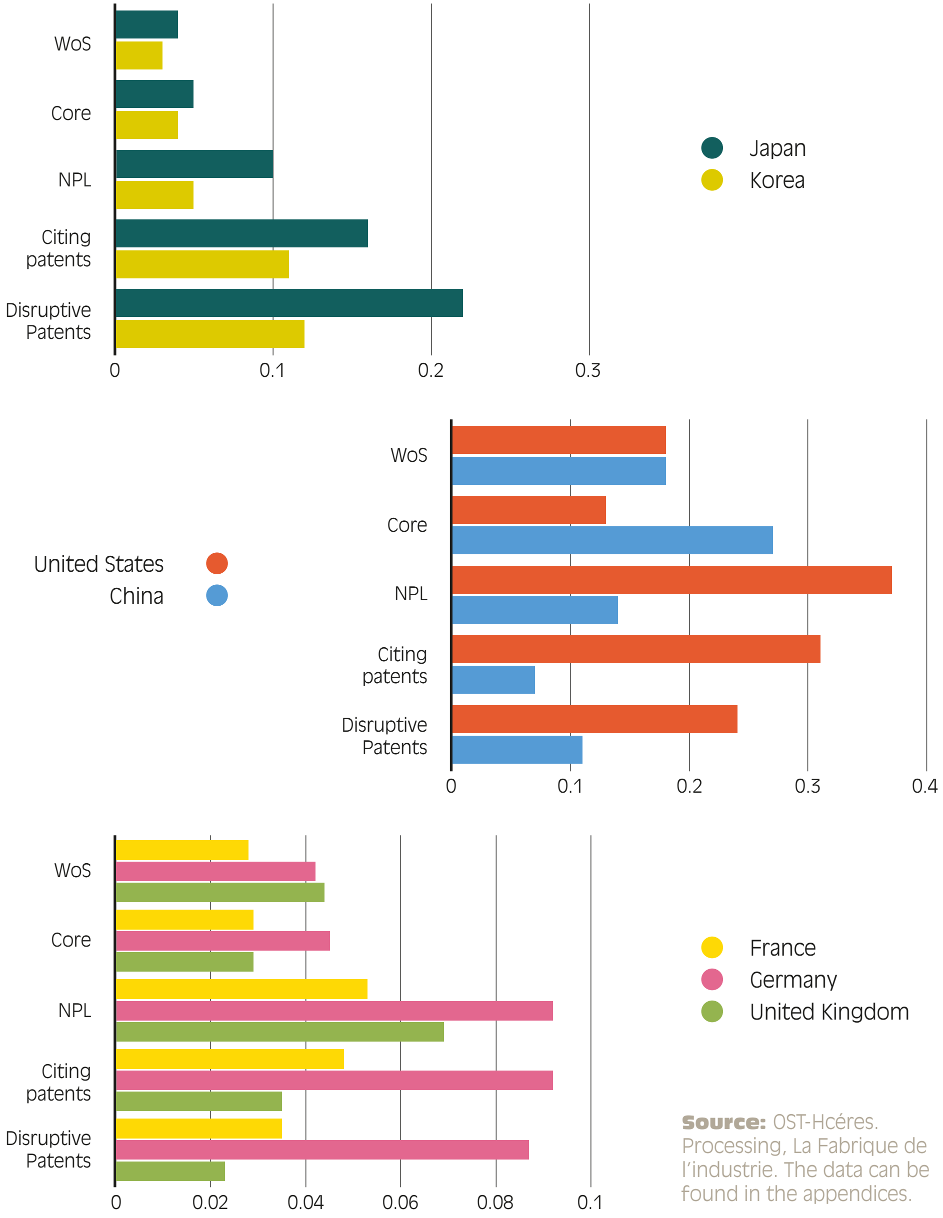
3. Countries file patents in each disruptive technology. A fraction of these patents directly cite articles as a reference.

Indicator 4: share of countries in citing patents, in each technology

Indicator 5: share of countries in disruptive patents, in each technology

fig. **3.2**

Average global share of seven countries at the successive stages of the innovation process



Source: OST-Hcéres. Processing, La Fabrique de l'industrie. The data can be found in the appendices.

The simplified figure below, and the complete figure provided in Appendix 1, show to what extent these countries are not uniformly involved in disruptive technologies. On the contrary, their global shares vary widely depending on the step of the process. Let us start by looking at Japan. This country is at the origin of 4% of the research papers referenced in the total corpus, taking all disciplines together. If we look only at the scientific core of disruptive technologies (in other words, the three scientific fields the most frequently cited by patents, which are singular combinations of sub-domains in physics, engineering and life sciences), its global share rises to an average of 5%. If we restrict the scope of analysis even more and only consider publications actually cited by patents (NPL citations), then Japan's global share rises to 10%. Following the same path throughout the innovation process, but this time studying citing patents, in other words, the sub-set of disruptive patents that cite research papers, Japan's global share increases to 16%. Lastly, if we consider all disruptive patents, it reaches 22%.

Apart from the very first one, these figures are averages calculated for all of the technologies studied. As we can see on the complete figure in Appendix 1, this continuous growth of Japan's global share can be seen for each technology: the country's capacity to 'ramp up', from research to innovation, applies to the entire sample. We can also see that Korea has a similar profile, although with smaller global shares at these different stages; its role also grows as it moves downstream in the process.

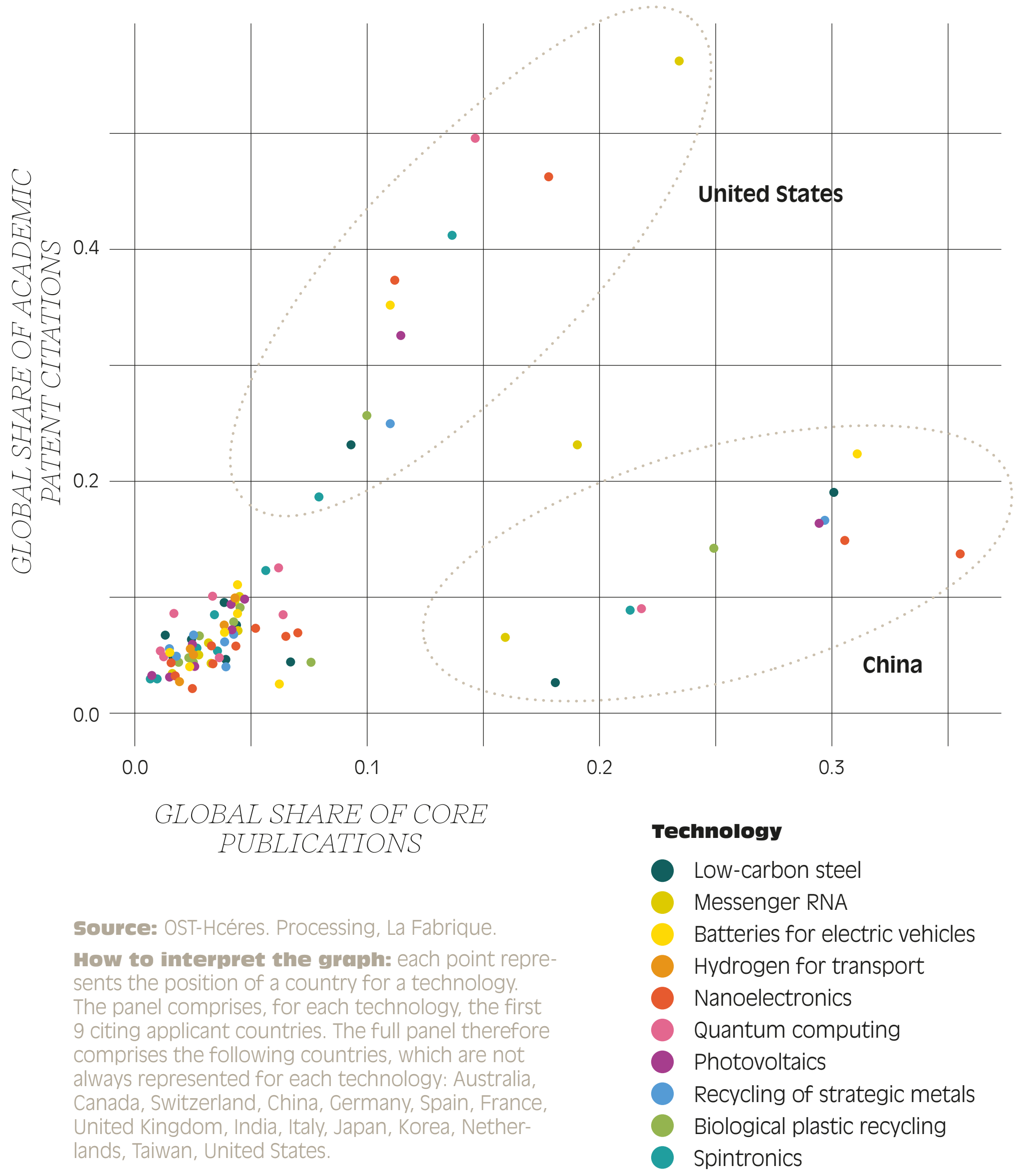
The United States has a radically different profile. Its global share in the total corpus is 18%. If we look only at the scientific core of technologies, the country's global share drops to an average of 13%. However, if we only look at the fraction of these articles that are actually cited by patents, i.e. NPL citations, then the US share sharply rises to represent 37% of the global total! As a result, even with a slight drop in the second two stages of this sequential process, respectively for citing patents and the totality of disruptive patents, the global share of the United States in disruptive technologies reaches an average of 24%, which is significantly higher than its weight in all scientific publications at the start of the process. We can retain that the country occupies a decisive place in the production of 'patentable science' or, more precisely, scientific articles mentioned by patents.

The last bar chart shows analogue diagrams for three European countries: France, Germany and the United Kingdom. At first glance, the profile of these three countries is relatively similar to that of the United States, although with some important differences. France represents 2.8% of global publications and a similar percentage of publications in the scientific core of technologies studied. Its global share amounts to 5.3% when looking only at articles cited by patents: France therefore, like the United States, boasts an attractive scientific output in the eyes of patent applicants. Unfortunately, the country then successively drops back when looking at citing patents, then at all disruptive patents, where its global share drops to 3.5%. Germany, which starts a little higher (4.2% of global scientific articles), is similarly attractive in terms of scientific publications for patent applicants, and produces 9.2% of the literature cited by patents. However, unlike France, the country moves very little further down the process, and is ultimately at the origin of 8.7% of disruptive patents filed in the world, on average for all of the technologies in our sample. In contrast, the United Kingdom, whose scientific publications are also very attractive, when comparing its global weight in NPL citations and in the core of each technology, drops down quite sharply in the move from science to patents, and only represents 2.3% of the global total of disruptive patents on average for the technologies in our study.

The situation is very different for China. To start with, its weight in global science is very close to that of the United States at 18% of articles identified in the entire corpus. Chinese research is clearly highly oriented towards engineering science, physics and chemistry since its average position in the scientific core of disruptive technologies is much higher at around 27%. Nevertheless, when looking only at articles that are cited by patents, China's global share shoots down to 14%. Concerning patents that cite scientific papers, it drops down again to 7%. Even after picking up slightly at the end of the process, the country only totals 11% of the disruptive patents in our study, which is significantly lower than its share of global scientific publications. The implication is that China makes a very intense scientific effort, particularly in the fields that serve as a scientific foundation for disruptive technologies, but this scientific output does not succeed in convincing global patent applicants or in fuelling its national capacity to file disruptive patents. The figure below illustrates this point by showing the correlation between the global share of core publications and the global share of NPL citations, for each country and each technology. On the bottom right of the graph, we can see that Chinese research in the core scientific fields of each technology is rarely converted into academic citations by patents, in contrast with other countries, and in particular the United States (shown at the top

fig. **3.3**

Position, for each country and each technology, based on the global share of core publications and global share of academic patent citations



Source: OST-Hcéres. Processing, La Fabrique.

How to interpret the graph: each point represents the position of a country for a technology. The panel comprises, for each technology, the first 9 citing applicant countries. The full panel therefore comprises the following countries, which are not always represented for each technology: Australia, Canada, Switzerland, China, Germany, Spain, France, United Kingdom, India, Italy, Japan, Korea, Netherlands, Taiwan, United States.

of the graph). This observation is in line with the results of Gazni and Ghaseminik (*op. cit.*), which relate to patents with a high technological impact filed with the US office (i.e., ranking in the top 1% in terms of citations received by other patents) from 2012 to 2016.

In summary, these seven countries have relative strong points that both vary depending on the stage of the innovation process and are relatively stable from one technology to the next. This observation leads us to postulate that some national innovation systems, combining public policies and industrial capacities, are more effective than others at these different stages, almost independently from the technologies considered. It therefore seems that the United States, along with the three European countries studied, have a comparative advantage in the upstream phase of the process, which involves extracting from their scientific production a sub-set of articles that are useful and pertinent for patent applicants. In contrast, Japan and Korea successfully increase their global share at every stage of the process moving away from science and closer to the market. As we shall see in what follows, the science-market decoupling seems fairly obvious in Western countries, whereas we could put forward the idea of a better alignment between public and private innovation efforts from Japan and Korea. China today appears to be in an intermediary position, marked by a spectacular scientific publication output in the domains concerned that nevertheless does not yet convince international patent applicants. We do not possess robust elements to affirm whether this situation is evolving (apart from the fact that the country is very active in patent applications).

NATIONAL CHARACTERISTICS OBSERVABLE FOR ALL TECHNOLOGIES

We here reproduce the main results of Appendix L, which aims to separately examine the scope of two effects: the ‘country’ effect, and the ‘technology’ effect. As mentioned above, the hypothesis of a ‘country’ effect is based on the idea that the relations between our data vary significantly from one country to the next, for different potential reasons: the effectiveness of their public policies and institutions and of their private ecosystems, a sum of geographic impacts that can be put down to the size of the countries studied, more developed linguistic or cultural affinities between some countries, etc. This hypothesis is tacitly admitted every time a benchmarking exercise encourages a state to take inspiration from ‘good practices’ identified in other countries. In addition, the hypothesis of a ‘technology’ effect states that these correlations vary significantly from one technology to the next due to the intrinsic characteristics of the economic and scientific sectors concerned: the intensity of cutting-edge knowledge, fixed costs and minimal durations of investments to be made to achieve a solvent innovation, the pace of entry of new competitors, the capital intensity, etc. All of these things, as we know, vary greatly from one market to another. The notion of a ‘technological regime’ was in fact coined to illustrate this idea that all technologies do not have the same metabolism or activating levers, which makes the comparative analysis of public policies between countries complicated. As we shall see stage by stage, the ‘country’ effect appears significant in all of the correlations tested, and the ‘technology’ effect only rarely so.

Excellence

Here we call ‘excellence’, for a given technology and country, the relationship between its global share of research articles cited by patents and its global share of articles published in the technology’s scientific core.
An indicator of excellence can then be calculated for each country, as the average of the values observed for the twelve technologies.

GLOSSARY

Firstly, we examine to what extent, for each country and each technology, the research effort in the core fields is largely converted into NPL citations – satisfying a criterion that we call **excellence**. Table L-1 indicates that the coefficient of the correlation between these two figures[27] varies very significantly from one country to the next, but not from one technology to the next: the hypothesis of a ‘country’ effect is therefore validated, while that of a ‘technology’ effect is rejected. Taking China and Korea as reference countries, France and Japan stand out with slightly higher correlation coefficients, followed by Germany, and lastly the United States and the United Kingdom with the steepest slopes. This excellence criterion is without doubt a distinctive characteristic of powerful English-speaking countries.[28]

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[27] — This therefore involves the correlation between the global share of core publications (explanatory variable) and the global share of NPL citations by patents (dependent variable), for each country and each technology.

[28] — Strictly speaking, we give here the same name and meaning to two different indicators. The criterion of excellence, as defined at the start of the paragraph and featuring in the summary table at the end of the chapter, is a ratio between two global shares: first, for each country and each technology, then for each country on average for all of the technologies studied. In addition, the analysis of covariances provided in Appendix L, the conclusions of which are presented here, aims to distinguish the possible ‘country’ and ‘technology’ effects: it therefore relates to the correlation coefficient between these global shares. Assimilating these two definitions is equivalent to disregarding the constant terms of the regressions (the intercepts). As shown in Appendix L, this arithmetical approximation does not skew interpretations.

> «
> It is at this stage that the European weakness in transforming its research into disruptive innovations is probably the most obvious.
> »

In the next step, we look at the extent to which disruptive patent applications that explicitly draw from science (citing patents) are correlated with publications of papers cited by patents (NPL citations), which we call **coherence**. As in the previous case, the L-2 table shows that the terms of the correlation between these two figures[29] does vary significantly from one country to the next. Once again, the hypothesis of a 'country' effect is the only one to be validated. The order of the countries is not, however, the same: the French, British and Chinese economies have a propensity to file citing patents more or less independently from their weight in NPL citations. German industrialists, curiously, are more likely to file citing patents relating to scientific fields where German research is less present - the slope is negative (this may be an artefact related to the sample of chosen technologies).

Coherence

We call 'coherence', for a given technology and country, the relationship between its global share of citing patents and its global share of articles cited by patents.
A coherence indicator can then be computed for each country, as the average of the values observed for the twelve technologies.

GLOSSARY

The propensity of US, Japanese and Korean companies to file citing patents is very strongly correlated with the tendency of national laboratories to publish articles that will then be taken up by patents. It is at this stage that the European weakness in transforming its research into disruptive innovations is probably the most obvious.

Thirdly, we test the correlation between the global share of citing patents and the global share of disruptive patents, in relation to a criterion that we call **upscaling** (table L-3). As in the two previous cases, the hypothesis of a 'technology' effect is not validated. However, we also observe that there is no clear difference in the correlation coefficients from one country to the next in this final step.

Upscaling

We call 'upscaling', for a given technology and country, the relationship between its global share of disruptive patents and its global share of citing patents.
An indicator can then be chosen for each country, as the average of the values observed for the twelve technologies.

GLOSSARY

We then carry out two final tests that this time employ relative indicators, in other words, indicators of intensity: publications or patents per capita, scientific specialization index, etc. The aim here is to eliminate a potential bias related to the size of the economies studied.[30]

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[29] — This therefore involves the correlation between the global share of NPL citations (explanatory variable) and the global share of citing patents (dependent variable), for each country and each technology.

[30] — If a country represents 15% of global GDP, we might expect it to represent around 15% of all the variables studied, which would reveal artificial correlations between the variables which are in reality all dependent on the size of the economy.

The first of these two tests consists in looking at whether a research effort directed in a more than proportional manner in a given field (i.e., a high specialization index for a country in this field) translates into higher production per capita of articles in the same field that will be cited by patents - a criterion that we call **selectivity** (*cf.* Table L-4). As in the previous cases, the hypothesis of a 'technology' effect is not validated (except for the specific case of messenger RNA, possibly due to the influence of the USA), while a 'country' effect is confirmed, although only moderately significant.[31] For China, Japan, France and Germany, the line is almost horizontal: the number per capita of academic citations by patents is not boosted by a country's specialization in the fields concerned. For Korea, the United States and the United Kingdom, however, the slope is clearly positive: the more research in these countries specializes in the core scientific fields, the higher the number per capita of NPL citations by patents.

The last correlation tested here, by way of a summary, is the correlation that we can observe between the number per capita of patent academic citations and the number per capita of disruptive patents (Table L-5). The two 'country' and 'technology' effects are confirmed here, although the former is more significant than the latter. The lines relating to the four Western countries (France, Germany, United Kingdom and United States) are almost horizontal: their number per capita of disruptive patents is not higher in technologies for which they display particular scientific excellence, measured by the number per capita of NPL citations. China, and even more so Korea and Japan, present rising curves: their number per capita of disruptive patents is positively correlated with their number per capita of academic patent citations. It is tempting to conclude that, in these three countries, public and private innovation efforts are more aligned than in Western countries, where they work independently from each other. Unsurprisingly, the slope therefore rises particularly steeply in the fields of hydrogen, photovoltaics and batteries.

Selectivity

We call 'selectivity, for a given technology and country, the relationship between the number per capita of scientific articles cited by patents and the weighted index of the country's specialization in the three core scientific domains.

GLOSSARY

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[31]— In this case, this involves the correlation between the relative specialization of a given country in the three core scientific fields of a technology (explanatory variable) and the number per capita of academic citations mentioned in patents for the technology in question (dependent variable).

THE VIEW OF VICTOIRE DE MARGERIE

CEO OF RONDOL, MEMBER OF THE LA FABRIQUE DE L'INDUSTRIE STEERING COMMITTEE

Aside

THIS STUDY MAKES A VERY INTERESTING analysis of how disruptive innovations emerge in the United States, China, Europe and of course, France. I would like to add three observations and suggestions that could see France move as quickly as the United States in generating these disruptive innovations, and as fast as China to then take them into industry.

1. A very important point in the conclusion of this note is that numerous research projects in France do not target having an impact. Research aims at publication in top journals or patent applications, but often does not have a simple objective of 'disruption', like reducing operating costs or capital intensity and, obviously, improving the performance of a product or process (e.g., decreasing the energy consumption of data storage, reducing the consumption of water used in mining, reducing the weight of batteries, etc.). Yet it is that kind of impact that sees research resulting in profitable industrial activity.

2. A common attitude in France is that research – and then innovation –only comes from a particular type of people: engineers aged between 20 and 40. We totally overlook work generated by other kinds of profiles (different academic backgrounds, no academic background, over forty, etc.). And that is a real waste of talent, because those people go to innovate or create their own businesses abroad, or stay in France without contributing as much as they could.

3. Lastly, when we identify high-impact innovation driven by an entrepreneur, that entrepreneur loses an incredible amount of time applying for subsidies. It would be more effective to help them develop proofs of concept with real industrial clients. After unsuccessfully seeking subsidies and thanks to the development of proofs of concept with Segens in France, YKK in Canada and Daikin in Germany, my deep tech start-up moved on with its research to offer industrial solutions and better care to patients and clients, at a lower cost.”

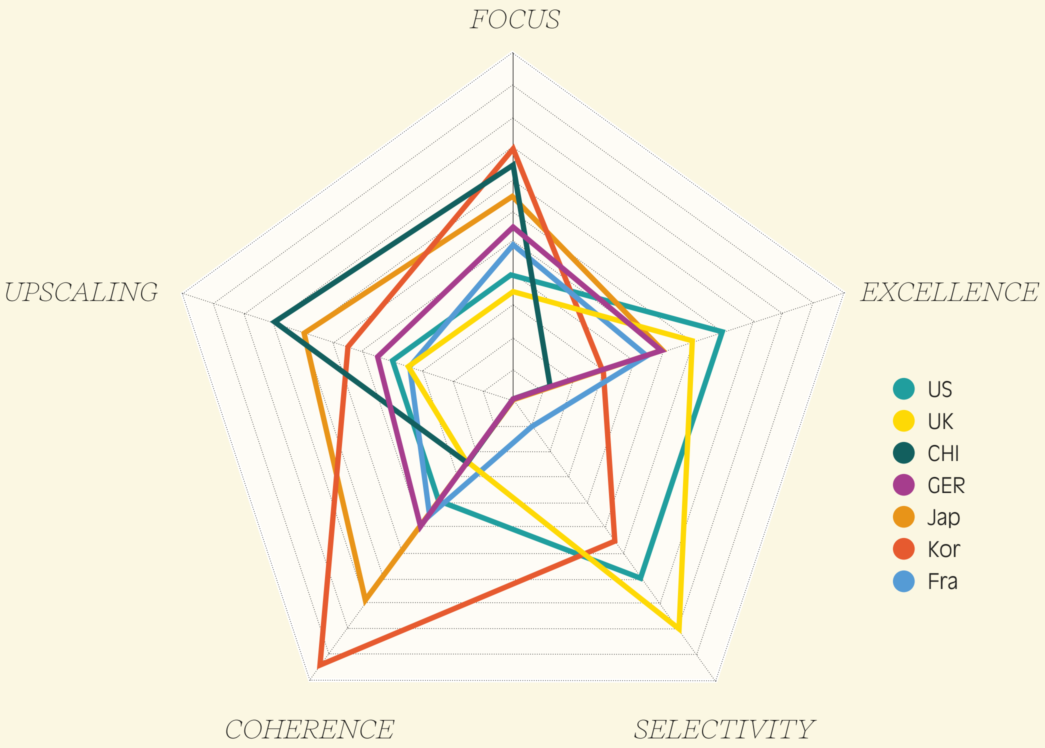
fig.

3.4

Summary characterization of the profile of seven countries at different stages of the sequential process of disruptive innovation

How to interpret the data: the *focus* of a country designates the ratio between its average global share in the scientific core of the twelve disruptive technologies and its global share in the total corpus (OST-WoS), taking all fields together. *Excellence* designates, for each technology, the ratio between its global share of academic patent citations and its global share of publications in the core. A country's *selectivity* is given by the slope of the regression line between the number per capita of NPL citations and the relative specialization index (cf. Table L-4, in Appendix L). A country's *coherence* designates the ratio of its global share of citing patents and its global share of academic patent citations. Lastly, *upscaling* designates for a given country the ratio between its global share of disruptive patents and its global share of citing patents.

	US	*UK*	*JAP*	*KOR*	*CHI*	*FRA*
Focus: concentrates its scientific production in the core fields	– (0.8)	– (0.7)	+ (1.3)	++ (1.6)	++ (1.5)	0 (1.0)
Excellence: produces fertile publications from its scientific output	++ (2.8)	++ (2.4)	++ (2.0)	+ (1.2)	– – (0.5)	+ (1.8)
Selectivity: specializes in scientific fields of excellence	+ (57.6)	++ (71.2)	0 (–1.8)	+ (44.2)	0 (0.5)	0 (7.8)
Coherence: aligns technological efforts with scientific output	– (0.8)	– – (0.5)	+ (1.6)	++ (2.1)	– – (0.5)	– (0.9)
Upscaling: generates disruptive patents from citing patents	– (0.8)	– (0.7)	+ (1.4)	+ (1.1)	0 (0.9)	– (0.7)



Note: All of these criteria constitute the capacity of states to ultimately obtain a high global share of patent applications in disruptive technologies based on their global weight in scientific production. Arithmetically, we can even construct the following formula:

$$\frac{\text{global share of disruptive patents}}{\text{global share of scientific production}} = \text{focus} \times \text{excellence} \times \text{coherence} \times \text{upscaling}$$

> *« A country's relative position does not always correspond to the usual indicators of excellence in bibliometrics: in particular, the positions of China, Japan and France. This can perhaps be explained by a disciplinary bias due to the choice of technologies in the sample. »*
>
> **Frédérique Sachwald**, director of the OST

ANGLO-AMERICAN EXCELLENCE VERSUS ASIAN COHERENCE?

The figure 3.4 summarizes the previous results in the form of a set of criteria. The terms *excellence*, *selectivity*, *coherence* and *upscaling* have already been defined above. We also add the criterion of *focus*, which designates a country's propensity to concentrate its scientific production in disciplines useful for technologies: this is a ratio between its average global share in the scientific core of the different technologies, and its global share in the Web of Science, taking all disciplines together.

These indicators are proposed here for the seven countries previously studied, and presented in the form of a radar chart that provides a visual overview of the preceding analyses.

Firstly, the United Kingdom and the United States stand out for their aptitude to combine excellence and selectivity: their research systems are therefore capable of producing a high quantity of scientific papers that will prove useful to patent applicants. Korea, which also shows a high level of selectivity, in particular occupies a remarkable position on the coherence and focus criteria: very close alignment between the technological efforts of its industry and the scientific efforts of its research system, which are also quite strongly centred on the core technology scientific fields.[32] We can add, looking at this table, that it is the only country to never present a below-average score on each of the criteria. Japan also has a comparatively high score on the two criteria of coherence and focus, added to an impressive upscaling capacity and a noteworthy score for the excellence criterion. China stands out at both extremes of the process, for the criteria of focus and upscaling. Compared to these countries, France and Germany have lower scores for all criteria.

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[32] — These situations of alignment or disalignment, in each country, between the fields of published research papers and those of patent applications partly reflect sectorial structures dating back a long way. The aim here is not to entirely attribute them to the short-term effectiveness of public policies.

THE VIEW OF SIR VINCE CABLE

FORMER SECRETARY OF STATE FOR BUSINESS, INNOVATION AND SKILLS IN THE UNITED KINGDOM (2010-2015)

J IT IS A VERY NEAT PIECE OF RESEARCH which gives powerful evidence to reinforce the worries about a 'European paradox' and specifically 'French paradox': high quality science and mediocre innovation. The use of patent data to measure the progress of innovation in 'disruptive technologies' proves to be a good way to quantify and test the arguments.

In the UK we are used to this phenomenon, the 'paradox', being especially British. We pride ourselves on the quality of British scientific research and beat ourselves up for letting it be siphoned off into commercially successful innovation elsewhere. In fact some recent work on scientific citations shows that British science is living off its reputation and is not so impressive in fact. If we look at AI almost all the quality science originates in Deep Mind and for synthetic biology in the MRC lab. In Cambridge, there isn't much else. There is less ambiguity about the poor record in innovation. Key constraints as we move downstream are the lack of public funding for POC (proof of concept) and private funding for growth out of a successful start-up due to 'short-termism' in our capital markets. I see this on a daily basis as Chairman of a – so far – successful hydrogen/transport company which cannot raise capital to expand and is repeatedly begging our shareholder base to keep us in business.

My one suggestion for further work is that your concept of 'Europe' might separately look at the Nordics, especially Denmark and Finland, which seem to be very good at producing successful growth companies including in disruptive technologies (e.g. offshore wind) but from a very slender science base.

Point of view

by **Joonmo Ahn**

Blurring the lines between science and market

THANK YOU FOR GIVING ME AN OPPORTUNITY to read this book and provide a comment on the contents. This study attempts to investigate a long-standing problem – how countries can promote disruptive innovation – using immense data on the connections between scientific publications and patents. Making a global comparison, this study clearly shows what France lacks compared to other European countries, US, China or Asian countries (Korea and Japan). Although the use of the macro data of publications and patents is sometimes criticised (since that information cannot fully capture the sophisticated nature of innovation), this study tries to empirically show the connection between academic publications and industrial patents; this is one of the most important contributions of this study. Cleary, patentable research is core material of innovation – regardless of the validity of traditional linear models, so well-designed public policy must be developed and employed to promote disruptive innovation.

Having said that, to enhance the quality of the study, I would like to suggest the following comments for the authors' consideration.

1. It might be worth considering the advent of so-called science economy, e.g., quantum mechanics and advanced bio like synthetic biology. Most technologies, including disruptive technologies, have followed a step-by-step development process like the linear model of innovation from basic research to commercial development. However, nowadays, some disruptive technologies jump directly from the science lab to commercial production, skipping the middle stream of innovation. IonQ – a quantum computing firm established by university researchers – could be a good example of blurring the boundary between science and industry.

Joonmo Ahn
Professor at Korea University.

2. The authors could usefully provide a strong rationale for the choice of these twelve disruptive technologies. From my perspective, I agree that some technologies (e.g. quantum) are disruptive while I do not agree with other choices. It seems that relatively many clean technologies are included. Providing clear selection criteria on the twelve disruptive technologies or following global standards announced by a leading think-tank could be an alternative solution.

3. Related to the second point, digital technologies are missing. For example, artificial intelligence is changing the entire landscape of innovation, but A.I. is not included as a disruptive technology.

4. For transnational knowledge flows, due to unique relationships among European countries (EU), a direct comparison of global knowledge utilization could lead to biased interpretations. For example, the knowledge flow in France may not be the same as that in Korea or Japan, in the sense that Korea and Japan do not belong to the EU.

5. Recent trade conflicts have occurred between the US and China, provoking a global decoupling in leading edge technologies such as semiconductors. Strong US laws such as CHIPS and IRA Acts pinpoint export control aimed at China, while German scholars argue the concept of technology sovereignty. This trend may lead to protectionism in many countries, which might distort/contaminate publication and patent data.

6. As noted in the manuscript, Korea has followed a unique path in terms of innovation development, and important drivers are geopolitical location (i.e., competition with China and Japan), manufacturing-oriented industry structure, high national enthusiasm on tertiary education, and benchmarking against US and Japan policies.

4

Chapter

The global circulation of knowledge

In all disruptive technologies, knowledge circulates between the authors of papers and the applicants of patents on a very open global market, so that applicants mainly cite foreign articles. Each country could therefore consider the capacity of its research to produce patentable science and that of its companies to draw from the best scientific sources in the world as independent assets.

TRANSNATIONAL FLOWS FROM SCIENCE TO TECHNOLOGY

This chapter[33] is devoted to analysing citation flows. To do so, we adopt the following definitions. We call *scientific evaporation*, for a given country and technology, the share of foreign patents that feature in the citations of papers produced by national laboratories. This involves appraising to what extent domestic science 'escapes' from applicants from the same country, thus fuelling foreign innovation efforts. Conversely, we call *scientific capture*, also for a given country and technology, the share of foreign articles cited by domestic patents. The idea here is to measure domestic applicants' openness to these foreign scientific sources.

The figure below represents, for 12 countries and 10 technologies, the coefficients for scientific evaporation and capture. The countries are shown on the horizontal axis; for each one, the 10 values taken by the evaporation and capture coefficients, depending on the technology studied, are summarized in the form of boxplots.[34]

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[33] — This chapter is based on the detailed results featuring in Appendix J of this publication.

[34] — In each box, the central line represents the median value of the sample (50th percentile) and the white rectangle the space between the 25th and 75th percentiles, also called the 'interquartile range' (IQR). The black lines on either side of the box extend it by a length that is 1.5 times the IQR, thus indicating the range of values within which all values are theoretically expected to lie. More precisely, each line extends as far as the last value observed within this range of 1.5 IQR. So-called 'extreme' or 'aberrant' values, below or above the lines, are represented by points.

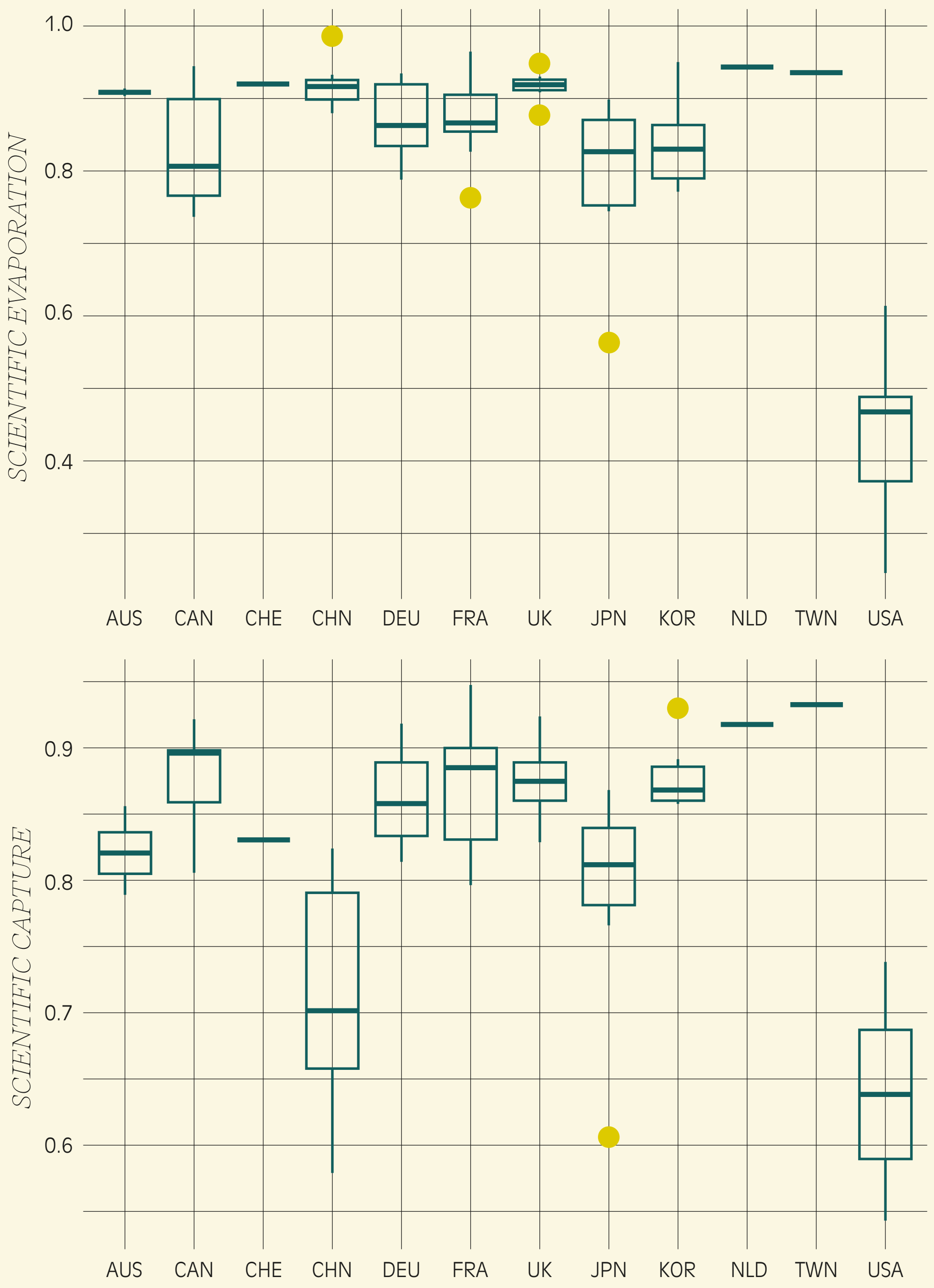


fig. 4.1

Rate of scientific evaporation and capture for all of the technologies studied for a panel of 12 countries

Source: OST-Hcéres. Processing, La Fabrique.

NB: for each technology, the panel comprises the first 9 publishing countries and the first 9 citing applicant countries. The full panel therefore includes the following countries, which are not always represented for each technology: Australia, Canada, Switzerland, China, Germany, France, United Kingdom, Japan, Korea, Netherlands, Taiwan, United States.

How to interpret the data: in Australia, the scientific evaporation rates calculated for each of the technologies available are comprised within an interval from 90% to 92% and the scientific capture rates are comprised within an interval from 79% to 86%.

We observe that, for all of the technologies studied, the scientific evaporation coefficient is very high, mostly between 80% and 90% for all countries, except for the United States, situated between 40% and 50%. Similarly, the scientific capture rate is very high, once again mostly between 80% and 90%, except for China (between 65% and 80%) and the United States (between 60% and 70%). Whatever the country and the technology considered, the immense majority of scientific publications produced by domestic laboratories therefore benefit foreign disruptive patent applicants.

SMALL COUNTRIES, EXPORTERS OF SCIENCE

We confirm the robust correlation between scientific capture and evaporation, shown in the figure below and detailed calculations in Table J-2 in the appendices, after excluding China from the sample. The fact that applicants from a given country draw greatly from foreign scientific sources (thus leading to a high capture rate) is not a sign that the country's science output is insufficient in quantity and would be denigrated by foreign companies, quite the opposite.

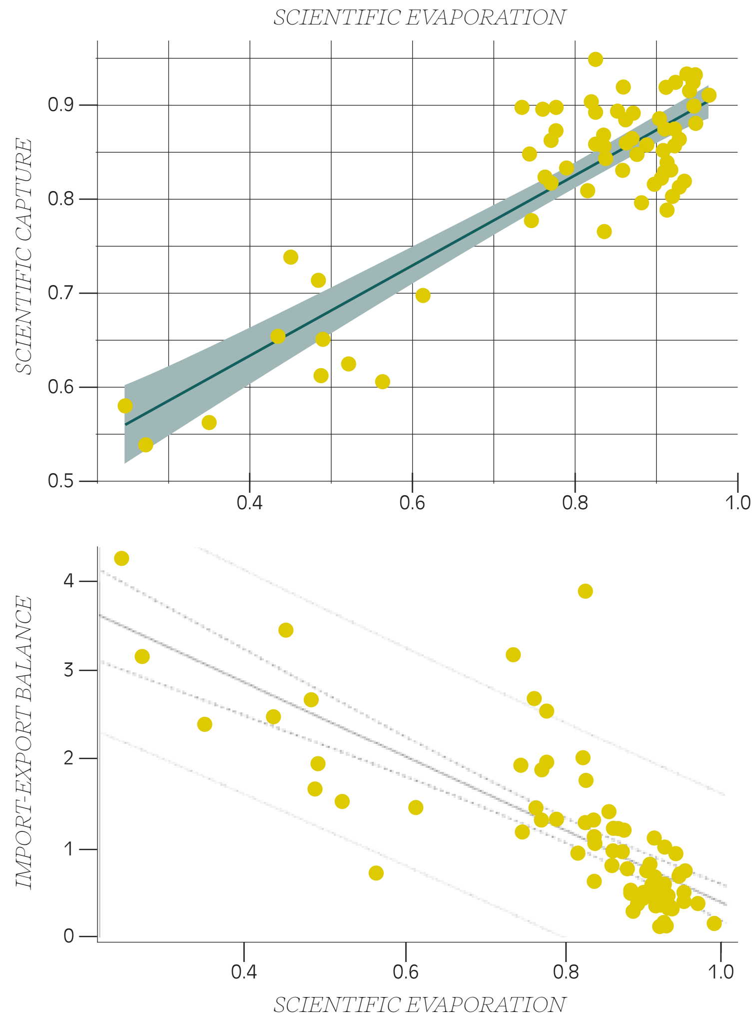
Looking closely at the graph, we can also see that the large countries – and mainly the United States – behave in relative terms as net importers of science compared to the rest of the world: for some technologies, their capture rate is double their evaporation rate. In addition, as shown by Graph J-3 in the appendices, we can see that the scientific evaporation rate is a significantly decreasing function of the global share of NPL citations. In other words, the less a country publishes scientific papers that are picked up by patents, the more that country 'loses' a large share of what it publishes to the benefit of foreign applicants.

At this stage, we therefore need a third definition: we call *import-export balance,* for a given country and technology, the ratio between the number of 'incoming' citations (when foreign publications are cited by domestic patents) and the number of 'outgoing' citations (when domestic publications are cited by foreign patents). Thus, we can see on the second graph in this figure and on Table J-4 in the appendices, that this import-export balance of citations is significantly and negatively correlated to the evaporation rate, and drops below the unit threshold for the highest x values. In other words, small countries, which have a high evaporation rate, are net science exporters.

> « The less a country publishes scientific papers that are picked up by patents, the more that country 'loses' a large share of what it publishes to the benefit of foreign applicants. »

fig. **4.2**

Linear regression between scientific evaporation and capture for 10 technologies and 11 countries



Source: OST-Hcéres. Processing, La Fabrique (see details in Tables J-2 & J-4 in Appendix J).

NB: for each technology, the panel comprises the first 9 publishing countries and the first 9 citing applicant countries. After removing China, the full panel therefore includes the following countries, which are not always represented for each technology: Australia, Canada, Switzerland, Germany, France, United Kingdom, Japan, Korea, Netherlands, Taiwan, United States.

How to interpret the data: each point represents a given technology and a given country. Top figure: the evaporation coefficient is shown on the x-axis and the capture coefficient on the y-axis. The slope of the regression line is not close to 1, but closer to 1.5 (the regression table in the appendix shows an estimated value of 1.54). Consequently, the points on the top right of the graph are very close to an equilibrium – the two rates being close to 90% – but the capture rate decreases at almost half the speed of the evaporation rate going down towards the bottom left-hand corner of the graph. Bottom figure: the scientific evaporation rate is shown on the x-axis and the import-export balance on the y-axis. These two correlations are significant. The regression lines and confidence intervals at 95% are also represented.

GLOBAL SOURCING

Countries do not have the same global share of patent applications or research papers; yet the capture and evaporation rates are influenced by these different predispositions. To remove this effect and obtain a normalized reading of the capture and evaporation phenomena, we call *relative scientific retention capacity*, once again for a given country and technology, the propensity of scientific papers published by national laboratories to benefit domestic patent applicants.[35] We call *relative domestic sourcing capacity*, for a given country and technology, the propensity of national patent applicants to draw from domestic scientific sources.[36]

The simple presentation of values per country of these relative capacities does not bring any obvious lesson (*cf.* Graph J-5, in the appendices), apart from the fact that we can observe a local bent (or 'national preference') everywhere. However, Graph J-6 shows that the relative capacity for scientific retention, in other words the weight of domestic applicants among users of science from a given country, is at its minimum for countries that have a large weight in the core and in NPL citations, and at its maximum for those with the lowest weight. In other words, the industrial 'return on investment' for the national production of knowledge, which is always positive, is not the preserve of large scientific or industrial nations, but rather of modest contributors to global disruptive science.

This is even clearer regarding the relative capacity for domestic sourcing, proportionately inverse to the global weight of academic patent citations, core publications, and even disruptive patents (*cf.* Graph J-7). Put differently, the more the 'national preference' of an industry for its domestic research tends towards 1, its minimum, the more a country plays a significant role in disruptive science or patents. On the other hand, it is at its maximum for countries that are modest scientific and technological contributors. Therefore, innovators, like scientists, are very open to the global knowledge market.

35— This relative retention capacity amounts to 1 if the domestic share of patents citing papers published by national laboratories is equal to the country's global share of patent applications for the technology considered.

36— This relative capacity for domestic sourcing amounts to 1 if the domestic share of papers cited by national patents is equal to the country's global share of publications in the technology's scientific core (a technology's core is constituted by the three scientific fields most frequently cited by the corresponding patents).

MAPPING KNOWLEDGE SPILLOVERS

We have now established the following points. First, scientific capture and evaporation rates are very high, around 80% or even 90%, in all technologies and for all countries apart from the United States and China. Thus, innovators and scientists correspond on a very open global knowledge market: even taking into account a habitual 'local bent' in all of the actors concerned, knowledge flows between authors of papers and applicants of disruptive patents only rarely take place domestically and even less so as part of local interactions. This could be seen as the manifestation of a surface area effect: innovators in small countries, each working in their technological niche, probably do not have the capacity to exploit all of the potential offered by domestic science, which in turn cannot respond to all of the scientific issues raised by applicants from the country. However, this explanation is only partial: nothing indicated that 'average' states (Japan, Korea, various European states, etc.) would turn out to be so similar regarding these two criteria, given that we know that their industries and national R&D efforts differ considerably. Therefore, we can deduce that science clearly circulates freely and abundantly in the world, between those who produce it and those who commercialize it.[37] The fortress or strongbox allegory turns out to be inappropriate, especially given that the papers cited by disruptive patents represent at best 0.5% of the literature on their scientific core: innovators filing disruptive patents are faced with accessible literature 'in the order of infinity'.

Second, it is not *a priori* surprising that the capture rate is significantly lower in the United States than elsewhere, in other words, US companies feel the need less frequently than their international competitors to draw from foreign academic sources to support their patents. On the other hand, the fact that the scientific evaporation coefficient is also larger for small countries may seem counterintuitive: it is rarely assumed that 'patentable' papers published by the CNRS or the Max-Planck Institute are proportionately more sought-after by patent applicants all over the world than papers published by the MIT. This result is therefore worth underlining: the scientific evaporation and capture rates are robustly correlated, for each country and each technology, except for the particular case of China. Here we can make an analogy with industrial value chains, where the most

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37— Knowledge circulates naturally just as much, if not more, between academic researchers at the research stage. In the case of France, for example, 63% of the scientific papers identified in the present study are joint international publications (the papers are counted in fractional units, therefore an article jointly published by two researchers from two different countries counts 0.5 for each country).

dynamic exporting countries are often the most open to imports (in particular imports of intermediate goods that they need for exports). To return to disruptive technologies, all of the countries studied here, including France, therefore fit into a global network of exchanging scientific results that ostensibly seems quite balanced.

Third, the ratio between these two coefficients only becomes imbalanced as we gradually move towards the bigger countries – in other words, the United States. The United States is a net importer of science compared to the rest of the world. This means one of two things: either its capture rate is high in relation to its size, or its evaporation rate is low all things being equal elsewhere. The fact that the country's relative capacity for scientific retention (which is the opposite of evaporation, normalized) is positioned at the median of the countries studied, while its relative domestic sourcing capacity (the opposite of capture, normalized) is the lowest in the sample points to the first hypothesis. We must therefore ascertain two distinct results, which are only ostensibly contradictory. On the one hand, because the United States benefits from its large size and high global weight, we observe a bigger than average overlap between science from their laboratories and the science that their patent applicants draw from: this is what is indicated by its lower capture rate compared to other countries. On the other hand, once these national indicators have been normalized by relating them to the global weight of each country, it appears that US patent applicants – mostly companies – make a more than proportionate effort to draw from global science sources.[38]

Fourth, the scientific evaporation rate is a significantly decreasing function of the global share of academic patent citations. Put simply, the more modest a country's contribution to global 'patentable science', the more it tends to lose a large share of what it publishes to the benefit of foreign applicants.

Fifth, we obtain confirmation of the two previous results by observing that the ratio between incoming citations and outgoing citations (the import–export balance) attains values of 2 to 4 for the United States, and tends to drop below 1 for the lowest contributors, precisely those with the highest evaporation and capture rates. The smallest countries are therefore net science exporters, while the United States, whose research undoubtedly fuels the technological efforts of the entire world, looks abroad for 2 to 4 times more scientific sources than foreign countries come to find in the US.

Sixth, the relative domestic sourcing and retention capacities, in other words the normalized domestic and industrial 'return on investment' rates of the national production of knowledge, are always higher than one. However, they are not exclusive to large scientific and industrial nations, but on the contrary are characteristic of the lowest contributors to global disruptive science. Since knowledge is a spillover that is difficult to internalize, inevitably, in terms of volume, the research produced by large scientific nations, starting with the US, feeds abundantly into foreign industries. The United States, of all the countries studied, therefore shows the lowest return rate on its national R&D effort and 'supplies' other countries with the biggest volume of patentable knowledge. But it is also by far the country whose applicants most intensely supplement the contributions of domestic science with references to foreign literature, to the point that it is clearly the highest importer of scientific papers cited by disruptive patents. These results irrefutably add to those accumulated since the 1980s on the topology of knowledge spillovers (*cf.* box).

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[38] — Bibliometric statisticians are well aware that citation practices can vary from one patent office to the next due to their specific procedures (Bacchiocchi and Montobbio, 2010). In particular, in the United States, the 'duty of candor' rule requires patent applicants to disclose all pertinent information, including prior art that they know of, likely to affect the patentability of their invention. This obligation aims to guarantee the integrity of the invention's examination process. In the European, Japanese and Chinese offices (EPO, JPO and CNIPA), no equivalent rule exists and the examiners have the responsibility of carrying out their own research to identify pertinent prior art and evaluating the patentability of the invention. This difference can lead to different citation rates between patent applications in the US and other countries. The present study nevertheless draws from the patent families present in at least two offices, which limits this phenomenon. Moreover, these particular features generally do not have an impact on the choice of research paper cited by patent applicants.

LOCAL AND GLOBAL KNOWLEDGE SPILLOVERS

PORTER (*op. cit.*) AND KRUGMAN (*op. cit.*) provided the first scientific explanations of the phenomenon of the geographic concentration of companies and, in particular, the creation of innovation clusters like Silicon Valley. Although land is more expensive there and circulations more congested, companies nevertheless find a competitive advantage that can be summed up by the term 'economies of agglomeration,' thanks to three main mechanisms: the sharing of skilled labour, the presence of competent suppliers and, what interests us more specifically, the existence of knowledge spillovers. The latter, which are facilitated by the mobility of people and their informal exchanges, for companies takes the form of additional productivity or innovation due to their 'mere' proximity with other productive or innovative companies. The theoretical reflection of these two authors then received empirical confirmations, such as by Jaffe (1986). Should we see in our results on the global circulation of knowledge any reason to question the importance of economies of agglomeration? The answer is no, for several reasons. The first is that these effects combine and do not contradict each other.

Since the first studies of clusters, it is accepted that knowledge spillovers concern so-called 'tacit' knowledge, by definition difficult to express and transmit (like practical skills, knowhow and personal experience) just as much as so-called 'codified' knowledge, transmitted explicitly and easily exchangeable at a distance, according to the distinction proposed by Polanyi (1967). The patent citations that we work on naturally reveal codified knowledge. In fact, for the same reason, economists attempting to understand how companies organize their 'open innovation' systems starting from the work of Chesbrough (*op. cit.*) on the global circulation of knowledge, also end up making this observation that patent citation flows are largely international, while public-private partnership research contracts often relate to a local base, precisely due to the essential weight of informal parameters in the emergence of these collaborations (Stefan and Bengtsson, 2016). A second reason is the existence of intense academic reflection to attempt to identify the geographic scale covered by knowledge spillovers, which goes beyond the framework of application of regional clusters. Coe and Helpman (1993), for example, detect 'significant' benefits of a country's investment in R&D for the total factor productivity of its commercial partners, mainly when the latter are small (they even calculate that a quarter of the profits of R&D investments of the seven biggest global economies are captured by their commercial partners). Conversely, Grillitsch and Nilsson (2015) underline that companies located in peripheral regions, like Scandinavia, benefit less from such spillovers and have to develop adaptation strategies. Keller (2001) observes that from 1970 to 1995, the spread of technologies moved from an essentially local area (with a 50% decrease in spillovers every 1,200 km)[*] to more fluid circulation, mainly due to the impact of global trade, international investments and linguistic proximity.[**] A third reason is that spillovers are not manifested in the same way and with the same intensity, depending on the size of the company and their own level of investment in R&D (Jaffe, *op. cit.*), whether or not they are part of a global group (Barrios *et al.*, 2012; Zhao and Islam, 2017), their business sector (Álvarez and Molero, 2005), the development level of the region (Qiu *et al.*, 2017), its metropolitan character, and the public or private nature of the investment (Kang and Dall'erba, 2016), etc.

This very fertile reflection has also been the object of reservations and limitations. Some of them are methodological; for example Tappeiner *et al.* (2008) point out the difficulty of measuring spillovers reliably. They can also be more conceptual, for example when Duranton and Puga (2004) show that clusters can lose their economies of agglomeration and therefore their attraction, when knowledge spillovers are still active but are overridden by the costs of congestion, such as in the former industrial areas of Europe and the United States.

[*] See also Fritsch and Franke (2004), Holl *et al.* (2023).

[**] See also Eugster *at al.* (2022).

Point of view

by **Antonin Bergeaud**

The role of collaborations between companies and scientists

Antonin Bergeaud
Professor of Economics, HEC Paris.

EMPIRICAL STUDIES ON INNOVATION have been quick to underline the strong heterogeneity of quality and value of companies' R&D investment results. In a study published in 2017, Kogan *et al.* thus attribute a monetary value to each patent filed by listed US companies; based on the market reaction at the time of its publication. The median patent turns out to have a value ten times lower than that of a patent in the 95th percentile, and forty times lower than that of a patent in the 99th percentile. This very large difference has led the literature to pay close attention to these unusual patents, which also have an impact on the productivity of companies (Kalyani, 2022).

An effective industrial policy must therefore establish conditions to foster the development of this type of 'disruptive' innovation. But how? A first part of the answer is that uniform support policies for research and development are clearly not the solution, since not all companies have the capacity to generate radical, impactful innovations. A second part of the answer involves going back to the source. What are the specific features of these unusual patents? As shown by Marx and Fuegi (2020), one notable characteristic is that they tend to be more based on academic science. This study proposes a particularly pertinent analysis by linking each patent associated with one of the twelve disruptive technologies to the scientific papers that it cites as a reference, and that we might legitimately imagine served as input for developing the radical improvement of a product, or in the actual creation of a new good or service.

It is worth bearing in mind that this type of data analysis is particularly difficult. Tens of millions of patents exist (in the United States alone, 400,000 patents are accepted every year), and these need to be meticulously associated with technologies, and attributed to a company or an inventor. The next step involves finding the research papers cited in a database once again containing tens of millions of documents. Technical advances in natural language processing (NLP) combined with the collaborative efforts of numerous researchers have only recently made it possible to effectively following the production chain of an innovation, from the initial theoretical development up to the commercialization of the product.

Thanks to this analysis of massive data, the author of the study is able to look at the fundamental question of determining who is at the origin of the ideas behind these disruptive innovations. The observation for France and Europe is negative. The Draghi Report published in 2024 clearly indicated a technological slackening, but it seems that Europe also lags behind on the production of knowledge, albeit with a less obvious gap.

Could this scientific lagging behind be the source of a technological lag? This question is complex because ideas circulate freely and science produced on the other side of the Atlantic also benefits European companies, as clearly shown by this study. The link could be more subtle and difficult to measure. By abandoning the field of scientific excellence, in particular in applied domains, companies find it harder to take advantage of these positive spillovers which, despite the digital revolution, remain very local (Hunt *et al.*, 2024).

The development of capabilities, in other words capacities to integrate, digest and use new scientific discoveries, is more effective when frequent exchanges, including informal ones, take place between companies and scientists. This can involve exchanges of human capital (Cifre doctoral thesis partnerships, young doctor programme, mobility of researchers) or through tax incentives to collaborate (outsourcing part of the research tax credit, young university company programme, etc.). Programmes encouraging these kinds of collaboration will probably have beneficial impacts on disruptive innovation. This has previously been the case in France (Bergeaud *et al.*, 2022), in particular in comparison with current subsidies which are relatively unaware of the existence of such collaborations.

5

Chapter

How to improve national efforts on disruptive innovation

France does not meet the mark to reach its disruptive innovation targets, and its scientific specialization is not the reason. Innovation, while undoubtedly fuelled by science, is primarily determined by the presence of a knowledge-intensive industry. It is in this area that public action can be decisive.

IN FRANCE, RESULTS STILL FALL SHORT OF AMBITIONS

There is enough converging evidence to demonstrate that the position of France falls short of its ambitions in terms of new disruptive technologies, for example judging by the country's share of global patent applications. This result - which probably applies to other European countries - was documented in our previous note (Bellit and Charlet, *op. cit.*) and we can make some additional observations here.

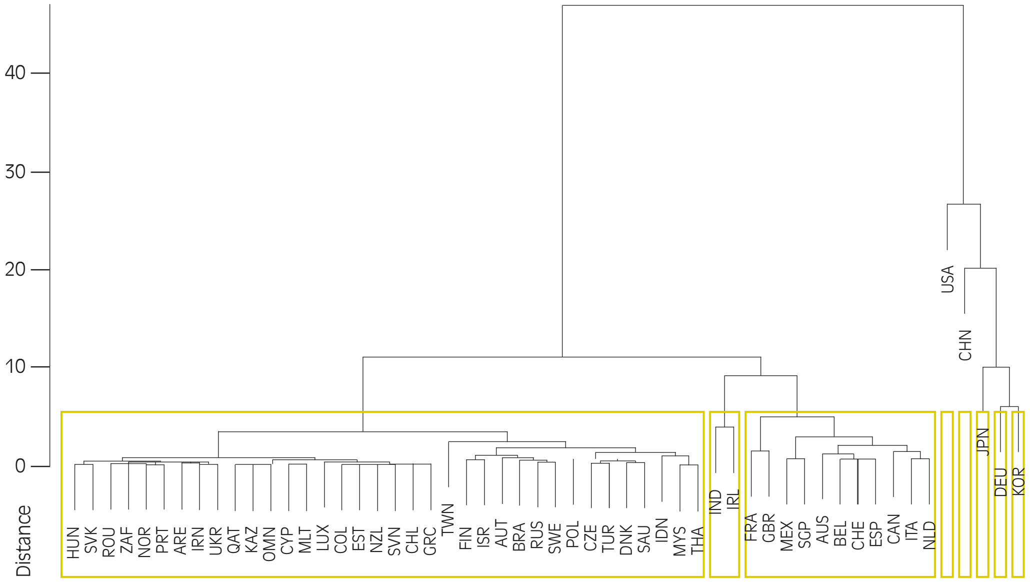
Firstly, we provide the results of two principle component analyses, a detailed version of which features in Appendix M. They were carried out on 53 countries characterized by their position in the scientific and technical domains studied in this publication, in addition to macroeconomic variables like GDP and exports of various categories of goods.

In the first of these PCAs, the countries are characterized by variables expressed in global shares (share of scientific publications and patents in the different technologies, share of GDP, added value, exports, etc.). The volume effect is clearly visible: the more a country dominates for one variable, and therefore in a technology or scientific field, the more it tends to do so for all of the others. And this is precisely the case of the leading countries that we identified at the start of this note. Thus, if we read the dendrogram resulting from this PCA downwards until we end up with eight country clusters (the case at the top of the following figure), we firstly see five dominant countries that stand out from the

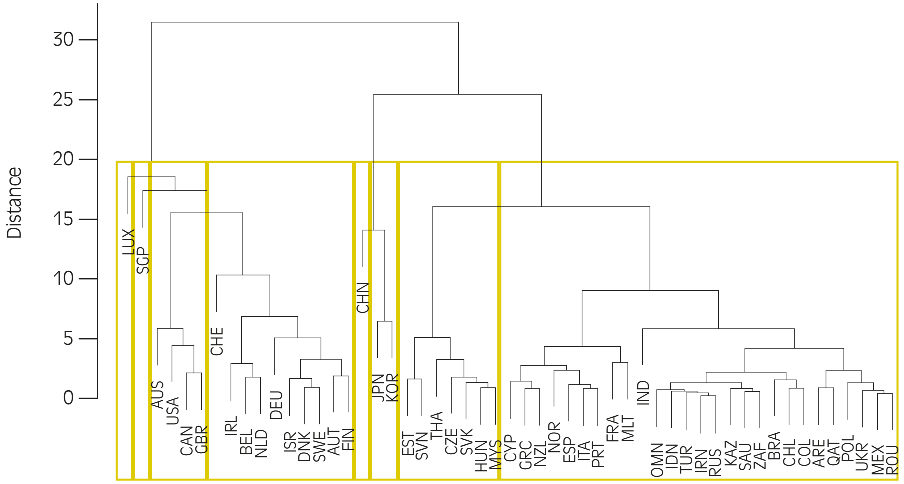
fig. **5.1**

Results of PCAs on 53 countries described by variables expressed in global shares (a) **and relative effort** (b et c)

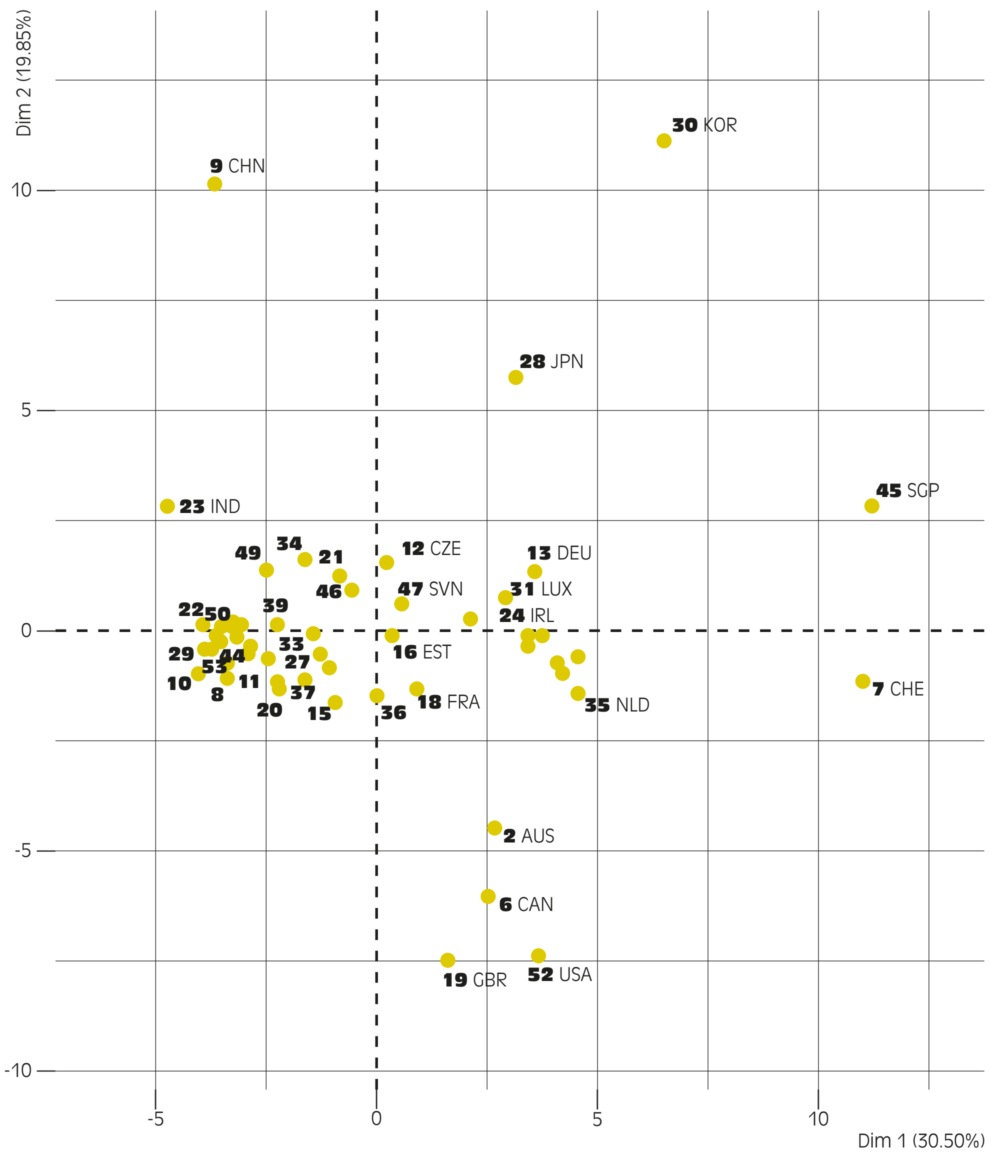
a) *DENDROGRAM BASED ON PCA (IN GLOBAL SHARES)*



c) *DENDROGRAM BASED ON PCA (IN RELATIVE TERMS)*



b) *PCA GRAPH OF INDIVIDUALS (RELATIVE MEASUREMENTS)*



Sources: OST-Hcéres, OECD and World Bank. Processing, La Fabrique.

How to interpret the data: the dendrograms show the bottom-up ranking of countries, by level of proximity regarding the variables studied in the PCA. The position of the clusters on the y-axis represents the distance between individuals then between clusters that need to be exceeded for them to be considered close. Middle figure: the countries are projected in the plane formed by the first two dimensions of the PCA.

others: United States, China, Japan, Germany and Korea. A sixth cluster comprises France, the United Kingdom, and nine other middle-size countries. Then a seventh cluster comprises two countries (India and Ireland), and the last one includes all of the others. In quantitative terms, France and the United Kingdom are therefore a long way from the five dominating countries and have difficulty standing apart from a group made up of countries with smaller volumes (Spain, Italy, Belgium, Switzerland, Netherlands, Canada).

We then carried out a second PCA of the same countries and the same sizes, but this time with relative measurements: expenditure and value added are related to GDP, the number of publications and patents are broken down per capita, etc. The idea of this additional observation is to identify the effort of each country independently from its size.[39] The projection of countries on the plane formed by the first two dimensions of this PCA (top table, middle square) shows that several groups stand out. China is quite isolated in the northwest quadrant (low scientific effort per capita or per GDP point, and strong specialization in scientific fields and in industry in general); the same applies to India. Along a diagonal north-east line, we find successively Japan and Korea, which homogeneously combine their research effort with an equivalent specialization effort in the core technology scientific fields and in industry. Thirdly, to the far east of the plane, we find Singapore and Switzerland, with very high research efforts and an average scientific specialization in the core fields. To the south, four English-speaking countries are very close to each other (United States, United Kingdom, Canada and Australia). The research effort of these countries seems positive, but paradoxically with high levels of deindustrialization and a lack of specialization in the core technology scientific fields. France is located quite close to the scatter plot's centre of gravity.

As in the previous case, we supplement this results analysis with a dendrogram in order to gather countries by level of proximity (bottom figure in previous table), to obtain eight clusters. Luxembourg and Singapore each form a specific cluster. Luxembourg stands out quite artificially due to its very high GDP per capita and, given its low population and high fiscal attractiveness, the high number of patent applicants per capita, in particular for carbon-free steel. Singapore mostly stands out due to the unusual weight of its ITC and high-tech exports relative to its GDP. China also forms a specific cluster; Japan and Korea together make another one.

> « Germanic and Nordic countries, which stand out due to their proximity. »

The four English-speaking countries previously noted as being close once again make a fifth cluster. The last three groups include more countries. One of them is made up of the Germanic and Nordic countries (apart from Norway and with the addition of Israel), which stand out due to their proximity. Another cluster mostly includes Eastern European countries, along with Malaysia and Thailand. The eighth cluster is larger, and gathers mostly Mediterranean and Persian Gulf countries, in addition to India, Russia... and France.

Lastly, we show here the variations in global rankings for patent applications between our previous study and this one. The corpus exploited by the previous study related to the years 2010 to 2020, with 2020 only being about 50% complete, which totals 114 months. The current version of the corpus concerns 2010 to 2021, with 2021 being 95% complete, i.e., an additional 18 months. As a result, the reference period is 16% bigger. This may seem marginal; nevertheless, the table shows to what extent China and the United States are more active than France in terms of patent applications. The case of China is particularly striking: this 'simple' expansion of the field of study by 18 months is enough to usually bring the country another two to three percentage points and push it up one or two places in the general rankings. The variations in the French position are far less compelling.

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[39] The first two dimensions of this second PCA capture 50% of the variance: the first in particular shows the research effort per capita (WoS publications, NPL publications in the different technologies, etc.), while the second shows more the specialization indices in academic disciplines and the share of industry in GDP.

fig. 5.2

Main changes in the disruptive patent corpus over 18 months

	UNITED STATES			CHINA			FRANCE		
TECHNOLOGY	Number of patent families	Global share	Rank	Number of patent families	Global share	Rank	Number of patent families	Global share	Rank
Hydrogen for transport	+186	-0.7 pp	2=2	+131	+0.7 pp	6=6	+95	+0.2 pp	5=5
Batteries for electric vehicles	+615	-0.7 pp	4=4	+868	+2.9 pp	5=5	+158	+0.2 pp	6=6
Photovoltaics	+550	-0.7 pp	2<4	+2 191	+3.8 pp	4>3	+103	-0.2 pp	7=7
Offshore wind power	+25	-0.8 pp	3=3	+41	+1.5 pp	8>5	+25	+0.0 pp	6=6
Recycling of strategic metals	+195	-1.2 pp	2<3	+441	+2.4 pp	3>2	+46	- 0.5 pp	6<7
Sustainable aviation fuels	+26	-3.9 pp	1=1	+3	-0.3 pp	4<6	+6	+0.8 pp	6>5
Nanoelectronics	+159	-2.1 pp	1=1	+213	+0.9 pp	2=2	+11	-0.3 pp	6<7
Spintronics	+117	-2.3 pp	2=2	+113	+1.5 pp	4=4	+27	-0.1 pp	7=7
Quantum computing	+446	-6.4 pp	1=1	+171	+2.4 pp	3=3	+51	+0.6 pp	8<7
Messenger RNA	+522	+1.0 pp	1=1	+140	+2.9 pp	5>2	+25	+0.0 pp	7=7
Low-carbon steel	+103	-1.2 pp	3<4	+249	+3.0 pp	4>2	+15	-0.5 pp	8<9
Biological plastic recycling	+293	+0.4 pp	1<2	+131	+0.5 pp	4=4	+71	-1.1 pp	5<6

Source: OST-Hcéres. Processing, La Fabrique.

NB: this table illustrates the variations between the two versions of the disruptive patent corpuses. The previous study covered 2010 to 2020, with 2020 only being about 50% complete. The current corpus covers 2010 to 2021, with 2021 being about 95% complete.

How to interpret the data: for 'hydrogen for transport', the United States filed 186 additional patent families from mid-2020 to end 2021. Over the entire corpus starting in 2010, this translates into a 0.7 percentage point drop in its global share. The global rank of the US is unchanged (2nd). However, in the 'photovoltaics' field, the country slipped from 2nd to 4th in the global rankings in the space of 18 months, and China moved up from 4th to 3rd.

Thus, it seems that our country lags significantly far behind the global leaders, both for disruptive patent applications and the publication of research papers feeding into them, whether in terms of global share (which works to the advantage of large countries), relative intensity (which highlights countries making significant efforts), or dynamics. Recent trends do not therefore point to a short- or mid-term improvement in the French situation. As a reminder, the box below features the government's priority research and innovation targets.

RESEARCH AND INNOVATION PRIORITIES FOR FRANCE, ON 31-12-2024

THE FRENCH GOVERNMENT organizes its political roadmap into four priority areas: ‘full employment and reindustrialization’, ‘progress and public services’, ‘ecological transition’, and ‘republican order’. Research and innovation mostly comes under the first area, which is broken down into six ‘projects for employment and industry’, the first of which is called ‘investing for the future with France 2030’. At present, public policies have only been formulated in terms of the amount of public money invested. The stated objective is to commit 53.2 billion euros to investment between October 2021 and December 2026; the latest figures available report 29.9 billion euros attributed on 1 December 2023 (i.e., 56% of the earmarked amount during 40% of the scheduled period).

The France 2030 investment plan is broken down into ten ‘societal objectives’ on three main themes: produce better (energy, industries, transport), live better (food, health, culture) and understand our world better (training, space, deep seabed). These ten objectives are: (i) promote the emergence of a French supply of small modular reactors (SMRs) by 2035 and support breakthrough innovation in the sector; (ii) become the leader in green hydrogen and renewable energies by 2030; (iii) decarbonize our industry to meet our commitment to reduce greenhouse gas emissions from this sector by 35% between 2015 and 2030; (iv) produce nearly 2 million electric and hybrid vehicles a year in France by 2030; (v) produce the first low-carbon aircraft in France by 2030; (vi) invest in healthy, sustainable and traceable food to accelerate the agricultural and food revolutions; (vii) produce at least 20 biomedicines in France, in particular for the treatment of cancer and chronic diseases, and create the medical devices of the future; (viii) place France at the forefront of the production of cultural and creative content, and immersive technologies; (ix) participate fully in space exploration; (x) invest in the deep seabed. The priority areas of France 2030 only partially coincide with the disruptive technologies that we are studying here, but attaining objectives (ii), (iv) and (vi) seems challenging judging by the position of France in the twelve technologies in our study.

Lastly, it is worth bearing in mind that the twelve disruptive technologies examined in this publication have been identified in publications such as the expert report commissioned by the Ministry of the Economy from Benoît Potier (2020), whose mandate was to identify twenty-two emerging markets – including ten priority markets – in which France had “the potential to play a leading role”. These ten priority markets are: (i) precision agriculture and agricultural equipment; (ii) sustainable food for health; (iii) animal and plant biocontrol; (iv) digital health; (v) biotherapies and bioproduction of innovative therapies; (vi) hydrogen for energy systems; (vii) decarbonization of industry; (viii) new sustainable generation of ‘high-performance’ composite materials; (ix) quantum technologies; and (x) cyber security. The other twelve markets that could be the focus of a later acceleration of strategy are: (i) sustainable fuels; (ii) data storage and processing infrastructures; (iii) offshore wind; (iv) photovoltaics; (v) innovative buildings; (vi) recycling of building materials; (vii) waste recycling and recovery; viii) bio-sourced products; (ix) e-learning and ed-tech; (x) 3D printing; (xi) batteries for electric vehicles; and (xii) microelectronic hardware and software for embedded AI.

Sources: government website, Potier (*op cit.*).

'RIGHT' OR 'WRONG' SCIENTIFIC SPECIALIZATION IS NOT THE ISSUE

We might think that this French weakness results from an insufficient focus of our research on academic fields likely to generate innovative technologies. This hypothesis is partly based on the observation that, taking all technologies and countries together, the scientific publications cited by disruptive patents very often come from the same fields, and in particular from the PE4 panel covering 'physical and analytical chemical sciences' (see figure). We might reasonably deduce that proactive scientific efforts in these fields would lead to higher numbers of disruptive patent applications.

Nevertheless, this hypothesis must be rejected. As seen in Chapter 3, some countries like the United States are very active in patent applications and yet only produce a comparatively modest volume of scientific papers in the core technology fields. China is a counter example: the country is very active in scientific papers on the core technologies, but this is insufficient to ensure their presence in academic patent citations or in actual patent applications. This disconnection between scientific activity and technological activity is easier to understand when bearing in mind that most of the articles cited by patents are of foreign origin, as shown in Chapter 4.

The table below, which relates to the particular case of 'hydrogen for transport', confirms that there is no connection between a country's level of specialization in a scientific field (i.e., the field's preponderance in the entirety of its academic output) and this country's weight in the resulting disruptive patent applications. .

While the fact that a country specializes in 'technologically fertile' scientific fields is not enough to automatically guarantee a high rank for patent applications or academic patent citations, quality does come into play: what counts for a country is not so much producing a high number of research papers as encouraging the production of articles that will be judged to be 'good' or 'interesting' by patent applicants all over the world. As expressed by Dominique Guellec, scientific adviser to the OST: "*It's true that some sectorial and technological specializations are more advantageous than others for a country, and that targeted policies can help establish them. However, specialization doesn't exclusively result from direct policy choices; it mainly results from the general economic activity conditions in the country and from broader policy choices, i.e., the capacity for business innovation and growth, labour skills and mobility, and the capacity of public research. The corresponding policies concern entrepreneurship, tax, the labour market, education, and research. These different factors condition the existence and availability of the required resources to be present in cutting-edge sectors, without which a proactive policy would prove useless or even dangerous, since it would introduce additional burdens on sectors not selected by the state.*"

fig. **5.3**

Specialization index in the three scientific domains of the 'hydrogen for transport' core technology

RANK IN THE CORE	PUBLISHING COUNTRY	ERC PANEL	INDEX OF SPECIALIZATION*	RANK IN WOS, ACCORDING TO LEVEL OF SPECIALIZATION
1	United States	PE4	0.62	66
2	China	PE4	1.77	3
3	Japan	PE4	1.15	22
4	Germany	PE4	0.92	32
5	South Korea	PE4	1.70	6
6	United States	PE4	0.54	80
7	France	PE4	0.87	36
1	United States	PE8	0.60	111
2	China	PE8	1.53	19
3	Japan	PE8	0.71	93
4	Germany	PE8	0.90	69
5	South Korea	PE8	1.04	60
6	United Kingdom	PE8	0.76	87
7	France	PE8	0.86	75
1	United States	PE6	0.77	82
3	Germany	PE6	1.06	48
4	United Kingdom	PE6	0.82	73
6	Japan	PE6	0.93	60
7	China	PE6	1.37	27
8	France	PE6	1.13	41

Source: OST-Hcéres.

NB: a country's specialization index in a given domain shows the ratio between its global share of publications in this field and its global share in all scientific publications, taking all fields together. The source data can be found in Appendix H.

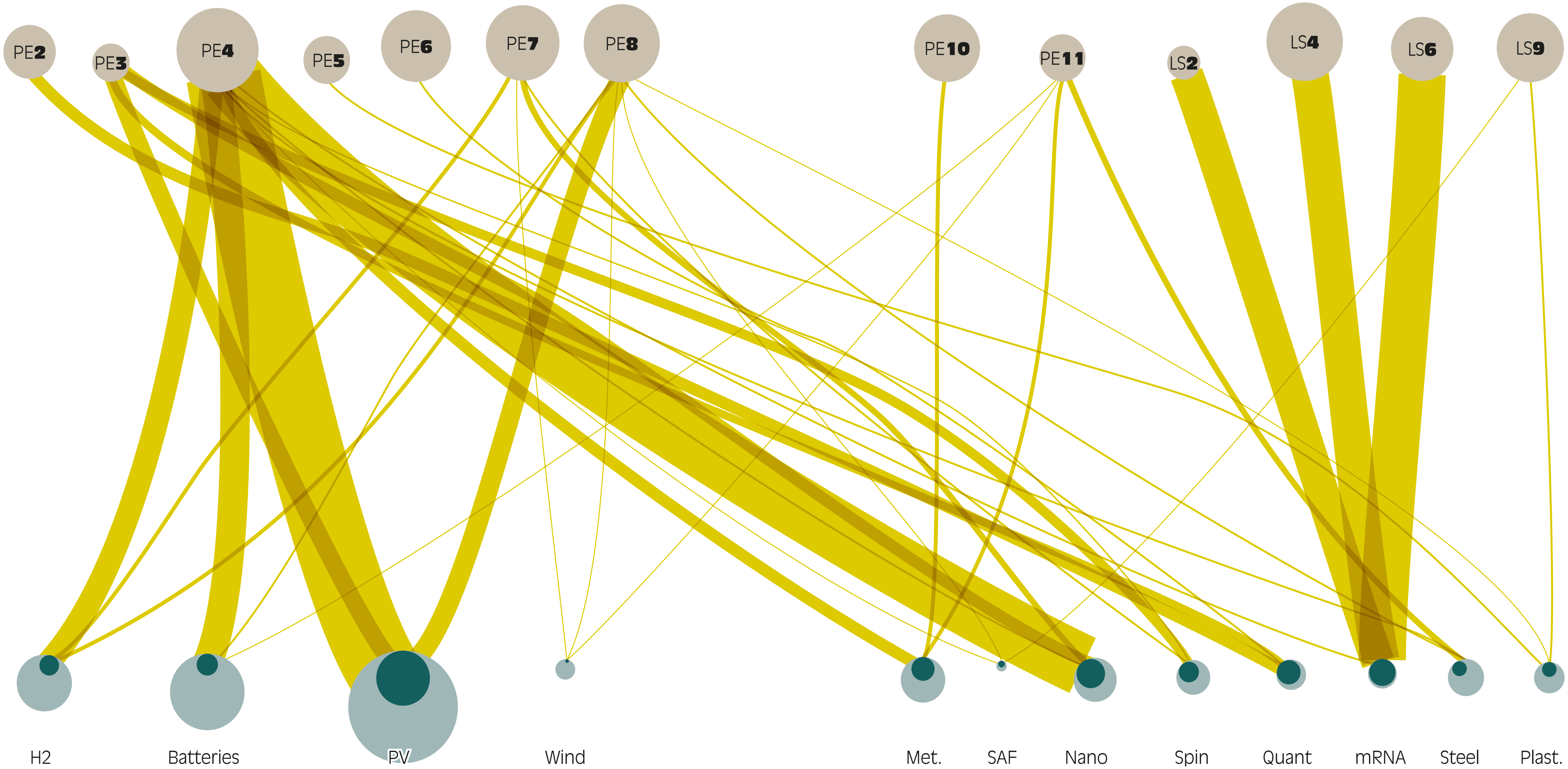

fig. **5.4**

Flow of citations between core publications, by theme panel, and disruptive patents for each technology

● Cited articles
● Citing patents
● Disruptive patents
▬ Number of citations

Sources: OST-Hcéres, OECD and World Bank. Processing, La Fabrique.

NB: source data feature in Appendix B. The thickness of the lines is proportional to the number of citations.

DISRUPTIVE INNOVATION IS BOTH SCIENCE-PUSHED AND DEMAND-PULLED

Appendices K and M feature several series of regressions that aim to pinpoint the main mechanisms or attributes that statistically drive up the global share of disruptive patent applications, for a given country and technology.

A first point common to all of these analyses is that they only produce significant results on a dual condition: the first is to remove China from the sample, because it almost always represents an aberrant case that skews the regression equation; and the second is to carry out tests on the logarithms of global shares to normalize the residuals, in other words to cancel out the deformation caused by large countries.[40] Put differently, China is currently still following a different technical-economic trajectory than the other countries tested: the relationships between the quantities measured always situate it 'off field', on its own regression line. The country weighs very significantly on some variables (e.g., exports and manufacturing production), but remains relatively moderate when it comes to counting disruptive patents or academic patent citations – in a few years' time, we will be able to see whether its dynamic patent applications will have removed this particular feature. In the second case, the reason that the regression residuals do not spontaneously have a normal distribution is not only because countries are of different sizes, but also and especially because we can observe case by case large distances from the 'average' – more precisely from the regression line – for a given technology and country, even though each regression appears to be mathematically robust. This means that the particular features are numerous and sometimes very marked: each country thus conserves, for each technology, a specific latitude to accentuate or not its research effort or technological development.

This being established, what do the regressions show us? Table M-2 firstly illustrates that the correlation is not convincing between the global shares of disruptive patents and global shares of research papers in the total corpus: a country's weight in global science therefore only provides a very approximative indication of its weight in disruptive patents for a given technology. The correlation is clearer when we attempt to compare global shares of disruptive patents with global shares of GDP or manufacturing value added, even clearer with the global shares in public expenditure on R&D, and particularly evident with global shares in private expenditure on R&D (with a coefficient very close to a unit). In sum, explanatory variables too far from the innovation industrial process (GDP, WoS publications, etc.) provide much less eloquent results and, as we get closer to the 'reactor core', it is always the variable relating to the private sector that presents the best correlation (GDP rather than WoS publications, national expenditure on research and development from enterprise (BERD) rather than from the administration (publicly funded GERD)). Consequently, innovative activity in disruptive technologies is mostly related to downstream industries.

> What counts for a country is not so much producing a high number of research papers as encouraging the production of articles that will be judged to be 'good' or 'interesting' by patent applicants all over the world.

However, upstream, the sequential chain that goes from public financing of research to these patent applications, and including core research papers and academic patent citations, is also marked by correlations that are always significant 'step-by-step' (*cf.* Tables M-3 to M-7), bearing in mind previous remarks regarding the dispersal of observations. Disruptive innovation is therefore not only demand-pulled, it is also science-pushed, although the robustness of the latter correlation is slightly less convincing overall than the former.

Moreover, our multivariate equation attempt illustrates this (Table M-8). The global shares in disruptive patent applications initially appear to be positively and significantly con-

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[40] We naturally thought of counting relative units (per GDP point or per capita) to remove this difficulty, but apart from the PCA that we comment on above, these attempts did not produce convincing results.

nected to the global share of manufacturing value added and, although less significantly, to the global share of private R&D expenditure. In this equation attempt, the global share of core publications takes the form of a third variable with a positive correlation (although moderately significant) and the global share in research papers taking all fields together appears significant, but with a negative sign (this does not mean that having an intense scientific output is disadvantageous for the innovation activity of these countries, but rather that a negative adjustment must be added, if we rely on the global shares of industrial value added and private financing of R&D).[41]

Tables K-6 to K-8, centred respectively on ITC, health and transport, show how the balance between the influence of upstream scientific activity and downstream industrial activity can fluctuate from one sector to the next. In the case of ITCs, which cover three technologies in our sample (spintronics, quantum computing, nanoelectronics), the global shares of disruptive patent applications are much more closely correlated to those of academic patent citations (therefore upstream) than to those of downstream commercial activity, measured by exports of goods and services. In the case of health (one single disruptive technology: messenger RNA), patent applications appear to depend as much on upstream scientific output (core publications) as on the size of the downstream market (national expenditure on health). Lastly, in the transport field (batteries for EVs and hydrogen), patent applications are also correlated to upstream scientific output (NPL citations) and downstream market size (industrial VA of the sector). In the first two cases, it is not possible to combine upstream and downstream explanatory variables without weakening the model, which suggests that they are interconnected, while the third case (transport) does not present this feature.

Overall, if we were to retain only one correlation, the most convincing is the one that connects global shares of disruptive patent applications with global shares of private R&D financing.

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[41]— The coefficient of the WoS variable is positive when the regression is tested on it alone (*cf.* Table M-2). We therefore need to make a negative adjustment to the other three positive effects that accumulate. This explains the very good scores of countries like Japan and Korea, which obtain high rates of disruptive patents from a relatively low global share of WoS.

FRANCE WEAK ON BOTH SCIENTIFIC AND INDUSTRIAL FRONTS[42]

The above results show that the position of France needs to be examined on several levels, upstream and downstream in the industrial innovation process, to make a thorough diagnosis of its disappointing patent application results.

Firstly, its production of knowledge appears to be less and less dynamic, in a highly demanding international context where an increasing number of countries are boosting their investments in their research capacities. Based on a comparative analysis of research papers published since 2010, Lahatte and Sachwald (2024) show that France dropped from ninth to thirteenth place among the principle producers of research papers. China has undoubtedly overtaken the United States to become the global leader, but the relative drop of France cannot simply be explained by the dynamism of China and emerging countries. It is striking that France is one of the rare countries to see the number of its scientific publications decrease from 2010 to 2022 while other high-income countries, like the United States, Germany and the United Kingdom, saw clear growth (*cf.* figure).

The authors also point out that the average impact index of publications resulting from French research dipped over the last decade, going from 1.1 in 2010 to 1 in 2021. Several states on the contrary have an index greater than 1, sometimes even above 1.20, like the United Kingdom, the Netherlands, Switzerland, the United States and Australia. China, Italy, Germany and Canada have indexes between 1 and 1.15 for 2021.

France is therefore not only one of the few Western countries to see its scientific publication output drop; in addition, the influence of its output, which was already low in 2010, has continued its downward trend. This is confirmed by another indicator: the number of grants obtained by French laboratories from the European Research Council (ERC). The ERC offers competitive funding for research projects that push the frontiers of knowledge, making it a label of excellence in Europe. From 2014 to 2018, France obtained 11.8% of ERC grants compared to respectively 19.8% and 16.9% for the United Kingdom and Germany (*cf.* figure): this French portion is below its share in public research, which is also the case for Germany and Italy, whereas the United Kingdom, the Netherlands and Switzerland perform remarkably well in terms of their public R&D effort.

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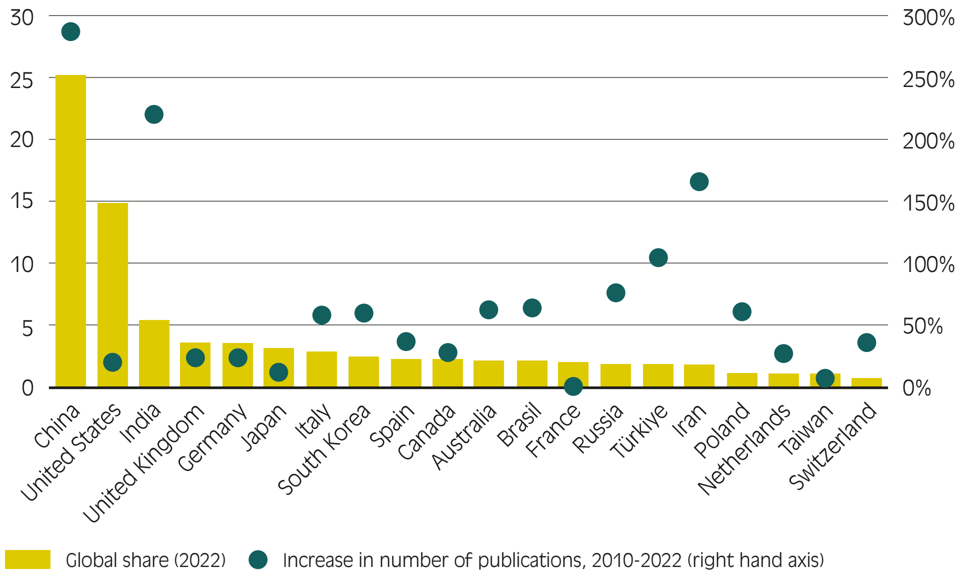
[42]— This section owes much to the previous work done by Sonia Bellit.

fig. **5.5**

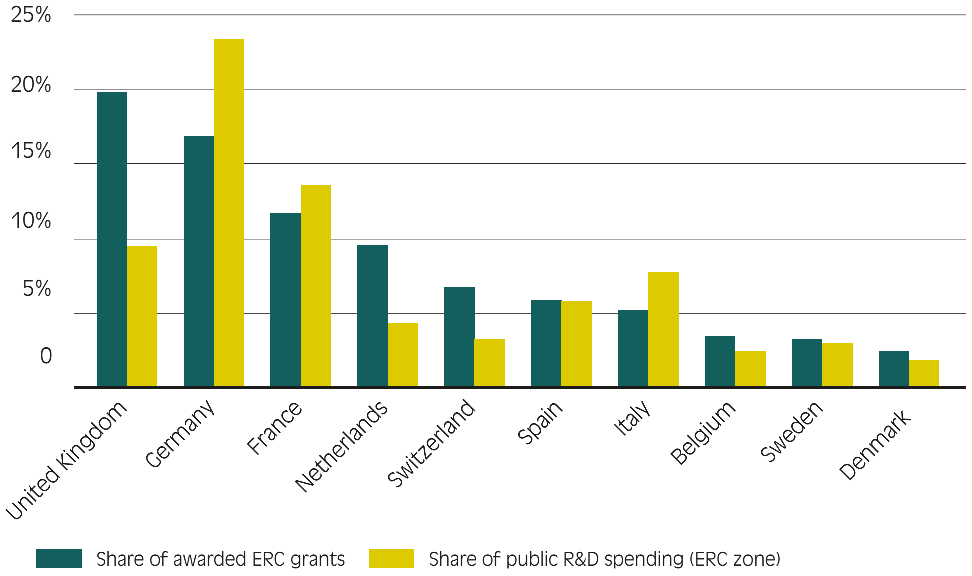
Global share and growth rate of publications for the leading 20 publishing countries, 2010-2022



Source: Lahatte and Sachwald (2024).

fig. **5.6**

Share of ERC grants obtained from 2014 to 2018 and share of public R&D expenditure in the same geographic area



Source: OST (2021).

Bearing the above in mind, we can observe that the decline of France as a scientific power over at least two decades has more to do with a comparatively insufficient effort from its industrial base. We know that, with R&D expenditure representing 2.2% of GDP in 2021, France ranks fairly low among OECD countries, a long way from the Korean leader (4.9% of GDP) and more generally the countries whose investment exceeds 3%, such as the United States, Sweden, Japan and Germany (cf. figure). This difference is certainly not new, but it is getting bigger: in 2010, the share of GDP devoted to R&D in France was about the same as it is today, while other countries have progressed significantly - South Korea spent slightly more than 3% of its GDP on R&D in 2010. Even if public R&D expenditure has seen its weight in GDP shrink slightly in recent years, the reason why France is lagging behind can mostly be put down to the private sector, and more precisely to its sectoral structure: not only does industry represent a smaller share of GDP than elsewhere, but high-tech and knowledge-intensive activities are under-represented (if France and Germany had the same industrial structure as the OECD average, then the private R&D effort expressed in GDP points would be higher in France than in Germany).[43]

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[43] See Le Ru (2012), Bourdu (2013).

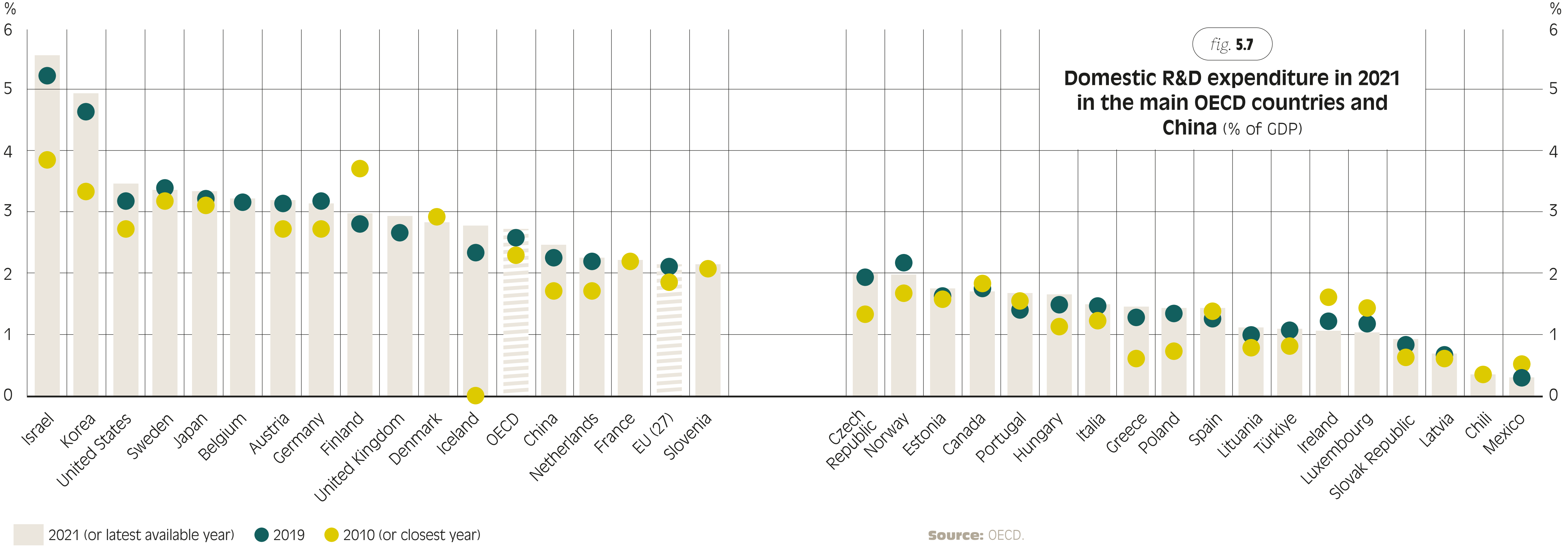

fig. **5.7**

Domestic R&D expenditure in 2021 in the main OECD countries and China (% of GDP)

Source: OECD.

The question raised by these statistical reminders is to determine why some economies – even as culturally diverse as Korea and the United States – see their industrial base develop rapidly, while others, like France and Germany, do not seem to have changed in twenty years.[44] More precisely, what role have states played in these changes? Do they necessarily involve a structural transformation of industry? Up to what point would innovation not be able to accelerate with the same sectoral structure? The answers to these questions do not seem to be the same depending on the country. Sweden, for example, can rely on companies that invest a lot more in R&D than their European partners in the same sectors (Bourdu, 2013). In the United States, where the unitary R&D effort of each company is not particularly high, it is frequently suggested that some public funding agencies (DARPA, BARDA) have played a key role in the development of certain technologies and even some innovative ecosystems, encouraging many researchers to recommend the creation of identical agencies in Europe.[45] However, it is striking that DARPA always pursues public objectives (such as responding to the needs of the army or public health requirements) and does not

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[44] — Close inspection of the previous graph shows that changes can also be negative, as in the case of Finland after the decline of Nokia in the ITC sector.

[45] — Tagliapietra and Veugelers (*op. cit.*), Bonvillian (2024), Bonvillian and Van Atta (2011), Mazzucato and Whitfill (2022), Azoulay *et al.* (2019)

seem to make a priority of participating in renewing the US productive base as such. The nature of its action, as an industrial policy tool, therefore merits close study. In South Korea, on the other hand, recent technological progress results from proactive policies, which are driven by the state's ambition to see the country become a global leader in an increasing number of domains (Faure, 2014). Although Korean companies make the most R&D expenditure (79% in 2021 according to the OECD), they are strongly structured by government guidelines that establish the main innovation objectives to pursue. *Chaebols*, family-run industrial conglomerates that weigh heavily in the Korean economy, are themselves the result of a government plan dating from the 1960s and targeting a number of key technologies including electronics and transport. As a result, private R&D investments are very often supported by public funding, which requires companies to make massive investments in exchange for privileged access to calls for tender (*ibid.*). Recent projects on semi-conductors are a good illustration: South Korea's ambition is to construct the biggest, most innovating semi-conductor manufacturing cluster in the world thanks to a total private investment of almost 430 billion euros by Samsung Electronics and SK Hynix. These companies will receive financial support from the Korean government, and the creation of infrastructure.

These questions, a comprehensive response to which lies beyond the scope of this study, can be compared with research that measures and compares the two plausible but opposite effects of public R&D expenditure on its private counterpart: crowding in and crowding out (*cf.* box).

CROWDING IN VS. CROWDING OUT

DIAMOND (1999) REJECTS, based on US data, the hypothesis of a crowding out effect of federal R&D expenditure on companies' actual R&D efforts, and concludes that decreases in federal expenditure will probably not be compensated by an increase in private expenditure on R&D. More recently, Beck *et al.* (2018) has come to the same conclusion. Conolly (1997) also observes – this time on funding for academic research – that there is no detectable crowding out effect between the different research financing sources, but on the contrary, a crowding in effect, with each partner motivated to turn towards higher-level teams.

Damrich *et al.* (2022) add an important nuance to previous studies. They admit that standard economic theory recognizes the existence of these crowding in effects, but point out that they are difficult to actually observe, in particular since public and private R&D efforts (in proportion to GDP) have recently tended to move in different directions in most developed countries. To explain this paradox, they model science as a 'contribution good', somewhere between a pure public good and a pure private good.* By concentrating on the distribution of scientific and commercial talents between public and private sectors, they identify diverse mechanisms through which governmental action can generate both crowding in and crowding out effects on the private sector.

They define two key stages for public policies: the accumulation of a critical mass of knowledge in fields not yet invested by the private sector, and encouragement to increase efforts in existing fields. Crowding in effects on the private sector can override crowding out effects provided that public policy is devised well… although a universal recipe is difficult to define. Moreover, the model suggests the existence of an optimal level of public science where income from innovation is maximized (on classically competitive goods markets, and except for cases where the state is itself the client, such as defence and public health), and beyond which the crowding out effects on the private sector increase again.

* Similar to public goods, knowledge is reputedly non-rival, but its value comes into play when researchers add new knowledge to the existing stock: not only because the merit attributed by peers to this contribution acts as an individual incentive to researchers, but because the addition of this knowledge to the 'common pool' facilitates access to the stock of previous knowledge and potential income in the perspective of its commercialization. This model was developed in particular by Kealey and Ricketts (2021).

Last

Conclusion

THE RESULTS OF THIS STUDY demonstrate that disruptive innovation is a phenomenon that is both marginal in terms of the number of patents and research papers that concern it, and radical in its capacity to transform markets and move science forward. Despite their high impact, these articles and patents are less visible than the many more numerous ones paving the path of knowledge that runs from science to innovation, through a long chain of interconnections: citation links. The junction between these two vast worlds concerns a minority of articles and papers, among which the most cited papers and disruptive patents are overrepresented.

Countries' performance on disruptive innovation depends on three main factors: the volume of their scientific and technological activity; the excellence of their research, in other words, their capacity to publish high-impact papers; and the capacity of their private sector, ideally aligned with public efforts, to scale up. The first of these three criteria is by definition confined to the biggest global economies and the most industrialized countries. The second seems particularly perceptible in the United States and the United Kingdom, although Korea and Japan also do well. The third is mostly the realm of the two Asian powers. France does not perform remarkably well in any of these areas. China, perhaps temporarily, presents a particularly strong counter performance, making a very strong scientific effort without yet producing patent results as high as other countries.

While the position of the biggest technological powers on the planet therefore appears almost bimodal, between those that mostly succeed in producing 'patentable science' and those that instead 'covert the try' on the innovation field, the reason is mainly because knowledge circulates abundantly and very freely in the world, between authors of publications and patent applicants. Apart from the specific case of the United States, all countries contribute scientifically to foreign disruptive patents much more often than they do to domestic ones; similarly, a country's own disruptive patents draw much more from foreign scientific sources than from national ones. An initial conclusion is that public policies that encourage the passage from research to innovation at local or national scale only capture part of the phenomenon that they intend to boost.

What escapes them, the ‘angel’s share’ that we could call global scientific influence and that economists call ‘knowledge spillovers’, does not always turn out to be a pure loss. In fact, the second conclusion that we can draw from the analysis of these citation flows is that, in volume, the United States is the only country that abundantly ‘supplies’ its science to foreign innovators. However, an observation of the net flows reveals a very different perspective: US patent applicants draw two to three times more scientific references from foreign academic sources than the opposite. In the absence of a comparable extraversion of their industries, the other countries, both small- and medium-sized, ostensibly obtain a better rate of return on their national research efforts to the benefit of their domestic industry, but are in reality more often net exporters of science compared to the rest of the world. This observation may seem to go against several standard representations, both in terms of the justification of national research efforts (examined exclusively at national scale) and the innovation methods characteristic of the main economic powers (where a dominant flow of knowledge from Europe to Asia is readily imagined). It also raises the question of how to encourage European companies to draw from the best scientific sources to boost their innovation.

This pronounced geographic decoupling between the places where science is produced and the places where disruptive technologies are developed invites us to consider with caution the nevertheless common idea of a ‘French (or European) paradox’, which would explain our low performance in innovation. In our study, the position of a given country concerning disruptive innovation appears to be closely correlated with the technological power of its domestic industry (itself a result of the volume and intensity of its inventive activities), but also with the excellence of its research system, which must be capable of publishing large quantities of high-impact research papers that inspire patent applicants. It does not seem possible to abandon the twofold explanation of an innovation process that is mainly industry-pulled but also science-pushed, at the risk of having only a partial perception of the phenomenon – the balance between these two forces most probably varying depending on technology and the market. The idea that France and its European neighbours might be held back in their innovation efforts ‘only’ because of an ineffective link or even cultural divorce between two otherwise dynamic spheres, science and industry, therefore proves insufficient in light of the observations featuring in this study.

Without doubt, some Asian countries have proved better than Europe in aligning the research and innovation efforts of their public and private sectors. European performances in this area are thus, if not paradoxical, at least perfectible. We should nevertheless point out that this alignment has been observed here in macroeconomic and sectoral terms: at this stage, we cannot conclude anything on the compared impacts of public policies that aim to bring research and industry closer, either on an institutional basis or on a territorial scale, except to state that they will necessarily always be only partially effective. On the contrary, however popular the idea of a French and European paradox may be, the lagging behind of France on disruptive innovation mostly boils down to both insufficient public research, mainly in terms of volume but probably also impact, and in particular the fact that its productive base, which has a low level of industrialization and renewal, spontaneously provides an R&D effort that is no longer adequate to resolve the technological challenges of the 21st century. It would be worthwhile considering these two areas separately; at the very least, a close look at the performances of other countries invites us to consider that France could improve, and then advantageously exploit these two capacities recovered independently.

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More

Appendix

I

APPENDIX

Countries’ global share during the main steps of the innovation process

II

APPENDIX

Methodology

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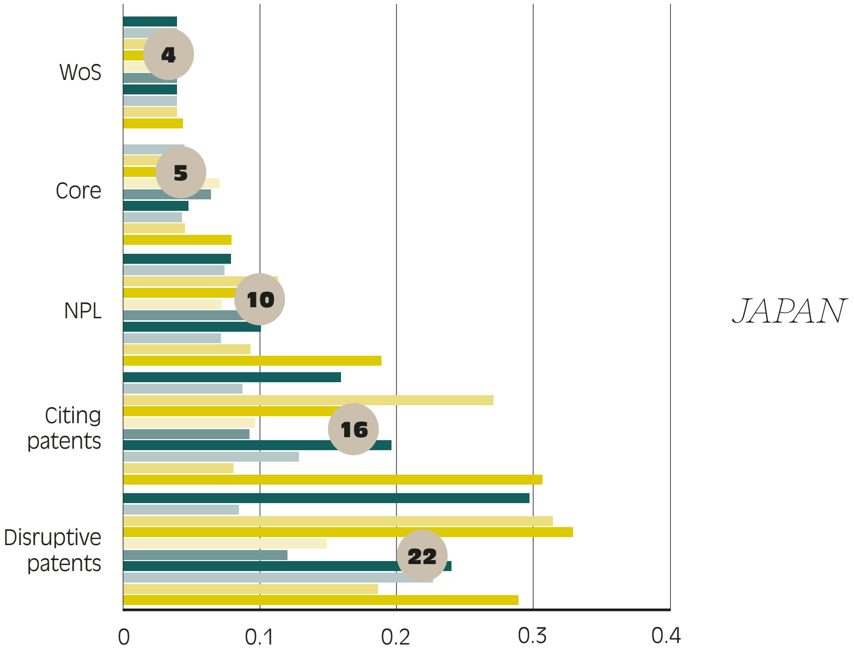
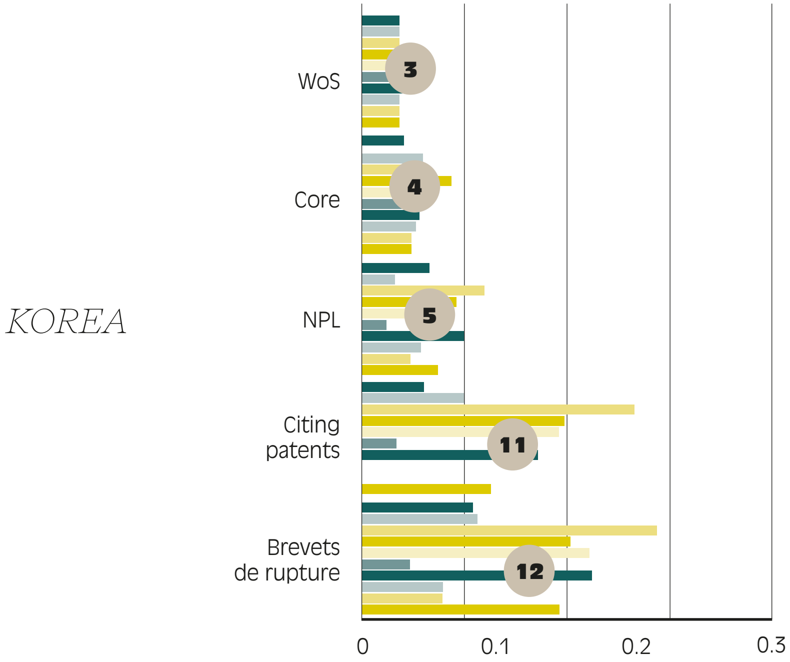
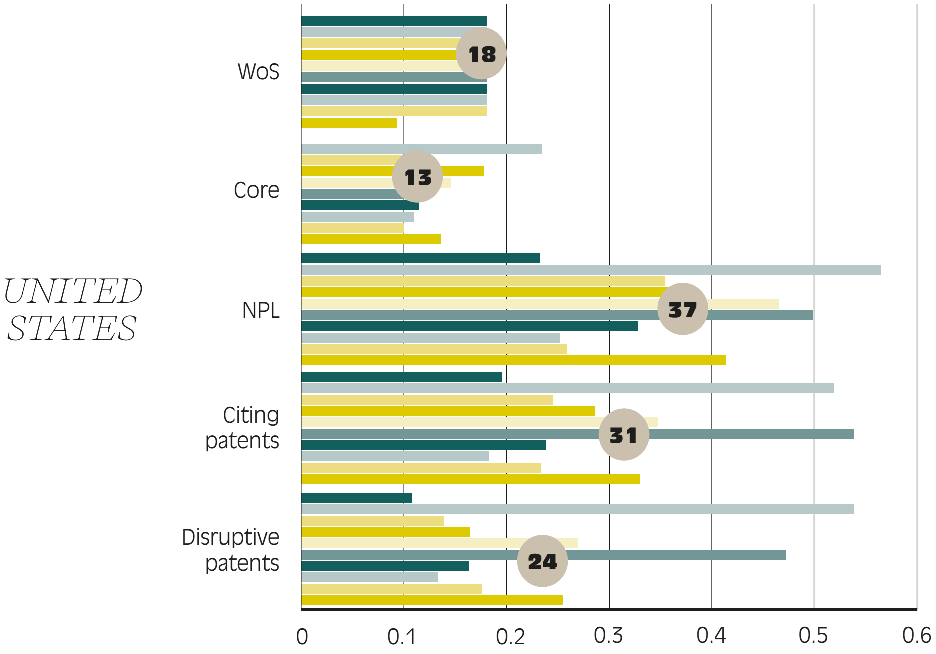
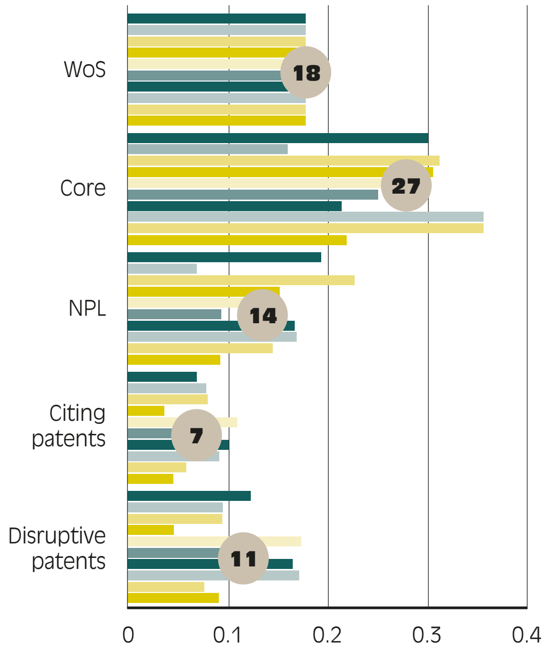
APPENDIX

Global shares of seven countries during the steps of the innovation process, on average and by technology









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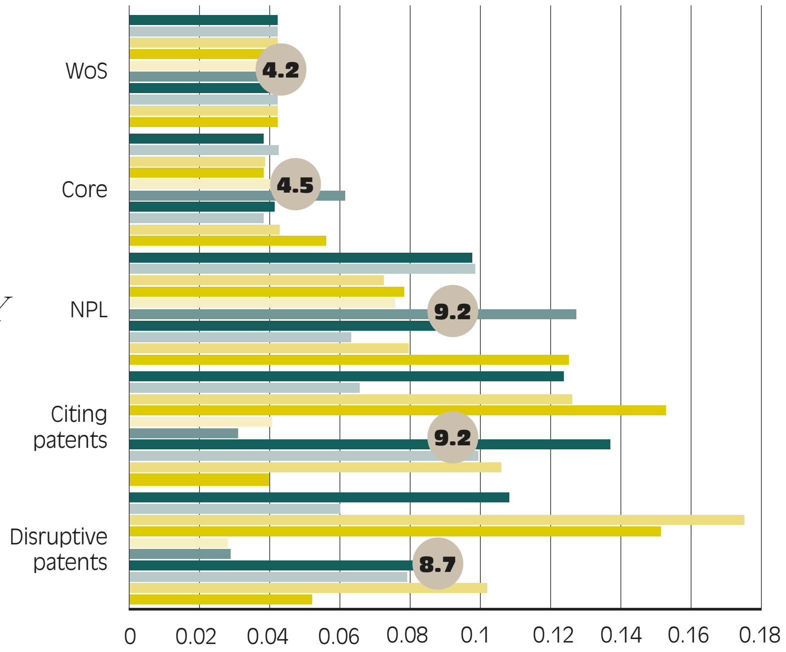

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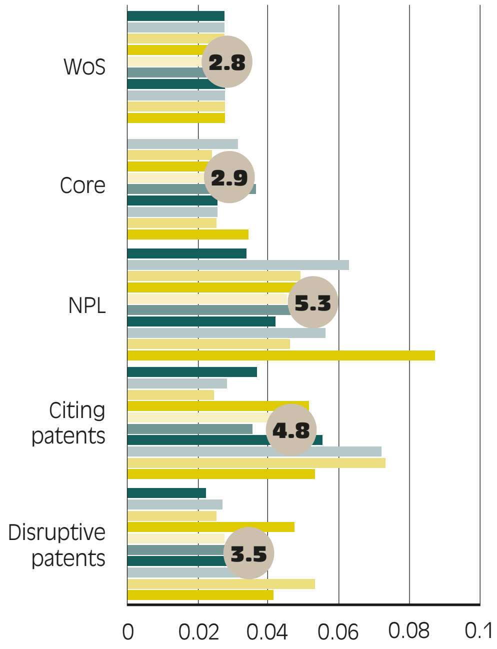

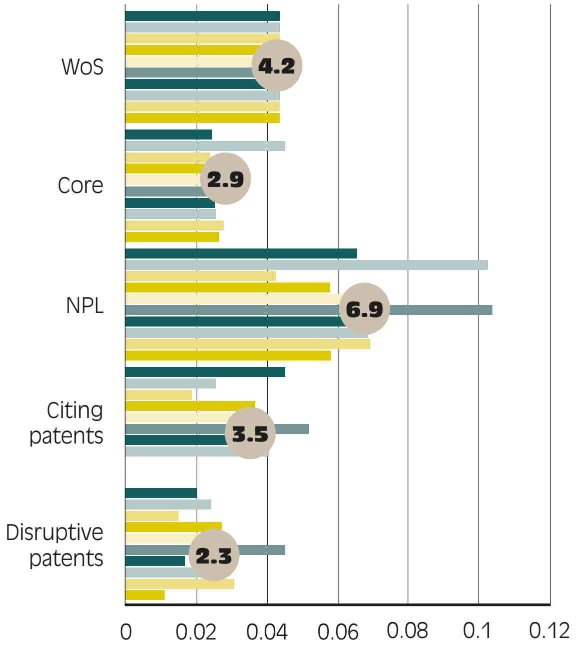

UNITED KINGDOM

II

ANNEXE

Methodology

PATENT DATA

The patent data exploited in this publication were provided by the French Science and Technology Observatory (OST). The OST's 'patent' database is built using Patstat, a base created by the European Patent Office (EPO) with the assistance of the OECD among others. The OST enriches this data, including from the OECD's Regpat database and the United States Patent and Trademark Office (USPTO).

The EPO updates and makes available the entire Patstat database twice a year, in April and October. The information employed in this study is based on the spring 2024 version of Patstat, and takes into account all of the patent applications published up to February 2024. The Patstat data are used to analyse the granting of patents and extensions.

Patstat contains records of patents filed after publication of the application, which takes place eighteen months after the date of the first application. It covers more than 80 national and regional patent offices throughout the world. In the spring 2024 version used, 2021 is not totally complete.

The indicators refer to the priority date (the oldest one) of patent family applications and to the address of applicants.

A patent family comprises one or more individual patents, exact copies of the priority patent(s) and filed with different national offices. Only those families that have patents spread over at least two offices, and those with a single member filed with the European Patent Office (EPO) or the World Intellectual Property Organization (WIPO), are included in the calculation of indicators, which we call 'international families'. The underlying idea is to exclude from the sample purely defensive patents relating to a single market, to obtain only those technologies that applicants hope to export.

Most of the indicators rely on counting presence to establish the list of applicant countries: when an applicant country is present in the patent family, it is credited with one unit of participation in this family. The total number indicates the degree of participation of an entity or country in inventive activity.

A country's share in the total number of patent applications, assimilated to a global share, is the ratio of the number of the country's patent families in relation to the total number of patent families.

IDENTIFICATION OF PATENTS ASSOCIATED WITH THE TWELVE DISRUPTIVE INNOVATIONS IN THE SAMPLE

For each of the twelve disruptive innovations in the sample, the patent families were first identified on the basis of their CPC (cooperative patent classification) codes. Each patent application relates to one or more technological domains, defined by patent office experts and organized in a tree-structured classification including sections, classes, sub-classes, groups, and sub-groups. This classification thus represents a very detailed arborescence that currently totals over 250,000 categories.

NB: a new sub-class, Y02, was created to identify technologies and applications for climate change adaptation or mitigation. This helped to identify patent families corresponding to disruptive innovations related to the ecological transition (e.g., offshore wind power).

In any case, the corpus is defined in a strict manner: patent families are selected if at least one of their members is designated by the code of the field in question. In order to identify promising technologies, keywords indicated by La Fabrique de L'Industrie were then searched for within the corpus defined.

NON-PATENT LITERATURE (NPL)

The Reliance on Science (ROS) database provides large-scale data, with over 40 million patent citations of scientific articles (Marx and Fuegi, 2022).

The scientific articles cited are identified via information in the base Microsoft Academics Graph – now called OpenAlex.[46] The updated data from the ROS base used for this work date from June 2024.

The analysis developed in this publication also draws from data from the OST 'publications' database. This is based on the Web of Science (WoS) from Clarivate Analytics, and on additional data regarding the identification of institutions in the affiliation addresses.

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[46] — The OpenAlex database, by the non-profit organization OurResearch, dates from 2022. It initially employed data from Microsoft Academic Graph (MAG), an open-source base of publication notices that was discontinued at the end of 2021. The ambition of this new service is to develop free-access, open-source tools. To date, it lists more than 250 million documents of different kinds covering all scientific fields.

The WoS lists scientific articles and conference proceedings that meet with a series of criteria regarding editorial quality (like peer reviews) and global academic influence. It has good coverage of internationalized disciplines and less good coverage of some applied disciplines and those with a strong national tradition. However, the database coverage is being developed and new journals are included every year, based on a selection process established by Clarivate Analytics.

The OST base was updated in 2023 and gathers publications from the *SCI-Science Citation Index Expanded, SSCI-Social Sciences Citation Index, A&HCI-Arts & Humanities Citation Index, CPCI-Conference Proceedings Citation Index (S and SSH) and ESCI-Emerging Sources Citation Index.* The latter features a bigger share of non-English-language human and social science items. The data and analyses contained in this publication were taken from update number 20, which includes the *ESCI* index.

TOTAL COUNTING AND FRACTIONAL COUNTING

Scientific papers co-authored by different researchers and laboratories can include several address lines related to different affiliations. Similarly, publications often relate to several scientific specialities. Two types of counting system can therefore be employed (Leydesdorff and Park, 2016; Perianes-Rodríguez *et al.*, 2016).

Total counting, or presence counting, consists in crediting each signatory with a publication. Similarly, if a publication is indexed in two research fields, it will count for 1 in each of these fields. The total count reflects an organization's *participation* in the publication, or the publication's presence in the research field.

Insofar as each publication is counted as many times as there are signatories, the total count is not additive. It therefore cannot be used to produce shares or percentages in the way usually done with these indicators.

Fractional counting, on the contrary, reflects the idea of *contribution* to a scientific paper. A fraction of the publication is attributed to each signatory party so as to retain a unitary sum. From a thematic point of view, the paper is fractioned in proportion to the number of disciplines that the publication's journal is associated with in the database. The total fraction combines the two fractions previously established to take into account both the actors and the scientific disciplines.

Fractional counting is additive at all scales and for all nomenclature levels. For this reason, it is employed to calculate the shares of publications within geographic groups and to compare countries and institutions.

CLASSIFICATION OF SCIENTIFIC ARTICLES BY RESEARCH DOMAIN

The WoS provides a detailed list of 254 scientific categories, which serves as a base to normalize the indicators used in this study.

A correspondence is established between these 254 WoS categories and the 27 panels of the European Research Council (ERC). The OST carries out a reclassification[47] to ensure that the allocation of each publication corresponds to the main speciality in its bibliographic references (Milojević, 2020; Lahatte and de Turckheim, *forthcoming*). Thus publications only have a single speciality, more precisely, each publication only has a single ERC research panel. The ERC panels are organized into three main scientific areas: Life Sciences (LS), Physical Sciences and Engineering (PE), and Social Sciences and Humanities (SH). The list of ERC panels is provided below.

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[47] The 254 disciplinary specialities in the WoS are allocated to journals, which are then associated with publications. This classification generates issues involving the multi-allocation of documents to specialities, then to disciplines (e.g. like ERC panels), which makes it necessary to apply fractional disciplinary counting in studies. To remedy this issue in the WoS, the OST carries out a meticulous reclassification process so that each document is linked to a single speciality. As a result, articles in the same journal can be classed into different specialities (Lahatte and de Turckheim, *forthcoming*).

fig. **I**

ERC panels, by domain and sub-domain

ER domains	ERC sub-domains
LS *LIFE SCIENCES*	**LS1** - Molecules of Life: Biological Mechanisms, Structures and Functions
	LS2 - Integrative Biology: From Genes and Genomes to Systems
	LS3 - Cell Biology, Development, Stem Cells and Regeneration
	LS4 - Physiology in Health, Disease and Ageing
	LS5 - Neuroscience and Disorders of the Nervous System
	LS6 - Immunity, Infection and Immunotherapy
	LS7 - Prevention, Diagnosis and Treatment of Human Diseases
	LS8 - Environmental Biology, Ecology and Evolution
	LS9 - Biotechnology and Biosystems Engineering
PE *PHYSICAL SCIENCES AND ENGINEERING*	**PE1** - Mathematics
	PE2 - Fundamental Constituents of Matter
	PE3 - Condensed Matter Physics
	PE4 - Physical and Analytical Chemical Sciences
	PE5 - Synthetic Chemistry and Materials
	PE6 - Computer Science and Informatics
	PE7 - Systems and Communication Engineering
	PE8 - Products and Processes Engineering
	PE9 - Universe Sciences
	PE10 - Earth System Science
	PE11 - Materials Engineering
SH *SOCIAL SCIENCES AND HUMANITIES*	**SH1** - Individuals, Markets and Organizations
	SH2 - Institutions, Governance and Legal Systems
	SH3 - The Social World and its Interactions
	SH4 – The Human Mind and its Complexity
	SH5 - Texts and Concepts
	SH6 – The Study of the Human Past
	SH7 - Human Mobility, Environment, and Space

DEFINITION OF BIBLIOMETRIC INDICATORS

The calculation of the indicators only employs the following types of documents: ‘articles’, ‘reviews’, ‘proceedings papers’ – therefore, for example, not ‘letters’ or ‘blog posts’. Documents in which some of the information is missing (WoS categories, country, etc.) and retracted papers are not included.

Number of publications

The number of publications is calculated for a given country, at a given nomenclature level, and for a given period. This indicator depends on the size of the actor considered, the country or institution, for example.

Share of publications

For a country (i), the share of publications in a research domain (P_D) is defined by its number of publications (y) in relation to the number of publications published in the world (Y) in the same research domain (D). This indicator represents the weight of the country in the global total, written as:

$$P_{iD} = \frac{y_{iD}}{Y_D}$$

For a research domain (D), at global level, the share of publications is defined by the number of publications of the discipline (Y_D) in relation to the total number of publications in the world (Y), written as:

$$P_D = \frac{Y_D}{Y}$$

Specialization index

The scientific specialization index as a global reference relates the share of a sub-domain of a country’s total publications

$\frac{y_{iD}}{y_i}$ to this same global ratio ($\frac{y_{iD}}{y_i}$).

As a result of normalization, the neutral value of the specialization index is 1. When an index is greater than 1, the country is specialized in the sub-domain compared to the reference perimeter. Symmetrically, it is not specialized for those sub-domains for which its index is lower than 1.

$$Sp_{iD} = \frac{\frac{y_{iD}}{y_i}}{\frac{Y_D}{Y}}$$

Impact indicators

Impact indicators are based on references made by research papers to other publications. Here, we employ two indicators relating to the most cited publications, i.e.: average number of citations of publications per decile and number of publications featuring in the top 1% most cited in the world.

Citation classes

Citation classes are made up of a list of scientific publications according to the intensity with which they are cited. They correspond to breakdowns of the total publications into decreasing percentiles (or deciles) based on the number of citations received at global level for a given citation window. The classes are constructed by research domain. The centile of the most cited publications in the world, for example, relates to the 1% of publications that received the most citations (van Leeuwen *et al.* 2003; Tijssen *et al.* 2002).

Citations matrices

Citation matrices compare, on the one hand, the top 9 countries for patent applications,[48] completed by a sub-total covering the rest of the world (RoW) and, on the other hand, the top 9 countries publishing research papers, once again completed by the rest of the world. These matrices count the citation links between patents and articles: each square indicates the number of times when articles from country X were cited by patents from country Y.

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[48] **48**— In the core matrices, we have opted to present citing applicants; the applicants that are not shown in the list of citing applicants are those with few citation links. This discrepancy between the two lists is confined to 12 countries in 8 technological domains (Austria and Sweden for batteries, Austria and Italy for low-carbon steel, South Korea for metal recycling, Italy for photovoltaics, South Korea for plastic recycling, Finland for quantum computing, Canada and China for sustainable aviation fuel, and South Korea and the Netherlands for offshore wind). Most of these countries rank low among the main patent applicant countries, and thus does not impact the lessons learned.

Scientific and strategic advisors

La Fabrique de l'industrie is working alongside a board of scientific and strategic advisors who oversee

—

the scientific quality, relevance and distinctiveness of the work we do,

—

as well as ensure diversity and balance in perspectives and opinions.

Members of this board participate in their own personal capacity and their companies or institutions do not commit in any way towards La Fabrique de l'industrie. Their participation does not means that they buy in each and every message, result or conclusion conveyed by La Fabrique de l'industrie.

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Les Notes *de La Fabrique*

53

How do disruptive innovations start?

Industry drawing from global science

Several studies attest to a French and European lag in the advent of disruptive technologies, those from which the industrial sectors of tomorrow will be born (hydrogen mobility, spintronics, recycling of strategic metals, etc.). However, our public research is not to be outdone in these sectors: where does the problem come from? Are the results of our laboratories mainly exploited by foreign companies? Is European science lagging behind in the segment, which is restricted by definition, of the most fruitful discoveries? Is it more simply a question of public investment?

This book provides new answers to these old questions, by analyzing the flow of citations between scientific articles and breakthrough patents. It provides an understanding of the particular kinetics of the research-based knowledge flows that drive technological advances in industry and the leading role played by the United States, Korea and Japan in this regard.

This Note is intended for public decision-makers, business leaders, researchers and students wishing to understand how. The results of research support the competitiveness of the most innovative companies now and in the future.

Vincent Charlet is an economist. After training as an engineer, he devoted himself to the analysis of the French research and innovation system (evaluation, construction of indicators, forecasting). From 2011, he participated in the creation of La Fabrique de l'industrie, a think tank of which he is the executive director.

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